

**MINISTRY OF HIGHER AND SECONDARY SPECIAL EDUCATION OF
THE REPUBLIC OF UZBEKISTAN**

INSTITUTE OF ENGINEERING AND ECONOMICS

FACULTY OF ENERGY

"Alternative energy sources" department

From the subject of "HEAT TECHNIQUE".

CURRICULUM COMPLEX

Karshi 2022

INTRODUCTION

This educational-methodical complex, which is made up on the subject of " Heat technique", is based on the requirements of DTS. In our republic, there is a need to deepen economic reforms and train qualified specialists in the development of market relations.

Throughout its historical development, mankind has used heat energy to a certain extent to meet various vital needs.

At first, it was the use of various protective devices for the purpose of protecting people from the cold, natural heating from the sun's rays or by lighting fires, then later, from cooking to industrial production of heat energy and energy from it. , heating supply systems, food processing industry and the like have reached the level of using modern and automated technical means to meet the needs of consumers.

By the end of the 20th century, the scale of heat energy production on our planet has reached such a level that now it is on the one hand accelerating the expiration of the fuel reserves formed on our earth for several tens of millions of years, and on the other hand, the combustion products of the environment as a result of a sharp increase in the level of pollution caused significant changes in the climate of our planet. Naturally, one of the main ways to prevent the further rapid development of these processes, which are negative for human development, is the rational and more efficient use of the generated heat energy in various aspects of the national economy. The positive solution of this problem to a certain extent requires a deep analysis, accurate calculation of the processes of heat transfer and reception occurring in technical means based on the production and use of thermal energy, and in necessary cases, the performance of appropriate experimental research.

That is why the goal of teaching this subject is the main processes in heat energy; status changes; the main parameters involved in the change of state; their types; occurring cycles; the main factors influencing the occurrence of heat transfer, heat exchange devices, their heat calculation, methods of analysis, and teaching the basics of design.

Requirements for knowledge, skills and competences of students in science: in order to acquire knowledge, competences and skills, students should master the following:

- sudden changes in state parameters, connection between them;
- measuring the parameters of the working body;
- to analyze the ongoing processes and come to a conclusion;
- analysis of what conditions affect the parameters of the working body;
- what dimensions to pay attention to when designing heat exchangers.

" Heat technique" is considered the main subject in the bachelor's course 60730300 - Construction of buildings and structures (objects of the oil and gas processing industry) and is taught in the 3rd semester. Mathematical and natural (higher mathematics, physics, theoretical mechanics, applied mechanics) planned in the program implementation curriculum; they are required to have sufficient knowledge and skills in general professional (machine detailing, material science) and other subjects.

This subject provides the student with the necessary knowledge to perform the above tasks.

It is important to use advanced and modern teaching methods and apply new informational and pedagogical technologies for students to master the science of "Heat technique". Textbooks, educational and methodical manuals, lecture texts, handouts, and electronic materials are used in mastering the subject.

Advanced pedagogical technologies are used in lectures, practical and laboratory work, and course work.

**REPUBLIC OF UZBEKISTAN
MINISTRY OF HIGHER AND SECONDARY SPECIAL
EDUCATION**

KARSHI INSTITUTE OF ENGINEERING ECONOMICS

**HEAT TECHNIQUE
of science**

SCIENCE PROGRAM

Field of knowledge:	720,000 – Production - technical field
Field of study:	710,000 – Engineering
Areas of education:	60730300 – Construction of buildings and structures (objects of the oil and gas processing industry)

Karshi 2022

	Science (module) code ISTEX1115	Academic year 2022-2023	Semester 3	ECTS credit 4
	Science (module) type Compulsory subjects	Language of education English		Weekly lesson time 4
1	The name of the subject	Audience training (hour)	Independent education	Total download
	Heat technique	60	60	120
2	<p>2. The content of science</p> <p>2.1 The purpose and tasks of teaching science</p> <p>The purpose of teaching science: The purpose of teaching science is to guide every student studying in these areas in the types, structure, cycles of heat engines in the field of thermal energy, as well as the thermodynamic processes and heat transfer that occur in them . is the formation of knowledge, skills and qualifications suitable for the profile.</p> <p>The task of science is to teach students the theoretical and practical laws of hydraulics and to teach them specific engineering problems and the processes of heat and electricity generation.</p> <p>2.2 The main theoretical part (lecture sessions).</p> <p>Science content topics:</p> <p>Module 1. Enter</p> <p>Topic 1: Introduction to the science of " Heat technique " .</p> <p>History and development trends of heat engineering. Results of socio-economic reforms in our republic in non-energy fields and territorial problems and achievements of science, technology and technology. Tasks of science. Thermodynamic system and working body. A social thermodynamic state parameters. Thermodynamic surface. Basic gas laws. Ideal gas equation of state . Gas constant.</p> <p>Module 2. Thermodynamics</p> <p>Topic 2: Heat capacity. Molecular-kinetic theory of heat capacity of gases. Actual and average heat capacities. Empirical expressions of gas heat capacities. Dependence of heat capacity on process and temperature.</p> <p>Topic 3: Mixtures of ideal gases. Dalton's law. Methods of administration of the composition of the mixture. The composition of mixture pointers and its representation through component pointers.</p> <p>Topic 4: Law of conservation and circulation of energy. Amount of work and heat in a thermodynamic process. of thermodynamics Law I. of thermodynamics Definition of I-law. Expression of the I-law through internal energy. Absorption (expansion) work. Enthalpy. of thermodynamics Representation of the I-law by ni ent al pia .</p> <p>Topic 5: Analysis of the main thermodynamic processes. Analysis of isobaric, zochoric and isothermal, adiabatic and polytropic processes.</p> <p>Topic 6: Definitions of the second law of thermodynamics. Right and inverse periodicity. Thermal FIK of the heating device. Cooling coefficient Carnot cycle and theorem. Carnot's correct, reversible cycles. FIK Analytical view of the II law of thermodynamics for reversible processes and cycles.</p> <p>Module 3. Water vapor and its properties</p> <p>Topic 7: Water vapor. Evaporation and condensation. Dependence of saturated vapor pressure on temperature. Equilibrium state in phase transition. Evaporation and turning steam back into water. Phase transition heat. Degree of dryness. Melting. Sublimation. PT diagram of a phase transition. Tertiary point. Specific volume, enthalpy, entropy of wet saturated, dry and superheated steam. Thermodynamic tables of water and water vapor. the main processes of steam generation. Humid air. Water vapor PV, TS, hs diagrams</p> <p>Module 4. Basics of heat exchange</p> <p>Topic 8: Basics of heat exchange. Basic concepts. Basics of heat transfer: heat conduction, convective heat exchange, radiation.</p> <p>Topic 9: Basics of convective heat transfer. Convective heat exchange. A free convention. Forced convection. Newton-Richmann equation. Reynolds, Prandtl, Nusselt, Grashof criteria. Understanding of thermal and hydrodynamic boundary layers. Radiation. Basic laws of heat transfer by radiation method. Laws of Planck, Wien, Stefan-Bolsmann, Kirchhoff, Lambert.</p> <p>Topic 10: Radiation . Basic laws of heat exchange by radiation method. Laws of Planck, Wien, Stefan-Bolsmann, Kirchhoff, Lambert.</p> <p>Module 5. Heat energy devices.</p> <p>Topic 11 : Heat exchange devices. Types of heat exchangers. Recuperative, regenerative and mixed heat exchange devices. Hydrodynamic calculation of heat exchangers.</p> <p>Topic 12: Compressor. compressors, general information, principle of operation air drawing of CO-7A compressor, FIK</p> <p>Topic 13: Refrigeration machines and their cycles .</p>			

Topic 14: Fuel. Properties of fuel. Solid, liquid and gaseous fuel.

Topic 15: Heat pumps

2.3 Instructions and recommendations for practical training.

The following topics are recommended for practical training:

1. Basic thermodynamic state parameters.
2. Ideal gas mixtures.
3. Isothermic, isothermal, isothermal _ _ processes, adiabatic and polytropical processes .
4. Circular processes. Carnot cycle.
5. Internal combustion engine cycles.
6. Thermal conductivity of flat walls and cylindrical walls.
7. Heat transfer.
8. Heat exchange devices.

Practical training should be conducted by one professor-teacher for one academic group in an auditorium equipped with multimedia devices. It is desirable that the classes are conducted using active and interactive methods, appropriate pedagogical and information technologies are used.

2.4 Instructions and recommendations for laboratory work.

The following topics are recommended for laboratory work:

1. Pressure and temperature measuring devices.
2. Determination of heat capacity of air.
3. Determination of thermal conductivity coefficient of insulating material in the form of a pipe.
4. Determination of the heat transfer coefficient of a horizontal pipe.
5. Introduction to the structure and operation of the CO-7A compressor.

2.5 Instructions and recommendations on course work (project).

Course work (project) is not planned.

2.6. Independent education and independent work.

1. Ideal gas equation of state .
2. I deal with gas mixtures .
3. Heat capacities of I deal gases
4. The first law of thermodynamics. .
5. Isothermic, isothermal, isothermal _ _ processes, adiabatic and polytropical processes .
6. The II law of thermodynamics.
7. Circular processes. Carnot cycle.
8. Thermal conductivity of flat walls and cylindrical walls.
9. I thermal conductivity.
10. Radiation laws.
11. Basic laws of heat transfer by radiation method. Laws of Planck, Wien, Stefan-Boltsmann, Kirchhoff, Lambert.
12. Heat exchange devices.
13. Steam and gas turbine devices.
14. Compressor devices.
15. Internal combustion engines, heat energy devices.

3. Results of science education (competencies to be formed).

- 3.
- 3.1. As a result of mastering the subject, the student:
 - To have an idea about heat, heat-related processes and devices, processes that go with them;
 - to know the types and methods of mathematical modeling, the requirements for mathematical models and to have the skills to use them;

	<ul style="list-style-type: none"> • should have the ability to study and analyze existing problems in heat energy processes and devices and to adopt preliminary solutions to existing problems
4	<p>4. Educational technologies and methods:</p> <ul style="list-style-type: none"> • lectures; • interactive case studies; • seminars (logical thinking, quick questions and answers); • work in groups; • making presentations; • individual projects; • projects for teamwork and advocacy.
5.	<p>5. Requirements for obtaining loans: To be able to fully master the theoretical and methodological concepts of science, to accurately reflect the results of the analysis, to independently observe the studied processes and to perform the tasks and assignments given in the current and interim control forms, and to write on the final control submit work.</p>
6.	<p>6. Literature.</p> <ol style="list-style-type: none"> 1. S. Kleein., G. Nellis. Thermodynamics. Cambridge, 2012. 2. G'.N.Uzokov, DNMamedova, Sh.K.Yakhshiboyev, HAAlmardanov. A collection of experiments on " Thermodynamics and heat engineering". Study guide.- K arshi: Intellect , 2021. 3. G'.N.Uzokov, DNMamedova, Sh.K.Yakhshiboyev, HAAlmardanov. Instruction manual for conducting practical training in "Thermodynamics and heat engineering". Study guide. - K arshi: Intellect, 2021. 4. Zohidov RA, Alimova MM, Mazhudovova Sh.S., "Theoretical basis of thermal engineering" . Study manual, - Tashkent: Publishing House of the National Society of Philosophers of Uzbekistan, 2010. 5. Zoxidov R., Avezov RR, Vardiyashvili AB, Alimova MM, "Theoretical basis of heat engineering" textbook, part 1.-T: TDTU, 2005. 6. Zokhidov R., Alimova MM, Mazhudovova Sh.S. A collection of problems in the science of technical thermodynamics and heat transfer.-Tashkent: TDTU, 2006. <p style="text-align: center;"><i>Additional literature</i></p> <ol style="list-style-type: none"> 7. Mirziyoev Sh.M. We will build a free and prosperous, democratic country of Uzbekistan together. Speech at the joint meeting of the chambers of the Oliy Majlis dedicated to the inauguration ceremony of the President of the Republic of Uzbekistan. T.-"Uzbekistan" NMIU, 2016.-56 p. 8. Mirziyoev Sh.M. We will build our great future together with our brave and noble people.-T.-"Uzbekistan" NMIU, 2017.-488 p. 9. On the strategy of actions for further development of the Republic of Uzbekistan. - T. Decree No. PF-4947 of February 7, 2017. 10. Zohidov RA, Alimova MM, Mazhudova Sh.S., Isakhodjaev XS, "Theoretical foundations of heat engineering". Study guide, - Tashkent.: Cholpon, 2006. 11. Koroli MA, Mazhudova Sh.S. Modern pedagogical technologies. Methodological development.-Tashkent.:TDTU, 2003. 12 . Pod ed. Zakharova AA Technicheskaya thermodynamics and thermotechnics.- M.: Academy, 2006. <p style="text-align: center;">Internet site</p>

	<ol style="list-style-type: none"> 1. www.gov.uz - the government portal of the Republic of Uzbekistan. 2. www.lex.uz - National database of legal documents of the Republic of Uzbekistan. 3. www.Zionet.uz 4. http://dhes.imemrsu.ru/studies/tot/It.htm ; 5. http://rbip.bookchamber.ru/description.aspx?product.no=854 ; 6. www.temperature.org.
7	<p>Science program of the Scientific Council of the Anti-Engineering Institute of Economics in 2022 year " 28.06 " Approved by the decision No. 11 .</p> <p>Scientific program of the department "Alternative energy sources" No. 20/1 dated 2022 year 23.06, methodological commission of the "Energy" faculty No. 11 dated 2022 year 24.06 and Stylistic Council of the institute No. 11 dated 2022 year 25.06 - considered in numerous meetings.</p>
8	<p>Responsible for subject/module: HA Almardanov - <i>"Alternative energy sources" head teacher</i></p>
10	<p>Reviewers: Uzokov G'.N. - Professor of the Department of "Alternative Energy Sources" of KEII AA Vardyashvili - Head of the Department of "Alternative and Renewable Energy Sources" KarSU</p>

**REPUBLIC OF UZBEKISTAN
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KARSHI INSTITUTE OF ENGINEERING ECONOMICS

Registered:

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2022 year " 25 " 06.

"I APPROVE"

Vice-Rector for Academic Affairs

_____ O. N. Bozorov

" _____ " _____ 20 22- year

**HEAT TECHNIQUE
of science**

SYLLABUS

Field of knowledge:

720 000 – Production - technical field

Field of study:

710 000 – Engineering

Areas of education:

60730300 – Construction of buildings
and structures (objects of the oil and gas
processing industry)

Karshi 2022

Science (module) code ISO1304		Academic year 2022-2023	Semester 3	ECTS credit 4
Science (module) type Compulsory subjects		Language of education English		Weekly lesson time 4
1	The name of the subject	Audience training (hour)	Independent education	Total download
	Heat technique	60	60	120
1.1	Faculty	Energy		
1.2	Department name	Alternative energy sources		
1.3	Teachers	FISH.	Phone number	e-mail
1.4	Speaker	Almardanov YES	+998 904288191	hamid_8191@mail.ru
1.5	Practical training	Almardanov YES	91-474-93-54	
1.6	Laboratory work	Almardanov YES	97 312-53-73	
2	2. The content of science			
	2.1 The purpose and tasks of teaching science			
	The purpose of teaching science: The purpose of teaching science is to guide every student studying in these areas in the types, structure, cycles of heat engines in the field of thermal energy, as well as the thermodynamic processes and heat transfer that occur in them . is the formation of knowledge, skills and qualifications suitable for the profile.			
	The task of science is to teach students the theoretical and practical laws of hydraulics and to teach them specific engineering problems and the processes of heat and electricity generation.			
	2.2 The main theoretical part (lecture sessions).			
	Science content topics:			
	Module 1. Enter			
	T/r	Subject	hour	
	1	" Heat technique " . History and development trends of heat engineering. Results of socio-economic reforms in our republic in non-energy fields and territorial problems and achievements of science, technology and technology. Tasks of science. Thermodynamic system and working body. A social thermodynamic state parameters. Thermodynamic surface. Basic gas laws. Ideal gas equation of state . Gas constant.	2	
	2	Topic 2: Heat capacity. Molecular-kinetic theory of heat capacity of gases. Actual and average heat capacities. Empirical expressions of gas heat capacities. Dependence of heat capacity on process and temperature.	2	
3	Topic 3: Mixtures of ideal gases. Dalton's law. Methods of administration of the composition of the mixture. The composition of mixture pointers and its representation through component pointers.	2		
4	Topic 4: Law of conservation and circulation of energy. Amount of work and heat in a thermodynamic process. of thermodynamics Law I. of thermodynamics Definition of I-law. Expression of the I-law through internal energy. Absorption (expansion) work. Enthalpy. of thermodynamics Representation of the I-law by ni ent al pia .	2		
5	Topic 5: Analysis of the main thermodynamic processes. Analysis of isobaric, zochoric and isothermal, adiabatic and polytropic processes.	2		
6	Topic 6: Definitions of the second law of thermodynamics. Right and inverse periodicity. Thermal FIK of the heating device. Cooling coefficient Carnot cycle and theorem. Carnot's correct, reversible cycles. FIK Analytical view of the II law of thermodynamics for reversible processes and cycles.	2		
7	Topic 7: Water vapor. Evaporation and condensation. Dependence of saturated vapor pressure on temperature. Equilibrium state in phase transition. Evaporation and turning steam back into water. Phase transition heat. Degree of dryness. Melting. Sublimation. PT diagram of a phase transition. Tertiary point. Specific volume, enthalpy, entropy of wet saturated, dry and superheated steam.	2		

	Thermodynamic tables of water and water vapor. the main processes of steam generation. Humid air. Water vapor PV, TS, hs diagrams	
8	Topic 8: Basics of heat exchange. Basic concepts. Basics of heat transfer: heat conduction, convective heat exchange, radiation.	2
9	Topic 9 : Fundamentals of convective heat exchange. Convective heat exchange. A free convection. Forced convection. Newton-Richmann equation. Reynolds, Prandtl, Nusselt, Grashof criteria. Understanding of thermal and hydrodynamic boundary layers. Radiation. Basic laws of heat transfer by radiation method. Laws of Planck, Wien, Stefan-Bolsmann, Kirchhoff, Lambert.	2
10	Topic 10: Radiation . Basic laws of heat exchange by radiation method. Laws of Planck, Wien, Stefan-Bolsmann, Kirchhoff, Lambert.	2
11	Topic 11: Heat exchange devices. Types of heat exchangers. Recuperative, regenerative and mixed heat exchange devices. Hydrodynamic calculation of heat exchangers.	2
12	Topic 12: Compressor. compressors, general information, principle of operation air drawing of CO-7A compressor, FIK	2
13	Topic 13: Refrigeration machines and their cycles.	2
14	Topic 14: Fuel. Properties of fuel. Solid, liquid and gaseous fuel. .	2
15	Topic 15: Heat pumps	2
	TOTAL	30

2.3 Instructions and recommendations for practical training.

The following topics are recommended for practical training:

T/r	Subject	hour
1	Basic thermodynamic state parameters.	2
2	Ideal gas mixtures.	2
3	Iso bar, iso cho r, isothermal processes, adiabatic and polytropical processes .	2
4	Circular processes. Carnot cycle. Heat exchange processes	2
5	Internal combustion engine cycles.	2
6	Thermal conductivity of flat walls and cylindrical walls.	2
7	Thermal conductivity.	2
8	Heat exchange devices.	2
	Total:	16

Practical training should be conducted by one professor-teacher for one academic group in an auditorium equipped with multimedia devices. It is desirable that the classes are conducted using active and interactive methods, appropriate pedagogical and information technologies are used.

2.4 Instructions and recommendations for laboratory work.

The following topics are recommended for laboratory work:

T/r	Subject	hour
1	Pressure and temperature measuring devices.	4
2	Determination of heat capacity of air.	2
3	Determination of thermal conductivity coefficient of insulating material in the form of a pipe.	2
4	Determination of the heat transfer coefficient of a horizontal pipe.	2
5	Introduction to the structure and operation of the CO-7A compressor.	4
	Total:	14

2.5 Instructions and recommendations on course work (project).

Course work (project) is not planned.

2.6. Independent education and independent work.

T/r	Subject	hour
1.	Ideal gas equation of state.	4
2.	I deal with gas mixtures .	4
3.	Heat capacities of I deal gases	4
4.	The first law of thermodynamics. .	4

	5.	I zo ba r, iso xo r , isothermal processes, adiabatic and polytropical processes .	4
	6.	The II law of thermodynamics.	4
	7.	Circular processes. Carnot cycle.	4
	8.	Thermal conductivity of flat walls and cylindrical walls.	4
	9.	I thermal conductivity.	4
	10.	Radiation laws.	4
	11.	Basic laws of heat exchange by radiation method. Laws of Planck, Wien, Stephan-Bolsmann, Kirchhoff, Lambert.	4
	12.	Heat exchange devices.	4
	13.	Steam and gas turbine installations.	4
	14.	Compressor devices.	4
	15.	Internal combustion engines Heat energy devices.	4
		Total:	60
	<p>3. Results of science education (competencies to be formed).</p> <p>3.1. As a result of mastering the subject, the student:</p> <ul style="list-style-type: none"> • To have an idea about heat, heat-related processes and devices, processes that go with them; • to know the types and methods of mathematical modeling, the requirements for mathematical models and to have the skills to use them; • should have the ability to study and analyze existing problems in heat energy processes and devices and to adopt preliminary solutions to existing problems 		
	<p>4. Educational technologies and methods:</p> <ul style="list-style-type: none"> • lectures; • interactive case studies; • seminars (logical thinking, quick questions and answers); • work in groups; • making presentations; • individual projects; • projects for teamwork and advocacy. 		
	<p>5. Requirements for obtaining loans:</p> <p>To be able to fully master the theoretical and methodological concepts of science, to accurately reflect the results of the analysis, to independently observe the studied processes and to perform the tasks and assignments given in the current and interim control forms, and to write on the final control submit work.</p>		
	<p>6. Literature.</p> <ol style="list-style-type: none"> 1. S. Klelein., G. Nellis. Thermodynamics. Cambridge, 2012. 2. G'.N.Uzokov, DNMamedova, Sh.K.Yakhshiboyev, HAAlmardanov. A collection of experiments on " Thermodynamics and heat engineering". Study guide.- Q arshi: Intellect , 2021. 3. G'.N.Uzokov, DNMamedova, Sh.K.Yakhshiboyev, HAAlmardanov. Instruction manual for conducting practical training in "Thermodynamics and heat engineering". Study guide. - Against: Intellect, 2021. 4. Zohidov RA, Alimova MM, Mazhudovova Sh.S., "Theoretical basis of thermal engineering" . Study manual, - Tashkent: Publishing House of the National Society of Philosophers of Uzbekistan, 2010. 		

	<p>5. Zoxidov R., Avezov RR, Vardiyashvili AB, Alimova MM, "Theoretical basis of heat engineering" textbook, part 1.-T: TDTU, 2005.</p> <p>6. Zokhidov R., Alimova MM, Mazhudovova Sh.S. A collection of problems in the science of technical thermodynamics and heat transfer.-Tashkent: TDTU, 2006.</p> <p style="text-align: center;">Additional literature</p> <p>7. Mirziyoev Sh.M. We will build a free and prosperous, democratic country of Uzbekistan together. Speech at the joint meeting of the chambers of the Oliy Majlis dedicated to the inauguration ceremony of the President of the Republic of Uzbekistan. T.-"Uzbekistan" NMIU, 2016.-56 p.</p> <p>8. Mirziyoev Sh.M. We will build our great future together with our brave and noble people. -T.-"Uzbekistan" NMIU, 2017.-488 p.</p> <p>9. On the strategy of actions for further development of the Republic of Uzbekistan. - T. Decree No. PF-4947 of February 7, 2017.</p> <p>10. Zohidov RA, Alimova MM, Mazhudova Sh.S., Isakhodjaev XS, "Theoretical foundations of heat engineering". Study guide, - Tashkent.: Cholpon, 2006.</p> <p>11. Koroli MA, Mazhudova Sh.S. Modern pedagogical technologies. Methodological development.-Tashkent.:TDTU, 2003.</p> <p>12. Pod ed. Zakharova AA Technicheskaya thermodynamics and thermotechnics.-M.: Academy, 2006.</p> <p style="text-align: center;">Internet site</p> <p>7. www.gov.uz - the government portal of the Republic of Uzbekistan.</p> <p>8. www.lex.uz - National database of legal documents of the Republic of Uzbekistan.</p> <p>9. www.Zionet.uz</p> <p>10. htt//dhes. i m em rsu.ru/studies/tot/ I it.htm l ;</p> <p>11. htt// rbip . bookchamber .ru/ de s cription.aspx?product.no=854 ;</p> <p>12. www. temperature . org.</p>
7	Syllabus of the Department of "Alternative Energy Sources" dated 2022 year ____ No. ____, "Energy" Faculty Methodical Commission No. ____ dated 202 2 year ____ and Stylistic Council of the Institute No. ____ dated 2022 year ____ - considered in numerous meetings.
8	Responsible for subject/module: <i>HAAImardanov - head teacher of "Alternative energy sources" department</i>
10	Reviewers: AA Vardyashvili - Head of the Department of "Alternative and Renewable Energy Sources" KarSU Uzokov G'.N. - Professor of the Department of "Alternative Energy Sources" of KEII.

60730300 – Construction of buildings and structures (objects of the oil and gas processing industry)

HEAT TECHNIQUE

from science

text of lectures

Karshi2022

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Lecture 1

INTRODUCTION

Heat engineering is one of the general engineering fundamental sciences, which teaches methods of generating heat, methods of converting heat into another type of energy, methods of heat transfer and the use of heat.

Heat engineering serves as the basis of the energy theory for the study of special subjects in the preparation of bachelors. In metallurgy, mechanical engineering, mining, agriculture and other fields of industry, heat generation and release, heat exchange, heat processes occurring in machines, devices, and efficient use of electricity and heat are important. The science of heat engineering plays a key role in the education and training of highly qualified and competitive personnel. This subject helps students to be interested in science, to apply laws in technology, to calculate processes, to determine the optimal conditions of thermal power devices.

The science of heat engineering consists of three sections:

1. Technical thermodynamics
2. Heat transfer
3. Heat energy devices

The word thermodynamics is derived from the Greek words "thermos" - heat, "dynamikos" - power.

Technical thermodynamics is a science that studies the conversion of energy from one type to another, i.e., heat into work and work into heat, in various processes that occur with thermal effects. Technical thermodynamics as a science, the discovery of the law of circulation and conservation of energy by MV Lomonosov (1746), proof of the movement of microparticles of hot substances in his work "Causes of heat and cold" (1747), (1765) the first universal steam by the Russian mechanic IIPolzunov ' developed as a result of the invention of the machine, the drawing of universal piston engines and the creation of the second law of thermodynamics.

R. Mayer (1872), D. Joule (1843-1846), EXLens (1844), S. Carnot (1824), R. Clausius (1854) and V. Thomson contributed to the development of thermodynamics. (1856) made a great contribution with their work. The creation of the second law of thermodynamics shows ways to increase the useful efficiency of engines.

To design and build heating equipment, it is necessary to know its function, operation method and heat transfer processes that take place there. Heat is transferred in three ways: conduction, convection, and radiation. Heat energy devices are used in the execution of each technological process. Heat energy devices convert energy from one type to another. Mathematical science has a great role in calculating specific problems, generating expressions and determining connections between them. It requires knowledge of physics and chemistry in the study and analysis of bodies, phenomena and processes.

The knowledge gained from the science of heat engineering will contribute to building a free and prosperous Motherland, a free and prosperous life, to the development of our independent republic, to the education of a well-rounded person with a wide intellectual level and morals.

Section I TECHNICAL THERMODYNAMICS

Working body and thermodynamic system

In heat engines, the conversion of heat into work is carried out with the help of a working body. The working medium can be gas or steam.

A set of bodies that exchange heat with each other and with the environment is called a **thermodynamic system**. In energy, all machines of a power plant or individual parts of a heat engine and piston cylinders containing gas are examples of a thermodynamic system.

All bodies that are not part of the studied thermodynamic system are called **environment**.

A thermodynamic system can be open, closed, isolated and adiabatic.

is open if it can exchange energy with other systems A **thermodynamic system** (gas turbine device) is called a **closed thermodynamic system (internal combustion engines) if energy cannot be exchanged.**

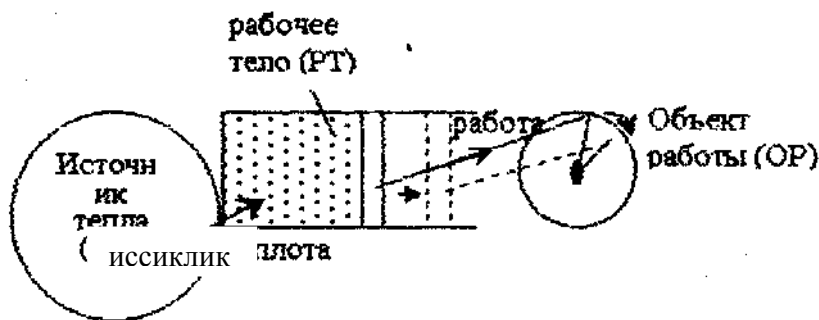


Figure 1. Thermodynamic system

If the system does not interact with the environment, it is called an **isolated thermodynamic system**, if the system does not exchange heat with the environment, it is called an **adiabatic system**.

Basic thermodynamic state parameters

For any thermodynamic system, the sum of several physical quantities will be indicated, through which it will be possible to distinguish the given system from another system, and to check the changes in the system, to check the interaction of the system with the environment. The sum of such quantities is called **the state of the system**.

The quantities that represent the physical state of the working body are called **state parameters**. State parameters include: absolute pressure, absolute temperature, specific volume, density, internal energy, enthalpy, entropy, etc. Since pressure, temperature and specific volume are parameters that change dramatically when the state of the body changes, they are called **thermal parameters**.

Pressure. The force acting vertically on a unit face of a surface is called **pressure**.

$$R = \frac{F}{S}, [Pa] = \left[\frac{H}{M^2} \right] \quad (1)$$

1N/m² - this unit is called Pascal (1 Pa). Since 1 Pa is not very large, kPa and MPa are used in the technique.

$$1 \text{ kPa (kilopascal)} = 10^3 \text{ Pa}$$

$$1 \text{ MPa (megapascal)} = 10^6 \text{ Pa.}$$

In addition to these units, 1 bar = 10⁵ Pa is a pressure close to atmospheric pressure.

Another unit of pressure measurement is 1 kg force/cm² (kg k/cm²) or in another form it is written as follows: kG/cm², which is 1 kG/cm² = 1 at this is called technical atmosphere.

The relationship between pressure units is as follows:

$$1 \text{ MPa} = 10 \text{ bar} = 10.2 \text{ at} = 10^6 \text{ Pa}$$

$$1 \text{ at} = 1 \text{ kg k/cm}^2 = 10^4 \text{ mm water surface};$$

$$1 \text{ atm} = 101,325 \text{ kPa} = 760 \text{ mm of wire.} = 10333 \text{ mm above water.}$$

The physical atmosphere (1 atm) is equal to 760 mm above sea level at a temperature of 0⁰ c.

Pressure is divided into the following types:

1. Atmospheric or barometric pressure R_{bar} is the pressure of atmospheric air;
2. Excess or manometric pressure R_{ort} (R_{man}) – pressure higher than atmospheric pressure;
3. Vacuum (dilution) R_{vac} is a pressure less than atmospheric pressure;
4. Absolute pressure R_{mut} is the total pressure acting on the body;

Of these, only absolute pressure can be a state parameter of a gas or liquid.

If the pressure in a container is higher than atmospheric pressure, then

$$R_{\text{mut}} = R_{\text{bar}} + R_{\text{ort}} \quad (2)$$

If, on the contrary, the pressure in the container is less than the atmospheric pressure, then:

$$R_{\text{mut}} = R_{\text{bar}} - R_{\text{vac}} \quad (3)$$

We can see the ratio between different measurement units of pressure through the table below.

Table 1.1

Units	Pa	bar	kg k /c m ²	mm wire.	mm of water above
1Pa	1	10 ⁻⁵	1.02 · 10 ⁻⁵	7.5024 · 10 ⁻³	0.702
1 bar	10 ⁵	1	1.02	7.5024 · 10 ²	1.02 · 10 ⁴
1 kg k /c m ²	9.8 · 10 ⁴	0.9806	1	735	10 ⁴
1 mm wire	133	1.33 · 10 ⁻³	1.36 · 10 ³	1	13.6
1 mm of water.	9.8067	9.80 · 10 ⁻⁵	10 ⁻⁴	7.35 · 10 ⁻²	1

Temperature. Temperature is a quantity that indicates the degree of heating of a body, in other words, it is a quantity that is proportional to the average kinetic energy of gas molecules.

There are 2 types of temperature:

1. Absolute temperature – T, ⁰K (Kelvin scale)
2. Emperic temperature -t, ⁰C (Celsius scale)

The number of temperature values is indicated by temperature scales. Temperature scales are divided into celsius (⁰C) or degrees - Kelvin, Fahrenheit and Rheomeure scales. The melting temperature of ice is 0⁰C and the boiling temperature of water is 100⁰C. The difference of the thermometer reading at these points divided by 100 is considered as one degree Celsius (⁰C).

In the Fahrenheit scale used in England and the United States, the melting temperature of ice is 32⁰°C and the boiling point is 212⁰°C, so

$$t^{\circ}\text{C} = \frac{5}{9}(t^{\circ}\text{F} - 32)$$

$$t^{\circ}\text{F} = \frac{9}{5}t^{\circ}\text{C} + 32$$

C I system, absolute temperature is measured on the Kelvin scale. In practice, every device measures in degrees Celsius. Therefore, we write the connection between them as follows: $T^{\circ}K = t^{\circ}C + 273.15$

Ratio between different temperature scales

Table 1.2

Scales _ _ n omi	celsius scale, $t, ^{\circ}S$	Rankin scale $T, ^{\circ}Ra$	Fahrenheit scale, $t, ^{\circ}F$	Rheomyur scale $t^{\circ}R$
celsius scale, $^{\circ}S$	—	$5/9 T^{\circ}Ra - 273.15$	$t, ^{\circ}F - 32$ 1.8	$1.25t^{\circ}R$
rankin scale, $^{\circ}Ra$	$1.8 (t^{\circ}C + 273.15)$	—	$t^{\circ}F + 459.7$	$1.8(1.25t^{\circ}R + 273.15)$
Faran is a gate class , $^{\circ}F$	$1.8t^{\circ}C + 32$	$t^{\circ}Ra - 459.67$	—	$9/4t^{\circ}R$
Reomer scale, $^{\circ}R$	$0.8t^{\circ}C$	$0.8(5/9T^{\circ}Ra - 273.15)$	$4/9(t^{\circ}F - 32)$	—

Comparative size. The volume equal to the mass unit of the body is called **specific volume** :

$$v = \frac{V}{m}, \frac{M^3}{\kappa 2} \quad (4)$$

density ρ is the inverse of specific volume.

$$\rho = \frac{1}{v} = \frac{m}{V}, \frac{\kappa 2}{M^3} \quad (5)$$

CONTROL QUESTIONS

1. What is a thermodynamic system?
2. What is a working body?
3. What parameters are called state parameters?
4. Give an understanding of pressure and its types.
5. What is temperature?
6. What is absolute temperature?
7. Connection between scales.
8. Define density and specific density.

2nd lecture

Ideal gas equation of state

The concept of an ideal gas is introduced to simplify thermodynamic investigation methods.

In ideal gases:

- 1) There are no mutual attraction forces between gas molecules.
- 2) It is small enough not to take into account the size of gas molecules.
- 3) Collisions of gas molecules occur in the same way as collisions of elastic balls.

rarefied real gases are close to those of an ideal gas (eg; N, helium). In reality, there is no such thing as an ideal gas. But the study of ideal gas laws helps to determine how a real gas behaves under different conditions.

To derive the equation of state of an ideal gas, we recall the basic ideal gas laws.

Boyle-Marriott's law: the change in pressure is inversely proportional to the change in volume when the temperature remains constant

$$R v = \text{const}$$

Gay-Lussac's law: the change in volume is directly proportional to the change in temperature when the pressure remains constant

$$\frac{v}{T} = \text{const}$$

Combining both laws gives the equation of state:

$$\frac{P v}{T} = \text{const}$$

The ratio of the absolute pressure of the gas multiplied by its volume to the absolute temperature does not change and is denoted by R. This quantity is called **the gas constant**.

$$\frac{P v}{T} = R \quad (6)$$

Thus, we created an equation that relates the gas parameters R, v and T, that is, the equation of state of an ideal gas.

$$R \text{ is the gas constant } \left[\frac{\text{JK}}{\text{kgK}} \right]$$

The physical meaning of the gas constant is:

The gas constant is the expansion work done by 1 kg of gas when it is heated to 10°C under conditions $R = \text{const}$.

The equation of state of an ideal gas for a 1 kg body:

$$Rv = RT \quad (7)$$

Equation of state for m kg of gas:

$$RV = mRT \quad (8)$$

Equation of state for 1 kmol gas:

$$R_{\mu}v = \mu RT \quad (9)$$

μR is the universal gas constant, we calculate its value for normal conditions. Under normal conditions, pressure $P=101325 \text{ Pa}$, temperature $T=273^\circ\text{K}$, and volume $\mu v=22.4 \text{ m}^3/\text{kmol}$.

$$\mu R = \frac{P}{T} = \frac{101325 * 22,4}{273} = 8314 \left[\frac{\text{JK}}{\text{kgK}} \right] \quad (10)$$

The gas constant of any gas is defined as:

$$R_i = \frac{\mu R}{\mu_i} \left[\frac{\text{JK}}{\text{kgK}} \right]$$

μ_i – Find the molecular weight of gas i.

Matter. Find the gas constant of oxygen.

$$R_0 = \frac{8314}{32} = 260 \left[\frac{\text{Ж}}{\text{кгК}} \right]$$

Find the gas constant of air.

$$R_{\text{air}} = \frac{8314}{29} = 287 \left[\frac{\text{Ж}}{\text{кгК}} \right]$$

Equation of state of a real gas

Real gas molecules have their own finite size and mutual attraction forces.

By introducing appropriate corrections to the Mendeleev-Clapeyron equation, an expression can be created that reflects the real gas situation. Van der Waals performed this task in 1873. He included a correction for the size dependence of the two molecules and a correction to account for the mutual forces of attraction between the molecules.

The Mendeleev-Clapeyron equation can be expressed as follows:

$$v = \frac{RT}{P} \quad (11)$$

real gas molecules have a final volume v_{mol} and taking into account the space between the molecules v_{bush} , the volume in which the molecules move is equal to $v - v$, $v = v_{\text{mol}} + v_{\text{bush}}$

$$P = \frac{RT}{v - \epsilon} \quad (12)$$

The impact of real gas molecules on the container wall is weaker. The pressure of a real gas is smaller than the pressure of an ideal gas Δp

$$\Delta p = \frac{a}{v^2}$$

$$P = \frac{RT}{v - \epsilon} - \Delta p$$

Based on these, we write the Van-Der-Waals equation:

$$\left(P + \frac{a}{v^2} \right) (v - \epsilon) = RT \quad (13)$$

where a , v are constant coefficients;

$$\frac{a}{v^2} - \text{internal pressure.}$$

Problem: The pressure of oxygen in a cylinder with a volume of 60 l and a temperature of 25 °C according to the manometer is 1100 kPa, the barometer reading is 745 mm.sim.ust. is equal to Find the mass of oxygen.

Solution:

$$R = R_{\text{bar}} + R_{\text{man}} = 1100 + 99.3 = 1199.3 \text{ kPa}$$

$$m = \frac{PV}{RT} = \frac{1199,3 \cdot 10^3 \cdot 0,06}{260 \cdot 298} = 0,9 \text{ кг}$$

3rd lecture

Heat capacity of ideal gases

In a thermodynamic process, the amount of heat given to a working body is determined by the relative heat capacity of this body. Relative **heat capacity** is the amount of heat required to heat 1 kg of body by 10 °C, and it is denoted by the letter c .

$$c_x = \frac{q}{t_2 - t_1}; \quad \left[\frac{\text{кгЖ}}{\text{кг}^{\circ}\text{C}} \right] \quad (18)$$

q - specific heat quantity, kJ/kg;
 t_1 – initial temperature;
 t_2 is the final temperature of the body;
x is the process type.

Heat capacity is not a constant quantity, as the temperature changes, so does the heat capacity. Heat capacity for ideal gases depends only on temperature.

$$c_x = f(T)$$

Therefore, the concept of 2 different quantities: average heat capacity and real heat capacity is introduced.

$$1) \text{ average heat capacity } c_x = \frac{q}{t_2 - t_1} \quad (19)$$

2) Real heat capacity refers to the average heat capacity when the temperature difference tends to zero.

$$c_{\text{right}} = \lim_{\Delta t \rightarrow 0} \frac{\Delta q}{\Delta t} = \frac{dq}{dt} \quad (20)$$

Relative heat capacity is of 3 types according to the quantity:

$$1) \text{ Mass heat capacity } - c_x \left[\frac{\text{kJ}}{\text{kg}^\circ\text{C}} \right]$$

2) Volumetric heat capacity - c'

$$c'_x = \frac{Q}{V_0(t_2 - t_1)} \left[\frac{\text{kJ}}{\text{m}^3 \text{C}} \right] \quad (21)$$

V_0 is the volume brought to normal conditions.

$$3) \text{ Molar heat capacity } - \mu c_x \left[\frac{\text{kJ}}{\text{kmol}^\circ\text{C}} \right]$$

The relationship between heat capacities:

$$c_x = c'_x v_0 = \frac{\mu c_x}{\mu} \quad (22)$$

In thermodynamic calculations, constant pressure r =heat capacity in the sopst process and constant volume v =heat capacity in the sopst process take place. Heat capacity in the process of constant pressure **isobaric** - mass (sr), **volumetric** (sr^1), **molar heat capacity** (μsr) is called Heat capacity in a constant volume process is **isochoric** - mass (s_v), **volumetric** (s_v^1), **molar heat capacity** (μs_v) is called.

Heat capacity at constant pressure c_r always the heat capacity at constant volume is greater than c_v .

$$c_r > c_v$$

This can be explained as follows, that is, in the process of $R=\text{const}$, some work is done due to the change in volume, while in the process of $V=\text{const}$, no work is done.

Isobar and isochoric heat capacities are related to each other by the following equation:

$$c_r - c_v = R. \text{ This equation is called Mayer's equation.}$$

We write Mayer's equation for molar heat capacity as follows:

$$\mu c_r - \mu c_v = \mu R 8314$$

The ratio of isobaric heat capacity to isochoric heat capacity is often used in thermodynamic calculations.

$$\frac{c_p}{c_v} = k \quad (23)$$

k is called the adiabatic index or Poisson's ratio.

We express the linear dependence of heat capacity on temperature by the following expression:

$$c = a + bt$$

In this expression, the coefficients a and b are constant quantities and depend on the progress of the process.

$c_m = \frac{c_1 + c_2}{2} = \frac{a + bt_1 + a + bt_2}{2}$ - writing the average heat capacity as a function of temperature.

$q = \left[a + \frac{b}{2}(t_1 + t_2) \right] (t_2 - t_1)$ is an expression for determining the amount of heat.

The dependence of the heat capacity on the temperature curve is determined from the following expression:

$$c = a + bt + dt^2$$

$$q = c_m \int_{t_1}^{t_2} (t_2 - t_1) \quad (24)$$

In thermodynamic calculations, the average heat capacity is determined from the following expression:

$$c_{1,2} = \frac{c|_0^t t_2 - c|_0^t t_1}{t_2 - t_1} \quad (25)$$

If the heat capacity does not depend on the temperature (s=sonst), its value is determined using the following table.

Gases	μc_v	μc_r	k
1 atom	12.6	20.9	1.66
2 atoms	20.9	29.2	1.4
3 and polyatomic	29.2	37.3	1.33

The following expressions are used for the heat capacity of gas mixtures:

$$c_{ar} = \sum_{i=1}^n g_i c_{pi} \quad \text{and} \quad c_v = \sum_{i=1}^n g_i c_{vi}$$

Volumetric heat capacity of the mixture:

$$c'_p = \sum_{i=1}^n r_i c'_{pi} \quad \text{and} \quad c'_v = \sum_{i=1}^n r_i c'_{vi}$$

Molar heat capacity of mixture:

$$m s_r = \sum_{i=1}^n r_i m c'_p \quad \text{and} \quad m s_v = \sum_{i=1}^n r_i m c'_{vi}$$

CONTROL QUESTIONS

1. Define ideal and real gases.
2. Write the equation of state of an ideal gas.
3. Write down the equation of state of a real gas.
4. What is an ideal gas mixture?
5. What is the composition of ideal gas mixtures?
6. What is heat capacity used for?
7. What is the heat capacity?
8. State the Mayer equation.

4th lecture
THE FIRST LAW OF THERMODYNAMICS

Amount of work and heat in a thermodynamic process

A change in the state of a body as a result of the interaction of the external environment is called **a thermodynamic process** .

A body in a state of equilibrium is a state in which , R, T and other physical properties are the same at each of its points . ν

If the gas in the cylinder is compressed or expanded with the help of a piston, the working body has different T and R at any point in the volume of the cylinder - this condition is called **an unbalanced condition** .

In thermodynamic processes, bodies exchange energy with each other, as a result of which the energy of one body increases and the other decreases.

In processes, body energy can be transferred from one body to another body in two different ways.

The first method:

In this case, energy is transferred from a hot body to a body that is colder than it. The amount of energy in this method is called **the amount of heat**, and the method of transfer is called the transfer of energy in the form of heat. Heat is denoted by Q, measured in J.

The second method: Under the influence of external pressure, the body changes its size. This method is called the transfer of energy in the form of work, and the amount of energy transferred is called **work** . Work is denoted by L, measured in J.

In general, energy is transferred both in the form of heat and in the form of work.

The work of 1 kg of the working body is determined by ℓ , $\left[\frac{\kappa \mathcal{K}}{\kappa \mathcal{Z}} \right]$; amount of heat is determined by

$$q, \left[\frac{\kappa \mathcal{K}}{\kappa \mathcal{Z}} \right].$$

Calculate the work done by the gas:

To consider the expression of work, we consider the change in gas volume in process 1-2.

Infinitesimal change in volume dv infinitesimal work for 1kg of gas:

$$d\ell = p dv \quad (26)$$

The work done in changing the volume of the gas from v_1 to v_2

$$\ell = \int_{v_1}^{v_2} p dv \quad \left[\frac{\kappa \mathcal{K}}{\kappa \mathcal{Z}} \right] \quad (27)$$

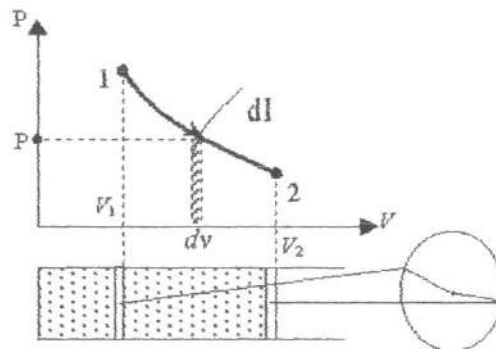


Figure 2. p- v diagram

1-2-3-4-1 surface in pv diagram is equal to work done and this diagram is called **work diagram** . The work done by a gas cannot be a function of state. In gas expansion $dv > 0$, work done $\ell > 0$ is positive, in contraction $dv < 0$, work done $\ell < 0$ is negative, if the volume does not change, it is equal to $\ell = 0$.

Internal energy and enthalpy

The internal energy of the body consists of initial, kinetic and potential energy of molecules.

$$U = U_{e_0} + U_{e_{kin}} + U_{e_{pot}} \quad (28)$$

For ideal gases:

$$U = U_{e_{hates}}$$

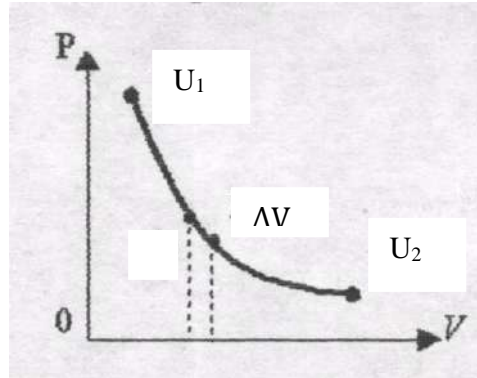


Figure 3.

Internal energy is a function of pressure, volume and temperature, $U = f(P, v, T)$

$$U = f(P)$$

$$u = f(v)$$

$$U = f(T)$$

If we show this written expression in the Pv diagram, it is expressed as follows, and it changes sharply with the change of P, v, T and changes with the change of the last parameters.

Internal energy does not depend on which way an object moves from one state to another, therefore

$$U_1 = U_2 = U$$

The change of internal energy of a body in a process does not depend on the nature of the process and is determined by the initial and final state of the body.

$$\Delta U = U_1 - U_2 = S_v(t_2 - t_1)$$

The sum of the internal energy of the system U and the pressure of the system P multiplied by the volume of the system V is called enthalpy and is defined by h .

$$H = U + pV \text{ [J], [kJ]} \quad (29)$$

Relative enthalpy:

$$h = u + pV \text{ [J/kg], [kJ/kg]} \quad (30)$$

Enthalpy and internal energy are state parameters and are called **caloric properties of matter**.

Enthalpy is a quantity that depends on temperature.

$$h = f(T)$$

$$dh = c_p dT$$

Enthalpy is also a state parameter and changes dramatically as P, v, T change, so $h = f(P, v, T)$.

The last written expression can also be explained by drawing it on the $P-v$ diagram.

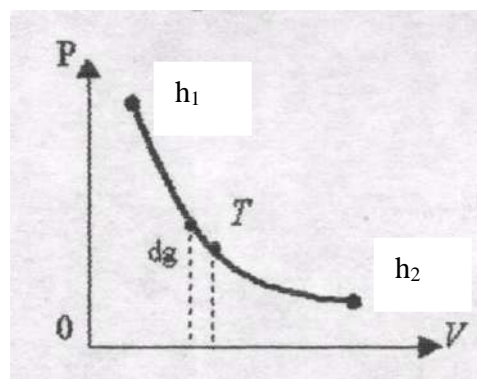


Figure 4.

Since enthalpy is a state parameter, it varies depending on the initial and final parameters of the body, so

$$h_{1a2} = h_{1b2} = h_{1c2}$$

The first law of thermodynamics

The first law of thermodynamics is an application of the law of conservation and circulation of energy.

Definition: The amount of heat supplied to the system is spent on changing the internal energy of the system and doing work.

$$Q = \Delta U + L \text{ [J]}$$

The first law of thermodynamics for a 1 kg body:

$$q = \Delta u + \ell \left[\frac{\text{kJ}}{\text{kg}} \right]$$

Δu is the change in internal energy

ℓ is the work done.

Analytical expression of the first law of thermodynamics:

$$dq = du + d\ell \quad (31)$$

The expression of the work is as follows:

$$d\ell = pdv \quad (32)$$

Writing the first law using internal energy:

$$dq = du + pdv \quad (33)$$

We derive the first law written using enthalpy:

$$pdv = d(p \cdot v) - vdp \quad (34)$$

$$dq = du + d(p \cdot v) - vdp = d(u + pv) - vdp \quad (35)$$

we define $u + pv = h$.

Write using enthalpy

$$dq = dh - vdp \quad (36)$$

The amount of heat depends on the nature of the thermodynamic process, writing the analytical expression of the first law using the heat capacity has the following form:

$$dq = c_v dt + pdv \quad du = c_v dT \quad (37)$$

$$dq = c_p dT - vdp \quad dh = c_p dT \quad (38)$$

CONTROL QUESTIONS

1. How is the work performed by a worker defined?
2. What is internal energy?
3. What is enthalpy?
4. Define the first law of thermodynamics.
5. Write down the analytical expression of the first law of thermodynamics.

7th lecture

THE SECOND LAW OF THERMODYNAMICS

The second law of thermodynamics

The first law of thermodynamics states that heat is converted to work and work is converted to heat, but it does not specify the conditions under which these conversions occur.

The first law of thermodynamics cannot answer the question of heat transfer from a hot body to a cold body and vice versa. Heat flows from a hot body to a cold body. It is possible to change the direction of the amount of heat due to the performance of work.

In nature, work is converted into heat due to friction, impact, etc.

In heat machines, heat is converted to work when there is a temperature difference between the heat source and the coolers. In this case, not all heat is converted into work.

The second law of thermodynamics states the direction and conditions of heat flow.

Mathematical expression of the second law of thermodynamics:

$$ds \geq \frac{dQ}{T} \quad (86)$$

where S is entropy;

dQ is the amount of heat received from the heat source;

T is the absolute temperature of the heat source.

The equals sign is for return processes; the inequality sign is used for irreversible processes.

Entropy

Entropy is also a state parameter, denoted by the letter S, and means change. When heat is applied to a system, its state changes. The heat given in the elemental part is equal to dq and temperature T.

$$\frac{dq}{T} = ds \quad (39)$$

Entropy is such a function of the state of the system that the infinitesimal change of this function in the reversible process is equal to the ratio of the infinitesimal amount of heat introduced into this system to the temperature in the state in which this heat was introduced.

$$S = \left[\frac{\kappa \mathcal{K}}{\kappa \text{e}^{\circ} C} \right] \quad (40)$$

$$dq = T \cdot ds$$

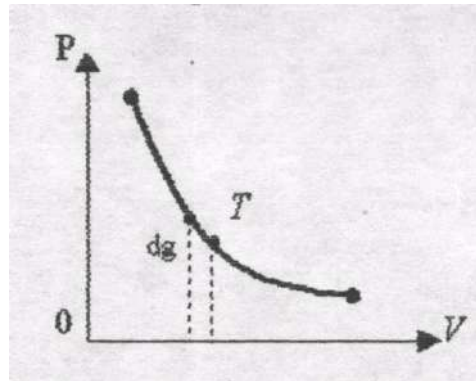


Figure 5

If: 1) $ds > 0$, $S_2 > S_1$ entropy increases

$dq > 0$, heat increases.

2) $ds < 0$, $S_2 < S_1$ entropy decreases

$dq < 0$ heat is released.

3) $ds = 0$, $S_2 = S_1$, $dq = 0$ adiabatic process.

Once we have an understanding of entropy, we can draw a heat diagram Ts diagram for any process taking place and explain the change in temperature and entropy in that process. A Ts diagram is a diagram that defines the heat of a process.

The second law of thermodynamics has many definitions. The main ones are:

Definition of Sadi Carnot: To convert heat into mechanical work, there must be a temperature difference (ie heat source and heat sink).

Clausius definition: Heat cannot transfer from a cold body to a hot body without compensation of its own.

Thomson definition: not all of the heat supplied to heat engines can be converted into work. Some of this heat is transferred to the cooler. If heat were completely converted to work, Type II perpetual motion machines would be created, but such motors cannot be created.

8th lecture

WATER VAPOR

Thermodynamic parameters of evaporation and steam

It is known that all substances can be in solid, liquid and gaseous state (phases) depending on temperature and pressure. The transition of a substance from one state to another is called a **phase change** or **phase transition**. For example, the transition of the liquid phase to the gas phase is the formation of steam; and the transition from the gas phase to the liquid phase is called **condensation**.

Evaporation: The change of substance from liquid state to vapor state is called **evaporation**. In this case, part of the molecules separates from the surface of the liquid and forms vapor on it. In evaporation, the released molecules overcome the gravitational force of the molecules remaining on the surface, that is, they do work against these forces. Molecules do this at the expense of their thermal motion, kinetic energy. It is known that not all molecules do this. Only molecules with very high kinetic energy can do this.

If the temperature of the liquid is kept constant, i.e. heat is continuously applied to it, then the number of molecules flying out will increase continuously. However, due to the irregular movement of vapor molecules, when they change from liquid to vapor, the opposite process - **condensation** - also occurs. If the evaporation takes place in a closed container, then the amount of vapor increases until equilibrium is reached, that is, until the amounts of liquid and vapor are constant. This means that the number of molecules leaving the liquid per unit time is equal to the number of molecules returning to the liquid per unit time.

Steam in dynamic equilibrium with its liquid is called **saturated steam**. At equilibrium, the density of steam is constant, this density corresponds to a certain pressure. This pressure is called **elasticity of saturated steam**.

Saturated vapor pressure increases with temperature. The higher the temperature, the more molecules of the liquid go into the gas phase, and the higher the equilibrium density and, therefore, the pressure of the vapor. Vapor that touches the liquid and saturates the space above it is called **saturated wet vapor**.

Saturated moisture vapor is a mixture of steam and very small water droplets. The amount of liquid particles in the steam determines how dry or wet the steam is.

If the liquid is heated at a constant pressure, the speed of movement of its molecules throughout the volume increases and the formation of steam increases. At a certain temperature, which strictly corresponds to the pressure at which steam is formed, the evaporation process turns into a boiling process.

Boiling: Intensive turning of a liquid into steam not only from its free surface, but throughout its volume, and the rapid formation and multiplication of steam bubbles is called **boiling**.

The temperature and pressure at which boiling occurs are related. They are **the saturation temperature** t_m and **saturation pressure** p_m is called

Steam with temperature and pressure equal to saturation pressure and temperature, but without water particles, is called **dry saturated steam**.

Vapor density of saturated steam: Like the amount of wet steam, the amount of dry steam can vary from 0 to 1 during steam formation.

If 1 kg of steam contains X kg of dry steam and $(1 - X)$ kg of moisture, then the quantity X is called the steam content or **the degree of dryness of the steam**, that is, this quantity is the amount of dry steam in the wet steam.

$(1 - X)$ - the quantity is called **moisture content** or **humidity level of steam** .
 For example, if $X = 0.85$, $(1 - X) = (1 - 0.85) = 0.15$, i.e., saturated wet steam is 85% dry steam, 15% there will be water.

Superheated Steam : If heat is applied to saturated dry steam at constant pressure, its temperature rises, its volume increases and the saturated dry steam becomes superheated steam. The degree of superheating of steam, Δt , is determined from the temperature difference:

$$\Delta t = t - t_m \quad (90)$$

t - temperature of superheated steam;
 $t_m - t$ is the temperature of the generated dry steam.

P – V of water vapor , Ts and hs diagrams

When considering how the process of steam formation is depicted on the *pv diagram*, we include the following designations :

- a) all parameters of the liquid at 0°S with the "zero" index (t_0, v_0, i_0, S_0).
- b) parameters at the saturation temperature with one line (t', v', i', S').
- v) the parameters of saturated dry steam with two bars (v'', i', S'').
- g) saturated wet steam parameters with index x (v_x, i_x, S_x).
- d) We set the superheated steam parameters without index (v, i, S).

Assume that there is 1 kg of water under the piston in a cylinder and it needs to be converted into steam. Let us assume that a load - *r force is applied* to the piston of the cylinder from the outside , and this force ensures that the pressure inside the cylinder remains constant.

In the diagram, the relative volume of water and the generated steam is placed on the abscissa axis, and the pressure in the cylinder is placed on the ordinate axis. It should be noted that the curves in the diagram do not correspond to the actual ratio of water and steam volumes. This is because the volume of water at low pressures is negligible compared to the volume of saturated steam at that pressure. Thus, if we follow strict proportions when constructing a diagram and determine the volume of water with a section expressed in millimeters on the abscissa axis, then it would be necessary to express the volume of saturated dry steam in meters. It was necessary to start drawing up the diagram by heating the liquid from 0°C to boiling temperature. But in this interval, the volume of water changes so little that it is not important to depict it in a diagram.

Therefore, the formation of steam PV we start with the temperature corresponding to the boiling of water in the diagram:

The beginning of steam generation is marked by point 1^1 on the diagram . This is 1 kg of water at saturation temperature and pressure (in $r_1; t_1$) in the cylinder v_1 the word that occupies the volume. At the same time, there will be only one-phase system - water in the cylinder. As heat is added to the cylinder, the water gradually turns into steam. The process of steam formation at constant pressure is $1^1 - 1^{11}$ isobar. This isobar is also an isotherm at the same time, because the heat supplied at this time is not spent on increasing the temperature of water and steam, but on molecules overcoming the force of gravity and the expansion of steam.

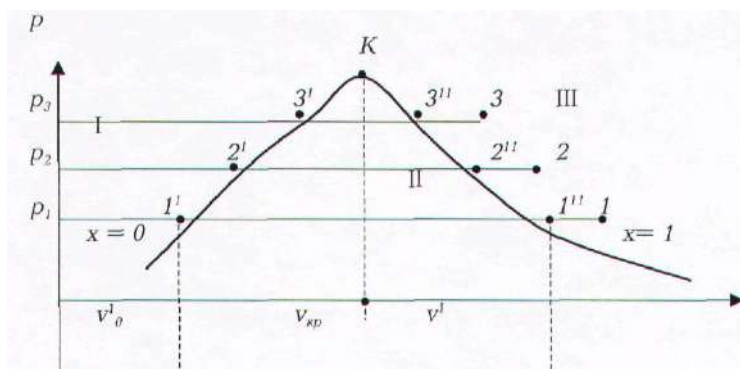


Figure 14. $p v$ diagram of water vapor

At this time, there is a two-phase medium in the cylinder: water - steam, this medium is called wet steam.

1^{11} , the last particle of liquid turns into vapor. At this point, a given 1 kg of water is fully converted into 1 kg of saturated dry steam. Another phase medium appears in the cylinder - from the saturation temperature and pressure, parameters v^{11}, p^{11}, t^{11} is saturated **dry steam**.

1^{11} can go in the direction of superheating of steam or, on the contrary, in the direction of condensation.

If heat is continued to be supplied to the cylinder at constant pressure, then the conversion of saturated dry steam to superheated steam continues at the $1^{11} - 1$ isobar, which is no longer isothermal because the heat supplied it is used to heat up the steam and increase its temperature.

If heat is removed from saturated dry steam (point 1^{11}) at constant pressure and temperature, then 1 kg of saturated steam gradually condenses along the line $1^{11} - 1$ and turns into 1 kg of water (1^1 points). Thus, the process that goes from left to right along the line $1^1 - 1^{11}$ is called the steam formation process, and the process that goes from right to left along the line $1^{11} - 1^1$ is called the condensation process.

Now 1 kg of water $r_2 > r_1$ we will consider the process of turning into steam under pressure. It is known that with increasing pressure, the boiling point also increases. Boiling temperature of water $t_2 > t_1$ heats up to volume $v_2 > v_1$ increases up to Therefore, the point where water begins to boil moves to the right from point $2^1, 1^1$. As the pressure increases, the density of saturated dry steam increases $\left(v = \frac{1}{\rho} \right)$, which means the specific volume decreases. Therefore, point 2^{11} moves to

the left of point 1^{11} . If we increase the pressure, the specific volume of saturated dry steam becomes smaller, the difference between the volumes of water and steam at a certain temperature and corresponding pressure becomes zero. The boiling point of water and the end point of steam formation coincide at some point K . This point K is called the critical point of the substance. At the critical point, the difference between the liquid and its saturated vapor disappears. The relative volume and density of liquid and vapor remain the same. At the critical temperature and higher temperatures, water becomes like a gas, and when the pressure increases, its volume decreases. This state can be called a gaseous state.

Thus, the substance in the critical state is single-phase and has the properties of both gas and liquid bodies at the same time.

14, I is the state of sloppiness; II - saturated vapor state; III is a state of superheated steam.

Ts diagram of water vapor. This diagram is of great importance in the study of processes with water vapor and in their calculation. The important part of the diagram is that the area under the drawn curve represents the heat being transferred to and removed from the workpiece.

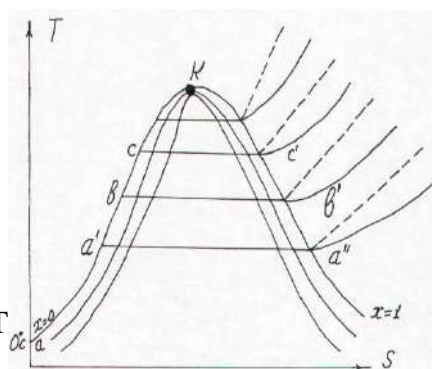


Figure 15. Ts

Each point on the diagram characterizes the exact position of the body. Since the entropy of the liquid at $0^{\circ}C$ is zero, it is located on the ordinate axis in the Ts coordinate. The heating of water from $0^{\circ}C$ to saturation temperature (t_T) continues with the process aa' . The process of steam formation ($t_T = \text{const}$) is represented by the horizontal line $a'a''$. And steam heating $a''d$

represented by an isobar line. But the steam heating isobar is steeper than the water heating isobar, because the subheating temperature is higher than the heating temperature. If we continue to pass such lines, the lines will converge at point K.

h - S diagrams of water vapor. The most modern tables and diagrams for water vapor were developed by Professor MPVukalovich. With the help of these diagrams, parameters such as saturation temperature, pressure, specific volume, enthalpy, entropy, dryness level of water vapor are determined. The *h - s diagram* for water vapor was first proposed by Mole in 1904. Currently, heat-technical calculations use the *h - s diagram* compiled by MPVukalovich. When constructing the *h - s diagram*, the enthalpy values are placed along the ordinate axis, and the entropy values along the abscissa. The third point of water is taken as the coordinate origin. The use of *Ts* and *h - s diagrams* of water vapor in the calculation of heat processes greatly simplifies heat-technical calculations. In most cases, tables are used to find water vapor. These tables help to determine all parameters of water vapor in terms of temperature and pressure.

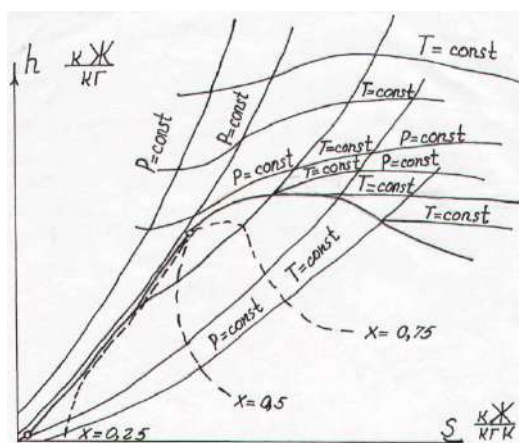


Figure 16. *h - s* diagram of water vapor

CONTROL QUESTIONS

1. What are the main properties of water vapor?
2. How many types of water vapor are divided into?
3. What is called moist saturated steam?
4. What are the parameters of dry saturated steam?
5. Superheated steam is characterized by what parameters?
6. Draw the *RV* diagram of water vapor.
7. Explain the changes in the parameters of water vapor in the liquid state on the *Ts* diagram.
8. How convenient is the *hs* diagram of water vapor?

9th lecture STEAM TURBINE PLANTS

In steam turbine devices, water vapor serves as the main working medium. In these devices, the thermal energy of water vapor is converted into mechanical energy, and in an electric generator, it is converted into electrical energy. The effect of drawing the appearance of steam turbine devices is as follows:

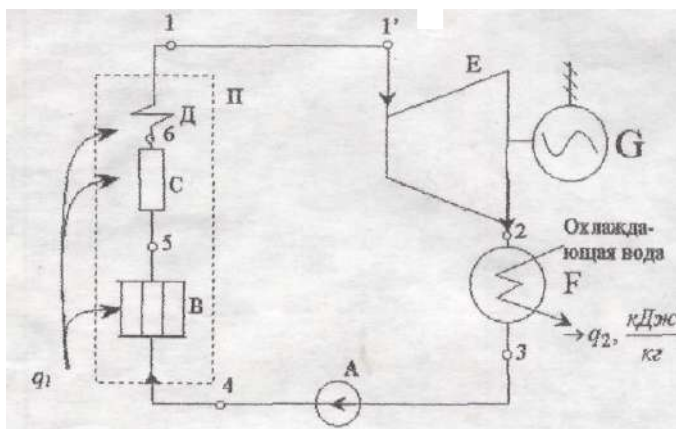
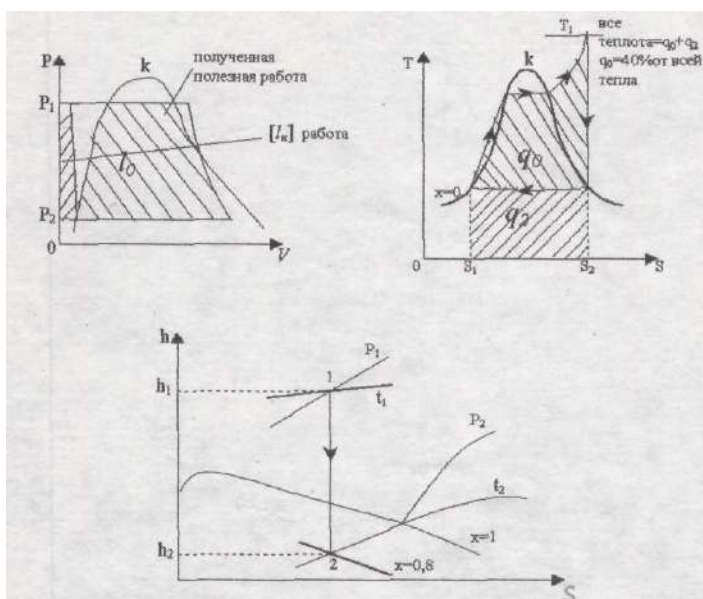


Figure 21. A drawing of a steam turbine device:
A-pump; P-steam boiler: V-water economizer, S-evaporating part, D- steam heater; Ye- steam turbine G-electric generator; F-capacitor

Chemically purified water and fuel are sent to the steam boiler, where the combustion process is carried out. In the water economizer, water is heated to boiling point, then in the evaporator section, moist saturated steam is produced. The steam is sent to a steam heater. There, the steam is further heated and converted into superheated steam. The superheated steam hits the blades of the turbine and creates motion, that is, the thermal energy of the steam is first converted into kinetic energy (in the turbine nozzle) and then into mechanical energy. Since the used steam is under very low pressure, it falls into the condenser and turns into water again, such a mass is called condensate.



22 . PV, Ts, and hs diagrams of the Rankine cycle: adiabatic expansion process in turbine 1-2; 2-3 working process in the capacitor; 3-4 pump work; 4-5 economizer work; Steam generation in the 5-6 steam boiler; 6-1 steam heating in a steam heater

With the help of water, the pressure is increased, it is sent to the steam boiler and all the processes are repeated. Such a cycle is called a **Rankine cycle**. Its FIC is determined as follows:

$$\eta_t = \frac{h_1 - h_2}{h_1 - h_2'} \quad (101)$$

where: h_1 , h_2 are the initial and final enthalpy of steam during the adiabatic expansion process in the turbine.

$h_2' = Sp_{k t 2}$; - enthalpy of boiling water at pressure R_k . The quantities in this expression are taken from the water vapor diagram. The next task is to increase the FIK of this cycle.

CONTROL QUESTIONS

1. Explain steam turbine devices.
2. Interpret the PV and Ts diagram of the Rankine cycle.
3. Write down the expression of Rankine cycle FIK.

10th lecture
SECTION II
HEAT TRANSFER of heat and mass transfer theory

During its historical development, mankind has been using thermal energy to a certain extent to meet various vital needs.

At first, this was in the form of using various protective devices to protect people from the cold, heating them naturally from the sun's rays or by lighting fires, then later, from cooking to the production of heat energy on an industrial scale, and from it, energy, heating supply systems, the food processing industry and the like have reached the level of using modern and automated technical means to meet the needs of consumers.

By the end of the 20th century, the scale of thermal energy production on our planet has reached such a level that now, on the one hand, it has accelerated the expiration of the fuel reserves formed on our earth for several tens of millions of years, and on the other hand, the combustion products of the environment with a sharp increase in the level of pollution and, as a result, led to significant changes in the climate of the planet. Naturally, one of the main directions of prevention of the further rapid development of these processes, which are negative for human development, is the rational and more efficient use of the generated thermal energy in various aspects of the national economy. The positive solution of this problem to a certain extent requires a deep analysis, accurate calculation of the processes of heat transfer and reception occurring in technical means based on the production and use of thermal energy, and in necessary cases, the performance of appropriate experimental research.

The theory of heat exchange is the science of the laws of heat distribution and transfer from one body to another, and together with the science of technical thermodynamics, it forms Heat engineering.

It is known that heat naturally flows only from hot (hot) bodies to cold (cold) bodies, and as a result of this process, hot bodies cool down and cold bodies warm up. But this process, which at first seemed very simple to us, actually consists of a set of heat exchange processes, such as heat conduction, convective heat exchange and radiation, which are quite complex and have different mechanisms.

The process of heat transfer is based on the transfer of heat from parts of bodies with a high temperature to parts with a low temperature by means of the thermal temperature of these microscopic particles. This process is sometimes called conductive heat transfer process in thermal engineering and ideally it is specific only to solid bodies.

Heat transfer in liquids and gases is carried out as a result of the interaction of their constituent macroscopic parts, and this process is called the process of convective heat exchange. Usually, the process of convective heat exchange occurs in combination with the process of heat conduction.

The process of heat exchange by radiation is based on the transfer of heat from hot bodies to cold bodies by means of electromagnetic waves. The process of heat exchange between the surface of a solid body and gases or liquids can usually be carried out by means of radiation, in addition to heat exchange by touching each other. Such a process is called the radiative convective heat exchange process in heat engineering and includes all three processes described above and of different nature.

One of the most common heat exchange processes in life and in various fields of technology is separated by a wall consisting of a solid body. A process that occurs between two liquid or gaseous media, such a process is called a heat transfer process in the theory and practice of heat engineering.

In most cases, the heat transfer process occurs in combination with a certain number of mass transfer processes, such as evaporation, condensation, and such a process is called the heat and mass transfer process.

11th lecture HEAT CONDUCTIVITY

Basic concepts

Temperature field. The set of temperatures at different points of the body is called the temperature field.

$$t=f(x,y,z, \tau)$$

τ - time.

The temperature field exists in 2 different states:

1. Stable temperature field (temperature does not change over time).
2. Unstable temperature field (temperature changes over time).

The temperature field is three-dimensional $t=f(x,u,z)$, two-dimensional $t = f(x,u)$ and one-dimensional $t = (x)$.

Temperature gradient. If we connect the points of the body with the same temperature, an isothermal surface is formed. Consider 2 isothermal surfaces: a surface with temperature t and a surface with temperature multiple of t . Δ These surfaces do not intersect. If we move different directions from point A to the isothermal surface, the temperature change will be different. If we move along the direction normal to the isothermal surface, the temperature change will be higher.

the temperature change (t) Δ to the normal distance n between the isotherms is called **the temperature gradient** .

$$\text{grad } t = \lim_{\Delta n \rightarrow 0} \left(\frac{\Delta t}{\Delta n} \right) = \frac{\partial t}{\partial n} \quad (184)$$

Differential equation of heat transfer. The differential equation of heat conduction determines the relationship between the quantities involved in heat transfer through heat conduction.

$$\frac{\partial t}{\partial \tau} = a \nabla^2 t + \frac{q_v}{c \rho} \quad (185)$$

a – temperature conductivity coefficient; $a = \frac{\lambda}{c \cdot \rho}$;

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \text{ Laplace operator}$$

q_v is the internal heat source of the body.

Single value conditions. In order to apply the differential equation to a concrete phenomenon, it is necessary to know the conditions of single-valuedness.

1. Geometric condition (body dimensions, structure);
2. Physical condition (physical properties of the body);
3. Time condition (stable, unstable state);
4. Boundary conditions:

I order boundary condition $t = f(x,u,z, \tau)$

The second-order boundary condition $q = f(x, u, z, \tau)$

Third- order boundary condition liquid temperature: t_{c_1}, t_{c_2}

$$\alpha(t_c - t_{c_0}) = -\lambda \left(\frac{\partial t}{\partial n} \right)$$

Fourier's law. The basic law of heat conduction is Fourier's law. According to Fourier's law, the amount of heat passing through an isothermal dF (m^2) surface in a unit of time t (s) is proportional to the temperature gradient dQ (J) $\partial t / \partial n$ (K/m):

$$dQ = -\lambda (\partial t / \partial n) \cdot dF \cdot dt \quad (186)$$

where: λ is the heat transfer coefficient (W/mK), a physical quantity of the object, the value of which is numerically equal to the specific heat flow passing through the unit layer of the wall in a unit of time when the temperature difference is $1^\circ C$.

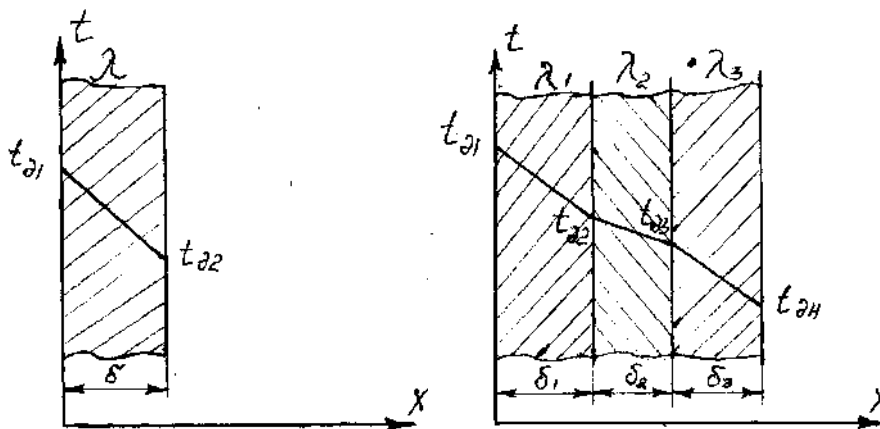
The amount of heat that passes through an isothermal surface per unit of time is called **the heat flux density**.

$$q = Q / F \cdot t$$

$$q = -l (\partial t / \partial n), W/m^2 \quad (187)$$

A flat single-layer wall in a stable state thermal conductivity

thickness d (mm) and heat transfer coefficient l is given (Fig. 41). Temperatures on the outer surface and inner surface of the wall are constant, t_{d1} and t_{d2} . Under the given conditions, the temperature field is one-dimensional, the temperature changes only in the direction perpendicular to the wall surface.



We write the Fourier equation for this flat wall:

$$q = -l \frac{\partial t}{\partial x} \quad (188)$$

this expression by dt

$$dt = - \frac{q}{\lambda} dx \quad (189)$$

Integrating the expression (189),

$$t = - \frac{q}{\lambda} x + s \quad (190)$$

we get the expression

s and t from the boundary condition, $s = t_{d1}$ when $x=0$, and $t = t_{d2}$ when $x = b$, and we get the expression for calculating the heat flux density:

$$q = (l / d) (t_{d1} - t_{d2}) W/m^2 \quad (191)$$

here: $t_{d1} - t_{d2} = \Delta t$ – temperature difference;

l / d – thermal conductivity of the wall, $W/m^2 \cdot K$,

d/l - thermal resistance of the wall.

The total amount of heat passing through the surface F of the wall in time t

$$Q = q F t = (l/d)(t_{d1} - t_{d2}) F t \quad (192)$$

For a flat multilayer wall (for example, for a 3-layer wall (Fig. 7)), the heat flux density is found by the following expression.

$$q = \frac{t_{\delta_1} - t_{\delta_2}}{\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \dots + \frac{\delta_3}{\lambda_3}} = \frac{t_{\delta_1} - t_{\delta_{n+1}}}{\sum_{i=1}^n \frac{\delta_i}{\lambda_i}}, \text{ W/m}^2 \quad (193)$$

where: n is the number of layers;

$$\sum_{i=1}^n \frac{\delta_i}{\lambda_i} - \text{full thermal resistance of multi-layer wall.}$$

The temperatures between the layers in contact with each other can be found from the following expressions:

$$\begin{aligned} t_{\delta_2} &= t_{\delta_1} - q \frac{\delta_1}{\lambda_1} \\ t_{\delta_3} &= t_{\delta_2} - q \frac{\delta_2}{\lambda_2} \\ t_{\delta_4} &= t_{\delta_3} - q \frac{\delta_3}{\lambda_3} \end{aligned} \quad (194)$$

The direction of temperature change in a multi-layered flat wall is represented by a broken line.

Single-layer cylindrical in steady state thermal conductivity of the wall

$\lambda = \text{const}$, the temperature on the cylindrical wall changes according to the logarithmic curve and is expressed by the following equation.

$$t = t_{\delta_1} - (t_{\delta_1} - t_{\delta_2}) \frac{\ln \frac{d}{d_1}}{\ln \frac{d_2}{d_1}} \quad \text{0 S, (195)}$$

The amount of heat passing through a single-layer cylindrical wall of length ℓ is determined by the following expression:

$$Q = (2\pi\lambda\ell(t_{\delta_1} - t_{\delta_2})) / \ln \frac{d_2}{d_1} \text{ W, (196)}$$

The heat flux density per unit internal surface of the cylindrical wall can be given by:

$$q_1 = \frac{Q}{\pi d_1 \ell} = \frac{2\lambda(t_{\delta_1} - t_{\delta_2})}{d_1 \cdot \ln(d_2/d_1)} \text{ W/m, (197)}$$

and to the external surface unit:

$$q_2 = \frac{Q}{\pi d_2 \ell} = \frac{2\lambda(t_{\delta_1} - t_{\delta_2})}{d_2 \cdot \ln(d_2/d_1)} \text{ W/m, (198)}$$

and along the length of the pipe: (linear density of heat flow)

$$q_\ell = \frac{Q}{\ell} = \frac{\pi(t_{\partial_1} - t_{\partial_2})}{1/2\lambda \cdot \ln(d_2/d_1)} \text{ W/m. (199)}$$

For a multi-layer wall (two-layer) the linear heat flux density of the wall:

$$q_\ell = \frac{\pi(t_{\partial_1} - t_{\partial_3})}{1/2\lambda_1 \cdot \ln(d_2/d_1) + 1/2\lambda_2 \cdot \ln(d_3/d_2)} \text{ W/m, (200)}$$

Boundary temperatures between layers:

$$t_{\partial_2} = t_{\partial_1} - q_\ell \frac{1}{\pi} \cdot \frac{1}{2\lambda_1} \cdot \ln \frac{d_2}{d_1} \text{ (201)}$$

CONTROL QUESTIONS

1. What is the phenomenon of heat transfer?
2. Explain the conditions for the occurrence of the phenomenon of heat conduction.
3. State the conditions of single value?
4. State Fourier's law?
5. Explain the thermal conductivity of a single-layer flat wall.
6. Explain the thermal conductivity of a single and multi-layered cylindrical wall.
7. Determine the temperatures on the wall surfaces?

12th lecture CONVECTIVE HEAT EXCHANGE (GIVING HEAT) General concepts

Convective heat transfer or **heat transfer** refers to heat transfer between a solid body and a liquid or gas. Convective heat exchange is carried out simultaneously by two methods: convection and heat conduction. In this case, the heat dissipation depends continuously on the moving medium (liquid or gas).

In most cases, the rate of heat transfer depends on the speed of movement of the heat carrier relative to the heat transfer surface. The movement of the heat carrier can be free or forced.

Free movement or **free convection** means the movement of a liquid or gas in a system under the influence of an external non-uniform mass force field (gravitational, magnetic, electric or inertial field forces).

Forced motion or **forced convection** is the same area of external surface forces imposed on the system boundaries or mass forces exerted on the fluid within the system; is the movement that occurs due to the kinetic energy given to the liquid outside the system.

In practice, free convection in liquids or gases occurs due to the difference in density of hot and cold particles of the liquid.

Forced convection occurs under the influence of an external force such as a fan or pump.

The flow pattern of the fluid is the basis for the occurrence of convective heat exchange.

In 1884, Reynolds, based on his experiments, showed that the movement of a liquid can be **laminar** or **turbulent**.

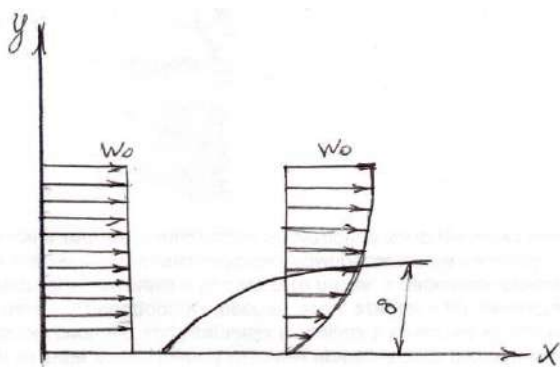
Laminar flow is the occurrence of liquid particles without uniform mixing . In this case, the normal heat transfer in the flow direction is carried out mainly by heat conduction. Since the thermal conductivity of the liquid is very small, the speed will not be very high.

When the flow rate exceeds a certain value, the state of motion changes dramatically, that is, an irregular flow occurs and the flow becomes completely mixed. Such flow is called **turbulent flow** .

In a turbulent flow, heat is dispersed in the flow by heat conduction due to the mixing of all particles, so the heat exchange is higher in a turbulent flow.

Reynolds showed that the order of fluid flow in a pipe is determined by a dimensionless value, this value is called **the Reynolds number** . Laminar liquid or gas moves uniformly in layers ($Re < 2300$), in turbulent flow layers move together ($Re > 10,000$).

The movement of liquid through the pipe has its own characteristics. Let's consider the movement of a fluid along a pipe with a constant speed (Fig. 43).



As the liquid begins to flow through the pipe, the liquid particles near the walls stick to the walls due to friction. As a result, the velocity near the walls decreases to zero. Since the fluid consumption does not change, the velocity increases in the middle of the pipe section. In this case, a hydrodynamic boundary layer is formed on the pipe walls. The thickness of this layer d increases downstream. As the speed increases, the thickness of the boundary layer increases. As the viscosity of the liquid increases, the thickness of the layer also increases. This in turn reduces heat transfer from the liquid to the surface of the solid.

When the fluid is in laminar motion along the pipe, the heat exchange is less due to the boundary layer formed, when the turbulent motion occurs, the thickness of the boundary layer decreases due to the increase in the movement speed of the immobilized liquid particles, as a result, the heat exchange increases.

The Newton-Richmann law is used to calculate the heat transfer process:

$$Q = a (t_d - t_m) F \quad (202)$$

where: Q is heat flow, W ;

a – heat transfer coefficient, $W/m^2 K$;

t_m – ambient temperature, $^{\circ}C$,

t_d – wall surface temperature, $^{\circ}C$;

F - heat exchange surface, m^2 .

The coefficient of heat transfer α is numerically equal to the amount of heat given when the temperature difference $(t_d - t_m)$ from the surface of $1 m^2$ to the environment or from the environment to the surface of $1 m^2$ is equal to $1^{\circ}C$ in 1 second, if $t_d > t_m$, $\Delta t = t_d - t_m$; if $t_m > t_d$ then $\Delta t = t_m - t_d$.

Heat flux density:

$$q = a \Delta t \text{ is equal to } W/m^2 \cdot (203)$$

Basics of similarity theory

Convective heat transfer is described by multivariable and univariate differential equations.

Analytical calculation of the heat transfer coefficient, solving the equations causes a lot of difficulties, so it is of great importance to determine the heat transfer coefficient experimentally based on the similarity theory.

The theory of similarity allows to determine whether the results obtained in experimental devices can be applied to other similar phenomena, that is, the processes are similar.

The main similarity criteria (numbers) of convective heat exchange are Reynolds, Grashof, Prandtl and Nusselt criteria.

$$Re = \frac{wx}{\nu} - \text{this equality expresses the ratio of flow inertia force to viscosity force.}$$

$$Gr = \frac{g\beta \Delta t x^3}{\nu^2} - \text{this equals the power of the rising current}$$

ratio to the viscosity

represents

$$Pr = \eta / \lambda - \text{the physical property of the heat carrier}$$

represents

$$Nu = a x / l - \text{representing convective heat exchange}$$

size.

where: w is the heat transfer speed, m/s;

x – geometric defining quantity, m;

ν – coefficient of kinematic viscosity, m²/s;

λ – thermal conductivity coefficient, W/m²/s;

g – acceleration of free fall, m/s²;

β – volume expansion temperature coefficient, $\frac{1}{K}$;

$\Delta t = t_d - t_m$ – temperature difference;

λ is the thermal conductivity of the heat carrier coefficient, W/mK.

a – heat transfer coefficient, W/m² K;

s – heat capacity of the heat carrier, j/kgK;

r is the density of the heat carrier, kg/m³.

The similarity criterion can be found by mathematical analysis of the process. The criteria for similarity of heat exchange processes should be numerically equal to each other. Similarity of heat exchange processes is explained by the same criterion equations.

The similarity equation of convective heat transfer and the criterion equation in the turbulent motion of the heat carrier (more forced) have the following form:

$$Nu = f(Re, Pr) \quad (204)$$

In laminar (more free) movement of the heat carrier, the similarity equation is:

$$Nu = f(Gr, Pr) \quad (205)$$

Heat supply in forced flow in pipes

When the fluid moves through the pipe, the fluid movement changes along the entire length and cross-section of the pipe under the influence of flow resistance forces. Fluid flow can be turbulent or laminar. Due to the change in the physical properties of the liquid, in laminar flow ($Re \leq 2300$), there can be two cases of isothermal movement - viscous and gravitational viscous.

The laws of heat transfer for such actions are different and they are explained by different criterion equations.

The approximate value of the heat transfer coefficient of a heat carrier moving in a laminar gravity-viscous state can be calculated using the following formula:

$$Nu_{sd} = 0.15 Re_{cd}^{0.33} \cdot Pr_c^{0.33} (Gr_{cd} \cdot Pr_c)^{0.1} \cdot \left(\frac{Pr_c}{Pr_\theta}\right)^{0.25} \cdot \varepsilon_e \quad (205)$$

where: ε_e is a correction that takes into account the ratio of pipe length ℓ to diameter d .

of ε_e The values of ℓ/d depending on the size are shown in the table. The index in the similarity criteria indicates whether the temperatures of the fluid or the wall are related to the medium. (d – wall; s – liquid).

When the liquid moves turbulently ($Re \geq 10000$), if $\ell/d > 50$, the average value of the heat transfer coefficient α can be found by the following formula.

$$Nu_{sd} = 0.02 Re_{cd}^{0.8} \cdot Pr^{0.43} \cdot \left(\frac{Pr_c}{Pr_\theta}\right)^{0.25} \quad (206)$$

Pr_d is taken according to the average temperature of the liquid in the wall.

The heat transfer coefficient of a gas moving turbulently in a straight pipe can be calculated using the following formula.

$$Nu_{s(x/d)} = 0.022 Re_{c(x/d)}^{0.8} \cdot Pr_c^{0.43} \cdot \varepsilon_\theta \quad (207)$$

If $x/d \geq 15$ then $\varepsilon_e \approx 1$ and if $x/d < 15$ then $\varepsilon_d = 1.38 (x/d)^{0.12}$.

If the diameter of the pipe is not round or has a serpentine shape, this should be taken into account when calculating.

Free movement of heat

Gravitational force creates free movement. Movements can be turbulent and laminar.

The heat transfer coefficient of the vertical wall in free laminar motion is found by the following formula:

$$Nu_{sx} = 0.6 (Gr_{sx} Pr_s)^{0.25} \left(\frac{Pr_c}{Pr_\theta}\right)^{0.25} \quad (208)$$

In laminar flow, when $t_s = \text{const}$, the heat transfer coefficient of the vertical wall is calculated by the following formula:

$$Nu_{s,\ell} = 0.63 (Gr_{s,\ell} Pr_s)^{0.25} \left(\frac{Pr_c}{Pr_\theta}\right)^{0.25} \quad (209)$$

The average heat transfer coefficient during free laminar movement of liquid around a horizontal pipe is calculated by the following formula:

$$Nu_{s,d} = 0.5(Gr_{s,d} Pr_s)^{0.25} \left(\frac{Pr_c}{Pr_\delta} \right)^{0.25} \quad (210)$$

of developed turbulent motion ($Gr_{s,x} Pr_s$), the coefficient of heat transfer in free movement along a vertical wall is found by the following formula:

$$Nu_{s,x} = 0.15(Gr_{s,x} Pr_s)^{0.53} \left(\frac{Pr_c}{Pr_\delta} \right)^{0.25} \quad (211)$$

(208), (209), (210), (211), the temperature away from the heated surface is taken as the determined temperature.

(208) and (211), x is taken as the quantity to be determined. x is the distance from the beginning of the wall to the area where the heat transfer coefficient is determined, in expression (209) ℓ is the length of the wall, and in formula (210) d is the outer diameter of the pipe.

If the volume of the liquid is not large, the wall is limited by various small holes, this is called a limited volume, where the heat transfer coefficient depends on the type of liquid, its movement, the temperature difference between the walls, and the geometric sizes of the holes.

In practical calculations, it is often necessary to find the heat flux from a fluid layer. In such conditions, the dual processes of finite volume are calculated by replacing them with the equivalent process of heat transfer:

$$q = (l_{eq} / d) (t_{\delta_1} - t_{\delta_2}), \text{ W/m}^2 \quad (212)$$

where: l_{eq} is the equivalent coefficient of heat transfer taking into account heat transfer and convection heat transfer in a limited volume, $l_{eq} = e_k l$ (213)

where: l is the thermal conductivity coefficient of the liquid, $\text{W}/\mu\text{K}$;

e_k is a coefficient representing the effect of convection on heat transfer.

($Cr - Pr$) with an accuracy of $d > 10^3$, it can be assumed that $e_k = 0.8 (Cr - Pr)^{0.25}$

As a detectable temperature:

$$t_j = 0.5 (t_{\delta_1} - t_{\delta_2}), \text{ } ^\circ\text{C} \quad (214)$$

d_m is taken as a determinable quantity. In the case of a horizontal hole, the temperature of the upper surface is higher than the temperature of the lower part, the liquid does not move and $\lambda_{eq} = \lambda$, the value of convective heat exchange is zero.

Issues

88 . When the diameter of the horizontal heat exchanger is $d = 400 \text{ mm}$, the temperature of its surface is $t_{qc} = 200 \text{ } ^\circ\text{C}$, and the temperature of the air in the room is equal to $t_h = 30 \text{ } ^\circ\text{C}$, determine the heat passing through the surface of 1 m^2 of the horizontal heat exchanger in a unit of time.

$$\text{Answer: } q = 1000 \text{ W / m}^2 .$$

Solution :

Heat flux density:

$$q = \alpha (t_{kc} - t_c)$$

Heat transfer coefficient for free convection:

$$Nu = 0.5 (Gr_c Pr_c)^{0.25}$$

At air temperature $t_x = 30 \text{ } ^\circ\text{C}$, we take the parameters from the table:

$$\gamma = 16.0 \cdot 10^{-6}, \text{ m}^2/\text{s}; \lambda = 2.67 \cdot 10^{-2}, \text{ W/m}^0\text{C}$$

$$\beta = 1/T = 1/30 + 273 = 1/303 \text{ K}^{-1}; \text{Pr} = 0.701$$

$$(\text{Gr}_c \text{Pr}_c) = \frac{g\beta\Delta t d^3}{\gamma^2} \text{Pr}_c = \frac{9,81 \cdot (200 - 30) 0,4^3}{303(16 \cdot 10^{-6})} 0,701 = 9.75 \cdot 10^8$$

$$\text{Nu} = 0.5 (\text{Gr}_c \text{Pr}_c)^{0.25} = 0.5 (9.75 \cdot 10^8)^{0.25} = 88.2$$

Here we find the heat transfer coefficient:

$$\alpha = \text{Nu} \frac{\lambda}{d} = 88.2 \frac{2.67 \cdot 10^{-2}}{0.4} = 5.9 \text{ W/m}^2\text{C}$$

Heat passing through the heat exchange surface of 1 m^2 in a unit of time
 $q = \alpha (t_{kc} - t_c) = 5.9 (200 - 30) = 1000 \text{ W/m}^2$.

89. Determine the heat transfer coefficient of a vertical plate with a height of 2 m, if the temperature of the surface of the plate is $t_{qs} = 100^0\text{C}$ and the temperature of the environment is equal to $t_x = 20^0\text{C}$.

$$\text{Answer: } \alpha = 7.92 \text{ W/m}^2\text{C}.$$

90. MS oil in the oil tank is kept at the same temperature using horizontal pipes with a diameter of 20 mm. Determine the coefficient of heat transfer from the surface of the pipe to the oil when the temperature of the oil is $t_s = 60^0\text{C}$ and the temperature of the pipe surface is $t_{qs} = 90^0\text{C}$.

$$\text{Answer : } \alpha = 96.2 \text{ W/m}^2\text{C}.$$

91. A vertical uninsulated pipe with a diameter of 76 mm and a height of 4 m gives heat to the air. The temperature of the air is 20^0C and the temperature on the surface of the pipe is equal to $t_{qs} = 80^0\text{C}$. Determine the heat output from the pipe.

$$\text{Answer: } Q = 413 \text{ W}$$

92. The width of the channel with a cubic cross-section $K = 10 \text{ mm}$ and the length $l = 1600 \text{ mm}$ is equal to Water flows from the channel at a speed of $w = 4 \text{ m/c}$. Determine the heat transfer coefficient and heat flow from the channel wall to the water when the temperature of the water is $t_s = 40^0\text{C}$ and the temperature on the inner surface of the channel is $t_{qs} = 90^0\text{C}$

$$\text{Answer: } \alpha = 20300 \text{ W/m}^2\text{C}, Q = 50994 \text{ B t}.$$

Solution :

We determine the equivalent diameter of the channel:

$$d_e = \frac{4f}{u} = \frac{4a^2}{4a} = a = 0,01 \text{ m}$$

where f is the surface of the channel, m^2 .

u - the perimeter of the channel, m .

of water at temperature $t_c = 40^0\text{C}$,

$$\nu_s = 0.659 \cdot 10^{-6} \text{ m}^2/\text{s}; \lambda_s = 0.634 \text{ W/m}^0\text{C}; \text{Pr}_s = 4.3$$

$$\text{Pr}_{qs} = 1.95 \text{ at } t_{qs} = 90^0\text{C}$$

Reynolds number

$$\text{Re} = \frac{w d_s}{\nu} = \frac{4 \cdot 0,01}{0,659 \cdot 10^{-6}} = 6,07 \cdot 10^4 > 10^4$$

The state of motion is turbulent

$$\text{Nu} = 0.021 \cdot \text{Re}^{0.8} \text{Pr}^{0.43} \left(\frac{\text{Pr}_c}{\text{Pr}_{k,c}} \right)^{0.25} = 0.021 (6.07 \cdot 10^4)^{0.8} (4.3)^{0.43} \left(\frac{4,3}{1,95} \right)^{0.25} = 320$$

Heat transfer coefficient

$$\alpha = Nu \frac{\lambda}{d_s} = 320 \frac{0,634}{0,01} = 20300 \frac{\text{Вт}}{\text{м}^2 \text{ } ^\circ\text{C}},$$

Heat density flow :

$$Q = \alpha (t_{\text{кc}} - t_{\text{c}}) \pi d l = 20300 (90 - 60) 3.14 \cdot 0,01 \cdot 1,6 = 50994 \text{ W} .$$

93. An air flow passes through a horizontal plate with length $l = 2$ m and width $a = 1.5$ m. The speed of the air flow is $w=3$ m/s, the temperature is 20 $^\circ\text{C}$, and the temperature on the surface of the plate is equal to 90 $^\circ\text{C}$. Determine the coefficient of heat transfer from the plate to the air and the amount of heat.

$$\text{Answer: } \alpha=4.87 \frac{\text{Вт}}{\text{м}^2 \text{ } ^\circ\text{C}}, \quad Q = 2050 \text{ W}$$

94. Water flows through a pipe with an inner diameter of $d=50$ mm at a speed of $W=0.8$ m/s. Determine the heat passing through the surface of 1 m pipe when the temperature of water is $t_s=50$ $^\circ\text{C}$, and the temperature of the pipe surface is $t_{\text{qs}}=65$ $^\circ\text{C}$.

$$\text{Answer: } q_{\ell} = 9.03 \text{ kW/m}.$$

95. A water calorimeter with an outer diameter of $d=15$ mm flows transversely to an air stream. Air moves at an angle of 90 $^\circ$ to the axis of the calorimeter with a speed of 2 m/s. The temperature of the air is 20 $^\circ\text{C}$ and the temperature of the outer surface of the calorimeter is equal to $t_{\text{qs}}=80$ $^\circ\text{C}$. Determine the heat transfer coefficient and the heat flux per unit length.

$$\text{Answer: } \alpha=36.3 \text{ W/2m}^2 \text{ } ^\circ\text{C}, \quad q_{\ell} = 102 \text{ W/m}.$$

CONTROL QUESTIONS

1. Explain convective heat transfer.
2. Why was similarity theory introduced?
3. What does the heat transfer coefficient depend on?
4. How does heat transfer occur in pipes?
5. How does heat transfer occur in free movement?
6. How does heat transfer occur during forced movement?
7. What does the Nusselt criterion represent?
8. What is laminar and turbulent flow?

Lecture 5 CONVECTIVE HEAT EXCHANGE (GIVING HEAT)

General concepts

Convective heat transfer or **heat transfer** refers to heat transfer between a solid body and a liquid or gas. Convective heat exchange is carried out simultaneously by two methods: convection and heat conduction. In this case, the heat dissipation depends continuously on the moving medium (liquid or gas).

In most cases, the rate of heat transfer depends on the speed of movement of the heat carrier relative to the heat transfer surface. The movement of the heat carrier can be free or forced.

Free movement or **free convection** means the movement of a liquid or gas in a system under the influence of an external non-uniform mass force field (gravitational, magnetic, electric or inertial field forces).

Forced motion or **forced convection** is the same area of external surface forces imposed on the system boundaries or mass forces exerted on the fluid within the system; is the movement that occurs due to the kinetic energy given to the liquid outside the system.

In practice, free convection in liquids or gases occurs due to the difference in density of hot and cold particles of the liquid.

Forced convection occurs under the influence of an external force such as a fan or pump.

The flow pattern of the fluid is the basis for the occurrence of convective heat exchange.

In 1884, Reynolds, based on his experiments, showed that the movement of a liquid can be **laminar** or **turbulent** .

Laminar flow is the occurrence of liquid particles without uniform mixing . In this case, the normal heat transfer in the flow direction is carried out mainly by heat conduction. Since the thermal conductivity of the liquid is very small, the speed will not be very high.

When the flow rate exceeds a certain value, the state of motion changes dramatically, that is, an irregular flow occurs and the flow becomes completely mixed. Such flow is called **turbulent flow** .

In a turbulent flow, heat is dispersed in the flow by heat conduction due to the mixing of all particles, so the heat exchange is higher in a turbulent flow.

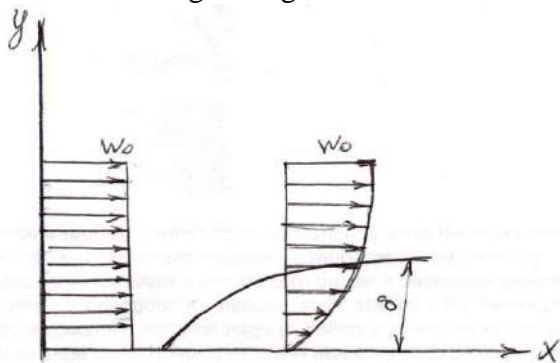


Figure 43

Reynolds showed that the order of fluid flow in a pipe is determined by a dimensionless value, this value is called **the Reynolds number** . Laminar liquid or gas moves uniformly in layers ($Re < 2300$), in turbulent flow layers move together ($Re > 10,000$).

The movement of liquid through the pipe has its own characteristics. Let's consider the movement of a fluid along a pipe with a constant speed (Fig. 43).

As the liquid begins to flow through the pipe, the liquid particles near the walls stick to the walls due to friction. As a result, the velocity near the walls decreases to zero. Since the fluid consumption does not change, the velocity increases in the middle of the pipe section. In this case, a hydrodynamic boundary layer is formed on the pipe walls. The thickness of this layer d increases downstream. As the speed increases, the thickness of the boundary layer increases. As the viscosity of the liquid increases, the thickness of the layer also increases. This in turn reduces heat transfer from the liquid to the surface of the solid.

When the fluid is in laminar motion along the pipe, the heat exchange is less due to the boundary layer formed, when the turbulent motion occurs, the thickness of the boundary layer decreases due to the increase in the movement speed of the immobilized liquid particles, as a result, the heat exchange increases.

The Newton-Richmann law is used to calculate the heat transfer process:

$$Q = a (t_d - t_m) F \quad (202)$$

where: Q is heat flow, W ;

a – heat transfer coefficient, $W/m^2 K$;

t_m – ambient temperature, $^{\circ}C$,

t_d – wall surface temperature, $^{\circ}\text{C}$;
 F - heat exchange surface, m^2 .

The coefficient of heat transfer α is numerically equal to the amount of heat given when the temperature difference ($t_d - t_m$) from the surface of 1 m^2 to the environment or from the environment to the surface of 1 m^2 is equal to 1°C in 1 second, if $t_d > t_m$, $\Delta t = t_d - t_m$; if $t_m > t_d$ then $\Delta t = t_m - t_d$.

Heat flux density:

$$q = \alpha \Delta t \text{ is equal to } \text{W}/\text{m}^2 \cdot (203)$$

Thermal conductivity of a single-layer flat wall under 3-order boundary conditions

The general process of heat dissipation usually occurs simultaneously in three ways: heat transfer by conduction, convection, and radiation. The implementation of all three methods can be different. Depending on the heat exchange conditions, one method may prevail over another.

As a result of the joint movement of heat exchange in the convection and radiation method, the process of heat diffusion between the wall and the gas flow occurs between them.

Heat is diffused between the radiating gas stream and the wall as a result of the combined effect of convection and radiant heat exchange, resulting in a comparable heat flow - this is called **double heat exchange** :

$$q = q_k + q_n; q = (\alpha_k + \alpha_n)(t_s - t_d) \quad (255)$$

where: q_k is the amount of heat given by convection; W/m^2 ;

q_n is the amount of heat given by radiation,
 W/m^2 ;

α_k – heat given by convection

providing heat that takes into account the quantity
coefficient, $\text{W}/\text{m}^2 \text{ K}$;

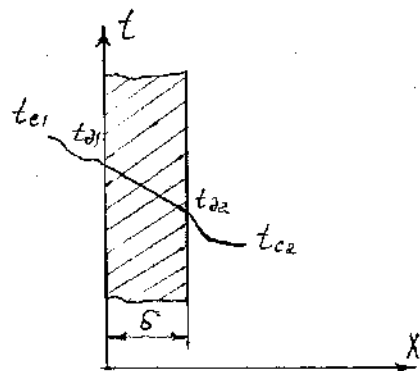
α_n is the heat transfer coefficient, $\text{W}/\text{m}^2 \text{ K}$, which takes into account the amount of heat given by radiation.

The coefficient of heat transfer in heat exchange by radiation is calculated by the following formula:

$$\alpha = \varepsilon c_0 \left[\frac{(T_c/100)^4 - (T_d/100)^4}{T_c - T_d} \right] \quad (256)$$

where : ε is the specified black level of the system.

The transfer of heat from one medium (liquid or gas) to another through a single-layer or multi-layer solid wall is called heat transfer.



57 .

The heat transfer coefficient λ (W/mK) of a single-layer wall with a thickness d and a surface area of 1 m^2 , ambient temperatures t_{s1} and t_{s2} and heat transfer coefficients α_1 and α_2 on both sides are given (Fig. 57). Heat passes from the warm environment to the wall by convection:

$$q = \alpha_1 (t_{c1} - t_{d1})$$

heat passes through the wall by conduction:

$$q = \frac{\lambda}{\delta} (t_{d1} - t_{d2})$$

passes from the wall to the environment by convection:

$$q = \alpha_2 (t_{d1} - t_{s2})$$

Expressing these expressions in terms of the temperature difference, and then adding them together, we get the heat transfer equation:

$$q = \frac{t_{c1} - t_{c2}}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}} = \kappa (t_{c1} - t_{c2}) \quad \text{BT/M}^2 \quad (257)$$

where k is the heat transfer coefficient.

$$\kappa = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}} \text{ W/m}^2 \text{ K} \quad (258)$$

The heat transfer coefficient is numerically equal to the amount of heat transferred from a unit surface when the temperature difference is equal to 1 °C in a unit of time. The quantity that is the inverse of the heat transfer coefficient is called **the total thermal resistance of heat transfer**.

$$R = \frac{1}{\kappa} = \frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2} \text{ m}^2 \text{ K/W} \quad (259)$$

9th lecture

Heat transfer of multilayer flat wall under 3-order boundary condition

The heat flux density passing through a multi-layer flat wall, for example, heat passing through a three-layer wall:

$$q = \frac{t_{c1} - t_{c2}}{\frac{1}{\alpha_1} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3} + \frac{1}{\alpha_2}} = \kappa (t_{c1} - t_{c2}) \text{ W/m}^2 \quad (260)$$

here:

$$\kappa = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3} + \frac{1}{\alpha_2}} \text{ W/m}^2 \text{ K}$$

F (m²) is equal to Q

$$Q = q F = k D t F W \quad (261)$$

The temperatures between the wall layers are found as follows:

$$t_{d1} = t_{c1} - q \frac{1}{\alpha_1}$$

$$t_{d2} = t_{c1} - q \left(\frac{1}{\alpha_1} + \frac{\delta_1}{\lambda_1} \right) \quad (262)$$

$$t_{d3} = t_{c1} - q \left(\frac{1}{\alpha_1} + \sum_{i=1}^n \frac{\delta_i}{\lambda_i} \right)$$

Thermal conductivity of a single-layer cylindrical wall under 3-order boundary conditions

Linear heat flux density:

$$q_\ell = \frac{\pi(t_{c1} - t_{c2})}{\frac{1}{\alpha_1 d_1} + \frac{1}{2\lambda} \ln \frac{d_2}{d_1} + \frac{1}{\alpha_2 d_2}} = \kappa_\ell \pi (t_{c1} - t_{c2}), \text{ W/m} \quad (263)$$

where: k_ℓ is the linear coefficient of heat transfer - it is numerically equal to the amount of heat passing from one environment to another in a unit of time when the temperature difference is equal to 1°C on the pipe wall 1 m long (Fig. 58).

ℓ , which is the inverse of the linear coefficient of heat transfer, is called **the linear thermal resistance** of heat transfer.

$$R_e = \frac{1}{\kappa_\ell} = \frac{1}{\alpha_1 d_1} + \frac{1}{2\lambda} \ln \frac{d_2}{d_1} + \frac{1}{\alpha_2 d_2}, \text{ m}^2 \text{ K/W. (264)}$$

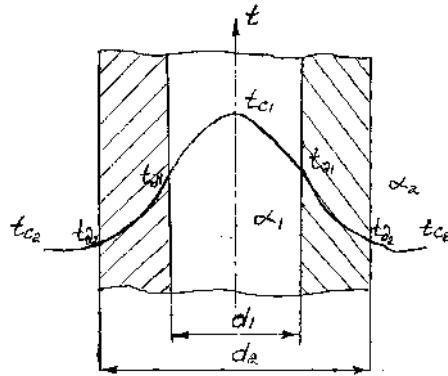


Figure 58

The heat flux density passing through a multi-layered cylindrical wall, for example, a double-layered cylindrical wall

$$q_e = \frac{\pi(t_{o1} - t_{o2})}{\frac{1}{\alpha_1 d_1} + \frac{1}{2\lambda_1} \ln \frac{d_1}{d_2} + \frac{1}{2\lambda_2} \ln \frac{d_3}{d_2} + \frac{1}{\alpha_3 d_3}} \quad (265)$$

The temperature between the layers is found by the following formulas:

$$t_{o1} = t_{c1} - q_e \frac{1}{\pi} \frac{1}{\alpha_1 d_1}$$

$$t_{o2} = t_{c1} - \frac{q_e}{\pi} \cdot \frac{1}{2\lambda_1} \ln \frac{d_2}{d_1} \quad (266)$$

$$t_{o3} = t_{c1} - \frac{q_e}{\pi} \cdot \frac{1}{2\lambda_2} \ln \frac{d_3}{d_{12}}$$

CONTROL QUESTIONS

1. How does complex heat exchange occur?
2. Explain heat transfer through a single layer flat wall.
3. Explain heat transfer through a multilayer flat wall.
4. Explain heat transfer through a single and multi-layer cylindrical wall.
5. What does the heat transfer coefficient mean?
6. What is linear resistance?

11th lecture Basics of similarity theory

Convective heat transfer is described by multivariable and univariate differential equations.

Analytical calculation of the heat transfer coefficient, solving the equations causes a lot of difficulties, so it is of great importance to determine the heat transfer coefficient experimentally based on the similarity theory.

The theory of similarity allows to determine whether the results obtained in experimental devices can be applied to other similar phenomena, that is, the processes are similar.

The main similarity criteria (numbers) of convective heat exchange are Reynolds, Grashof, Prandtl and Nusselt criteria.

$Re = \frac{wx}{\nu}$ – this equality expresses the ratio of flow inertia force to viscosity force.

$Gr = \frac{g\beta \Delta t x^3}{\nu^2}$ - this equals the power of the rising current

ratio to the viscosity
represents

$Pr = \nu / a$ – the physical property of the heat carrier
represents

$Nu = ax/l$ – representing convective heat exchange

where: w is the heat transfer speed, m/s;

x – geometric defining quantity, m;

ν – coefficient of kinematic viscosity, m²/s;

$a = l/s$ – temperature conductivity coefficient, m²/s;

g – acceleration of free fall, m/s²;

β – volume expansion temperature coefficient, $\frac{1}{K}$;

$\Delta t = t_d - t_m$ – temperature difference;

l is the thermal conductivity of the heat carrier
coefficient, W/mK.

a – heat transfer coefficient, W/m² K;

s – heat capacity of the heat carrier, j/kgK;

r is the density of the heat carrier, kg/m³.

The similarity criterion can be found by mathematical analysis of the process. The criteria for similarity of heat exchange processes should be numerically equal to each other. Similarity of heat exchange processes is explained by the same criterion equations.

The similarity equation of convective heat transfer and the criterion equation in the turbulent motion of the heat carrier (more forced) have the following form:

$$Nu = f(Re, Pr) \quad (204)$$

In laminar (more free) movement of the heat carrier, the similarity equation is:

$$Nu = f(Gr, Pr) \quad (205)$$

12th lecture Criterion equations Heat supply in forced flow in pipes

When the fluid moves through the pipe, the fluid movement changes along the entire length and cross-section of the pipe under the influence of flow resistance forces. Fluid flow can be turbulent or laminar. Due to the change in the physical properties of the liquid, in laminar flow ($Re \leq 2300$), there can be two cases of isothermal movement - viscous and gravitational viscous.

The laws of heat transfer for such actions are different and they are explained by different criterion equations.

The approximate value of the heat transfer coefficient of a heat carrier moving in a laminar gravity-viscous state can be calculated using the following formula:

$$\text{Nu}_{sd} = 0.15 \text{Re}_{cd}^{0,33} \cdot \text{Pr}_c^{0,33} (\text{Gr}_{cd} \cdot \text{Pr}_c)^{0,1} \cdot \left(\frac{\text{Pr}_c}{\text{Pr}_d}\right)^{0,25} \cdot \varepsilon_e \quad (205)$$

where: ε_e is a correction that takes into account the ratio of pipe length ℓ to diameter d .

of ε_e The values of ℓ/d depending on the size are shown in the table. The index in the similarity criteria indicates whether the temperatures of the fluid or the wall are related to the medium. (d – wall; s – liquid).

When the liquid moves turbulently ($\text{Re} \geq 10000$), if $\ell/d > 50$, the average value of the heat transfer coefficient α can be found by the following formula.

$$\text{Nu}_{sd} = 0.02 \text{Re}_{cd}^{0,8} \cdot \text{Pr}^{0,43} \cdot \left(\frac{\text{Pr}_c}{\text{Pr}_d}\right)^{0,25} \quad (206)$$

Pr_d is taken according to the average temperature of the liquid in the wall.

The heat transfer coefficient of a gas moving turbulently in a straight straight pipe can be calculated using the following formula.

$$\text{Nu}_{s(x/d)} = 0.022 \text{Re}_{c(x/d)}^{0,8} \cdot \text{Pr}_c^{0,43} \cdot \varepsilon_d \quad (207)$$

If $x/d \geq 15$ then $\varepsilon_e \approx 1$ and if $x/d < 15$ then $\varepsilon_d = 1.38 (x/d)^{0,12}$.

If the diameter of the pipe is not round or has a serpentine shape, this should be taken into account when calculating.

Free movement of heat

Gravitational force creates free movement. Movements can be turbulent and laminar.

The heat transfer coefficient of the vertical wall in free laminar motion is found by the following formula:

$$\text{Nu}_{sx} = 0.6 (\text{Gr}_{sx} \text{Pr}_s)^{0,25} \left(\frac{\text{Pr}_c}{\text{Pr}_d}\right)^{0,25} \quad (208)$$

In laminar flow, when $t_s = \text{const}$, the heat transfer coefficient of the vertical wall is calculated by the following formula:

$$\text{Nu}_{s,\ell} = 0.63 (\text{Gr}_{s,\ell} \text{Pr}_s)^{0,25} \left(\frac{\text{Pr}_c}{\text{Pr}_d}\right)^{0,25} \quad (209)$$

The average heat transfer coefficient during free laminar movement of liquid around a horizontal pipe is calculated by the following formula:

$$\text{Nu}_{s,d} = 0.5 (\text{Gr}_{s,d} \text{Pr}_s)^{0,25} \left(\frac{\text{Pr}_c}{\text{Pr}_d}\right)^{0,25} \quad (210)$$

of developed turbulent motion ($\text{Gr}_{s,x} \text{Pr}_s$), the coefficient of heat transfer in free movement along a vertical wall is found by the following formula:

$$\text{Nu}_{s,x} = 0.15 (\text{Gr}_{s,x} \text{Pr}_s)^{0,53} \left(\frac{\text{Pr}_c}{\text{Pr}_d}\right)^{0,25} \quad (211)$$

(208), (209), (210), (211), the temperature away from the heated surface is taken as the determined temperature.

(208) and (211), x is taken as the quantity to be determined. x is the distance from the beginning of the wall to the area where the heat transfer coefficient is determined, in expression (209) ℓ is the length of the wall, and in formula (210) d is the outer diameter of the pipe.

If the volume of the liquid is not large, the wall is limited by various small holes, this is called a limited volume, where the heat transfer coefficient depends on the type of liquid, its movement, the temperature difference between the walls, and the geometric sizes of the holes.

In practical calculations, it is often necessary to find the heat flux from a fluid layer. In such conditions, the dual processes of finite volume are calculated by replacing them with the equivalent process of heat transfer:

$$q = (l_{eq} / d) (t_{\alpha_1} - t_{\alpha_2}), \text{ W/m}^2 \quad (212)$$

where: l_{eq} is the equivalent coefficient of heat transfer taking into account heat transfer and convection heat transfer in a limited volume, $l_{eq} = e_k l$ (213)

where: l is the thermal conductivity coefficient of the liquid, $\text{W}/\mu\text{K}$;

e_k is a coefficient representing the effect of convection on heat transfer.

($Cr - Pr$) with an accuracy of $d > 10^{-3}$, it can be assumed that $e_k = 0.8 (Cr - Pr)^{0.25}$

As a detectable temperature:

$$t_j = 0.5 (t_{\alpha_1} - t_{\alpha_2}), \text{ } ^\circ\text{C} \quad (214)$$

d_m is taken as a determinable quantity. In the case of a horizontal hole, the temperature of the upper surface is higher than the temperature of the lower part, the liquid does not move and $\lambda_{eq} = \lambda$, the value of convective heat exchange is zero.

13th lecture Heat transfer on a flat surface

The process of flow along the surface.

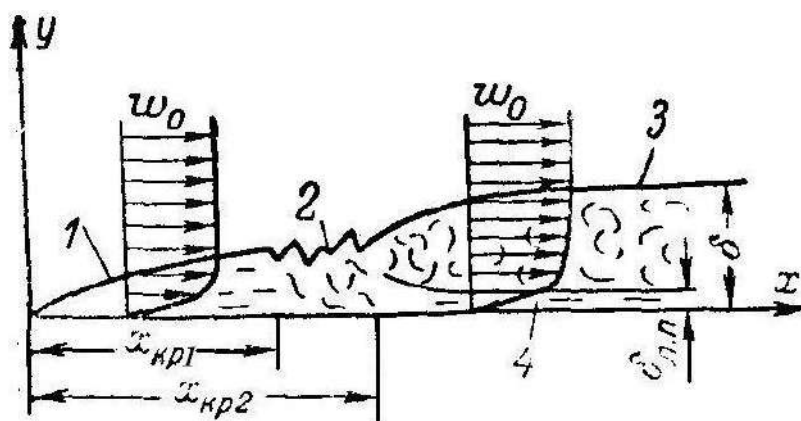
For the sake of simplicity, Ω_0 we assume that the flat surface is being washed by the fluid stream and that the velocity and temperature of the fluid away from the solid body are constant and ga tking . t_0 We assume that the flow is parallel to the surface of the plate.

A hydrodynamic boundary layer is formed near the plate. At the boundary of the layer, the velocity of the fluid varies from zero to the steady flow velocity.

The flow in the boundary layer can be both laminar and turbulent (Fig. 7.1). But in the turbulent boundary layer, there is no pulsation at the wall (the wall is impermeable and the fluid clings to the wall). Here the forces of adhesion are great. As a result, a very thin layer of liquid is formed on the wall, its flow regime is laminar, and this layer is called laminar or viscous layer.

Experience shows that the transition from a laminar flow to a turbulent flow does not occur at one point but occurs in some sections. The current in this section is unstable and is considered transient.

Laws of heat exchange for laminar and turbulent conditions are different, so it is important to determine their limits.

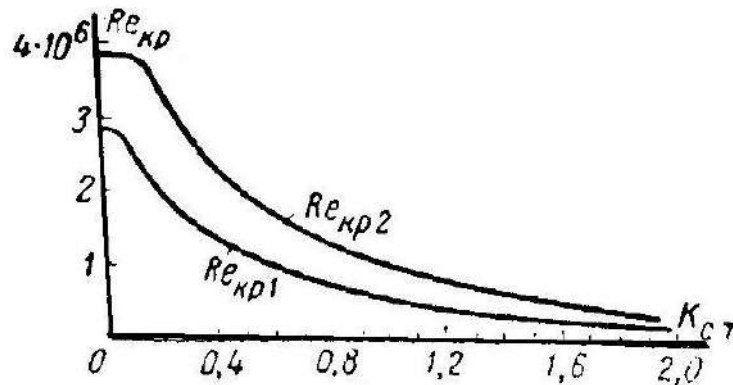


7 - 1 - picture.

The flow pattern in the boundary layers $Re = \frac{\omega_0 x}{\nu}$ is determined by the critical quantity, here x the length along the plate, measured from the leading edge. Experience shows that the transition to the turbulent state Re_{kp} occurs at values from $1 \cdot 10^4$ to $4 \cdot 10^6$

The degree of turbulence of the passing flow depends on K_{tg} the laminar layer disturbance and transition to stable turbulent flow Re . It is determined from the ratio below.

$$K_{tg} = \frac{\sqrt{\frac{1}{3}(\overline{\omega}_x^{12} + \overline{\omega}_y^{12} + \overline{\omega}_z^{12})}}{\omega_0}$$



7-2 - picture.

Here is $\overline{\omega}_x^{12}$, $\overline{\omega}_y^{12}$, $\overline{\omega}_z^{12}$ the time-averaged value of the squares of the components of the pulsations on the three coordinate axes.

7-2 shows the curves. From the curves, it is possible to determine the coordinates of the transition from the laminar state x_{kp1} to the turbulent flow state x_{kp2} . In the chart

$$Re_{kp1} = \frac{\omega_0 x_{kp1}}{\nu} \text{ and } Re_{kp2} = \frac{\omega_0 x_{kp2}}{\nu}$$

The degree of turbulence of the entrained flow depends on many factors. Determining it computationally is a big challenge. At the same time, the values of Re_{k1} and Re_{kp2} depend on the intensity of heat exchange, the change of pressure across the body, the ease of the front edge of the plate to the flow, the vibration of the body, the pulsation (vibration $\overline{\omega}$) of the fluid flow. Too many influencing factors make it difficult to identify transition points.

Therefore, when calculating the transient state, it is often considered as a point in practice, and the critical value is estimated based on those obtained from experiments.

can be assumed to be sufficiently flow-friendly. $Re_{kp1} \approx Re_{kp2} \approx Re_{kp} \approx 10^5$

In cases where there is heat exchange on the plate surface, a thermal boundary layer is formed in addition to the hydrodynamic boundary value. The temperature of the fluid at the boundaries of the heat layer ranges from the wall temperature at the surface of the plate to the temperature of the fluid away from the plate t_c

t_0 changes to

The differential equations of convection heating for the boundary layer can be greatly simplified. But in this case, the exact solution of the equation causes great difficulties.

Therefore, the calculation book requires approximate methods. An approximate calculus of hydrodynamic and thermal boundary layers can be performed using integral equations of boundary layers.

Heat transfer in laminar boundary layers.

We use the integral equation (7-4).

To calculate the heat transfer, it is necessary to know the velocity distribution in the boundary layers. Amaliet and theory show that the velocity distribution in the laminar boundary layer has a shape close to a parabola. It is convenient to express the speed distribution curve as a cubic parabolic equation.

$$\omega_x = ay + by^2 + cy^3 \quad (a)$$

The speed reduction equation must satisfy a number of conditions. must be $y = 0$ at $\omega_x = 0$ ("win" condition). It is recognized that the stresses directly near the wall are constant. It follows from the law of viscous friction that in such cases the velocity gradient is also constant. In $S = \mu \frac{d\omega_x}{dy}$ this $y = 0$ case $\frac{d\omega_x}{dy} = v$, it is known that the condition is fulfilled. In addition,

$\frac{d\omega_x}{dy} = v$ the condition of the outer boundaries of the boundary layer must be fulfilled.

(a) satisfies the listed conditions if

$$a = 1,5 \frac{\omega_0}{\delta}, c = -0,5 \frac{\omega_0}{\delta^3}, \text{ Ba } b = 0$$

The speed distribution equation takes the following form in such cases

$$\frac{\omega_x}{\omega_0} = 1,5 \left(\frac{y}{\delta} \right) - 0,5 \left(\frac{y}{\delta} \right)^2 \quad (b)$$

As is known from hydrodynamics, the thickness of the hydrodynamic boundary layer in the velocity distribution is determined by the following equation.

$$\delta = 4,64 \sqrt{\frac{yx}{\omega_0}} \quad (7-5)$$

The expression 7-5 shows that δ the distance from the front edge of the plate to the given point changes proportionally to the root of the square.

This expression can be given a dimensionless representation.

$$\frac{\delta}{x} = \frac{4,64}{\sqrt{\omega_0 x / v}} = \frac{4,64}{\sqrt{\text{Re}_x}} \quad (7-5^1)$$

Let's consider the solution of the heat flow equation. For the sake of simplification, we count the temperature starting from the temperature at the surface of the solid body, the temperature at the surface is assumed to be constant.

We will mark as soon as possible

$$v = t - t_c \quad \text{Ba} \quad v_0 = t_0 - t_c$$

Here is t_0 the temperature of the fluid inside the thermal boundary layer. In such cases, the boundary conditions are similar to those previously accepted for hydrodynamic boundary layers.

really $y = 0$ да $v = 0$ does. In addition, based on the energy equation, if it is taken into account that the heat in the liquid touching the wall is transferred only by heat conduction, then $(d^2v/dy^2)_{y=0} = 0$. The following conditions are fulfilled at the outer boundaries of the thermal layer.

$$v = v_0 = \text{const} \quad \text{Ba} \quad (dv/dy)_{y=k} = 0$$

As a result, the temperature distribution can be assumed to be similar to the velocity distribution.

$$\frac{v}{v_0} = 1,5 \left(\frac{y}{k} \right) - 0,5 \left(\frac{y}{k} \right)^3 \quad (\text{d})$$

it follows that

$$\frac{dv}{dy} = \frac{1,5v_0}{k} - \frac{1,5v_0}{k^3} y^2 \quad \left(\frac{dv}{dy} \right)_{y=0} = \frac{1,5v_0}{k} \quad (\text{eat})$$

We calculate the integral of the heat flow equation by integrating (7-4) at the boundaries of thermal boundary layers $y = 0$. $y = k$ We accept that from the beginning. $k = \delta$ In such cases, the integration in the boundaries $y = 0$ from $y = k$ to is considered as the integration in the thermal and hydrodynamic layer boundaries.

If $\delta > k$ the integral is distributed for the cases, then two laws of velocity distribution at the boundaries of the thermal boundary layers are given:

$y > \delta$ equation (δ) and $\delta \leq y \leq k - \omega_x = \omega_0 = \text{const}$ in accordance with the condition

The following follows from integration

$$\int_0^k (t_0 - t) \omega_x dy = \int_0^k (v_0 - v) \omega_x dy = v_0 \omega_0 \int_0^k \left[1 - 1,5 \left(\frac{y}{k} \right) + 0,5 \left(\frac{y}{k} \right)^3 \right] \left[1,5 \left(\frac{y}{\delta} \right) - 0,5 \left(\frac{y}{\delta} \right)^3 \right] dy = v_0 \omega_0 \delta \left[\frac{3}{20} \left(\frac{k}{\delta} \right)^2 - \frac{3}{280} \left(\frac{k}{\delta} \right)^4 \right]$$

$k \prec v$ since $\frac{k}{\delta} \prec 1$, therefore, the second term in the bracket on the right side of the equation is small compared to the first and can be taken into account with them.

the calculated value of the integral and the value according to (ye), $(dv/dy)_{y=0}$ we obtain the following:

$$\frac{3}{20} v_0 \omega_0 \frac{d}{dx} (\beta^2 \delta) = \frac{3}{2} a \frac{v_0}{\beta \delta}$$

or that

$$\frac{1}{10} \omega_0 \left(\beta^3 \delta \frac{d\delta}{dx} + 2\beta^2 \delta^2 \frac{d\beta}{dx} \right) = a$$

here $\beta = \frac{k}{\delta}$.

If not only the hydrodynamic layer, but also the thermal layer develops in front of the plate sleeve, i.e. there is no unheated region at the initial part of the plate $\frac{d\beta}{dx} = 0$, then

$$\frac{1}{10} \omega_0 \beta^3 \delta \frac{d\delta}{dx} = a$$

(7 - 5) shows the following.

$$\delta \frac{d\delta}{dx} = \frac{140}{13} \frac{v}{\omega_0}$$

Inserting this value into the previous equation and $\sqrt[3]{\frac{130}{140}} = 0,98 \approx 1$ assuming that ,

$$\beta = \sqrt[3]{\frac{a}{v}} \text{ we } \frac{k}{\delta} = \frac{1}{\sqrt[3]{P_x}} \text{ get}$$

More accurate solutions give the same result.

According to $\delta (7 - 5^{-1})$, we enter the value into the equation (7-6) and get the following:

$$k = \frac{4,64x}{\sqrt{\text{Re}} \sqrt[3]{P_r}}$$

here

$$\text{Re}_x = \frac{\omega_0 x}{v}$$

For droplet liquids, as a rule $P_r \gg 1$ and as a result $k \ll \delta$, the condition accepted when integrating the heat flow equation is fulfilled. It is especially valuable in oils. P_r At low oil temperatures, the Prandtl parameter can reach several tens of thousands of values. In gases, the Prandtl exponent varies from about 0.6 to 1, with a similar $P_r \approx 0,7$ temperature range. In such situations $k \ll \delta$, however, the difference between the thickness of the thermal and hydrodynamic layers is not large. For example $P_r \approx 0,6$, when $k = 1,18\delta$

For liquid metals $k \gg \delta$, we use the heat exchange equation obtained for them.

$$\alpha = \frac{\lambda}{v_0} \left(\frac{dv}{dy} \right)_{y=0}$$

We derive from the temperature distribution equation $\left(\frac{dv}{dy} \right)_{y=0} = v_0 \frac{3}{2} \frac{1}{k}$ If we put it in the equation of the heat exchanger, we get the following (drop the negative sign).

$$\alpha = \frac{3}{2} \frac{\lambda}{k} \quad (7-8)$$

Hence, the coefficient of thermal sensitivity is inversely proportional to the thickness of the thermal boundary layer.

(7-8) can be reduced to a dimensionless view. To do this, we multiply the left and right sides by and X/λ enter the value of corresponding to (7.7). k It will be the result.

$$Nu_x = 0,33 \sqrt{Re_x} \sqrt[3]{P_r}$$

here

$$Nu_x = \frac{d_x}{\lambda}, \quad Re = \frac{\omega_0 X}{\nu} \quad \text{ba} \quad P_r = \frac{\nu}{a} \quad (7-9)$$

It follows from the equation (7-9) that the coefficient of heat exchange is calculated as a function ω_0 of speed, linear dimensions and λ, ν, a physical parameters.

a of X can be written as follows.

$$\alpha = \frac{c}{\sqrt{X}} = cX^{-0,5}$$

The magnitude ω_0 determining the proportionality coefficient does not depend on C technical and λ, ν, α physical quantities X .

According to (x), the heat transfer coefficient at $x=0$ is infinitely large, X with the increase of, it has a final and slowly decreasing magnitude

(Fig. 7 – 4). Δ The change of such a character is explained by the fact that the temperature difference $v_0 = t_0 - t_c$ does not change along the plate, while the temperature gradient on the wall on this side Δ decreases continuously with the increase of x .

The temperature on the surface of the plate is constant only when expression (7-9) satisfies the following conditions, the physical parameters of the liquid do not depend on the temperature, and there is no unheated state at the top of the plate.

Analyses and theory show that not taking these factors into account can lead to significant errors.

Dependence of the temperature change on the surface of the heat exchanger plate along its length. A change in the length of the plate t_c can have a significant effect on heat transfer. As a result of the change in wall temperature, the temperature distribution in the thermal boundary layer changes, its thickness and the value of the temperature gradient in the liquid on the surface of the body changes.

The coefficient of heat exchange in the exact area of the plate depends on the development of the boundary layer from the previous area, as well as the change of the wall temperature in this area. This effect is complicated by the variability of the physical parameters of the liquid.

In many cases, surface temperature or temperature pressure changes can be expressed by the law of degrees.

$$v_{c(x)} = A x^m$$

here : $v_{c(x)} = t_{c(x)} - t_0 : t_0 = \text{const}$

$t_{c(x)}$ – local value of surface temperature

A are related x constants

$m = 0$ in accordance with $v_{c(x)} = A = t_c - t_0 = \text{const}$ the previously considered issue $t_c = \text{const}$.

Heat exchange in a noizothermic plate was studied with a number of variables [p. 79,155,139 and others]. The analysis of these cases shows m that in raising t_c . Heat exchange increases in such situations.

Effect of longitudinal surface temperature gradient (plate heat transfer) on varying surface temperature ($m \neq 0$) and ($m = 0$) can be calculated in the form of a ratio with a constant: ϵ we denote this ratio by

$$\epsilon = \frac{Nu_{x(m \neq 0)}}{Nu_{x(m=0)}} \text{ or } Nu_{x(m \neq 0)} = \epsilon Nu_{x(m=0)}$$

ϵ The value of ϵ is calculated analytically and m has been checked experimentally for some quantities: they are presented in Table 7 – 1 (taken from [p.7 – 9]).

$Pr > 1$ dependency when $\epsilon = f(m)$

m	-0,25	$0(t_c = \text{const})$	0,1	0,2	0,3	0,4	0,5			
							$(q_c = \text{const})$	0,8	1,0	2,0
ϵ	0,655	1	1,09	1,17	1,25	1,30	1,36	1,52	1,60	1,98

$Nu_{x(m=0)}$ size can be determined from expression (7-10). Taking into account the ratio (7-11), the following equation can be used to calculate the local coefficient of heat exchange when the temperature on the surface of the plate is variable and the boundary layer is laminar.

$$Nu_{жкx} = 033\varepsilon Re_{жкx}^{0,5} Pr_{жк}^{0,33} (Pr_{жк}/Pr_c)^{0,25}$$

Heat dissipation in a turbulent boundary layer

Currently, the development of the theoretical study of heat distribution in the case of turbulent fluid flow is carried out on the basis of the hydrodynamic theory of heat exchange.

The hydrodynamic theory of heat exchange is based on O. Reynold's idea of the unit of mechanical energy and convective transfer of heat.

This interpretation makes it possible to determine the relationship between heat transfer capacity and frictional resistance.

It becomes possible to develop formulas for calculating heat transfer based on hydrodynamic experience or resistance calculations.

The hydrodynamic theory gives a good enough result in revealing the essence of the turbulent heat exchange mechanism.

In the turbulent boundary layer, there is a thin laminar fluid layer-viscous or laminar layer on the surface of the body. In this layer, "y" a significant change in speed occurs in the direction normal to the surface of the body directed along the -axis. The temperature also changes mainly in this area of the laminar layer.

Heat transfer by thermal conduction is small, so it can be ignored.

Thus, the stress and heat flux density in the arbitrary plane of the laminar layer parallel to the wall surface is determined by the following equation:

$$S = \mu \frac{d\omega_x}{dy} \text{ (a) and } g = \lambda \frac{dt}{dy}$$

This implies that the heat is transferred transversely to the liminar flow only by heat conduction.

When the above equations are considered together without the minus sign, we get the following.

$$g = \int \frac{\lambda}{M} \cdot \frac{dt/dy}{d\omega_x/dy} \quad (15)$$

We distinguish an arbitrary plane parallel to the wall surface in a turbulent flow. (Fig. 7-9)

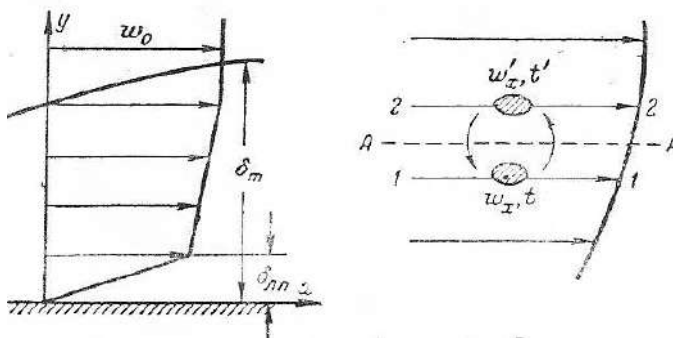
Continuous fluid particles pass through A – A in both directions due to turbulent oscillation. The amount of liquid with the speed and temperature t passing from the surface per unit of time from the bottom to the top. This amount of liquid moves from the 1 – 1 plane to the 2 – 2 plane. ω_x At steady state, this amount of liquid must pass from the 2 – 2 plane to the 1 – 1 plane, where the velocity ω'_x and the temperature t'_x is equal to Fluid particles moving from bottom to top $g_t C_p t'$ are equal to and particles moving down are equal to $g_T C_p t'$ carries heat equal to

If $t' > t$ so, the amount of heat transferred from the unit of the control surface to the unit of time through turbulent exchange is determined by the following formula.

$$g_T = g_T C_p (t' - t), \text{ BT/M}^2, \text{ W/ M}^2 \text{ (16)}$$

Since moving fluid particles have a certain speed, they carry kinetic energy along with heat. If $\omega'_x > \omega_x$, then the lower fluid particles get acceleration from the upper ones, and vice versa, that is, the upper fluid particles decrease in speed.

, the difference between the velocity of the fluid particles and W_x' the change in their momentum is reduced. W_x Thus, the turbulent exchange of liquids, despite the fact that their physical nature is completely different, acts like the collisional stress of molecules in a laminar flow.



The shock stress generated in the plane A-A due to turbulent exchange S_T is called turbulent stress. This tension can be determined using the momentum law. When this is applied to the view state it takes the following form.

$$S_T = g_T(W_x' - W_x)_{,H/M^2}$$

Heat transfer coefficients in the turbulent boundary layer are determined by the following equation.

$$Nu_{жж} = 0,0296 Re_{жe}^{0,8} Pr_{ж}^{0,43} (Pr_{ж}/Pr_e)^{0,25} \quad (35)$$

Average amounts are found by the following equation:

$$Nu_{жe} = 0,037 Re_{жe}^{0,8} Pr_{ж}^{0,43} (Pr_{ж}/Pr_e)^{0,25} \quad (36)$$

the determining t_0 temperature, the temperature of the fluid away from the body is taken (t_c except in the equation through Pr_c). X-coordinate [from formula (35)] or λ -plate length [from formula (36)] calculated from the point where heat exchange starts is used as a size determinant.

14th lecture Heat transfer when the fluid moves freely

Free movement occurs at the expense of integral (volumetric) forces. Such forces include gravity, centrifugal force, and high-strength electromagnetic field forces generated in the fluid. The free motion of a fluid under the influence of gravitational forces is well studied.

In the equation of motion (4 – 17), the gravitational forces are taken into account by the quantity pg , which has a force measurement in the volume unit. During heat exchange, the temperature of the fluid is variable. As a result of this, there is a difference in densities and, as a result, a difference in gravitational forces that gives the lifting (lowering) force.

In technical terms, the acceleration of gravity from one point of the considered medium to another is practically unchanged. Volumetric forces generated under the influence of the electromagnetic field or centrifugal effect in the studied liquid. The calculation of the variation of the vector F can change. If only gravity is considered, then $F = g$.

In this chapter, only heat dissipation in free gravitational motion is considered. In some cases, the results obtained for gravity and convection are used to estimate the free motion that occurs under the influence of other integral forces. is replaced by The result obtained in this way should be considered approximate, because the field of acceleration corresponding to different forces may differ from the field of gravitational acceleration.

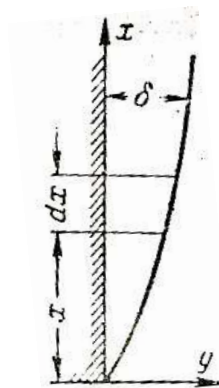
Heat is released when the fluid moves freely in large quantities.

In this paragraph, the free gravitational flow for the simplest geometrically shaped surface of a rigid body (vertical, horizontal cylinder) is considered. It is assumed that the volume of the liquid is so large that the free movement of other bodies in this volume does not affect the observed flow. As in forced convection, free fluid motion can be laminar or turbulent.

Heat dissipation in free laminar movement along a vertical plate. t_c Let a vertical plate whose surface does not change in temperature be located in a liquid or gas. Away from the plate, the fluid is stationary (no forced flow) and the temperature of the fluid away from the plate is the same and t_o equal to . We assume that to simplify the calculation $t_c > t_o$ (however, the obtained results are also valid for the inverse reciprocal of temperatures).

In this case, the rising motion of the heated layer of the liquid appears on the plate. The speed is zero, as before, away from the plate.

We place the coordinate head on the lower edge of the plate; We direct the X-axis along the plate, and we place the U-axis normal to the bottom of the plate (Fig. 1)



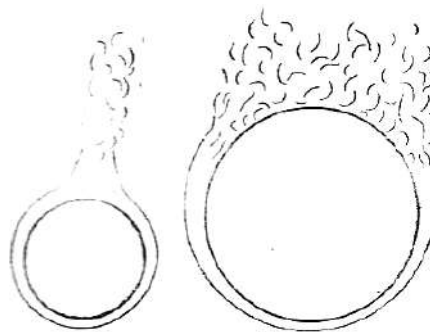
We assume that the plate is infinite along the Z axis. The process is stationary. To facilitate the solution of the problem, we assume the following:

- 1) Inertia forces are very small compared to gravity and viscous forces;
- 2) Convective heat transfer and heat conduction across the moving fluid layer can be neglected;
- 3) The pressure gradient is zero ;
- 4) The physical parameters of the liquid (not including the density) are unchanged; Density is a linear function of temperature.

Average heat dissipation of a vertical plate in laminar flow $t_c = const$.

$$Nu_e = 0.63(G_{re}P_r)^{0.25} \quad (12)$$

(11) and (12) need some precision



2 – picture. Free movement near horizontal pipes.

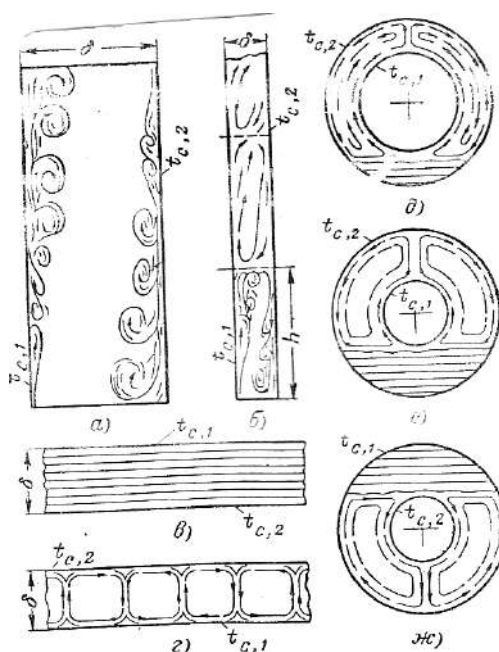
The nature of free movement near welded horizontal pipes is shown in Fig . 1 . The larger the pipe diameter, all other things being equal, the more laminar flow disturbances can occur further away from the pipes. To calculate the average coefficient of heat dissipation during free movement near horizontal pipes, the IMMixeeva(1.175) formula can be used:

$$Nu_{жд} = 0.50(Gr_{жд} Pr_{ж})^{0.25} (Pr_{ж}/Pr_c)^{0.25} \quad (16)$$

In the formula, the temperature of the liquid or gas far from the pipe is taken as the determinant, and the diameter of the pipe is taken as the determinant measure.

Heat release when fluid moves freely in a confined environment.

If the volume of the liquid is not large, the free movement of other bodies or parts of these bodies located in this volume can be felt in the observed flow. It is very difficult, if not impossible, to separate these actions and consider them separately.



3 – picture. Limited free movement.

In this case, motion and heat release depend on the type of fluid, its temperature and thermal pressure, including the shape and dimensions of the medium.

In horizontal slits built using two flat walls, the process is determined by the heated and cold surfaces and the distance between them. If the temperature of the upper wall is higher than that of the lower wall, there will be no free flow of liquid (Fig. 10 - 8 1). In this case, heat is transferred from the upper wall to the lower wall by heat conduction or radiation.

The temperature of the liquid is constant in the horizontal layers, and increases in the vertical direction. The above applies to a liquid whose density does not decrease with increasing temperature. If the temperature of the lower wall is higher than that of the upper wall, convection currents are formed in the slit under certain conditions. Hot particles of liquid with low density try to rise up. Alternating ascending and descending currents appear in the crack (Fig. 3g). When viewed from above, the flow field consists of a grid structure of hexagonal cells with a clear or more ambiguous structure. Inside these cells, the current moves upwards, and from the edges it returns downwards. This flow continues until a disordered turbulent flow occurs.

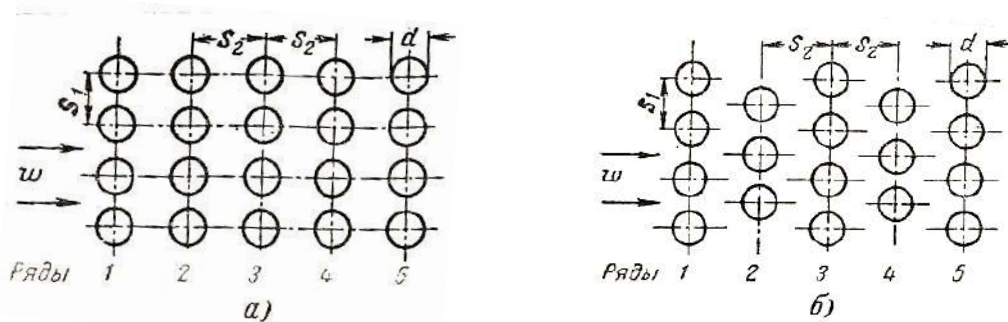
15th lecture
Heat transfer when moving along the pipe

16th lecture
Heat transfer when moving along a single pipe

17th lecture
Heat transfer in a set of pipes

Heat exchangers rarely consist of a single cross-washed pipe, since the heat exchange surface is not large. Pipes are usually bundled together. There are two main types of pipe joints in the technique: checkerboard and corridor (1 – picture).

Connection characteristics, transverse pitch S_1 (the distance between the axes of the pipes in the transverse direction of the liquid flow) and longitudinal row S_2 (the distance between the axes of two rows of pipes arranged consecutively in the direction of the liquid flow). S_1 and S_2 connections are also characterized by the outer diameter of the pipes and the number of groove rows in the fluid path (Figure 1) - five rows in each connection.



1 – picture. The scheme of the arrangement of tubes in corridor (a) and checkerboard (b) connections.

For a particular connection, the diameter of the pipes is d and S_1 vs S_2 pitches are typically quantities that vary both transversely and longitudinally with fluid flow.

The fluid flow in the joint is quite complex in nature. Because the side-by-side pipes of the connection affect each other, it is different from the washing of a single pipe. Usually, a bundle of pipes is placed in a channel of some kind. Therefore, the current in the link can be related to the current in the channel.

Two main types of fluid flow are known: laminar and turbulent. These modes can also exist when the fluid moves through the bond. The shape of the fluid flow depends more on the nature of the flow in the channel before the connection. If the flow in a channel with a barrier is turbulent in the absence of the barrier at given flow rates and temperatures, it will necessarily be turbulent with the barrier, because the barrier is a high-level turbulizer. However, if the connection is placed in a channel with a laminar flow, depending on the number of Re , it is possible to have one or another flow. The smaller Re is, the more stable the laminar flow is, the larger it is, the easier it is to transfer the flow to a turbulent state. At small values of Re , the flow can remain laminar. In this case, inter-tube slits appear to form crack channels with variable cross-sections (except for the case when the distance between the tubes is very large).

The following formula is derived:

$$Nu_{\text{ж}d} = c Re_{\text{ж}d}^n Pr_{\text{ж}}^{0,33} (Pr_{\text{ж}}/Pr_c)^{0,25} \varepsilon_1 \varepsilon_s, \quad (4)$$

Here, $s = 0.41$ and $n = 0.60$ for checkerboard connections and $s = 0.26$, $n = 0.65$ for corridor connections. In this formula (4), the outer diameter of the tube bundle is the main measurement. The velocity of the fluid to the criterion $Re_{\text{кр}}$ is calculated from the point of the thinnest cross-section of the link. The average temperature of the liquid is the main temperature (Re_c except when it is selected according to the wall temperature).

CONTROL QUESTIONS

1. Explain convective heat transfer.
2. Why was similarity theory introduced?
3. What does the heat transfer coefficient depend on?
4. How does heat transfer occur in pipes?
5. How does heat transfer occur in free movement?
6. How does heat transfer occur during forced movement?
7. What does the Nusselt criterion represent?
8. What is laminar and turbulent flow?

18th lecture

Heat transfer in the case of aggregate

The boiling process is widely used in machinery, for example, in steam boilers, vaporizers, cooling devices, etc.

We can observe the boiling process on the surface of a solid and in the volume of a liquid. More solid surface boiling is common. The process of boiling is associated with the release of heat, so heat transfer in boiling is of more interest. The mechanism of the boiling process is distinguished from the mechanism of convective heat exchange by boundary layer processes. The vapor bubbles bring the boundary layer to a state of turbulation. The conditions for the formation of the boiling process are as follows: the liquid must be heated to a temperature higher than the saturation temperature, and there must be evaporation centers (BM) on the heat exchange surface. Surface roughness, air bubbles, and dust particles are examples of BM.

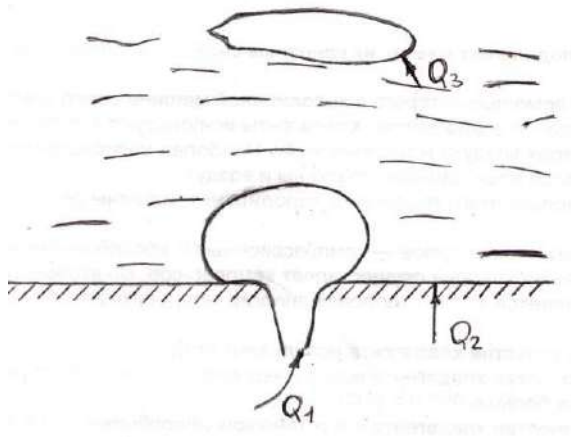


Figure 47

can be obtained from the foot of the vapor bubble (Q_1), the boundary layer (Q_2) and the updraft core (Q_3). A vapor bubble located in the center of evaporation is affected by the pressure force inside the vapor bubble (R_1) and the pressure force (R) of the surrounding liquid. The conditions of equality of these forces are written by the Laplace equation:

$$\Delta R = R_1 - R = \frac{2\sigma}{R_{kr}}, \quad (233)$$

where σ - surface tension force;

R_{kr} - critical radius - the minimum radius at which a bubble occurs.

If $\Delta R > \frac{2\sigma}{R_{kr}}$, the vapor bubble becomes larger.

If $\Delta R < \frac{2\sigma}{R_{kr}}$, the vapor bubble turns back into water.

The critical radius is determined from the following expression:

$$R_{kr} = \frac{2\sigma T_s}{r \rho_c (T_c - T_s)} \quad (234)$$

where T_s is the saturation temperature, K;

T_s – liquid temperature, K;

ρ_s – liquid density, kg/m³;

r – heat of vaporization, [kJ/kg].

We know that the appearance of bubbles on the surface of a solid body, their size, separation from the surface of the body depends on the temperature of the liquid and the surface of the solid body and the separation diameter (d_{aj}).

The enlarging or, in other words, the growing vapor bubble grows in diameter and when it reaches the separation diameter (Fig. 48) (d_{aj}), it separates from the surface and rises up along the surface of the liquid.

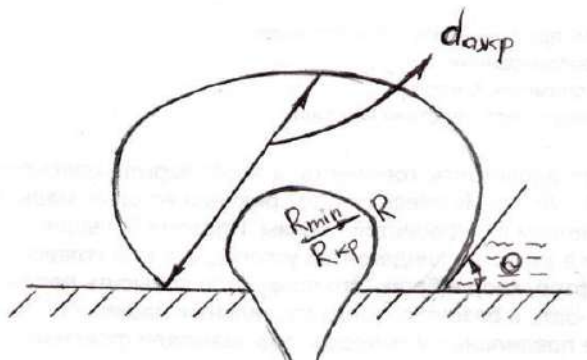


Figure 48

The separation diameter is calculated using the following expression.

$$d_{aj} = 0.0208\theta \sqrt{\frac{\sigma}{g(\rho_c - \rho_b)}} \quad (235)$$

in this θ - an edge corner;

g - acceleration of free fall;

ρ_b – steam density.

the edge angle θ increases, the surface of the boiling water deteriorates. The separation diameter increases. If $\theta > \frac{\pi}{2}$, the surface of the liquid does not get wet, the bubbles expand, and heat is transferred to the steam rather than to the water.

19th lecture
Heat transfer in boiling
Boiling process and its occurrence

Types of boiling

Boiling is divided into the following types: bubble, film and surface (or unheated liquid boiling).

In bubbling boiling (Fig. 49), steam bubbles appear on the surface and grow larger and separate from the surface, rapidly mixing the boundary layer. In this case, the liquid temperature is higher than the saturation temperature. Bubbles move throughout the liquid volume. The formation of bubbles depends on the temperature of the surface of the solid body.

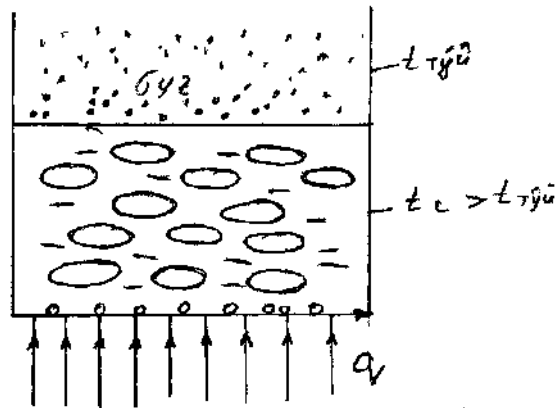


Figure 49

In film boiling (Fig. 50), there are so many vapor bubbles on the surface of a solid that they form a vapor film layer on the surface. creates resistance:

$$R = \frac{\delta_{\text{пленка}}}{\lambda_{\text{буль}}} \quad (236)$$

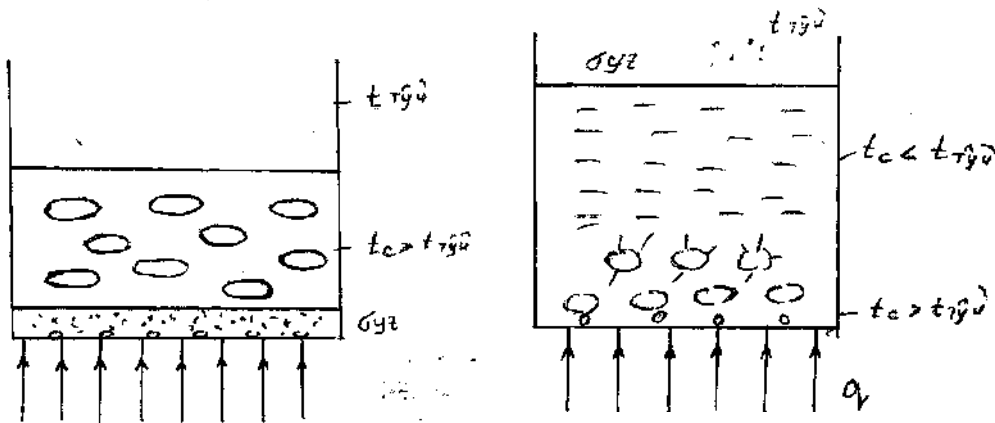


Figure 50 Figure 51

The higher the thermal resistance, the less heat is given. When boiling on the surface of a solid (Fig. 51), the liquid in the layer on the surface is heated. Bubbles formed on the surface of a solid body separate from the surface and fall to the core of the liquid that has not heated up to the boiling temperature, and the steam turns into water again. The boundary layer mixes rapidly and heat transfer remains high.

Boiling crises and factors affecting it

Let's consider the dependence of heat transfer on boiling (boiling curve).

The boiling curve has the following parts: (Fig. 52) 1-natural convection (liquid heating); 2-part of the slow formation of the boiling process; 3-accelerated bubbling part; 4th transition part (without norm); 5-film boiling (moderate).

The point K transition from bubble boiling to film boiling is called **I boiling crisis**. The heat load is called the first critical load and is denoted q_{kr1} . When the boiling crisis begins, the heat transfer coefficient deteriorates and the surface may be damaged due to the excessive increase in surface temperature.

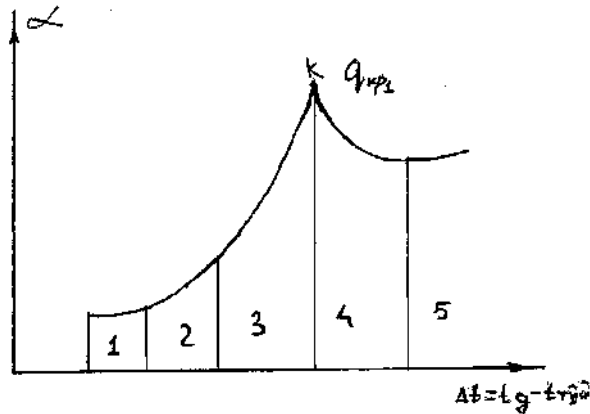


Figure 52

Due to the reduction of heat load, film boiling is replaced by bubble boiling. The transition point to film boiling is called **boiling crisis II** and is denoted by q_{kr2} , $q_{kr2} \ll q_{kr1}$.

For water $q_{kr1} = 1 \cdot 10^6 \text{ W/m}^2$, $\Delta t_{kr} = 25^\circ \text{C}$.

The critical heat load in free convection for a large volume of liquid is calculated by the following expression:

$$q_{kr1} = k \cdot r \sqrt{\rho''} \sqrt{g \sigma (\rho' - \rho'')} \quad (237)$$

where k is the constant size of the two-phase boundary layer, $k=0.13$.

The phenomenon of heat transfer during boiling can be calculated using both empirical and criterion equations. Empirical expressions look like this:

$$\alpha = A q^{0.7}$$

In the free convection section, it is determined from the following expression:

$$\alpha = f(\Delta t)$$

In the accelerated boiling section:

$$\alpha = f(\Delta t) \text{ and } \alpha = f(q)$$

For example, the expression for water is written as:

$$\alpha = 3.14 q^{0.7} r^{0.15} \quad (238)$$

The form of the criterion equation (Labunsev expression) is as follows:

$$Nu = c Re^n Pr^{\frac{1}{3}} \quad (239)$$

where $Nu = \frac{\alpha \ell}{\lambda}$ defining quantity

$$\ell_s = \frac{c_p \cdot \rho^1 \sigma T_r}{(r \rho)}, \quad (\text{m})$$

$$\text{Re} \geq 10^{-2}, \text{Nu} = 0.125 \text{Re}^{0.65} \text{Pr}_c^{\frac{1}{3}}$$

$$\text{Re} \leq 10^{-2}, \text{Nu} = 0.625 \text{Re}^{0.5} \text{Pr}_c^{\frac{1}{3}}$$

These expressions can be used when the value of pressure is $R=45 \cdot 10^{-2} \div 175 \cdot 10^{-5}$ Pa.

The following factors affect the heat transfer during boiling:

1. Heat load and temperature difference (boiling curve);
2. As the pressure increases, the heat transfer coefficient increases;
3. Physical properties of liquid:
 - a) heat transfer coefficient increases as the heat transfer coefficient increases;
 - b) as the kinematic viscosity coefficient (ν) increases, the heat transfer coefficient decreases.
 - c) σ the heat transfer coefficient decreases as it increases;
4. The speed of the liquid affects the heat transfer coefficient as follows – $W^{0.8}$;
5. The roughness of the surface leads to an increase in the coefficient of heat transfer, because the number of evaporation centers increases.

Boiling in large volumes and channels

Boiling is also present in large volumes and channels, and these are different from each other. Let's consider the field of temperatures in large-scale bubble boiling (Fig. 53).

The surface temperature is much higher than the boiling point. The temperature of the liquid, throughout its volume, is 0.2°C more than the saturation temperature, and in the case of vapor, it is equal to the saturation temperature.

In surface boiling (Fig. 54), the temperature in the liquid core is smaller than the saturation temperature, only the liquid in the boundary layer is warmer than the saturation temperature.

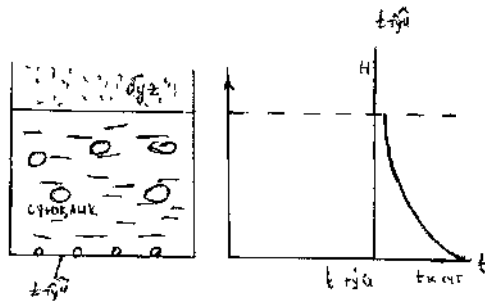


Figure 53

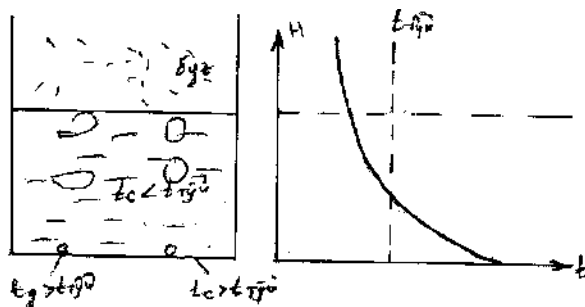


Figure 54

The structure of the 2-phase current in the channels varies along the height. Let's consider the parts that occur during boiling in the channels (Fig. 55).

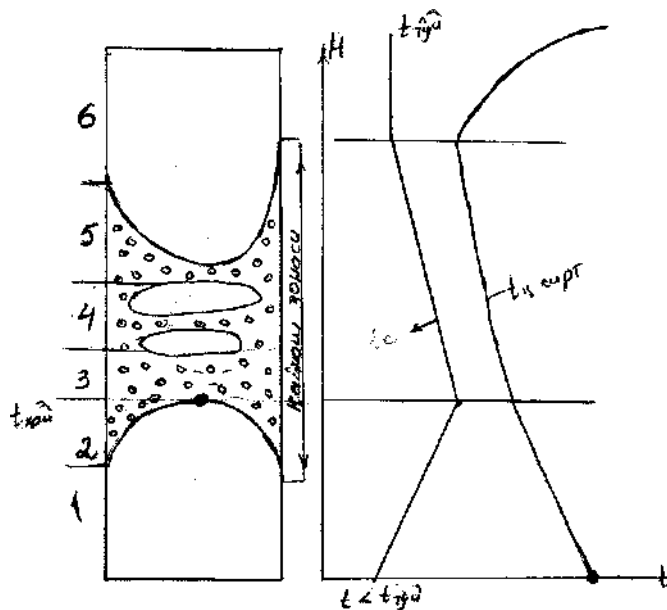


Figure 55

In the picture, part 1 of the economizer, the liquid is heated to boiling temperature, the convection part; 2- the boiling part on the surface of the solid body, the liquid only boils, and it is not yet boiled in the core of the flow; 3- accelerated bubbling part, which is called part of the emulsion state; 4- plug state part, in which the steam is in the form of a large plug and moves in the center, and the liquid boils on the surface; 5- annular part; Part 6, the liquid film dries on the surface, only moist vapor flows, this is convection, the heat transfer coefficient decreases, the temperature of the surface increases, this is called the second-order boiling crisis.

Let's consider several parameters of two-phase flow:

1. Volumetric steam storage

$$\varphi = \frac{M_b / \rho_b}{V_{ap}}, \quad (240)$$

where M_b is the mass of steam;

V_{ar} is the volume of steam-water mixture.

2. Mass consumption steam storage

$$X = \frac{G_b}{G_{ap}} = \frac{G_b}{G_b + G_c}, \quad (241)$$

G_{ar} – consumption of steam-liquid mixture, kg/sec.

3. Circulation speed

$$W_s = \frac{G_{ap}}{\rho_{ap} f}, \quad (242)$$

f- the cross-sectional surface of the channel.

4. Volume consumption steam storage

$$\beta = \frac{V_{\bar{6}}}{V_{ap}} = \frac{V_{\bar{6}}}{V_{\bar{6}} + V_c}, \quad (243)$$

$$V = \frac{G}{\rho}$$

5. True vapor storage

$$\psi = \frac{f_{\bar{6}}}{f_{\bar{6}} + f_c}, \quad (244)$$

f_b – the section of the cross-sectional surface of the channel covered with steam;

f_s – cross-sectional area of the channel covered with liquid;

6. Actual steam velocity

$$W_b = \frac{V_{\bar{6}}}{f_{\bar{6}}} \quad (245)$$

7. Phase slip speed

$$U = W_b - W_s, \quad (246)$$

Heat transfer in film boiling is calculated by the following expression:

$$\alpha = s \sqrt[4]{\frac{\lambda_{\bar{6}}^3 r \rho_{\bar{6}} (\rho_c - \rho_{\bar{6}}) g}{\mu_{\bar{6}} \Delta t \ell_o}}, \quad (247)$$

where ℓ_o is a determining quantity - diameter in horizontal pipes, height in vertical pipes.

In the works of many authors, when the boiling of liquid metals is examined, it can be seen that a new type of heat transfer crisis has arisen, in which a rapid transition from single-phase convection to film boiling is called the term "third boiling crisis" (q_{kr3}):

$$q_{kr2} < q_{kr1}$$

Flow rate is the speed of the boiling process in the steam generator. But the origin of the dependence of the circulation of the current is different. It is different for straight, curved pipes, and smaller for curved pipes.

In order to accelerate the heat exchange during boiling, it is necessary to put porous surfaces, which will create more evaporation centers. It was observed that the boiling curve on porous surfaces is higher than that on flat surfaces, and q_{kr1} is three times higher.

The complexity of the boiling process makes it difficult to create mathematical models. In several large research centers, work is being carried out on the creation of mathematical models of heat transfer during boiling.

CONTROL QUESTIONS

1. What is a boil?
2. How many types of boiling process are divided?
3. Describe the conditions under which boiling occurs.
4. What does the formation of evaporation centers depend on?
5. What is evaporation?
6. Tell me about boiling crises.

20th lecture

Heat transfer when steam turns back into water.

Condensation phenomenon

When the steam comes into contact with a surface with a temperature lower than the saturation temperature, it turns back into water, this phenomenon is called **condensation** phenomenon, and the resulting mass is called **condensate**.

In practice, the phenomenon of condensation occurs in turbine condensers and heat exchangers.

The process of condensation is related to heat transfer, because the internal heat of vaporization is released when the steam turns back into water.

Condensation can occur both in the vapor volume and on the surface. Condensation in the vapor volume occurs when the vapor is cooled to the saturation temperature at a given pressure.

In many areas of the public economy, especially in heat energy, condensation, which is formed when steam collides with a cold surface, is used, that is, the process of condensation on the surface. Such condensation occurs only when the surface temperature is less than the saturation temperature at a given pressure. Sometimes a film of condensate, sometimes individual drops are formed on the surface of a solid body. The state of condensation in the first case is called film condensation, and **the state of condensation in the second case is called droplet condensation**.

When condensation occurs, it depends on whether the liquid is wetting the surface or not. If the liquid wets the surface (surface), there is film condensation. If the liquid does not wet the surface, then dropwise condensation will form.

Wetting and non-wetting of the surface is due to the effect of surface attraction. Let's see what causes surface gravity.

A particle located in a liquid volume is affected by mutual attraction forces. The sum of these forces is zero. A particle located on the surface is affected by this force, but it is an effect from one side, so the sum of some forces is called the surface attraction force, this force is directed into the liquid. Under the influence of these forces, the liquid tends to reduce its surface area. The ratio of the surface attraction force to the length at the phase separation boundary is called **the surface attraction force coefficient** and σ is denoted by. Taking these into account, the surface of the liquid forms an angle with the surface, θ defined by

In the diagram below, we can see how water is between this angular surface and a particle of size q (Fig. 44):

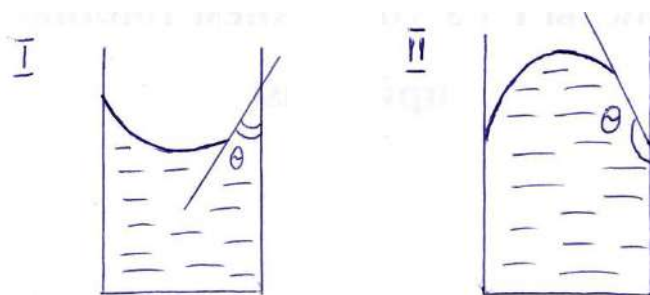


Figure 44

In case I: $0 < 90^\circ$ occurs, that is, the liquid wets the surface;

In case II: $0 > 90^\circ$ occurs, that is, the liquid does not wet the surface.

The coefficient of surface gravity is the same for both cases

where:

$$\sigma_{\text{сирт газ}} - \text{куч} - \text{сирт} - \text{газ};$$

$$\sigma_{\text{суюк. газ}} - \text{куч} - \text{суюклик} - \text{газ};$$

$$\sigma_{\text{сирт суюк}} - \text{куч} - \text{сирт} - \text{суюклик};$$

We can write the equality condition for a drop as follows:

$$\sigma_{\text{сирт газ}} = \sigma_{\text{сирт суюк}} + \sigma_{\text{сирт газ}} \cdot \cos \theta$$

$$\text{бундан: } \cos \theta = \frac{\sigma_{\text{сирт газ}} - \sigma_{\text{сирт суюк}}}{\sigma_{\text{сирт газ}}} \quad (215)$$

In droplet condensation, the heat transfer coefficient is always higher than in film condensation, because the film of the condenser has a thermal resistance, which slows down the

heat transfer. It is necessary to reduce this resistance or, in other words, separate the film of condensate. Then the resistance decreases and heat transfer increases. Hydrophobizers are used to artificially create droplet condensation. These substances are either added to the steam or poured into the condenser tubes.

Let's consider the state of condensation on a vertical surface. (Fig. 45).

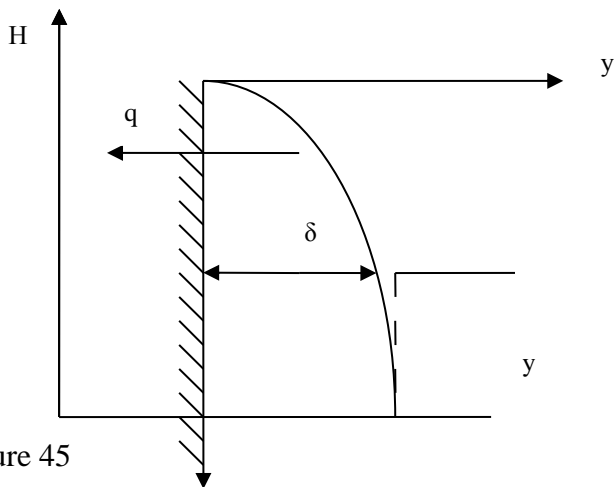


Figure 45

In general, the thermal resistance in the condensation process is the sum of the thermal resistance of the condensate film and the spatial transition thermal resistance.

$$R = \frac{1}{\alpha} = \frac{t_{\delta} - t_{cupm}}{q} = R_n + R_{\phi} \quad (216)$$

As can be seen from the graph of temperature changes in Fig. 45, a rise in temperature occurs at the separation boundary of steam with condensate. This temperature rise is the result of countercurrent flow of molecules in the thin surface layer. Some of the molecules return from the surface and join the steam again. As a result of this, a stream of molecules with different energies (temperatures) or unequal moves in a thin surface layer. Therefore, the temperature of the steam in this layer differs from the temperature of the condensate due to temperature changes. The more molecules return from the surface, the higher the temperature rise.

A characteristic of temperature increase is the condensation coefficient - K, which is determined by the ratio of the number of molecules carried by the liquid to the number of molecules hitting the wall.

There are theoretical expressions that relate the condensation coefficient to the thermal resistance of the space transition, which depends on the temperature and pressure of the steam. When the condensation coefficient is small, the value of the temperature increase will be larger, and the thermal resistance of the spatial transition will also have a large value. When water vapor has a small pressure, the condensation coefficient is $k=1$, which means that there is no temperature increase, so the spatial transfer thermal resistance $R_f = 0$.

The thermal resistance of the condensate film depends on the flow mode of the current. Heat from a laminar film is considered based on heat conduction, and in a turbulent film, convective heat transfer is considered. The values obtained from the experiments of various authors show that the critical Re number varies from 60 to 500.

1 kg of dry saturated steam to condensate, r heat is released. This is called **the spatial transition heat** and is denoted by r . In addition, cooling of the condensate occurs, because the temperature of the surface is lower than the saturation temperature. If the cooling of the condensate is less than the released heat, then we determine the amount of heat from the following expression:

$$Q = G \cdot r$$

where G is the amount of condensate formed.

In concrete problems, it is necessary to distinguish the condensation of moving and stationary vapors when considering heat transfer. The movement of steam affects the resistance of the condensate film, and therefore the intensity of heat exchange. In fact we have a condensation of moving steam, because instead of a volume of condensed steam, a new volume of steam appears at the surface, so that the steam is always in motion. For a vertical surface, the steam velocity is equal to:

$$W = \frac{q}{r \rho_0} \quad , \quad m/c \quad (217)$$

For saturated water vapor, $W = 0.23$ m/sec. At this speed, the steam cannot affect the condensate film, so it is considered immobile.

In film condensation of steam not moving on a vertical surface heat exchange

Dry saturated steam with surface temperature t is condensing on a vertical surface. The condensate film has a collinear temperature.

To consider such a situation, we pay attention to the following:

- 1) Inertial forces formed in the condensate film are smaller than the forces of viscosity and gravity;
- 2) There is no convective heat transfer from the film, and heat conduction across the film is not taken into account - heat is only transferred from the film.
- 3) It is assumed that there is no friction at the vapor-liquid phase boundary.
- 4) The temperature on the outer surface of the condensate film does not change and is equal to t_n .
- 5) Physical parameters do not depend on temperature.
- 6) The density of steam is less than the density of water.

Let's consider the changes in the state of laminar flow of the film.

We write the energy equation:

$$\frac{\partial t}{\partial \tau} + W_x \frac{\partial t}{\partial x} + W_y \frac{\partial t}{\partial y} + W_z \frac{\partial t}{\partial z} = a \left(\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2} \right) \quad (218)$$

since it is a steady state $\frac{\partial t}{\partial \tau} = 0$ (219)

since there is no convective heat transfer

$$W_x \frac{\partial t}{\partial x} + W_y \frac{\partial t}{\partial y} + W_z \frac{\partial t}{\partial z} = 0 \quad (220)$$

Since there is no heat transfer across the film as written at the beginning of the paragraph, we have:

$$\frac{\partial^2 t}{\partial x^2} = 0 \text{ and } \frac{\partial^2 t}{\partial z^2} = 0, \text{ then the energy equation is written as:}$$

$$\frac{\partial^2 t}{\partial y^2} = 0$$

Boundary conditions:

$$\begin{aligned} y = 0 \quad t = t_{\text{супр}} \quad \frac{\partial W_x}{\partial x} = 0 \\ y = \delta \quad t = t_n \quad \frac{\partial W_y}{\partial y} = 0 \end{aligned} \quad (221)$$

We integrate the energy equation:

$$\frac{\partial t}{\partial y} = c_1 ; \quad t = c_1 y + c_2$$

taking into account the boundary conditions:

$$y = 0 \quad c_2 = t_{cupm}$$

$$\text{if } y = \delta \quad t_n = c, \delta + t_{cupm} \rightarrow c_1 = \frac{t_T - t_{cupm}}{\delta}, \quad (222)$$

$$\text{бундан:} \quad \frac{\partial t}{\partial y} = \frac{t_T - t_{cupm}}{\delta} \quad (223)$$

Heat transfer coefficient

$$\alpha = \frac{q}{t_n - t_{cupm}} = \frac{\lambda \frac{\partial t}{\partial y}}{t_n - t_{cupm}} = \frac{\lambda}{\delta} \frac{t_c - t_{cupm}}{t_n - t_{cupm}} = \frac{\lambda_c}{\delta} \quad (224)$$

If heat is transferred through the film only by heat conduction, then $\alpha = \frac{\lambda_n}{\delta}$ it will be.

the heat transfer coefficient according to the last expression, α we need to know the thickness of the film along the height of the surface. We use the differential equation of motion to find an expression for the thickness of the film. Integrating the differential equation of motion, we get:

$$\delta = \sqrt{\frac{4\lambda\mu_c(t_T - t_{cupm})x}{r\rho_c^2 g}}, \quad (225)$$

As a result of putting the resulting equation into the previous equation,

$$\alpha = \frac{\lambda}{\delta} = \frac{\sqrt[4]{\lambda}}{\sqrt[4]{\frac{4\lambda\mu_c(t_\tau - t_{cupm})x}{r\rho_c^2 g}}} = \sqrt[4]{\frac{r\rho_c^2 g \lambda^3}{4\lambda\mu_c(t_\tau - t_{cupm})x}} \quad (226)$$

From this expression, the local value of the heat transfer coefficient can be calculated at the X section. (Fig. 46).

We use the following expression for the average heat transfer coefficient by height:

$$\bar{\alpha} = \frac{1}{h} \int_0^h \alpha dx \quad (227)$$

obtained from this expression α , integrating the equation, we write the expression for determining the average heat transfer coefficient for vertical surfaces:

$$\bar{\alpha} = 0,943 \sqrt{\frac{r^* \rho_c^2 \lambda_c^3 g}{\mu_c (t_\tau - t_{cupm}) h}} \quad (228)$$

This expression was written by Nusselt in 1916 and determines the coefficient of heat transfer from vertical surfaces.

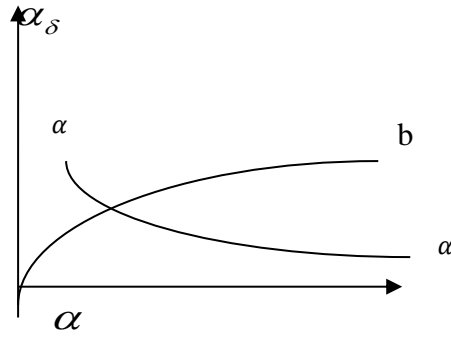


Figure 46

Condensation in horizontal pipes and pipe bundles

Nusselt is written as follows for horizontal pipes:

$$\bar{\alpha} = 0,7884 \sqrt{\frac{\rho^2 \lambda^3 g r}{\mu(t_\tau - t_{\text{сипт}})d}} \quad (229)$$

(229) $\bar{\alpha}$ is used for stationary steam condensation in expression. But in practice, the excitation currents are always condensed. The greater the speed of steam, the greater the temperature difference and pressure. Therefore, the heat transfer coefficient is large.

As a result of calculating the results of the experiment, the following expression is used for the condensation of moving dry saturated steam in a horizontal pipe:

$$\bar{Nu} = 0,72B Re_\delta^{0,16} Re_c^{-0,125} Ga^{0,045} \left(\frac{\mu_b}{\mu_c}\right)^{0,08} \quad (230)$$

$$\text{бу ерда :} \quad \bar{Nu} = \frac{\bar{\alpha}d}{R_c}; \quad Re_b = \frac{\bar{W}_b d}{\nu_b};$$

$$Re_c = \frac{\lambda_c \Delta t}{r \rho_c \nu_c}; \quad Ga = \frac{gd^3}{\nu_c^2}$$

Condensing devices are not composed of a single pipe, but of a set of pipes. Condensation in a bundle of tubes has a different rate of heat transfer than that of individual tubes. This can be explained by the following two factors:

- 1) During the movement of steam from the set of pipes, its speed decreases.
- 2) increases the thickness of the condensate film due to its movement from pipe to pipe.

in the condensate film reduces the heat transfer. Condensate flows into the pipe on the basis of individual drops or streams (jets), on the one hand, it increases the film of condensate, and on the other hand, it changes the movement of the flow, this situation brings the film into the state of turbulent flow. Therefore, the movement goes along the pipe.

To estimate the intensity of heat exchange, the following expression was obtained experimentally for individual pipes, which takes into account the amount of condensate entering the upper pipe.

$$\frac{\bar{\alpha}_n}{\alpha_1} = \left(\frac{\sum_{i=1}^n G_i}{G_n}\right)^{-0,07} \quad (231)$$

where: $\sum_{i=1}^n G_i$ - amount of total condensate coming to n rows of pipes;

G_n - the amount of condensate formed in the pipes in question;

n is the number of rows in a set of pipes located in a corridor or checkerboard;

$\bar{\alpha}_n$ - heat transfer coefficient of pipes with n rows;

α_1 - heat transfer coefficient of pipes in the first row from the top.

Calculations using this derived expression are complicated, since it is necessary to start the calculation from the first row and continue sequentially. If some reductions are made, that is, the difference in steam pressure and temperature is assumed to be at the height of the pipe, then the heat transfer coefficient is easier to calculate.

Heat transfer in dropwise condensation of steam

We learned from the above paragraphs that the occurrence of droplet condensation occurs due to the fact that the surface is not wetted by condensate. Experiments show that the droplet formation process is very fast, and then its speed decreases rapidly. Drops merge with each other and quickly fall off the surface.

In order for a droplet to form, the vapor must cool, that is, its temperature must be lower than the saturation temperature. This situation is due to the fact that the pressure on the flat surface of the drop is smaller than the pressure above. When the vapor turns into a droplet, it is formed when its radius is slightly larger than the critical radius.

The critical radius is determined by the Thomson equation:

$$R_k = \frac{2\delta T_\sigma}{r\rho_\tau(T_\sigma - T_{\text{iosa}})} \quad (232)$$

b where: T_σ - the temperature of the steam at the given pressure;

T_{iosa} - droplet surface temperature.

During drip condensation, there are cases where a condensate film is formed. But since the thickness of this film is very small, it splits very quickly and forms a droplet. In the empty place, a large film is formed, and it splits again quickly. The formation of condensate in the form of drops accelerates the condensation process, the thermal resistance is small.

In the process of droplet condensation, the temperature of the surface changes over time, the temperature change depends on the variation of the thermal resistance of the condensing steam. Taking into account such quantities, the following expressions were obtained to calculate the droplet condensation process:

$$Re_c = 8 \cdot 10^{-4} \div 3.3 \cdot 10^{-3}$$

$$\bar{Nu} = 3,2 \cdot 10^{-4} \quad Re_c^{-0.84} \Pi_\kappa^{0,16} \cdot Pr^{\frac{1}{3}}$$

$$Re_c = 3,3 \cdot 10^{-4} \div 1.8 \cdot 10^{-2}$$

$$\bar{Nu} = 5 \cdot 10^{-6} \quad Re^{-1,57} \Pi^{1,16} P^{\frac{1}{3}}$$

$$\text{бунда: } Nu = \frac{\bar{\alpha} R_k}{\lambda_c} = \frac{\bar{\alpha} \cdot 2\delta \cdot T_T}{\lambda_c \cdot r \cdot \rho_c (t_\delta - t_{\text{юза}})}$$

$$Re_c = \frac{\omega R_k}{v_c} = \frac{\lambda_c (t_\delta - t_{\text{юза}})}{\lambda_c \cdot r \cdot \rho_c}$$

$$Re_c = \frac{\xi \sigma R_k (t_\delta - t_{\text{юза}})}{\rho_c v_c^2} = \frac{2\xi \sigma^2 T_T}{r^* \rho_c^2 v_c^2}$$

$$Pr = \frac{v_c}{a_c}$$

ξ - temperature coefficient.

As a result of putting the criteria expressions in the criteria equations, we get the following expressions:

$$\alpha = c_1 \Delta t^{0,16}, \quad q = c_2 \Delta t^{1,16}$$

$$\alpha = c_3 \Delta t^{-0,57}, \quad q = c_4 \Delta t^{0,43}$$

In this:

c_1, c_2, c_3, c_4 - heat is an invariant quantity composed of physical quantities.

CONTROL QUESTIONS

1. What is condensation phenomenon?
2. What are the types of condensation?
3. How is droplet condensation formed?
4. Give an understanding of the conditions for the formation of film condensation.
5. Write down the expression for the heat transfer coefficient for horizontal and vertical pipes.

21st lecture RADIATION HEAT TRANSFER Basic concepts

The transfer of heat by radiation refers to the transfer of the internal energy of the body through electromagnetic waves.

The wavelength of radiation is expressed as λ (m) or frequency of oscillation $n = s / \lambda$, s^{-1} , where $s = 2.9979 \cdot 10^8$ m/s is the speed of propagation of electromagnetic waves in a vacuum.

Hard and the spectrum of radiation in liquid bodies is continuous. It is selective in gases, which means that gases emit light of the desired wavelength. Radiation flux refers to radiation energy per unit of time:

$$F = \frac{\delta Q}{d\tau} \quad (248)$$

F - radiation current, [W];

δQ - radiation energy, [J];

t is time, [s].

The ratio of the radiation flux to the surface of the body is called radiation:

$$Ye = \frac{\delta \Phi}{dF}, \quad W/m^2. \quad (249)$$

include waves with a wavelength of $\lambda = 0.4 \cdot 10^{-3} \div 0.8$ mm. When a system of bodies is irradiated, each of them emits reflected rays from themselves to other bodies.

Light or heat incident on a body is absorbed (Q_A), returns (Q_R), and passes away (Q_D) in this body.

$$Q = Q_A + Q_R + Q_D$$

$A = \frac{Q_A}{Q}$ - absorption coefficient;

$R = \frac{Q_R}{Q}$ - coefficient of return;

$D = \frac{Q_D}{Q}$ - transition coefficient.

The heat balance of radiant energy is equal to $A+R+D=1$.

If $A=1$; If $R=D=0$, the object is **absolutely black**, $R=1$, if $A=D=0$, the object is **absolutely white**, $D=1$; If $A=R=0$, the body is called a **transparent body**. There is no absolute white, black and transparent body in nature.

22nd lecture Basic laws of radiation

1. Stefan-Boltsmann law .

Radiant energy is directly proportional to the fourth power of absolute blackbody temperature:

$$E = s_0 T^4 \quad (250)$$

s_0 – Boltzman's constant; $s_0 = 5.67 \text{ W/m}^2 \text{ K}^4$.

In practical calculations, this law is expressed as follows:

$$Q = c (T/100)^4 F \quad (251)$$

where: s is the radiation coefficient of the gray body, $\text{W/m}^2 \text{ K}$.

The total heat flow from two flat, parallel objects with a higher temperature to a lower temperature object by radiation, separated by a transparent medium, is given by the following expression:

$$Q_{1-2} = Q_{\rightarrow\phi_1} - Q_{\rightarrow\phi_2} \quad (252)$$

$$Q_{1-2} = C_{\text{kel}} F [(T_1/100)^4 - (T_2/100)^4] \quad (253)$$

where: F is heat exchange surface, m^2 ;

S_{kel} is the given radiation coefficient, $\text{W/m}^2 \text{ K}$.

$$C_{\text{kel}} = \frac{1}{\frac{1}{c_1} + \frac{1}{c_2} - \frac{1}{c_0}} \text{ W/m}^2 \text{ K} \quad (254)$$

here: T_1, T_2 - the absolute temperature of the irradiating body and the environment, $^\circ\text{C}$;

s_1, s_2 – radiation coefficient of gray bodies;

$s_0 = 5.67 \text{ W/m}^2 \text{ K}$ is the radiation of an absolute black body coefficient.

$S_{\text{kel}} = \varepsilon \cdot s_0$, ε - blackness coefficient

In various radiant systems, screens are used to reduce heat transfer by radiation (Fig. 56).

_____ 1 picture 56.

_____ 3 _____

2.1, 2-radiating body; Screen 3.

If a screen is placed between two flat parallel surfaces, and if both the screen and the surfaces are made of the same material, then the amount of heat transferred is reduced by half. If n screens are placed, the amount of heat will be reduced by $n+1$ times.

2. Wien's law :

Represents the relationship between radiation intensity and wavelength:

$$\lambda_{\max} T = 2.9 \cdot 10^{-3} \text{ mK}$$

that is, the maximum wavelength depends on the absolute temperature of the objects, and it goes in the direction of decreasing temperature.

3. Kirchhoff's law :

Absolute black and gray represent the connection between the heat radiation absorption and properties of the objects. It is written by the following expression:

$$\frac{E_1}{A_1} = \frac{E_2}{A_2} = \frac{E_3}{A_3} = \dots = \frac{E_0}{A_0} = E_0(T)$$

where $E_0(T)$ is a property of an absolute black body.

This law is defined as:

The ratio of the radiative properties of bodies to the absorption properties is the same for all bodies, equal to the radiative properties of an absolute black body at this temperature.

As can be seen from the equation of this law, the degree of blackness of gray matter is numerically equal to its absorption property, i.e.

$$A = e$$

of e is constant, the absorption property of the gray matter does not depend on the wavelength and temperature.

CONTROL QUESTIONS

1. Describe the conditions for the occurrence of heat exchange by radiation.
2. What are absolute black, white and transparent bodies?
 3. What is the efficiency of radiation?
 4. Explain the laws of radiation.
 5. How is radiation energy determined when the object is parallel?
 6. Tell the function of the screen?

23rd lecture HEAT EXCHANGE DEVICES Heat exchange devices

Devices that transfer heat from a hot heat carrier (gas) to a cold heat carrier are called **heat exchangers**.

According to the method of operation, heat exchange devices can be divided into recuperative, regenerative and mixing devices.

In mixing heat exchangers, heat exchange is carried out by direct contact and mixing of hot and cold heat carriers. Examples of mixing heat exchangers are coolers, scrubbers, and other devices.

In regenerative heat exchange devices, heating (or cooling) is carried out by periodically washing the surface itself with a hot, sometimes cold heat carrier. First, the heated heat carrier is sent from the regenerator channels - combustion products from blast furnaces and marten furnaces, vats, etc. The heating surface of the regenerator takes heat from the heated gases and then transfers this heat to the cold heat carrier.

Regenerative heat exchangers are used in metallurgical, glassmaking and other furnaces where heated air is supplied.

In recuperative heat exchangers, heat is transferred from a hot fluid to a cold fluid through a solid surface. For example, steam generators, steam heaters, water heaters, etc. Recuperative heat exchange apparatus is divided into direct flow, reverse flow and cross flow apparatus.

In direct flow heat exchangers, hot and cold media flow parallel to each other.

Reverse flow devices have opposite directions. $\overleftarrow{\hspace{1cm}}$

In technology, recuperative heat exchange devices are widely used.

When calculating heat exchangers, a heat balance is created and its surface is determined.

$$Q = G_1 C_{P1} (t_1' - t_1'') = G_2 C_{P2} (t_2'' - t_2'), [W] \quad (267)$$

where: G_1 – consumption of hot liquid, kg/s;

G_2 – consumption of cold liquid, kg/s;

C_{P1} – heat capacity of hot liquid, kJ/kg °C;

C_{P2} – heat capacity of cold liquid, kJ/kg °C;

t_1' – the temperature of the hot liquid at the entrance to the device, °C;

t_1'' – the temperature of the hot liquid at the exit from the device, °C;

t_2' – the temperature of the cold liquid at the entrance to the device, °C;

t_2'' – the temperature of the cold liquid at the exit from the device, °C.

The heat transfer surface is found from the heat transfer expression.

$$Q = K \Delta t_{\log} F \quad [W] \quad (268)$$

K – heat transfer coefficient; $W / m^2 K$

Δt_{\log} is the average logarithmic temperature difference, °C.

F – surface area, m^2 .

The average logarithmic temperature difference is determined using a temperature graph (Fig. 58):

$$\Delta t_{\log} = \frac{\Delta t_{\text{kat}} - \Delta t_{\text{кич}}}{\ln \frac{\Delta t_{\text{kat}}}{\Delta t_{\text{кич}}}}$$

here:

Δt_{kat} – large temperature difference;

$\Delta t_{\text{is small}}$ – small temperature difference.

For example, for direct current, $\Delta t_{\text{cat}} = t_1' - t_2'$; $\Delta t_{\text{is small}} = t_1'' - t_2''$

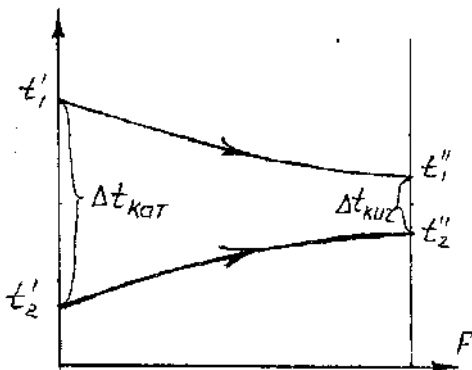


Figure 58. Direct current

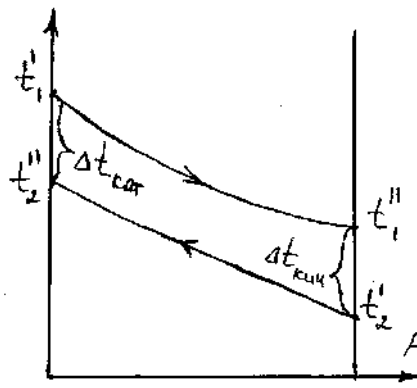


Fig. 59. Reverse flow

CONTROL QUESTIONS

1. What devices are called heat exchange devices?
2. How many types of heat exchangers are divided into?
3. Why is the heat balance established?
4. How many types of heat exchangers are divided according to the direction of heat carriers?
5. By which expression is the heat calculation of heat exchangers carried out.

GLOSSARY

State parameters - changes in the state of the working body;

The equation of state is an expression of thermal parameter connection;

Thermodynamic system - a set of bodies that exchange heat with each other and with the environment

Heat capacity - how much heat is given to the body;

The amount of heat is the transfer of energy in the form of heat

Work is the transfer of energy in the form of work

The first law of thermodynamics is the conversion of heat into work;

Thermodynamic processes - interpretation of the state of the working body;

The II law of thermodynamics - part of the heat is converted into work and the rest is transferred to the cooler;

Heat source - providing heat to the working body;

Cooler - receiving heat from the working body;

Useful work coefficient (FIK) - how much heat is converted into work;

Water vapor is a working body involved in thermodynamic processes;

Heat conduction - transfer of heat from one body to another due to temperature difference;

Convective heat exchange - transfer of heat from a solid body to the environment due to the movement of particles of the environment;

Radiation - the spread of heat due to the absorption of light or heat by objects in nature;

Boiling is a change in the aggregate state of the body;

Condensation - the formation of condensate due to the removal of heat from a boiling body;

Criterion is a dimensionless quantity that expresses the physical meaning of quantities in heat transfer;

Heat balance - the balance of given and spent heat;

Steam turbine equipment (STG) is a device that participates in the conversion of the heat of the working body into the work done;

Gas turbine devices (GTQ) - a device that uses gases produced by burning fuel;

Internal combustion engines (IYoD) - a device that performs work using the heat generated during fuel combustion;

Boiler room - steam generating device;

Condenser is a device that converts steam into water;

Economizer is a device that heats water.

Explanation words

Parameter – size;

Absolute - absolute;

Working medium - gas or steam

Comparison is a unit of substance;

Enthalpy – total energy;
 Entropy - heat cycle;
 Exergy - maximum work;
 Isobaric process is a process where the pressure does not change;
 Isochoric process is a process where the volume does not change;
 Isothermal process - a process where the temperature does not change;
 Adiabatic process - a process without heat exchange with the external environment;
 Polytropic process - embodiment of processes;
 Cycle is a circular process;
 Phase transition - a state of transition from one phase to another;
 Evaporation is the transition of liquid from the surface of the body to vapor;
 Sublimation - transition from a solid state to a vapor state;
 Desublimation - transition from a gas state to a solid state;
 Melting - transition from a solid state to a liquid state;
 Convection is movement of body particles;
 Criterion is a criterion;
 1.tne – 1 ton of oil equivalent (1 t.sh.yo. *1.5)

Applications
Table 1

SI system of international units

Bigness	Unit of measure	Unit writing
Basic units		
length	meter	m
mass	kilogram	kg
time	second	s
power of electricity	Ampere	A
Kelvin thermodynamic temperature	Kelvin	K
amount of substance	mol	mol
surface	meter square	m ²
volume	cubic meter	m ³
speed	meters per second	m/s
acceleration	meters per sec.sq	m/s ²
density	kilograms per cubic meter	kg/m ³

strength	Newton	N
pressure	Pascal	Pa
amount of work, energy, heat	Joule	J
power, heat flow	Watt	W
specific heat capacity	Joules per kilogram Kelvin	J/kgK
enthalpy	joules per kilogram	J/kg
heat flux density	Watts per square meter	W/m ²
heat transfer coefficient	Watts per meter Kelvin	W/(m ·K)
heat transfer coefficient	Watts per square meter Kelvin	W/(m ² ·K)
radiation coefficient	Watts per meter Kelvin 4 degrees	W/(m ² ·K ⁴)

Table 2

Energy	1 kcal=4.187 kJ
Strength	1 kgs=9.81 N
Relative weight	1 kg/cm ³ =9.81 N/m ³
Density	1 kg ·s ² /m ⁴ =9.81 kg/m ³
Pressure	1 kg/cm ² =0.981 ·10 ⁵ Pa
Dynamic viscosity coefficient	1 kg ·s/m ² =9.81 Pa ·s
Heat capacity	1kcal/(kg · ⁰ C)= 4.187 kJ/(kg · ⁰ C)
Enthalpy	1kcal/kg=4.187kJ/kg
Heat flow	1 kcal/hour=1.163 W
heat flux density	1 kcal/(m ² ·h)=1.163 W/m ²
heat flow volume density	1 kcal/(m ³ ·h)=1.163 W/m ³
heat transfer coefficient	1 kcal/(m ·h · ⁰ C)=1.163 W/m · ⁰ C
heat transfer coefficient	1 kcal/(m ² ·h · ⁰ C)=1.163 W/m ² · ⁰ C
radiation coefficient	1 kcal/(m ² ·h ·K ⁴) =1.163 W/(m ² ·K ⁴)

Table 3

Important gases and molecular mass, density and kilomolar volumes and gas constants under normal conditions

Substance	Chemical writing	molecular mass, μ	Density ρ , kg/m ³	kilomole volumes μ_v , m ³ /kg	Gas constant J/(kg ·K)
1	2	3	4	5	6
Air	-	28.96	1,239	22.40	287.0

Oxygen	O ₂	32.00	1,429	22.39	259.8
Nitrogen	N ₂	28,026	1,251	22.40	296.8
Atmospheric nitrogen	N ₂	28,16	(1,257)	(22.40)	(295.3)
Helium	Hey	4,003	0.179	22.42	2078.0
Argon	Ar	39,994	1,783	22.39	208.2
Hydrogen	H ₂	2,016	0.090	22.43	4124.0
Carbon monoxide	SO	28.01	1,250	22.40	296.8
Carbon-(IV) -oxide	SO ₂	44.01	1,977	22,26	188.9
sulfur-(IV) -oxide	SO ₂	64.06	2,926	21.89	129.8
Methane	SN ₄	16,032	0.717	22.39	518.8
Ethylene	S ₂ N ₄	28,052	1,251	22.41	296.6
Coke gas	-	11.50	0.515	22,33	721.0
Ammonia	NH ₃	17,032	0.771	22.08	488.3
Water vapor	N ₂ O	18,016	(0.804)	(22.40)	(461)

Table 4

Heat capacity of oxygen

Temperature t, °S	Molar heat capacity, J/(kmol · K)				Mass heat capacity, J/(kg · K)		Volumetric heat capacity, J/(m ³ · K)	
	μs _r	μs _v	μp.m ₋	μetc ₋	μp.m ₋	μetc ₋	μp.m ₋ ' ₋	μetc ₋ ' ₋
0	29,274	20,959	29,274	20,959	0.9148	0.6548	1.3059	0.9349
100	29,877	21,562	29,538	21,223	0.9232	0.6632	1.3176	0.9466
200	30,815	22,500	29,931	21,616	0.9353	0.6753	1.3352	0.9642
300	31,832	23,517	30,400	22,085	0.9500	0.6900	1.3561	0.9852
400	32,758	24,443	30,878	22,563	0.9651	0.7051	1.3775	1.0065
500	33,549	25,234	31,334	23,019	0.9793	0.7193	1.3980	1.0270
600	34,202	25,887	31,761	23,446	0.9927	0.7327	1.4168	1.0459
700	34,746	26,431	32,150	23,835	0.0048	0.7448	1.4344	1.0634
800	35,203	26,888	32,502	24,187	1.0157	0.7557	1.4499	1.0789
900	35,584	27,269	32,825	24,510	0.0258	0.7658	1.4645	1.0936
1000	35,914	27,599	33,118	24,803	1.0350	0.7750	1.4775	1.1066
1100	36,216	27,901	33,386	25,071	1.0434	0.7834	1.4892	1.1183
1200	36,488	28,173	33,633	25,318	1.0509	0.7913	1.5005	1.1296
1300	36,752	28,437	33,863	25,548	1.0580	0.7984	1.5106	1.1396
1400	36,999	28,684	34,076	25,761	1.0647	0.8051	1.5202	1.1493
1500	37,242	28,927	34,282	25,967	1.0714	0.8114	1.5294	1.1585
1600	37,480	29,165	34,474	26,159	1.0773	0.8173	1.5378	1.1669
1700	37,715	29,400	34,658	26,343	1.0831	0.8231	1.5462	1.1752

Table 5

Heat capacity of nitrogen

Temperature $t, ^\circ\text{S}$	Molar heat capacity, $\text{J}/(\text{kmol} \cdot \text{K})$				Mass heat capacity, $\text{J}/(\text{kg} \cdot \text{K})$		Volumetric heat capacity, $\text{J}/(\text{m}^3 \cdot \text{K})$	
	μs_r	μs_v	$\mu\text{p.m}_-$	μetc_-	$\mu\text{p.m}_-$	μetc_-	$\mu\text{p.m}'_-$	$\mu\text{etc}'_-$
0	29,115	20,800	29,115	20,800	1.0392	0.7423	1.2987	0.9278
100	29,199	20,884	29,144	20,829	1.0404	0.7427	1.3004	0.9295
200	29,471	21,156	29,228	20,913	1.0434	0.7465	1.3038	0.9328
300	29,952	21,637	29,383	21,068	1.0488	0.7519	1.3109	0.9399
400	30,576	22,261	29,601	21,286	1.0567	0.7599	1.3205	0.9496
500	31,250	22,935	29,864	21,549	1.0660	0.7691	1.3322	0.9613
600	31,920	23,605	30,149	21,834	1.0760	0.7792	1.3452	0.9743
700	32,540	24,225	30,451	22,136	1.0869	0.7900	1.3586	0.9877
800	33,101	24,786	30,748	22,433	1.0974	0.8005	1.3716	1.0006
900	33,599	25,284	31,037	22,722	1.1078	0.8110	1.3845	1.0136
1000	34,039	25,724	31,313	22,998	1.1179	0.8210	1.3971	1.0178
1100	34,424	26,109	31,577	23,262	1.1271	0.8302	1.4089	1.0379
1200	34,773	26,448	31,828	23,513	1.1359	0.8395	1.4202	1.0492
1300	35,070	26,745	32,067	23,752	1.1447	0.8478	1.4306	1.0597
1400	35,330	27,005	32,293	23,978	1.1526	0.8558	1.4407	1.0697
1500	35,556	27,231	32,502	24,187	1.1602	0.8633	1.4499	1.0789
1600	35,757	27,432	32,699	24,384	1.1673	0.8704	1.4587	1.0877
1700	35,937	27,612	32,883	24,568	1.1736	0.8771	1.4671	1.0961

Table 6

Heat capacity of carbon(II)-oxide

Temperature $t, ^\circ\text{S}$	Molar heat capacity, $\text{J}/(\text{kmol} \cdot \text{K})$				Mass heat capacity, $\text{J}/(\text{kg} \cdot \text{K})$		Volumetric heat capacity, $\text{J}/(\text{m}^3 \cdot \text{K})$	
	μs_r	μs_v	$\mu\text{p.m}_-$	μetc_-	$\mu\text{p.m}_-$	μetc_-	$\mu\text{p.m}'_-$	$\mu\text{etc}'_-$
0	35,860	27,545	35,860	27,545	0.8148	0.6259	1.5998	1.2288
100	40,206	31,891	38,112	29,797	0.8658	0.6770	1.7003	1.3293
200	43,689	35,374	40,059	31,744	0.9102	0.7214	1.7373	1.4164
300	46,515	38,200	41,755	33,440	0.9487	0.7599	1.8627	1.4918
400	48,860	40,515	43,250	34,935	0.9826	0.7938	1.9297	1.5587
500	50,825	42,500	44,573	36,258	1.0128	0.8240	1.9887	1.6178
600	52,452	44,137	45,753	37,438	1.03	0.8508	2.0411	1.6701
700	53,826	45,511	46,813	38,498	1.0639	0.8746	2.0884	1.7174
800	54,977	46,662	47,763	39,448	1.0852	0.8964	2.1311	1.7601
900	55,952	47,637	48,617	40,302	1.1045	0.9157	2.1692	1.7982
1000	56,773	48,458	49,392	41,077	1.1225	0.9332	2.2035	1.8326
1100	57,472	49,157	50,099	41,784	1.1384	0.9496	2.2349	1.8640
1200	58,071	49,756	50,740	42,425	1.1530	0.9638	2.2638	1.8929
1300	58,586	50,271	51,322	43,007	1.1660	0.9772	2.2898	1.9188
1400	59,030	50,715	51,858	43,543	1.1782	0.9893	2.3136	1.9427
1500	59,411	51,096	52,348	44,033	1,1895	1.0006	2.3354	1.9644
1600	59,737	51,422	52,800	44,485	1,1995	1.0107	2.3555	1.9845
1700	60,022	51,707	53,218	44,903	1.2091	1.0203	2.3743	2.0034

Table 7

Heat capacity of water vapor								
Temperature $t, ^\circ\text{S}$	Molar heat capacity, $\text{J}/(\text{kmol} \cdot \text{K})$				Mass heat capacity, $\text{J}/(\text{kg} \cdot \text{K})$		Volumetric heat capacity, $\text{J}/(\text{m}^3 \cdot \text{K})$	
	μs_r	μs_v	$\mu p.m_-$	μetc_-	$\mu p.m_-$	μetc_-	$\mu p.m'_-$	$\mu etc'_-$
0	33,499	25,184	33,499	25,184	1.8594	1.3980	1.4943	1.1237
100	34,055	25,740	33,741	25,426	1.8728	1.4114	1.5052	1.1342
200	34,964	26,649	34,118	25,803	1.8937	1.4323	1.5223	1.1514
300	36,036	27,721	34,575	26,260	1.9192	1.4574	1.5424	1.1715
400	37,191	28,876	35,090	26,775	1.9477	1.4863	1.5654	1,1945
500	38,406	30,091	35,630	27,315	1.9778	1.5160	1.5897	1.2188
600	39,662	31,347	36,195	27,880	2.0092	1.5474	1.6148	1.2439
700	40,951	32,636	36,789	28,474	2.0419	1.5805	1.6412	1.2703
800	42,249	33,934	37,392	29,077	2.0754	1.6140	1.6680	1.2971
900	43,513	35,198	38,008	29,693	2.1097	1.6483	1.6957	1.3247
1000	44,723	36,408	38,619	30,304	2.1436	1.6823	1.7229	1.3519
1100	45,858	37,543	39,226	30,911	2.1771	1.7158	1.7501	1.3791
1200	46,913	38,598	39,825	31,510	2.2106	1.7488	1.7769	1.4059
1300	47,897	39,582	40,407	32,092	2.2429	1.7815	1.8028	1.4319
1400	48,801	40,486	40,976	32,661	2.2743	1.8129	1.8280	1.4570
1500	49,639	41,324	41,525	33,210	2.3048	1.8434	1.8527	1.4817
1600	50,409	42,094	42,056	33,741	2.3346	1.8728	1.8761	1.5052
1700	51,133	42,818	42,576	34,261	2.3630	1.9016	1.8996	1.5286

Table 8

Heat capacity of air								
Temperature $t, ^\circ\text{S}$	Molar heat capacity, $\text{J}/(\text{kmol} \cdot \text{K})$				Mass heat capacity, $\text{J}/(\text{kg} \cdot \text{K})$		Volumetric heat capacity, $\text{J}/(\text{m}^3 \cdot \text{K})$	
	μs_r	μs_v	$\mu p.m_-$	μetc_-	$\mu p.m_-$	μetc_-	$\mu p.m'_-$	$\mu etc'_-$
0	29,073	20,758	29,073	20,758	1.0036	0.7164	1.2971	0.9261
100	29,266	20,951	29,152	20,758	1.0061	0.7193	1.3004	0.9295
200	29,676	21,361	29,299	20,984	1.0115	0.7243	1.3071	0.9362
300	30,266	21,951	29,521	21,206	1.0191	0.7319	1.3172	0.9462
400	30,949	22,634	29,789	21,474	1.0283	0.7415	1.3289	0.9579
500	31,640	23,325	30,095	21,780	1.0387	0.7519	1.3427	0.9718
600	32,301	23,986	30,405	22,090	1.0496	0.7624	1.3565	0.9856
700	32,900	24,585	30,723	22,408	1.0605	0.7733	1.3708	0.9998
800	33,432	25,117	31,028	22,713	1.0710	0.7842	1.3842	1.0312
900	33,905	25,590	31,321	23,006	1.0815	0.7942	1.3976	1.0262
1000	34,315	26.00	31,598	23,283	1.0907	0.8039	1.4097	1.0387
1100	34,679	26,394	31,862	23,547	1.0999	0.8127	1.4214	1.0505
1200	35,002	26,687	32,109	23,794	1.1082	0.8215	1.4327	1.0618
1300	35,291	26,976	32,343	24,028	1.1166	0.8294	1.4432	1.0722
1400	35,546	27,231	32,565	24,250	1.1242	0.8369	1.4528	1.0819
1500	35,772	27,457	32,774	24,259	1.1313	0.8441	1.4620	1.0911

1600	35,977	27,662	32,967	24,652	1.1380	0.8508	1.4708	1.0999
1700	36,170	27,855	33,151	24,836	1.1443	0.8570	1.4788	1.1078

Table 9

Physical properties of dry steam ($V=760$ mm sim.ust $\approx 1.01 \cdot 10^5$ Pa)

$t, ^\circ\text{S}$	$\rho, \text{kg/m}^3$	$s, \text{kJ}/(\text{kg} \cdot ^\circ\text{C})$	$\lambda, \text{W}/\text{m} \cdot ^\circ\text{C}$	$a \cdot 10^6, \text{m}^2/\text{s}$	$\mu \cdot 10^6, \text{Pa} \cdot \text{s}$	$\nu \cdot 10^6, \text{m}^2/\text{s}$	Pr
-50	1,584	1,013	2.04	12.7	14.6	9.23	0.728
-40	1,515	1,013	2.12	13.8	15.2	10.04	0.728
-30	1,453	1,013	2.20	14.9	15.7	10.80	0.723
-20	1,395	1,009	2.28	16.2	16.2	12.79	0.716
-10	1,342	1,009	2.36	17.4	16.7	12.43	0.712
0	1,293	1,005	2.44	18.8	17.2	13,28	0.707
10	1,247	1,005	2.51	20.0	17.6	14,16	0.705
20	1,205	1,005	2.59	21.4	18.1	15.06	0.703
30	1,165	1,005	2.63	22.9	18.6	16.00	0.701
40	1,128	1,005	2.76	24.3	19.1	16.96	0.699
50	1,093	1,005	2.83	25.7	19.6	17.95	0.698
60	1,060	1,005	2.90	26.2	20.1	18.97	0.696
70	1,029	1,009	2.96	28.6	20.6	20.02	0.694
80	1,000	1,009	3.05	30.2	21.1	21.09	0.692
—	—	—	—	—	—	—	—
23, 90	0.972	1,009	3.13	31.9	21.5	22.10	0.690
100	0.946	1,009	3.21	33.6	21.9	23.13	0.688
120	0.898	1,009	3.34	36.8	22.8	25.45	0.686
140	0.854	1,013	3.49	40.3	23.7	27.80	0.684
160	0.815	1,017	3.64	43.9	24.5	30.09	0.682
180	0.779	1,022	3.78	47.5	25.3	32.49	0.682

Table 10

Physical properties of water at the saturation line

$t, ^\circ\text{S}$	$r \cdot 10^{-5}, \text{Pa}$	$\rho, \text{kg}/\text{m}^3$	$h, \text{kJ}/\text{kg}$	$s_r, \text{kJ}/(\text{kg} \cdot ^\circ\text{C})$	$\lambda \cdot 10^{-2}, \text{W}/\text{m} \cdot ^\circ\text{C}$	$a \cdot 10^{-8}, \text{m}^2/\text{s}$	$\mu \cdot 10^{-6}, \text{Pa} \cdot \text{s}$	$\nu \cdot 10^{-6}, \text{m}^2/\text{s}$	$\beta \cdot 10^{-4}, \text{K}^{-1}$	$\sigma \cdot 10^{-4}, \text{N}/\text{m}$	Pr
0	1,013	999.9	0.00	4,212	55.1	13.1	1788	1,789	-0.63	756.4	13.67

10	1,013	999.7	42.04	4,191	57.4	13.7	13.06	1,306	+0.70	741.6	9.52
20	1,013	998.2	83.91	4,183	59.9	14.3	1004	1,006	1.82	726.9	7.02
30	1,013	995.7	125.7	4,174	61.8	14.9	801.5	0.805	3.21	712.2	5.42
40	1,013	992.2	167.5	4,174	63.5	15.3	653.3	0.659	3.87	696.5	4.31
50	1,013	988.1	209.3	4,174	64.8	15.7	549.4	0.556	4.49	676.9	3.54
60	1,013	983.2	251.1	4,179	65.9	16.0	469.9	0.478	5.11	662.2	2.98

Continued from table 10

1	2	3	4	5	6	7	8	9	10	11	12
70	1,013	977.8	293.0	4,187	66.8	16.3	406.1	0.415	5.70	643.5	2.55
80	1,013	971.8	335.0	4,195	67.4	16.6	355.1	0.365	6.32	625.9	2.21
90	1,013	965.3	377.0	4,208	68.0	16.8	314.9	0.326	6.95	607.2	1.95
100	1,013	958.4	419.1	4,220	68.3	16.9	282.5	0.295	7.52	588.6	1.75
110	1.43	951.0	461.4	4,233	68.5	17.0	259.0	0.272	8.08	569.0	1.60
120	1.98	943.1	503.7	4,250	68.6	17.1	237.4	0.252	8.64	548.4	1.47
130	2.70	934.8	546.4	4,266	68.6	17.2	217.8	0.233	9.19	528.8	1.36
140	3.61	926.1	589.1	4,287	68.5	17.2	201.1	0.217	9.72	507.2	1.26
150	4.76	917.0	632.2	4,313	68.4	17.3	186.4	0.203	10.3	486.6	1.17
160	6.18	907.4	675.4	4,346	68.3	17.3	173.6	0.191	10.7	466.0	1.10
170	7.92	897.3	719.3	4,380	67.9	17.3	162.8	0.181	11.3	443.4	1.05
180	10.03	886.9	763.3	4,417	67.4	17.2	153.0	0.173	11.9	422.8	1.00
190	12.55	876.0	807.8	4,459	67.0	17.1	144.2	0.165	12.6	400.2	0.96
200	15.55	863.0	852.5	4,505	66.3	17.0	136.4	0.158	13.3	376.7	0.93
210	19.08	852.8	897.7	4,555	65.5	16.9	130.5	0.153	14.1	354.1	0.91
220	23,20	840.3	943.7	4,614	64.5	16.6	124.6	0.148	14.8	331.6	0.89
230	27.98	827.3	990.2	4,681	63.7	16.4	119.7	0.145	15.9	310.0	0.88

Table 11

Physical properties of water vapor at the saturation line

$t, ^\circ\text{S}$	$r \cdot 10^{-5}, \text{Pa}$	$\rho'', \text{kg/m}^3$	$h'', \text{kJ/kg}$	$r, \text{kJ/kg}$	$s_r, \text{kJ/(kg} \cdot ^\circ\text{C)}$	$\lambda \cdot 10^{-2}, \text{W/m} \cdot ^\circ\text{C}$	$a \cdot 10^{-8}, \text{m}^2/\text{s}$	$\mu \cdot 10^{-6}, \text{Pa} \cdot \text{s}$	$\nu \cdot 10^{-6}, \text{m}^2/\text{s}$	Pr
100	1,013	0.598	2675.9	2256.8	2,135	2,372	18.58	11.97	20.02	1.08
110	1.43	0.826	2691.4	2230.8	2,177	2,489	13.83	12.46	15.07	1.09
120	1.98	1,121	2706.5	2230.0	2,206	2,593	10.50	12.85	11.46	1.09
130	2.70	1,496	2720.7	2202.8	2,257	2,686	7,972	13,24	8.85	1.11
140	3.61	1,966	2734.1	2174.3	2,315	2,791	6,130	13.54	6.89	1.12
150	4.76	2,547	2746.7	2145.0	2,395	2,884	4,728	13.93	5.47	1.16
160	6.18	3,258	2758.0	2114.4	2,479	3,012	3,722	14.32	4.39	1.18
170	7.92	4,122	2768.0	2082.6	2,583	3,128	2,939	14.72	3.57	1.21
180	10.03	5,157	2778.5	2049.5	2,709	3,268	2,339	15.11	2.93	1.25
190	12.55	6,394	2786.4	2015.2	2,856	3,419	1,872	15.60	2.44	1.30
200	15.55	7,862	2793.1	1978.8	3,023	3,547	1,492	15.99	2.03	1.36
210	19.08	9,588	2798.2	1940.7	3,199	3,722	1,214	16.38	1.71	1.41
220	23,20	11.62	2801.5	1900.5	3,408	3,896	0.983	16.87	1.45	1.47
230	27.98	13.99	2803.2	1857.8	3,634	4,094	0.806	17.36	1.24	1.54
240	33,48	16.76	2803.2	1813.0	3,881	4,291	0.658	17.76	1.06	1.61

Books

1. Zohidov RA, Avezov RR, Vardiyashvili AB, Alimova MM Heat technique. 1 q.kol., part 1, Tashkent, TDTU, 2005.
2. Baskakov AP Thermotechnics. M.: Energoatomizdat, 2001.
3. Bakhshieva LT i dr; pod ed. AA Zakharova. Technical thermodynamics and thermotechnics. M. "Academy"-2006.
4. Kudinov VA, Kartashov EM Technicheskaya thermodynamics. MV y sshaya school. 2005.
5. Isachenko VP, Osipova VA, Sukomel AS Teploperedacha. M.: - Energy, 1981.
6. Andrianova TN and dr. Sbornik zadach po tekhnicheskoy thermodynamics. M.: MEI, 2000.
7. Krasno shch ekov KA, Sukomel AS Sbornik zadach po teploperedache. M.: Energy, 1991.
8. http://dhes.ime.mrsu.ru/studies/tot/tot_lit.htm
9. http://rbip.bookchamber.ru/description.aspx?product_no=854

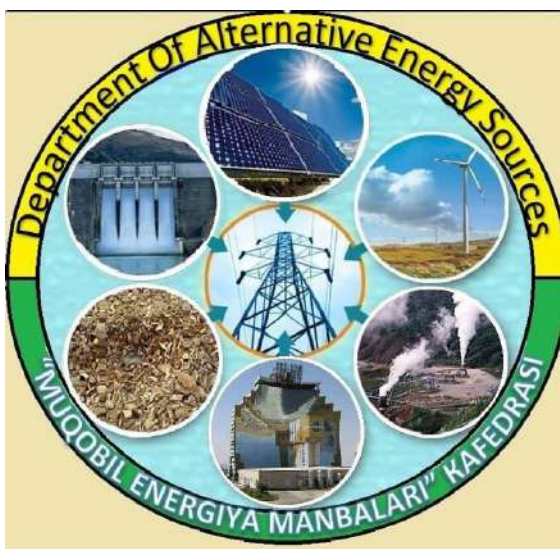
**REPUBLIC OF UZBEKISTAN
MINISTRY OF HIGHER AND SECONDARY SPECIAL
EDUCATION
INSTITUTE OF ENGINEERING AND ECONOMICS
"Alternative energy sources" department**



From the subject "HEAT TECHNIQUE".

to perform experimental work

METHODOLOGY GUIDE



Against - 2022

Developers:

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From the instruction manual 60730300 – Construction of buildings and structures (objects of the oil and gas processing industry) students of the field of education can also use it. It contains brief information on the performance of laboratory work on the most important topics of science .

Procedural instructions at the meeting of the "Alternative energy sources" department (statement No.____,____ ____2022), in the Stylistic Commission of the Faculty of Energy (statement No.____,____ ____2022) and in the Stylistic Council of the institute (statement No.____,____ ____2022 .) are discussed and recommended for use in the educational process.

Heat engineering, that is, the principles and laws of the theory of heat transfer, serve as a theoretical basis for the operation of various heat exchange devices in heat energy devices. In the field of thermal energy, the main heat exchangers used in IES and IEMs are heat transfer tube bundles which are flushed in a longitudinal or transverse direction, giving or receiving heat. For example, the steam used in the condenser of the thermal power plant condenses by giving heat to the technical water (cooling water) through the surface of the pipes.

Improving the efficiency of such devices or activating heat exchange processes is an important issue, which is solved on the basis of a complete scientific-experimental analysis of the heat exchange process.

This methodological instruction describes the method of determining the coefficient of heat transfer during the transverse flow of a set of pipes in the forced movement of liquids.

60730300 - Students studying construction of buildings and structures (objects of the oil and gas processing industry) based on their theoretical knowledge in the subject of "Heat mechanics", summarizing and analyzing the results of experiments and measurements they will have skills.

1 - LABORATORY WORK.

PRESSURE AND TEMPERATURE MEASURING INSTRUMENTS.

The purpose of the work: to form students' knowledge and skills about the types and principles of operation of pressure and temperature measuring devices.

Key words: manometer, vacuum meter, thermoelectric thermometer, optical pyrometers, thermocouples, resistance thermometers.

Necessary equipment: general and principle scheme of measuring instruments to study the structure of pressure and temperature measuring instruments, posters, samples of various types of measuring instruments, videos in the form of presentations to study the principle of operation.

A few slides of the presentation are attached.

To carry out the experimental work, it is necessary to familiarize yourself with the following literature:

1. Alimova MM, Mazhudova Sh.S., Isakhodjayev XS, Rakhimjonov RT, Umarjonova F.Sh. A collection of experiments on the subject "Theoretical foundations of heat engineering". Methodological manual., Part 1.-T.: TDTU, 2006.
2. Umarjonova F. Sh., Isakhodjaev XS, Mazhudova Sh. S., Alimova L., O., Akhmatova SR. Collection of laboratory works on "Heat technique". Methodical guide. - Tashkent, ToshDTU. 2014 - 94 p.

Duration of work - 4 hours.

I. General information.

the following 2 groups of temperature measurement :

I. Temperature measuring devices based on direct methods of temperature measurement include:

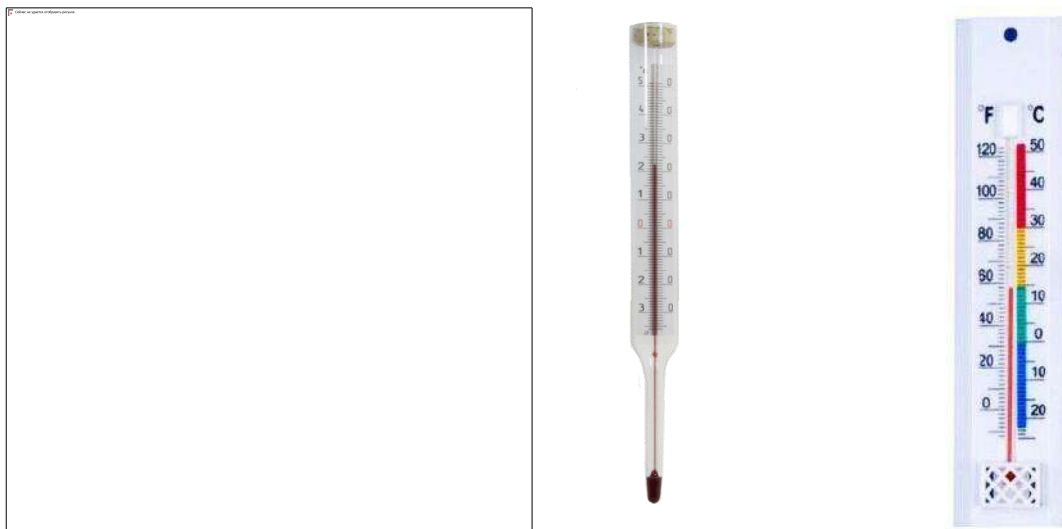
a) liquid glass thermometers.

are used for temperature measurements in the range from -200 to +750 C.°

How glass liquid thermometers work. The way liquid thermometers work is based on thermal expansion. Mercury, toluene, ethyl alcohol, etc. are used to fill liquid thermometers.

Among liquid thermometers, mercury thermometers are the most common. They have a number of advantages due to the important properties of mercury, which does not wet glass, is much easier to obtain chemically pure, and is stable over a wide temperature range at normal atmospheric pressure (-38.87 °C to +356.86 °C) maintains its liquid state.

Thermometers are made of different types of glass, depending on the function and temperature measurement range. Liquid glass thermometers have different construction forms, but two main constructions can be distinguished from this diversity. 1. Rod-shaped (photo - 1, a) and 2. with built-in scales (photo - 1, b).



Figure

1.1. a) stick and b) built-in scale thermometers.

Stick thermometers are heavy - (thick-walled) outer diameter It has a capillary diameter of 6 8 mm, which is equal to the diameter of the entire thermometer container . In such thermometers, the scale is written directly on the outer surface of the capillary.

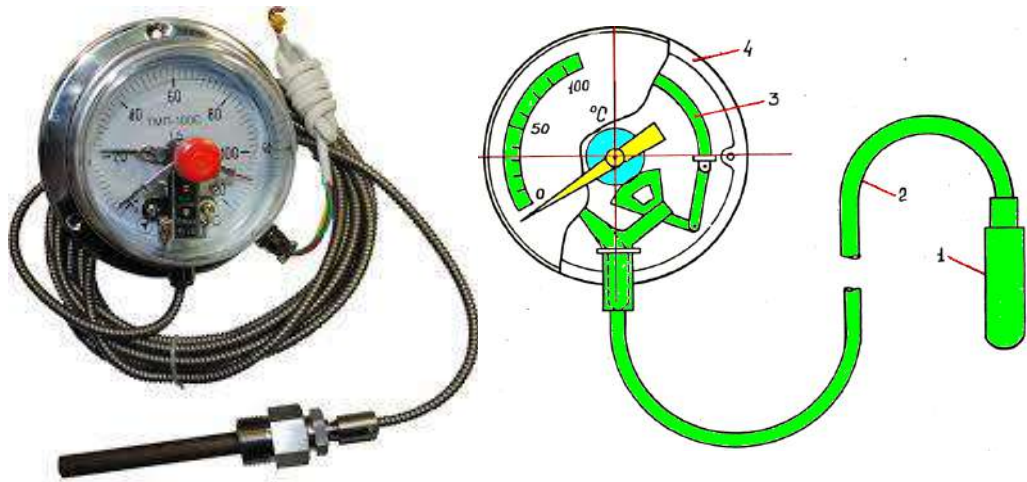
The characteristic aspect of the second construction is that the scale is not on the surface of the capillary, but is made of a milk-colored rectangular glass plate, which is installed behind the capillary tube welded to the cylindrical vessel.

Inset scale thermometers are more inertial than stick thermometers, but they are convenient for measuring temperature in laboratory and industrial settings. Liquid thermometers are often provided with a metal protective cover. Glass thermometers are simple, reasonably accurate, and inexpensive to manufacture.

b) Manometric thermometers.

A tubular spring serves as the gauge of this type of thermometer.

We will look at the structure, operation and main technical characteristics of the gas manometric thermometer (picture 2).



1.2 - picture. Manometric thermometer overview.

The thermo system of the thermometer : consists of thermoball 1, capillary 2, and manometric spring 3, which is lowered into the environment whose temperature is measured . The thermosystem of the thermometer is filled with a working substance - gas or liquid.

When heating the thermoballoon, the pressure in the closed dense (hermetic) thermosystem increases, and as a result, the spring is deformed (expands around the circumference) and its free side is excited. The movement of the free side of the spring is converted into a displacement of the pointer on the thermometer scale through the heated sector (tube) of the transmission mechanism.

are used to measure temperatures from -150 to $+600$ $^{\circ}\text{C}$ in liquid and gaseous media. It should be noted that Manometric thermometers allow to transmit the temperature indicator to a small distance (up to 60 meters). This is a great advantage despite the simplicity of the construction.

c) Electrical resistance thermometers.

Resistance thermometers are widely used to measure temperature indicators in the range from -260 to $+750$ $^{\circ}\text{C}$. In some cases, temperatures up to 1000 $^{\circ}\text{C}$ can be measured with these thermometers. The operation of resistance thermometers is based on the change in electrical resistance of substances with temperature changes. When measuring the

temperature with a resistance thermometer, it is lowered into the medium whose temperature is being measured. Knowing that the resistance of the thermometer depends on the temperature, it is possible to know the temperature of the environment in which it is standing by the change in the resistance of the thermometer. Resistance thermometers use a bridge to balance the measurement. The main detail of resistance thermometers is mica (frame) - transparent mineral plates, on which a thin wire of a sensitive element is wound. Platinum or copper is usually used as the metal of the sensitive element. Platinum resistance thermometers can measure temperatures from -260 to $+1000$ $^{\circ}\text{C}$, while copper resistance thermometers can measure temperatures from -50 to $+180$ $^{\circ}\text{C}$.

g) Thermoelectric thermometers.

The thermoelectric method of temperature measurement is based on certain dependences of the thermoelectric driving force on temperature from thermoelectric thermometers. If we take a circuit consisting of two different conductors A and B (Fig. 3.a) and heat one side of the conductors, an electric current will be generated in the circuit. The direction of the generated electric current is from the side of the first junction (heated) from B to A, from the unheated side from A to B, if we heat the second junction, the direction of the electric current goes in the opposite direction, this current is called electric current. The electric driving force produced as a result of the temperature difference between the two junctions of this chain is called thermoelectric driving force. The disadvantage of a thermocouple formed from two conductors is that the formed thermo E.Yu.K. an additional instrument must be connected to measure . If a third conductor with the same temperature on both sides is connected to this chain, then the resulting thermo E.Yu.K. A millivoltmeter or potentiometer can be connected to measure , thus forming a thermocouple. (Fig . 3b).

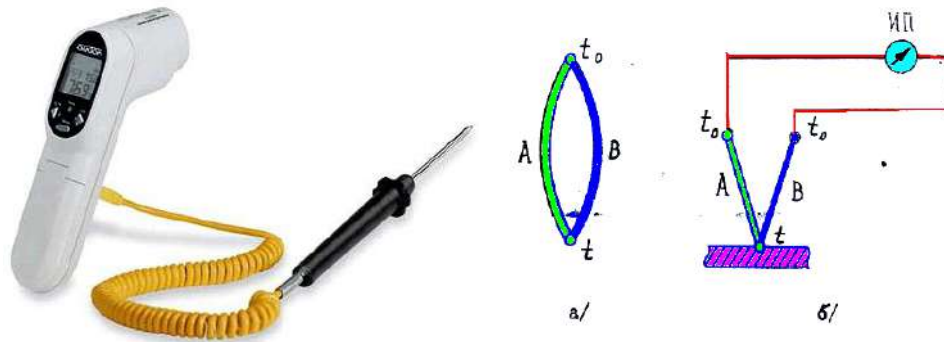


Figure 1.3. a) A and B-side thermoelectric thermometer; b) view of the thermocouple.

Conductors A and B of a thermocouple are called thermoelectrodes. To measure the temperature, the thermocouple junction 1, the so-called hot side of the thermocouple, is placed in the environment where the temperature is measured. If the second side (cold side) of the thermocouple has a constant temperature, it is possible to know the hot side of the thermocouple by the value of thermoEYuK. When calibrating the thermocouple, if its cold side is equal to the ambient temperature, it is necessary to correct the reading of the instrument. The value of the ambient temperature should be added to the indicated temperature value.

Thermocouples are divided into two groups depending on the characteristics of the thermoelectrode materials.

1. Thermocouples with thermoelectrodes made of expensive and simple materials.
2. Thermocouples with thermoelectrodes made of hard-melting compounds, their mixture with graphite or with other metals.

Thermocouples belonging to the first group are widely used in monitoring technological processes and scientific research. An example of a thermocouple made of precious metals is a platinum thermocouple, whose thermoelectrode is 90% platinum and 10% other metal.

Examples of common metal thermocouples are copper - copper (a combination of nickel and copper); chromal - aluminum (a combination of nickel and aluminum) and so on. The second group of thermocouples uses disilicide molybdenum, disilicide tungsten, titanium carbide, etc., and difficult-to-melt compounds. Thermocouples belonging to this group ÷measure temperatures up to 3000 3500 °C.

In general, thermocouples allow to determine the temperature range from - 200 °C to + 3500 °C.

II. Instruments based on indirect methods of temperature measurement

include :

Indirect measurement methods are based on the ability of heated objects to emit light, depending on the temperature. Measuring devices based on this method are called radiation pyrometers or **pyrometers** . They are used in all fields of technology and provide an opportunity to determine the temperature from 30 °C to 6000 °C. Pyrometers based on changes in the intensity of monochromatic radiation are called optical pyrometers. Pyrometers based on the measurement of absolute radiant power are called "equal strength" pyrometers.

Pyrometer types .

a) "Disappearing wire" optical pyrometers.

"Disappearing wire" optical pyrometers are used to determine the temperature of light in the visible spectrum. The measuring range of industrial pyrometers with "disappearing wire" is defined from 700 °C to 1600 °C. Determination of light temperature is based on comparing the effective light wavelength of the object being examined in pyrometers with the light of the wire of the pyrometer lamp. Pyrometer (picture 4) consists of telescope 5, measuring device 8 and source 9. The optical system of the pyrometer consists of a lens 1, an eyepiece 2, a red light filter 3 and a light absorbing mirror 7.

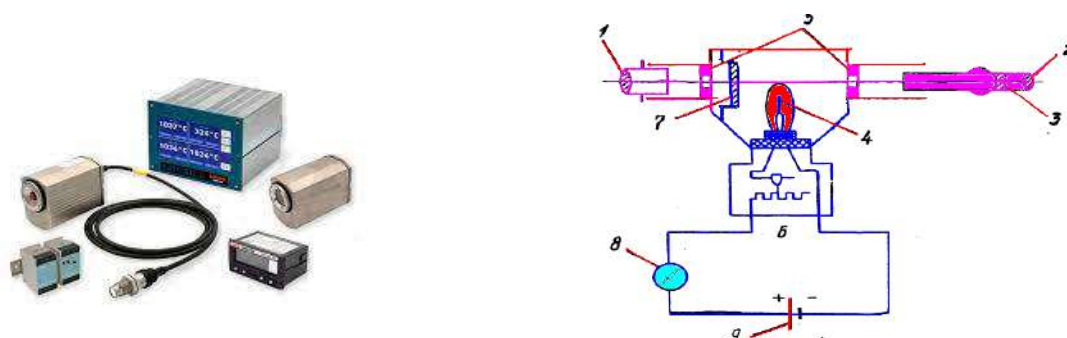


Figure 1.4. " Disappearing wire " optical pyrometer .

A pyrometric lamp 4 with arc-shaped tungsten wire 5 is placed at the focus of lens 1 . The principle of temperature measurement in optical pyrometers is as follows: the object whose temperature is being measured is clearly visible by rotating the lens

screw while pointing the telescope at the object emitting light. With the help of rheostat 6, we change the glow level of the wire, and it disappears against the background of the radiation surface. The loss of the wire arc means that the irradiator and the lamp wire have the same light and therefore the same temperature.

If it is necessary to determine the temperature of the radiation surface, the temperature of which is higher than 1400 C (the upper limit of tungsten wire ignition), then a light-absorbing mirror 7 is installed in front of the lamp. In this case, measurements are made by comparing the unextinguished light of the heat emitter. Therefore, when measuring any light temperature of the radiator, first the wire is heated up to 1400 C, and then to a temperature above 1400 C.

A red light filter 3 only passes light waves of a certain length. When adjusting the focus of the telescope 5, the light filter can be removed, but it must be fixed in place when the light of the lamp wire is equal to the light of the source of radiation.

b) Radiation pyrometers. Their mode of operation is based on the temperature of the light emitted by the object being measured. The concentration (revival) of the rays is carried out through an inclined mirror or lens 1 (Fig. 5).

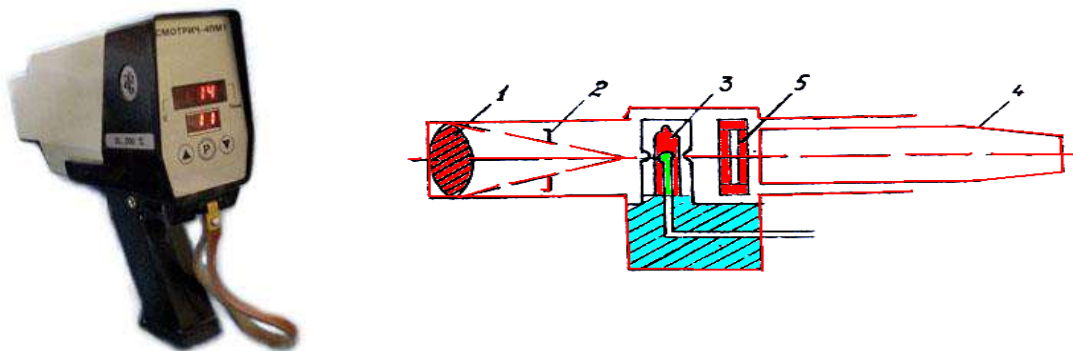


Figure 1.5. Radiaciton pyrometer .

Thermocouples with a number of thermocouples 3 are used in radiation pyrometers as a heat-sensing element. Since the radiation pyrometer has a fixed diaphragm 2, a movable eyepiece 4 and a tinted or opaque protective glass 5 are installed for the correction of the focus shape, which prevents the eye light from being detected when measuring high temperatures. protects. Radiation pyrometers allow to determine the temperature from 400 °C to 3500 °C.

Pressure gauges.

Pressure is the effect of a force acting on a unit surface and perpendicular to this surface.

Pressure is measured in pascals, 1 m² the force acting on a body with a surface area of pascal equal to 1 newton, or 1 Pa = 1 N/m² where 1 N=1 kg/cm² is the unit of pressure in pascal degrees or shares can also be brought.

$$1\text{kPa} = 10^3 \text{ Pa}$$

$$1 \text{ MPa} = 10^6 \text{ Pa}$$

$$1\text{mPa} = (\text{millipascal}) = 10^{-3} \text{ Pa etc.}$$

some literature , pressure units can be equated to:

$$1 \text{ kgs/m}^2 = 1\text{mm. wire.column} = 9.8066 \text{ Pa}$$

$$1 \text{ kgs/cm}^2 = 98.066 \text{ kPa} = 0.09066 \approx 0.1 \text{ MPa}$$

$$1 \text{ atm} = 101.325 \text{ kPa} = 760 \text{ mm. sim. column}$$

$$1 \text{ mm. sim. column} = 133,322 \text{ Pa}$$

$$1 \text{ bar} = 0.1 \text{ M Pa or } 10^5 \text{ Pa}$$

Pressure is divided into the following main types:

1. Absolute pressure ("in absolute " i.e. pressure calculated from absolute vacuum).
2. Excess pressure. Pressure greater than atmospheric (barometric) pressure and indicated by a manometer.
3. Atmospheric or "Barometric" pressure as indicated by a barometer.

Depending on the working process, pressure measuring devices are divided into liquid, spring, and piston types. The pressure detected in liquid instruments is determined by the pressure of the liquid column. Above that, the height indicates the pressure value being determined. The pressure detected in spring-loaded devices is determined by the elasticity of the spring. The deformation of the spring element serves as the value that determines the pressure. The pressure detected in piston monometers is determined by the weight acting on the surface of the piston.

Structure and operation of pressure measuring devices.

1. Liquid tools

Liquid manometers are the simplest of pressure measuring devices, but have a high degree of accuracy. The disadvantage of these manometers is that they can measure small pressures.

a) U-shaped manometers , which consist of a glass tube bent in the shape of the letter U, as shown in Fig . 1. 6. The tube is placed on a scale board and filled with liquid up to half. If one end of the tube is attached to the volume where the pressure should be determined, the other end is left open. In such a manometer, the liquid on one side rises and the other falls. The difference between the liquid heights indicates the pressure value: $R_{ort} = hg (\rho - \rho_c)$, Pa

where g is the acceleration of free fall;

h - liquid height difference;

ρ - liquid density .



1. 6 – picture. U is a manometer.

if $\rho < \rho_s$, the equation takes the following form. $R_{ort} = hg$ is mainly ρ determined by the U-shaped manometer, the pressure in mm, the mercury in mm , the water column in units. Because water or mercury is used as the working body (liquid).

Mm of mercury is multiplied by 130, 322 or 9.866 to convert the pressure value in mm of water column to Pa.

The maximum pressure to be detected by U-shaped manometers is determined by the length of the tube and the strength of the glass.

It is rarely detected above 200 kPa pascal with shaped manometers. It can be used to detect rarefaction or vacuum using shaped manometers. For this, one end of

the tube is attached to the surface where the thickness is to be determined, and one end is left open. If both ends of the instrument are attached to the surfaces whose pressure is to be determined, then the difference in liquid heights will indicate the different pressures on the two surfaces. Such monometers are called differential monometers or diffmonometers.

b) Chamber manometers:

The double measurement process, which is the main disadvantage of U-shaped monometers, is lost in the so-called cup monometers. These monometers differ from U-shaped monometers in that one tube is made of a wide and short container, and the other is made of a thin tube. The working liquid is poured into the short container until it reaches a value equal to the 0 mark on the scale. When measuring excess pressure, the object is connected to the instrument container through a tube, and when measuring rarefaction, it is connected to a measuring tube. When measuring the pressure difference, a large pressure vessel is connected to a small pressure measuring tube. Chamber monometers have a measuring range from 0 to 200 k Pa (Figure 1.7).



1.7 - picture. Chamber monometer.

c) Micromanometers:

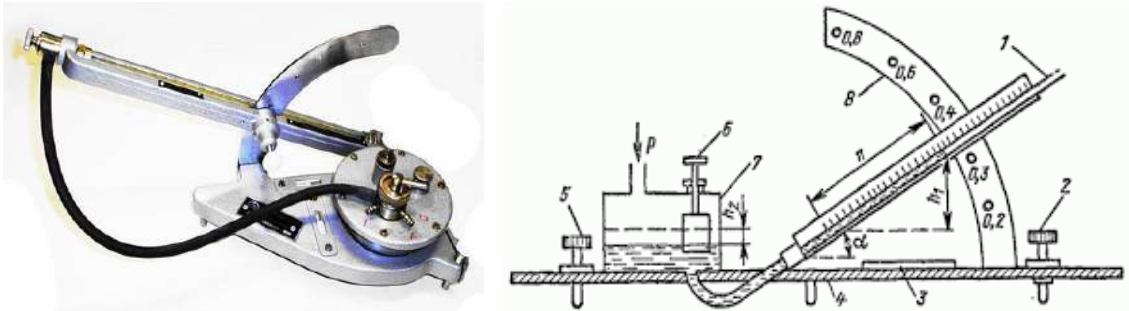
Micromanometers are used in laboratory laboratories and industrial enterprises to measure the pressure differences of small pressures of air and non-aggressive gases in the process of testing heat stress equipment. The simplest type of micromonometers is a bent tube monometer, which consists of monometers with a cup, in which the measuring tube is not horizontal or vertical, but is installed at an angle (Fig. 8).

In this case $h = l \sin \alpha$

Here : h – the height of the measured pressure liquid column in mm

l is the length of the liquid column in the bent tube.

As an example of a bent tube monometer, 100 mm the only parameters with a measurement limit of 25, 40, 63, water column can be given. These instruments have a measurement error of +1.5%.



1.8 - picture. Micromonometer .

Micromonometers of the MKK type with a variable angle of inclination of specially designed instruments are used for high-precision measurement in laboratory conditions and as a reference instrument. Instruments of this type consist of a wide container 1 attached to the side with a glass tube 2 marked with a measuring scale. The measuring tube 2 is mounted on the container yustament 3, which is mounted on a rotating bracket 4, which allows you to install the tube at different angles.

The numbers 0.1:0.2:0.3:0.4 are the scale indicator corresponding to the angle at which the tube is installed. Also provided with 2 screws that indicate the plane of installation of the tool. In the measuring tube, compression equipment is installed to bring the liquid to the 0 mark on the scale.

To bring the minus indicator to 0, the liquid level in the container 1 is turned by means of the screw device 7 connected to the squeezer 6 using the device 5 until the liquid level in the tube 6 hits the 0 mark. A multi-way caliper 8 is installed on the cover of the instrument, which serves to measure the vessel or tube against a given surface, depending on the measurement of pressure or thinness. Measuring range of MMn type micromonometers 0 – 120, 0 – 150, 0 – 250 mm over water is produced.

Spring pressure gauges:

The principles of operation of mechanical spring monometers are based on the deformation of various flexible elements, tube springs, bellows, etc.

Tube spring manometers. In the measurement of pressure and rarefaction, among the mechanical monometers, monometer with a coil spring (Bourdon spring) is widely used.

tube with an elliptic cross-sectional bubble arc of 180° - 270° serves as a flexible element. (Figure 1.9).



1.9 - picture . Tube spring m a nometer .

One end of the tube is connected with a plug and the other end is connected to a paste that serves to connect with the surface to be measured. The tube is installed in the housing 2. When excess pressure is applied to the inner part of the tube, its arc shape straightens, as a result, the connected part moves out of place. The movement of the end of the tube is transmitted to the device (arrow) by means of transmission mechanisms, which, in turn, turns and shows the required pressure. The deflection of the manometric tube is based on the change in the shape of its cross-section.

III. Procedure for conducting the experiment.

The considered instruments are installed in the laboratory device. The procedure for performing laboratory work is as follows:

1. To study the structure and operation method of liquid and mechanical manometers.
2. It is necessary to check the taps (valves) in the air pipes coming from the compressor.
3. Using the compressor, compress the air in the compressor receiver (air collecting tank) to 1-1.5 at., then the compressor is stopped.

4. Compressed air is sent to the laboratory device by opening the tap (valve) in the air-moving pipe.

The pressure difference is measured using a differential manometer.

The pressure in the pipeline is measured by opening the taps connected to the micromanometer and cup manometers.

Using the vacuum pump, the vacuum pressure is measured on the vacuum gauge, and the taps are closed by turning off the vacuum pump.

Familiarize with temperature measuring devices, draw them and explain their operation.

Measuring the temperature of the room with different thermometers and expressing it in Kelvin scale.

IV. Table for recording the results of the experiment .

Table 1.1

No	t °C	T, K	P _{VAK} mm.suv.u st	P _{BAR} mm.cm.u st	ABS _ atm
1					
2					
3					

V. Report of the work.

The report should include:

1. Brief description of manometers.
2. Diagrammatic representation of manometers.
3. What are the ways to measure temperature?
4. Describe the temperature scale in the SI system and technical system.

VI. Control questions.

1. What kind of device is called a temperature measuring device?
2. What are the types of thermometers?
3. Where are thermometers used?
4. Tell me about pressure and its measuring devices?
5. Advantages and disadvantages of thermometers and monometers count?

APPLICATIONS.

Appendix

1



Overview of modern temperature measuring devices.

Appendix 2



Overview of modern pressure measuring devices.

2 - LABORATORY WORK.

DETERMINATION OF HEAT CAPACITY OF AIR.

The purpose of the work: to improve students' skills in determining the heat capacity of air.

Key words : heat capacity, air consumption, rotameter, manometer.

Necessary equipment: To determine the isobaric heat capacity of air drawings of the device, videos in the form of presentations to study the principle of operation.

Some slides of the presentation are attached.

To carry out the experimental work, it is necessary to familiarize yourself with the following literature:

1. Alimova MM, Mazhudova Sh.S., Isakhodjayev XS, Rakhimjonov RT, Umarjonova F.Sh. A collection of experiments on the subject "Theoretical foundations of heat engineering". Methodological manual., Part 1.-T.: TDTU, 2006.
2. Zohidov RA, Alimova MM, Mazhudova Sh.S., Theoretical foundations of thermal engineering. Study guide.-Tashkent: Publishing House of the National Society of Philosophers of Uzbekistan, 2010.

Duration of work - 2 hours.

I. General information.

make it possible to express the caloric, i.e. heat state (i , u , c_p , c_v) properties of substances through thermodynamic parameters and thermal expansions of the main thermodynamic properties of substances $\left(\frac{\partial \mathcal{G}}{\partial T}\right)_p$; $\left(\frac{\partial p}{\partial T}\right)_v$

Thus, it is not necessary to directly experimentally determine the caloric properties of real gases, since the measurements are subject to considerable errors. The basic differential equations have the following form:

For enthalpy

$$\left(\frac{\partial i}{\partial T}\right) = -T \cdot \left(\frac{\partial \mathcal{G}}{\partial T}\right)_p + \mathcal{G} \quad (2.1)$$

For heat capacities

$$\left(\frac{\partial c_p}{\partial P}\right)_T = -T \cdot \left(\frac{\partial^2 \mathcal{G}}{\partial T^2}\right)_p \quad (2.2) \quad \left(\frac{\partial c_g}{\partial V}\right)_T = -T \cdot \left(\frac{\partial^2 P}{\partial T^2}\right)_g \quad (2.3)$$

So, for example, if in equation (2) the heat capacity of a real gas S_r is given at a given temperature and the $\left(\frac{\partial c_g}{\partial V}\right)_T$ experimental values of thermal expansion are given, S_r can be determined from the following formula:

$$c_p = c_{p_0} - T \int_{p_0}^p \left(\frac{\partial^2 g}{\partial T^2}\right)_p \cdot dP \quad (2.4)$$

3) can be used for practical calculations, the main thermodynamic properties of substances can be determined experimentally or through equations that can calculate their states. The simplest equation of state of real gases is the Van der Waals equation:

$$\left(p + \frac{a}{v^2}\right) \cdot (v - b) = R \cdot T \quad (2.5)$$

Equation (5) is the correction b that takes into account the final volume of the molecules and the pressure a/v^2 correction mean to taste __ The constants for individual substances can be determined by critical parameters a and b .

The critical pressure P_{kr} and the critical temperature T_{kr} are determined by the following formulas:

$$a = \frac{27R^2 \cdot T_{kp}^2}{(64p_{kp})}; \quad b = \frac{R \cdot T^2}{(8p_{kp})} \quad (2.6)$$

The gas constant is determined from the following equation.

$$R = \frac{8314,3}{\mu} \quad (2.7)$$

The accuracy of the Van-der-Waals equation is not high, therefore, at the moment, the equation of state of gases is also used, which is spread over the coefficient of compressibility Z in terms of density ρ levels in the theoretically based virial form of the equation of state of gases.

$$\frac{P_g}{R \cdot T} = A + \beta\rho + c\rho^2 + \delta\rho^3 + \dots + \quad (2.8)$$

Here: $\rho = \frac{1}{v}$; β ; c ; δ ; ... - second, third, fourth, etc. virial coefficients.

Each of the virial coefficients in the equation can be more precisely justified based on the molecular properties of the gas.

The second virial coefficient V takes into account the deviation from the ideal gas equation of state due to the interaction of two molecules, and the third coefficient takes into account the interaction of three molecules, etc.

Thus, the equation of the virial state explains the results of a macroscopic experiment in terms of the interaction of molecules. Experimental methods of studying the thermodynamic properties of real substances are used to determine the variable coefficients of the equation of state and to calculate the thermodynamic properties of the studied substance. To experimentally determine the variable coefficients, it is necessary to measure pressure p , temperature t and specific volume v . Enthalpy and heat capacity are determined experimentally with a calorimeter. The amount of the studied substance is placed in a previously known calorimetric container. When determining the heat capacity of steam and gases, flow calorimeters are used, because the heat spent on heating the calorimeter parts and heat losses can be significantly reduced due to the increase in the amount of substance passing through the calorimeter.

The heat capacity can be determined from the following expression:

$$\bar{c}_p = \frac{Q}{M \cdot (t_2 - t_1)} \quad (2.9)$$

Here, Q is the amount of heat, J/s, given to the substance per unit of time; M - mass consumption of substance (kg/sec); t_1 , t_2 are the initial and final temperature of the experiment °C.

II. Order of work.

Determination of the average specific heat capacity of air at constant pressure in the range from room temperature 20° to 60 °C.

III. Experience of the device description .

of the device worker part it 's hot _ _ _ losses _ _ himself _ _ spending discharger calorimeter h is calculated (Figure 1). Calorimeter 2- of surface body many p _ y o' lli heat exchange hardware organize because it does inside bottle 4 electr. in the tube heater placed _

Air flow creates adiabatic, i.e. non-heat-exchanged, conditions in external channels. The voltage of the electric current supplied to the calorimeter heater is

measured by a voltmeter 6, and the current is measured by an ammeter 5 and adjusted using an autotransformer.

The air temperature at the inlet and outlet of the calorimeter is measured by TXK thermocouples 7. The electromotive force in thermocouples is recorded on the potentiometer (millivoltmeter) at 9. Windmill 1 h provides power through the calorimeter . The air consumption is adjusted by the barrier 10, and the pressure difference is measured by the U-shaped manometer.

IV. Experience fulfillment order .

The wind by moving the valve, the blockage in the pipe will be opened. The calorimeter heater is turned on. With the help of an autotransformer, the initial voltage given by the teacher is set. Ammeter and voltmeter readings are recorded.

It is raised until the steady state is established, that is, to the state that characterizes the constant readings of the potentiometer, which records the air temperature at the inlet and outlet of the calorimeter, and to the recording of the readings of the measuring instruments. wished The pressure of the environment is measured using a barometer. The air consumption is determined from the table given for the pressure difference Δp and for the standard diaphragm .

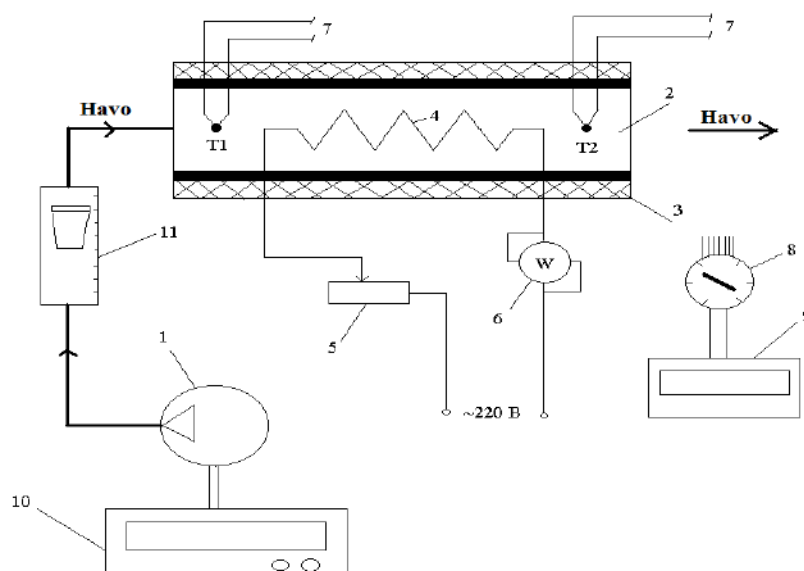


Figure 2.1. Overview of the experimental device.

V. Processing of measurement results.

Based on the results of the experiment, it is necessary to determine the average specific heat capacity from the expression (2.9) when the air pressure does not change. Due to the low temperature of the experiment, the heat losses in the calorimeter are small, so they can be neglected.

1. We determine the hourly air consumption from the following expression:

$$M = 0,01252 \cdot \alpha \cdot \varepsilon \cdot \kappa_i^2 \cdot d^2 \cdot \sqrt{\Delta p \cdot \rho} \quad \text{kg/soat}; (2.10)$$

α - spending coefficient;

ε - the correction coefficient h accounting for air expansion ;

k is the correction coefficient that takes into account thermal expansion of diaphragms and pipes ;

d - diaphragm hole diameter, mm;

Δp is the pressure difference before and after the diaphragm;

ρ - air density to the diaphragm, kg/m³.

2. We determine the amount of heat supplied to the air:

$$Q = U \cdot J = U^2 / R (2.11)$$

Determine the temperature difference h at the inlet and outlet of the calorimeter .

$$\Delta t = t_2 - t_1 (2.12)$$

4. Calculate the average isobaric heat capacity h of air .

VI. Table for recording the results of the experiment .

Table 2.1

No	t ₁ , °C	t ₂ , °C	He, V	I, A	R, Om	W, m ³ /s	P _{VAK} , mm.suv.u st	P _{BAR} , mm.cm.u st	ABS, atm
1									
2									
3									

VII. Work report.

The report should include:

1. Work briefly description .
2. of the device principle scheme .

3. Draw the principle scheme of the device for determining the isobaric heat capacity of air.

VIII. Control questions.

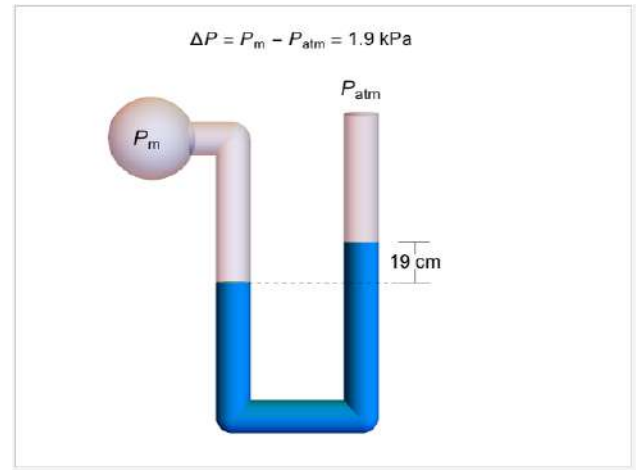
1. What is average heat capacity?
2. Are heat losses to the environment considered in this work ?
3. What for?
4. How is air consumption measured?
5. Real of gases how h olat equations do you know

Appendix-1



Modern consumption meters.

Appendix-2



Modern pressure measuring devices.

3 - LABORATORY WORK.

DETERMINATION OF HEAT CONDUCTIVITY COEFFICIENT OF PIPE FORM INSULATION MATERIAL.

(calculated through the EHM program)

The purpose of the work: to consolidate knowledge on the theory of heat conduction and gain practical knowledge on conducting experiments.

As a result of the work, the following should be learned:

1. The physical nature of the heat conduction process;
2. Familiarity with the meaning of Fourier's law and its application to simple geometric bodies;

3. The concept of heat transfer coefficient and the cylindrical method of its determination.

Key words: thermal conductivity coefficient, insulating material, thermocouple, calorimeter, temperature gradient, temperature area, equivalent diameter.

Necessary equipment: a drawing of the device for determining the coefficient of thermal conductivity of the insulating material, videos in the form of a presentation to study the principle of operation.

Some slides of the presentation are attached.

To carry out the experimental work, it is necessary to familiarize yourself with the following literature:

1. Svetkov FF, Grigorev BA *Teplomassoobmen*, -MEI.: 2001.
2. Umarjonova F. Sh., Isakhodjaev XS, Mazhudova Sh. S., Alimova L., O., Akhmatova SR. Collection of laboratory works on "Heat technique". Methodical guide. - Tashkent, ToshDTU. 2014 - 94 p.

Duration of work - 2 hours.

I. General information

Heat conduction is the process of heat transfer through the contact of particles of different parts or parts of the same body.

The speed of heat dissipation is numerically determined by the heat flux density vector passing through the isothermal surface in a unit of time .

This vector is located normal to the isothermal surface and is directed in the direction of decreasing temperature.

According to Fourier's law q , the heat flux Q passing through the elemental isothermal surface dF in time dt is proportional to the temperature gradient $\frac{dt}{dn} = gradt$ dQ .

$$dQ = -\lambda \frac{dt}{dn} dF d\tau (3.1)$$

Integrating the above equation, we obtain the following expression for a cylindrical layer:

$$Q = \frac{2\pi\lambda l(t_1 - t_2)}{\ln \frac{d_2}{d_1}}, \text{ Bm (3.2)}$$

here

l is the length of the cylindrical shaft , m

d₁ , d₂ - inner and outer diameters of the cylindrical sphere , m

t₁ and **t₂** are the average arithmetic temperatures of °C the inner and outer layers of the cylindrical sphere ,

The cylinder length **l** , diameters **d₁** and **d₂** are known, we determine the thermal conductivity coefficient of the material from the above equation by measuring **t₁** , **t₂** and **Q**:

$$\lambda = \frac{Q \ln \frac{d_2}{d_1}}{2\pi l(t_1 - t_2)} \text{ W/m}^* \text{ k (3.3)}$$

II. The structure of the experimental device.

The scheme of the experimental device shown in Figure 6.1 is made of a pipe with a length of $l=0.96$ m and a cylindrical layer of insulating material /asbocement/ with an inner diameter of $d_1=32$ mm and an outer diameter of $d_2=66$ mm. An electric heater /6/ is placed inside the pipe. The current is adjusted with a laboratory transformer /2/, the heat capacity is determined according to the readings of the voltmeter and ammeter. The temperature of the studied material is measured using 8 chromel-copel thermocouples. The hot end of the thermocouple is placed on the inner and outer surfaces of the studied material, 4 in each layer . The welded cold end is placed in a Dewar container /7/ filled with melted ice. The thermocouples are connected to the potentiometer PP-1 /5/ through the connector /3/. Table I is used to convert EYK to temperature.

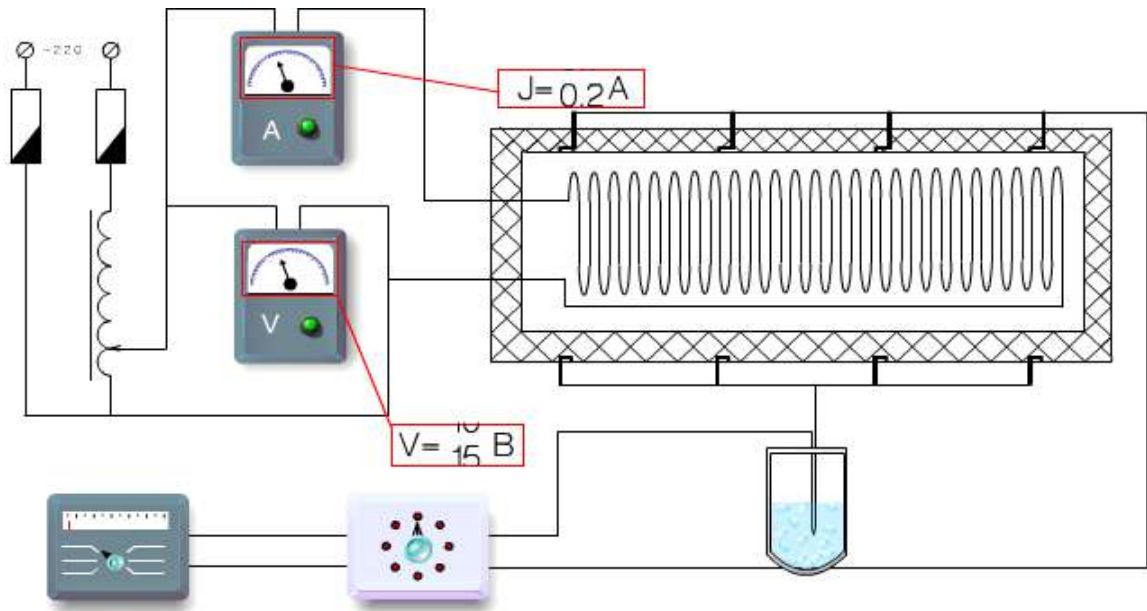


Figure 3.1. Overview of the experimental device.

To create a one-dimensional heat flow, the length of the pipe is much larger than the diameter. In order to reduce the loss of heat, the sides of the pipe are protected with heat-insulating material. The electric heater is evenly distributed along the length of the pipe.

III. Conducting an experiment and calculating its results.

After getting acquainted with the theoretical foundations of the work and the construction of the experimental device, it is necessary to prepare a practical form for recording the results of observations and check the connection of devices. It is necessary to pay attention to the presence of ice in the Dewar container. After the teacher has checked the scheme, you can start experimenting.

The readings of all measuring devices are recorded in the table every 10-15 minutes until the system thermal condition is balanced. The measurement can be started after the system is balanced, that is, after the instrument indicator has not changed for a certain time.

The next experiment will be conducted in a different temperature regime. For this, the power to the electric heater is changed. Adding the device to work and changing this mode should be done only by the teacher. To calculate the results of the experiment, the measured data are used when the system is balanced. Usually, the average value of the last 3 measurement results is taken.

thermal conductivity coefficient of the studied material is determined from the following equation:

$$\lambda = \frac{Q \ln \frac{d_2}{d_1}}{2\pi l(t_1 - t_2)}, \text{ W/m}^*\text{k} \quad (3.4)$$

The amount of heat Q is determined by the power absorbed by the electric heater .

$$Q = J * \Delta U, \text{ v} \quad (3.5)$$

here

J- power to the heater , A

ΔU –voltage drop in the heater, V

heat transfer coefficient of the studied material is taken for the average temperature.

$$\bar{t} = \frac{t_1 + t_2}{2}, \text{ } ^\circ\text{C}$$

At 3-4 temperatures, it is necessary to draw a graph of the relationship between the heat transfer coefficient and the average temperature of the material being studied (Fig. 6.2).

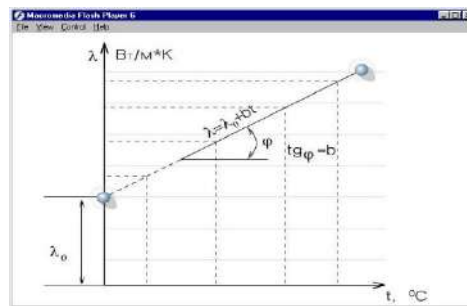


Figure 3.2

The relationship between the coefficient of thermal conductivity and the temperature of the studied material.

It is known that there is a linear relationship between the coefficient of thermal conductivity and temperature:

$$\lambda = \lambda_0 + b\bar{t} \text{ W/m}^*\text{k} \quad (3.6)$$

λ_0 and coefficient "b" from the studied material .

IV. The case report must contain the following:

1. Summary of the work.
2. The basic scheme of the device.

3. Tables with indicators of measuring devices and calculation results.
4. The graph of the connection between the heat transfer coefficient and the temperature and λ_0 the values of ni and coefficient "b".

Chrom-Copel thermocouples $^{\circ}\text{C}$ transition table from EYK in degrees ().

t, $^{\circ}\text{C}$	0	1	2	3	4	5	6	7	8	9
70	4.76	4.83	4.90	4.98	5.05	5.12	5.20	5.27	5.34	5.41
80	5.48	5.56	5.63	5.70	5.78	5.85	5.92	5.99	6.07	6.14
90	6.21	6.29	6.36	6.43	6.51	6.58	6.65	6.73	6.80	6.87
100	6.95	7.03	7.10	7.17	7.25	7.32	7.40	7.47	7.54	7.62
110	7.69	7.77	7.84	7.91	7.99	8.06	8.13	8.21	8.28	8.35
120	8.43	8.50	8.58	8.65	8.73	8.80	8.88	8.95	90.3	9.10

V. Table for recording the results of the experiment.

Table 3.1

N o	J. A	Δ U, V	Q W	t_1		t_2		t_3		t_4		t_5		t_6		t_7		t_8		t s1 0	t s2 0	l
				m	$^{\circ}\text{C}$	m	$^{\circ}\text{C}$	m	$^{\circ}$	m	$^{\circ}\text{C}$	m	$^{\circ}\text{C}$	m	$^{\circ}\text{C}$	m	$^{\circ}$	m	$^{\circ}$			
				V		V		V	C	V		V		V		V		V	C			
1																						
2																						
3																						

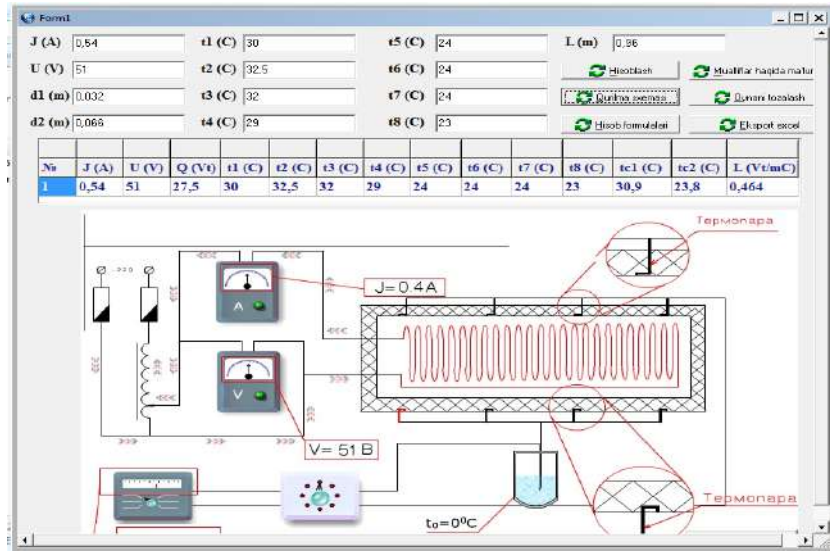
VI. Report on the work.

The report should include:

1. Work briefly description .
2. of the device principle scheme .
3. Draw a graph of the relationship between the coefficient of thermal conductivity and the average temperature of the material under study .

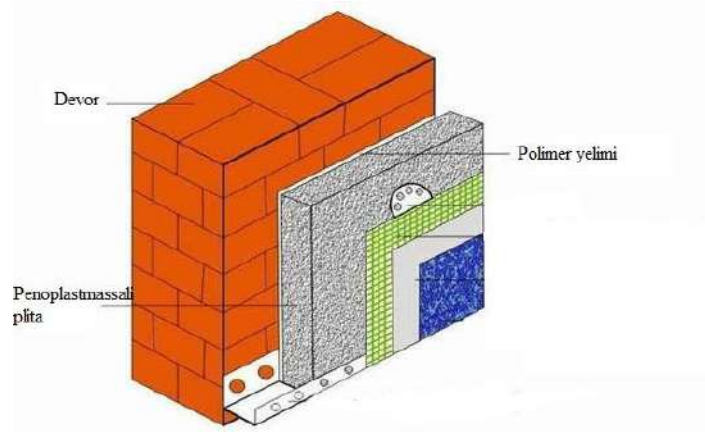
VII. Control questions.

1. What is the heat transfer coefficient?
2. What does Fourier's law study?
3. Write the formula for determining heat flow?
4. Why is the length of the pipe much larger than the diameter?
5. How is the amount of heat released from an electric heater determined?



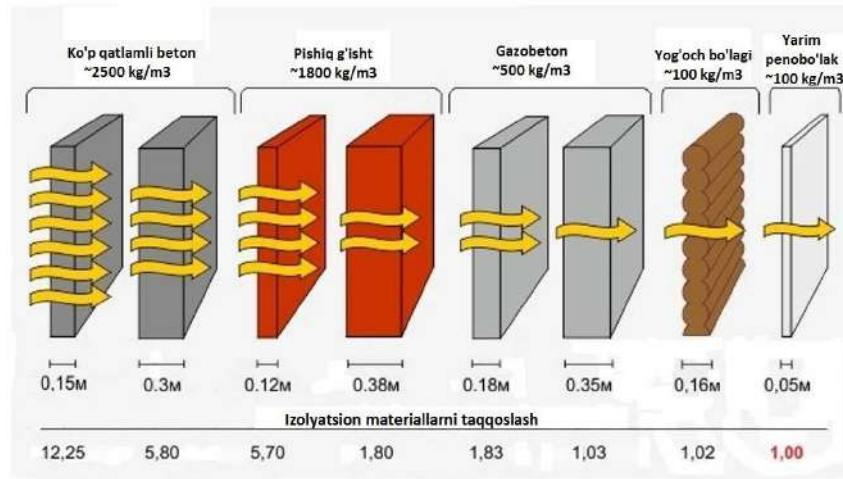
The program created in EHM for determining the thermal conductivity coefficient of insulating material.

Appendix-2



Layering of insulating materials.

Appendix-3



EXPERIMENTAL WORK 4.

DETERMINATION OF HEAT TRANSMISSION COEFFICIENT OF HORIZONTAL PIPE.

(calculated through the EHM program)

The purpose of the work: to strengthen knowledge on the theory of heat transfer in free movement of air and to develop skills for conducting experiments. As a result of the work, the convective heat exchange in the free movement of air (liquid) in a large volume should be studied, as well as the dependence of the heat transfer coefficient on various factors should be determined.

Key words: heat transfer coefficient, insulating material, thermocouple, calorimeter, temperature gradient, temperature area, equivalent diameter.

Necessary equipment: drawing of the device for determining the heat transfer coefficient of the insulating material, videos in the form of a presentation to study the principle of operation.

Some slides of the presentation are attached.

To carry out the experimental work, it is necessary to familiarize yourself with the following literature:

1. Taktayeva LN, Rakhimjonov RT, Alimova MM, Mazhodova SH.S. Thermal and hydraulic calculation of recuperative heat exchangers. Methodical guide for independent work. - Tashkent.: TDTU, 2006.
2. Umarjonova F. Sh., Isakhodjaev XS, Mazhudova Sh. S., Alimova L., O., Akhmatova SR. Collection of laboratory works on "Heat technique". Methodical guide. - Tashkent, ToshDTU. 2014 - 94 p.

Duration of work - 2 hours.

I. General information.

The movement of fluid due to the difference in density of heated and cold particles is called free movement.

If the pipe in the air is heated, the air will heat up and become less dense. As a result, heated air particles rise up, and cold air particles take their place. The higher the speed of air movement and the greater the temperature difference between the wall and the environment, the greater the amount of heat transferred.

Therefore, heat transfer is determined primarily by the difference in wall and ambient temperatures. In addition, the rate of heat transfer depends on the physical properties of the environment, the shape and condition of the solid surface, and other factors.

The heat transfer coefficient is determined according to the Newton-Richmann law.

$$\alpha = \frac{Q_K}{F(t_{K.C} - t_M)}, \text{ W/m}^2 \cdot \text{K} \quad (4.1)$$

where: Q_K – in the method of convection from a heated pipe amount of heat supplied, W;

F – pipe surface area, m^2 ;

t_{KS} – solid surface average temperature, $^{\circ}\text{C}$;

t_M – the temperature of the environment (liquid or air), $^{\circ}\text{C}$.

II. Description of the experimental device.

The experimental device is located in a room with a relatively stable temperature. A horizontal copper pipe (1) with diameter $d=32$ mm and length $l=1490$ mm is uniformly heated using an electric heater (2). The power consumption of the electric heater is adjusted by experimental autotransformer LATR-1 (5) and measured by voltmeter (6) and ammeter (7). In order to reduce heat loss, the ends of the pipe are insulated. To measure the temperature of the heating surface, eight copper-constant thermocouples (thermocouples) (3) were attached to the tube wall, and their cold ends were placed in a Dewar container (8) filled with ice. Conductive forces of thermocouples are measured using a laboratory potentiometer PP-63 (4). Table 7.1 is used to convert the EUUK value of thermocouples to degrees . The air

temperature in the room is measured using mercury thermometers away from the pipes.

III. Procedure for performing the experiment.

After getting acquainted with the theoretical basis of the work and the description of the experimental device, it is necessary to prepare a report form for recording the observation (appendix 3) and check that the measuring instruments are connected correctly. After checking the scheme with the teacher, you can start the experiment.

All measurements are carried out at constant temperature. This condition is expressed by the fact that the indicators of measuring instruments do not change over time, and it settles in the device after 30-40 minutes.

After the steady state of heat has been decided, it is necessary to record the readings of all instruments 3-4 times every 6-10 minutes. The working state of the device is changed at least 4 times. Connecting the device and changing its working status is done with the teacher.

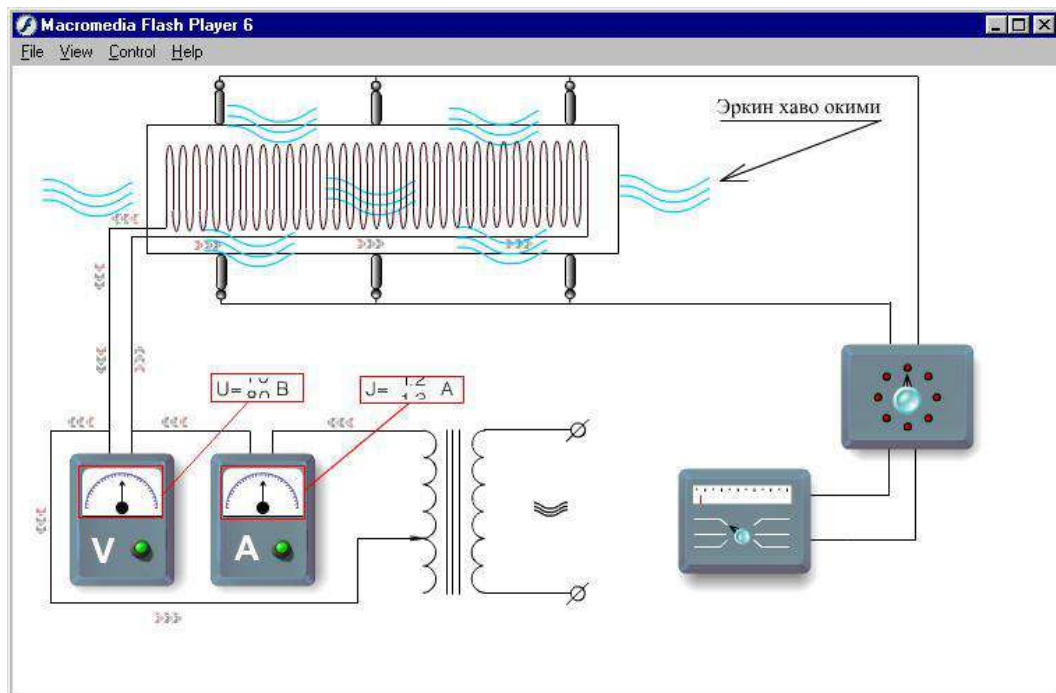


Figure 4.1. Overview of the experimental device.

IV. Calculation procedure.

Convection heat transfer from the experimental pipe to the surrounding air is determined by the following equation:

$$Q_K = Q_0 - Q_N, W \quad (4.2)$$

where: $Q_0 = I \Delta U$ – separated from the electric heater inside the pipe total heat amount, W;

I - current, A;

ΔU - voltage drop, V;

Q_N is the release of the amount of heat by radiation from the pipe, Wt.

$$Q_N = C_K \left[\left(\frac{T_{K.C.}}{100} \right)^4 - \left(\frac{T_{M.}}{100} \right)^4 \right] F, \text{ vt (4.3)}$$

where: C_K is the given radiation coefficient, $W/m^2 \cdot K^4$.

The surface of the surrounding objects is several times larger than the surface of the experimental pipe, so the given radiation coefficient can be taken as equal to the radiation coefficient of the experimental pipe.

$$C_K = C = 4.25 W/m^2 \cdot K^4. (4.4)$$

T_{ks} , T_m - the surface of the test pipe and the absolute temperature of the environment.

To calculate the temperature of the experimental pipe, we take the average of the values measured at eight points.

(1) from Eq in the operation of the device in at least four modes calculate the value and draw a graph.

$$\alpha = f(t_{ks} - t_s) \quad (4.5)$$

The resulting graph is relevant only for the experimental pipeline under investigation.

In order to apply the results of the experiment to other pipelines, it is necessary to generalize the results of the calculations with the help of criterion relationships.

$$Nu_{s,d} = f(Gr \cdot Pr)_{s,d}, (4.6)$$

Here: $Nu = \frac{\alpha d}{\lambda}$ - Nusselt criterion;

$$Gr = \frac{g \beta \Delta t d^3}{\nu^2} - \text{Grasgoff criterion};$$

$$Pr = \frac{\nu}{a} - \text{Prandtl criterion};$$

λ - heat transfer coefficient of air, W/m K;

a - coefficient of thermal conductivity of air; m^2/s ;

γ - coefficient of kinematic viscosity of air, m²/s;

Δt - temperature difference; °C

$$\beta = \frac{1}{t_M + 273} \quad \text{-- volume expansion coefficient of air, K}^{-1};$$

$$g = 9.811 \quad \text{-- acceleration of free fall, m}^2/\text{s};$$

Physical parameters ($\lambda, a, \gamma, \beta, Pr$) is taken from the table according to the temperature of the air in the room.

The values of the similarity criteria obtained for each state of the device are included in the graph in the logarithmic coordinate system

The resulting straight line equation will look like this:

$$\text{LgNu}_{s,d} = \text{lg}C + n \text{lg}(Gr, Pr)_{s,d} \quad (4.7)$$

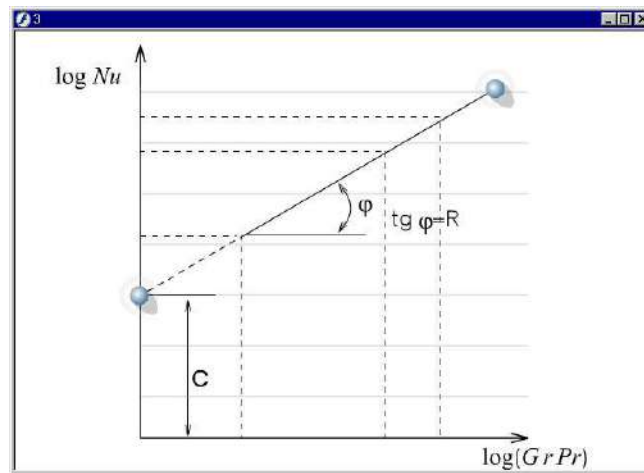


Figure 4.2

The degree is determined by the slope of the straight line and the tangent of the angle to the abscissa axis, and the constant C is determined for any point on the straight line by the following ratio:

$$C = \frac{Nu_{c,d}}{(Gr \cdot Pr)_{c,d}} \quad (4.8)$$

$$n = \text{tg } \varphi$$

V. Table for recording the results of the experiment.

Table 4.1

N	J.	Q	t ₁	t ₂	t ₃	t ₄	t ₅	t ₆	t ₇	t ₈	t	t	l
o	A	W									s1	s2	

		Δ		m	$^{\circ}\text{C}$	m	$^{\circ}\text{C}$	m	$^{\circ}$	m	$^{\circ}\text{C}$	m	$^{\circ}\text{C}$	m	$^{\circ}\text{C}$	m	$^{\circ}$	$^{\circ}$	$^{\circ}$	
		U,		V		V		V	C	V		V		V		V	C	C	C	
1																				
2																				
3																				

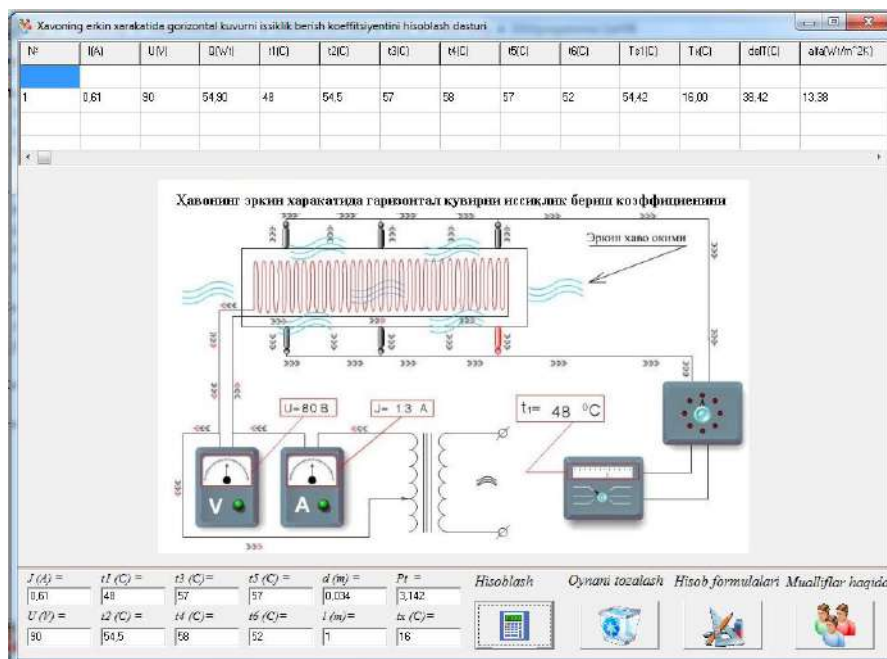
VI. Work report.

The report should include:

1. Work briefly description .
2. of the device principle scheme .
3. Draw the principle scheme of the laboratory device for determining the coefficient of heat transfer when air moves freely.

VII. Control questions.

1. What insulation materials do you know?
2. What parameters of insulation materials are important?
3. What should be the coefficient of heat transfer of insulation materials?
4. What other layers can be implemented?
5. What does the heat transfer coefficient depend on?



A software product created in EHM to determine the coefficient of heat transfer during free movement of air.

EXPERIMENTAL WORK 5.

CO-7A COMPRESSOR ELEMENTS AND MODE OF OPERATION.

The purpose of the work: The purpose of the experimental work is to study the structural structure of the compressor in depth and study the principle of operation of the compressor device, as well as drawing a sketch.

Key words: compressor , piston, cylinder, working pressure, compressed air, degree of pressure increase.

Necessary equipment: a drawing of the device to study the structural structure of the compressor , video clips in the form of a presentation to study the principle of operation.

Some slides of the presentation are attached.

To carry out the experimental work, it is necessary to familiarize yourself with the following literature:

1. Alimova MM, Mazhudova Sh.S., Isakhodjayev XS, Rakhimjonov RT, Umarjonova F.Sh. A collection of experiments on the subject "Theoretical foundations of heat engineering". Methodological manual., Part 1.-T.: TDTU, 2006.
2. Pod ed. Zakharovoy AA Technicheskaya thermodynamics and temperature engineering. - M.: Academy, 2006.

Duration of work - 4 hours.

I. General information

Production capacity 30 m³/hour;

Working pressure 6 kgs/cm² (6* 10⁵ Pa);

Cylinder diameter 78 mm;

Piston diameter 75 mm;

The number of cylinders is 2;

Piston travel distance 85 mm;

The rotation speed of the crankshaft is 1000 rpm;

The direction of rotation of the crankshaft is clockwise
(by a mechanic) reverse direction;

Oil consumption is not more than 40 g/ h ;

Pressure adjustment limit 2÷6 kgs/cm² ;

Type of electric motor AOL2-32-2;

Power 4 kW;

The rotation number of the shaft is 2880 rev/min;

The volume of the receiver is 22 liters.

are machines used to compress gases, including air, with a pressure higher than 3 atm . Compressed air obtained in compressors is widely used in various fields of technology . For example, in compressed air hammers; in the metallurgical industry: spraying air into furnaces , in the construction of metals under high pressure: performing finishing works, cleaning the surface of metal ingots with sandblasting, etc.

Compressors are divided into two types:

- 1) Piston compressors;
- 2) Centrifugal compressors.

When the operation of compressor machines is analyzed from a thermodynamic point of view, the difference between the real process and ideal processes in gas compression is that in the real process, the harmful volume and other losses are taken into account , while in the ideal process they are not taken into account. Let's look at the indicator diagram of a reciprocating compressor .

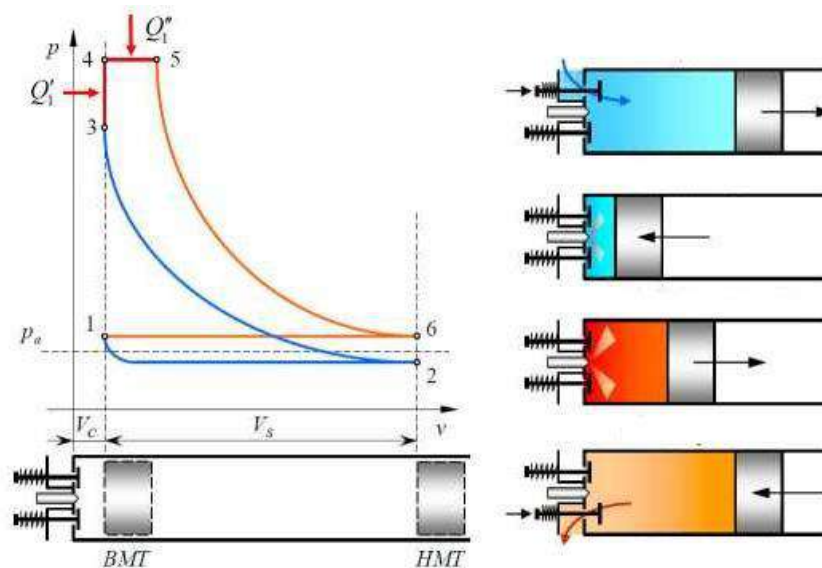


Figure 5.1. Indicator diagram of 4-stroke compressor operation.

The ratio of the volume of gas entering the cylinder V_u to the working volume of the cylinder V_h , taken from the actual indicator diagram , is called volumetric FIK of the compressor:

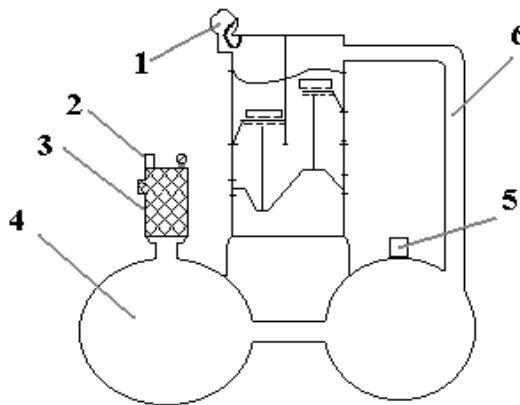
$$\eta_v = \frac{V_u}{V_h} \quad (5.1)$$

Due to the fact that the gas escapes through various openings in the compressor, the volume of gas actually pushed into the cylinder will be smaller than the gas volume V_u obtained from the actual indicator diagram. The ratio of V to the working volume V_h is called the transmission coefficient.

$$\lambda = \frac{V}{V_h} \quad (5.2)$$

Values of volumetric FIK and transmission coefficients

$$\eta_v = 0.75 - 0.95; \lambda = 0.65 - 0.85$$



5.2 - picture. Scheme of the CO-7A compressor.

- 1 - air filter; 2 - pressure regulator; 3- oil - moisture cleaner;
4 - receiver; 5 - safety valve; 6 - drive pipe.

II. A drawing of the compressor CO-7A and the air passage in it.

is filled with air that has passed through the air filter (1) . When the piston moves up again, the air in the cylinder is compressed with a greater pressure than the atmospheric pressure, as a result of which the push valve closes and the external air is cut off from the cylinder (Fig. 5.2). The upward movement of the piston continues and the air in the cylinder is compressed until it overcomes the drive valve and the resistance of the compressed air in the drive pipe. At this moment, the drive valve opens, compressed air is driven from the cylinder by a piston into the drive chamber in the cylinder head, and the drive pipe (6) flows into the arc receiver (4), and then to the oil dehumidifier (3). Air oil is sent from the dehumidifier to the consumer through two distribution taps. The dehumidifier is equipped with a manometer to

monitor the pressure and a pressure regulator (2) to adjust the compressed pressure . A safety valve (5) is installed on the receiver so that the pressure in the compressor does not exceed the norm .

The CO-7A is a simple-acting, air-cooled, two-cylinder, single-stage piston compressor. The compressor crankcase and cylinder block are cast from the side. To cool the cylinders, annular edges are installed in the cylinder block . The head of the compressor cylinders is cast from aluminum , and its outer side is equipped with edges for cooling. The space b on the inside of the cover is divided into two parts by the barrier, that is, the push and drive spaces b . Each cylinder is provided with spring-loaded push and pull valves.

Connecting rods - made of steel by stamping method . A babbitt casting is installed on the lower head , and a bushing made of bronze tape is pressed into the upper head . The pistons are cast from aluminum alloy , each with two compression and two oil displacement piston rings. The crankshaft is cast in steel and rests on two radial thrust bearings.

The air filter is in the form of a cylinder and serves to clean the air entering the thrust cavity at the bottom of the cylinder head .

Oil-moisture cleaner - in the form of a welded balloon , inside which there is a glass filled with Rashig cells . The function of the dehumidifier is to clean the compressed air sent to the consumer from oil and water particles. The separated oil and water flow to the bottom of the balloon and are periodically drained from the drain hole .

Pressure regulator - the pressure can be adjusted from 2 to 6 kgs/ cm^2 . The required pressure is maintained by releasing excess compressed air . spring corresponding to the required pressure, and then the adjustment screw is closed with a nut (5) .

is adjusted to 7 kgs/ cm^2 and serves to prevent the pressure from exceeding the norm.

consists of two steel pipes connected to each other in terms of structure , and serves to: a) balance the air vibration caused by the advance and return movement of the compressor piston; b) to eliminate air pressure fluctuations when compressed air

is consumed flat ; v) to clean water and oil particles that have entered the receiver together with air.

Oil is poured into the crankcase through the hole that closes the oil connector. The oil level is determined using an oil gauge. The oil level should be between the upper and lower marks on the dipstick . Compressor oil is used for lubrication. Electric motor bearings are occasionally clogged with tar and similar thick oil. The compressor is started by means of a motor wound with a t'set .

III. Experimental determination of the power consumed by the electric motor when the compressed air of the compressor device is different .

After familiarizing with the structure of the compressor device, by gradually reducing the cross-sectional surface of the compressor device in the distribution of the resistance in the compressed air path , it is artificially different to determine the power consumed by the electric motor. is entered.

For this:

a) A table is prepared to record the indication of the instruments .

valves in the oil and moisture separator is closed and the second distributor valve is fully opened .

The electric motor is started by adjusting the pressure regulator to a known pressure that will not change during the experiment .

g) The reading of the manometer is 1 atm. until it shows , the second distributor valve is gradually closed. Pressure 1 atm. after reaching , the readings of the ammeter and voltmeter are recorded .

d) until the pressure gauge shows 2 , 3, 4 atm, the second distributor valve is gradually closed, and at the same time 2 , 3, 4 atm. ammeter and voltmeter readings are recorded . After recording the last reading of the manometer at 4 atm., the electric motor t is stopped .

IV. A table for recording the results of the experiment.

Table 5.1

The air pressure	Indications of electrical measuring instruments	The power of the electric motor
------------------	---	---------------------------------

indicated by the manometer	Power, A	Voltage V	calculated from the expression (3).
at 1 atm			
at 2 atm			
at 3 atm			
at 4 atm			

the measurements are made, the power consumed by the electric motor is calculated from the following expression:

$$W = 1.73 \cdot I \cdot U \cdot \cos \varphi, (W) \quad (5.3)$$

in this expression: I is current, A

U - current voltage, V

$\cos \varphi = 0.89$.

V. Calculation of compressor output power.

a) The theoretical output power of a single-stage, two-cylinder, simple-moving compressor is determined from the following expression :

$$V_m = 2 \cdot \frac{\pi D^2}{4} \cdot 60 \cdot S \cdot n, m^3/\text{hour} \quad (5.4)$$

in this expression: 2 – the number of compressor cylinders;

S – piston y'oli, m;

D – piston diameter, m;

n is the number of revolutions of the compressor shaft, times/min.

b) The actual production capacity of this compressor is determined from the following expression:

$$V = V_m \cdot \lambda = 2 \cdot \frac{\pi D^2}{4} \cdot 60 \cdot S \cdot n \cdot \lambda, m^3/\text{hour} \quad (5.5)$$

in this expression: λ - transfer coefficient.

VI. Work report

The report should include:

1. Work briefly description .
2. of the device principle scheme .
3. Draw the basic diagram of the compressor.

VII. Control questions

- 1 . What is called a compressor?
- 2 . What is the function of the compressor?
- 3 . What are the types of compressors?
4. What are the main components of the compressor?
- 5 . What are the main components of a piston compressor?
- 6 . In what areas are compressors used?
7. What is the CO-7A compressor cooled with ?
- 8 . CO-7A compressor, how many stages ?
9. What is the function of the receiver ?
10. CO-7A compressor pressure adjustment limit ?



Appendix-1



Modern compressors.

References.

- 1 . G'.N.Uzokov, DNMamedova, Sh.K.Yakhshiboyev, HAAlmardanov. A collection of experiments on " Thermodynamics and heat engineering". Study guide.- Q arshi: Intellect , 2021.
2. G'.N.Uzokov, DNMamedova, Sh.K.Yakhshiboyev, HAAlmardanov. Instruction manual for conducting practical training in "Thermodynamics and heat engineering". Study guide. - Against: Intellect, 2021.
3. Alimova Mamlakat Mirkhodievna, Mazhludova Shahlo Saidgapparovna, Isakhodjaev Khairulla Sunnatillaevich, Rakhimjonov Rustam Tokhtaevich, Umarjonova Feruza Sharafutdinovna Methodical manual of experimental work in the subject "Theoretical foundations of heat engineering". Part 1-2-3. TDTU-2004
4. Zohidov RA, Alimova MM, Mazhodova Sh.S., Isakhodjaev XS. Heat engineering. Vocational training manual for vocational colleges, Tashkent. Cholpon - 2006.
5. Andrianova TN and dr. Sbornik zadach po tekhnicheskoy termodinamike, M.: 2006

6. Pod ed. Zakharovoy AA Technicheskaya thermodynamics and temperature engineering. - M: Academy, 2006.
7. Taktaeva LN, Koroli MA, Mazhudovova Sh. Test tasks for evaluation of training results. Tosh.dav.tex.un – ti. 2004.
8. Taktaeva LN, Koroli MA Thermal and hydraulic calculation of recuperative heat exchanger apparatus. Methodological instruction. Tashkent, TGTU, 2006.
9. Taktaeva LN, Rakhimjonov RT, Alimova MM, Mazhudovova Sh.S. Thermal and hydraulic calculation of recuperative heat exchangers. Methodical guide for independent work. TDTU, Tashkent, 2006.
10. Koroli MA, Mazhudovova Sh.S. Modern pedagogical technologies. Methodological development, TDTU, Tashkent, 2003.
11. Koroli MA, Islamov ON Modern approaches to learning technical sciences. Methodological development, Tashkent, TDTU, 2003.
12. Koroli MA, Islamov ON. A set of problems and situations for comprehensive development of students' analytical thinking. Methodological development, TDTU, Tashkent, 2003.

Internet Information:

13. www.Ziya.net
14. http://dhes.ime.mrsu.ru/studies/tot/tot_lit.htm
15. http://rbip.bookchamber.ru/description.aspxproduct_no=854
16. <http://energy – mgn.nm.ru/progr36.htm>

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**OF HIGHER AND SECONDARY SPECIAL EDUCATION OF THE REPUBLIC
OF UZBEKISTAN**

INSTITUTE OF ENGINEERING AND ECONOMICS



"Alternative energy sources " cafe

**"Heat technique"
from science**

PRACTICAL EXERCISES

to perform

**USLUBIY
KO'RSATMA**



Against 2022

Developer:

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From the instruction manual 60730300 – Construction of buildings and structures (objects of the oil and gas processing industry) students of the field of education can also use it. It contains examples of solving problems related to the most important topics of science and brief information about the topics, as well as examples of problems related to independent work.

Procedural instructions at the meeting of the "Alternative energy sources" department (statement No. __, __ __2022), in the Stylistic Commission of the Faculty of Energy (statement No. __, __ __2022) and in the Stylistic Council of the institute (statement No. __, __ __2022 .) are discussed and recommended for use in the educational process.

Enter

Energy plays an important role in the life of people and society, especially electricity and thermal energy are widely used in all sectors of the economy. The development of human civilization has always been closely related to the amount and types of energy used. During the 20th century, especially in the last 40 years, the amount of energy used for economic development in the world has increased significantly. More fossil fuels have been mined for electricity generation and heat utilization systems in the last 40 years than in all of human history. Today, the amount of fuel used in the world is 12 billion tons of oil equivalent per year (about 2 tons of oil equivalent per person). According to the International Energy Agency, until 2030, the rate of primary energy production is expected to increase by an average of 1.7% annually. Fossil fuels such as oil, natural gas, coal and uranium currently form the basis of the world's energy balance and will remain so for the foreseeable future.

As a result of economic development in our country, by 2030, the amount of electricity produced annually will reach 105 billion kilowatt hours, increase the share of renewable energy sources in the country's energy balance to 20-25%, and reduce energy consumption in heating systems by 2-2.5 times.

Therefore, training highly qualified and competitive personnel in this field is an urgent task. This, in turn, creates the need to create training manuals for practical training in technical higher education institutions to form students' skills in solving problems of thermodynamics and heat engineering and to strengthen their theoretical knowledge. This instruction manual, prepared by the authors, can be used by students of 60730300 - Construction of buildings and structures (objects of the oil and gas processing industry) .

1 – SUBJECT: PARAMETERS OF BASIC THERMODYNAMIC STATE.

Theoretical information .

Matter exists in three basic states in nature : gas , liquid, and solid. It is inevitable that one body and one substance can be in different states under different conditions . The substance under investigation is always in one state under given constant conditions, for example, water at atmospheric pressure and 400°C temperature does not exist as a liquid or solid, but only as a vapor.

Physical state parameters determining the physical state of a thermodynamic system _____
 _____ d e b a t a l a d . If the thermodynamic equilibrium of the system is violated, that is, heat is supplied or removed, the gas is compressed or allowed to expand, then some or all parameters of the considered system will change their value.

The most convenient, and therefore the most common, of the state parameters are **the absolute temperature** , **absolute pressure** , and **specific volume** (or density) of a body.

Temperature. Temperature is the quantity that determines the degree of heating of a body. According to the molecular-kinetic theory, the degree of heating (temperature) of the body depends on the speed of movement of the molecules of this body. When heat is applied to a body, the speed of movement of molecules increases. In this case, the body heats up, that is, its temperature rises. When heat is removed, the speed of movement of molecules begins to decrease, that is, the body cools. Its temperature will decrease.

Thus, the temperature of this body (gas) is a measure of the average kinetic energy of gas molecules. From this point of view, temperature should be studied in the unit of energy. But this method is technically inconvenient.

In thermodynamic studies, the scale proposed by the great English physicist Kelvin in 1848 is used. The zero of the Kelvin scale is the temperature at which the movement of ideal gas molecules stops. This temperature is called **absolute zero** . Absolute zero on the Celsius scale ° is equal to 273.15 C. Temperature calculated on the Kelvin scale is always positive. It is called absolute temperature and is denoted by " T " .

In practice, the Celsius scale is also more commonly used. The triple point of water is taken as the starting point of this scale (more precisely, 0.01 °C or 273.16 °K). It is related to the temperature obtained on the absolute scale as follows:

$$T = t + 273.15 \tag{1.1}$$

Currently, the Fahrenheit, Reomur and Rankine scales can be used in technical calculations. Temperature scales are given in Table 1 .

Ratio between different temperature scales.

Table 1.1.

Name of scales	Celsius scale, t, °C	Rankin scale, T, °Ra	Fahrenheit scale, t, °φ	Rheomyur scale, t, °R
Celsius scale, °C	-	$\frac{3}{9} T^{\circ} Ra - 273,15$	$\frac{t^{\circ} \varphi - 32}{1,8}$	$1.25 t^{\circ} R$
R a n k i n a scale, °Ra	$1.8(t^{\circ} C + 273.15)$	-	$t^{\circ} \varphi + 459.67$	$1.8(1.25 t^{\circ} R + 273.15)$
Fahrenheit scale°	$1.8t^{\circ} C + 32$	$t^{\circ} Ra - 459.67$	-	$\frac{9}{4} t^{\circ} R$

Reomyur scale, °R	0.8 t °C	$0,8(\frac{5}{9}T^{\circ}Ra - 273,15)$	$\frac{4}{9}(t^{\circ}\varphi - 32)$	-
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2. The other critical state parameter is **absolute pressure** . It consists of the force acting normal to the surface of the body and obtained relative to the surface unit of this surface.

Pressure - The force acting normal to the surface unit of the surface is called pressure, i.e

$$P = \frac{F}{S} \quad (1.2)$$

where P is pressure; F – power; S is the surface. Pressure is measured in N/m^2 in the SI system .

1 N/m^2 pressure is measured in " Pascal ". Since 1 pascal is a small quantity, kPa ($10^3 Pa$), MPa ($10^6 Pa$) are used to measure pressure in technology. Bar, technical atmosphere ($1 kg \cdot F/cm^2$), millimeter of water or mercury column are also used to measure pressure. The differences between them are as follows:

The ratio between different units of pressure

Table 1.2

Units	Pa	bar	kg·k / cm ²	m m mercury above	mm water u s t
1 Pa	1	10^{-5}	$1.02 \cdot 10^{-5}$	$7.5024 \cdot 10^{-3}$	0.102
1 bar	10^5	1	1.02	$7.5024 \cdot 10^2$	$1.02 \cdot 10^4$
1 kg·F/cm ²	$9.8067 \cdot 10^4$	0.98067	1	735	10^4
1 mmmercury above	133	$1.33 \cdot 10^{-3}$	$1.36 \cdot 10^3$	1	13.6
1 mmwater u s t	9.8067	$9.8067 \cdot 10^{-5}$	10^{-4}	$7.35 \cdot 10^{-2}$	1

Many processes occur at pressures greater than atmospheric (barometric) pressure (steam pressure in a steam boiler). This pressure difference is called overpressure or manometric pressure.

The sum of manometric and atmospheric pressure is called absolute (absolute) pressure:

$$R_{abs} = R_{ort} + R_{atm} \quad (1.3)$$

Manometric or overpressure is equal to:

$$R_{ort} = R_{abs} - R_{atm} = \rho gh \quad (1.4)$$

If the gas pressure in a container is less than the atmospheric pressure ($R_{abs} < R_{atm}$),

$$R_{abs} = R_{atm} - R_{vak} \quad (1.5)$$

where R_{vak} is rarefaction, vacuum pressure.

Overpressure and vacuum pressure state parameters are not calculated, because they can have different values depending on the atmospheric pressure at the same absolute pressure. Therefore, only the absolute pressure is the basic state parameter of the substance.

3. **Comparative size.** Relative volume is a quantity equal to the ratio of the volume occupied by the body to its mass:

$$v = \frac{V}{m} \quad (1.6)$$

where V is the volume of the substance, m^3 ; m is the mass of the substance, kg.

The specific volume of a substance is measured in m^3/kg or cm^3/kg .

If $\rho = \frac{m}{V}$ we consider that the density of a substance is determined by the equation, then the specific volume:

$$v = \frac{1}{\rho} \quad (1.7)$$

So, the specific volume is the inverse of the density, i.e

$$\rho = \frac{1}{V}; \quad \rho \cdot V = 1 \quad (1.8)$$

Examples of issues related to the topic.

Issue 1 . 1 m^3 the mass of methane gas 0,7 kg is equal to Determine the volume and density of the comparison?

<p>Berilganlar: $V=1 m^3$ $m=0,7 kg$ <hr/> $v=?$ $\rho=?$</p>	
--	--

<p>Formula: $m = \rho \cdot V$ $v = \frac{1}{\rho}$</p>	
--	--

<p>Yechilishi: $\rho = \frac{m}{V} = \frac{0,7}{1} = 0,7 \frac{kg}{m^3}$ $v = \frac{1}{0,7} = 1.42 \frac{m^3}{kg}$</p>	
---	--

Answer: $\rho = 0,7 \frac{kg}{m^3}; v = 1.42 \frac{m^3}{kg}$.

2 . Air pressure 760 mm. to the column of mercury, if the partial pressure of nitrogen 598,2 mm is equal to the column of mercury, determine the partial pressure of oxygen in the air ?

Y e c h i s h :

partial pressure of oxygen is equal to:

$$P_{O_2} = P_{ar} - P_{N_2} = 760 - 598,2 = 161,8 \text{ mm. sim. he t .}$$

Issue 3. If the pressure of the air at 0 °C 770 mm is equal to according to the mercury barometer, express this pressure in *bars* and *Pa* ?

Everything:

1 bar = 760 mmsim. above knowing that

$$770 \text{ mmsim. above} = \frac{770}{760} = 1.027 \text{ bar} = 102\,641 \text{ Pa}$$

Issue 4. If the indicator of the manometer is $P = 305 \text{ mm.sim. above}$, the pressure through the barometer is equal to $P_{\text{bar}} = 745 \text{ mm. below}$, then determine the absolute pressure of the gas in the container?

Solution: The absolute absolute pressure in the vessel P_{mut} is higher than the barometric pressure, so it is equal to the sum of the manometric (excess) P_m and barometric P_b pressures:

$$P_{\text{mut}} = P_b + P_m = 1050 \text{ mm.sim.ust.} = 1,4 \cdot 10^5 \text{ N/M}^2 = 1,4 \text{ bar}$$

5 . If the manometer indicator $P = 1.3 \text{ bar}$ installed in the steam boiler, the atmospheric pressure according to the mercury barometer indicator at $t = 25^\circ \text{C}$ is equal to $P_{\text{atm}} = 680 \text{ mm.sim.ust. steam}$ ' determine the absolute pressure of the boiler?

Everything:

We determine the absolute pressure according to the following formula:

$$R_{\text{abs}} = R_{\text{ort}} + R_{\text{atm}}$$

Knowing that the atmospheric pressure at $t = 25^\circ \text{C}$, the indicator of the mercury barometer is equal to $P_{\text{atm}} = 680 \text{ mm.sim.ust.}$, we determine its pressure at 0°C :

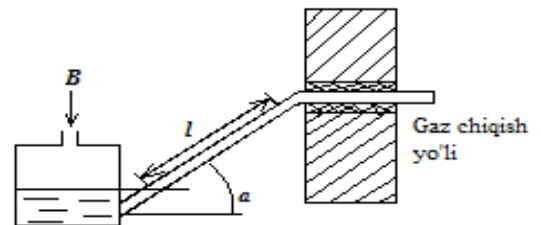
$$P_{\text{atm}} = 680 - \frac{4,31 \cdot 680}{1000} = 680 - 2,93 = 677,07 \text{ mm wire. above}$$

Absolute pressure of the steam boiler

$$P_{\text{abs}} = 1,3 + \frac{667,07}{750} = 1,3 + 0,9 = 2,2 \text{ bar}$$

Answer: $P_{\text{abs}} = 2,2 \text{ bar}$

6 . To measure rarefaction (vacuum) in the gas pipeline of a steam boiler, a thiagometer with an inclined tube is used (Fig. 1.1). The slope angle of the pipe $\alpha = 30^\circ$ is equal to The length of the water passage $l = 160 \text{ mm}$. If the mercury barometer reading is $P_{\text{atm}} = 740 \text{ mm.sim.ust}$ (at 0°C), determine the absolute pressure of the gas?



1.1-rasm

Everything:

We determine the absolute pressure in a vacuum according to the following formula:

$$R_{abs} = R_{atm} - R_{vak}$$

$$R_{vak} = rgh$$

$$\frac{h}{l} = \sin \alpha ; h = l \cdot \sin \alpha$$

$$P_{vak} = \rho gl \cdot \sin \alpha = 1000 \cdot 9,81 \cdot 160 \cdot 10^{-3} \cdot 0,5 = 784,8 Pa$$

$$1 Pa = 7,5 \cdot 10^{-3} \text{ mmsim. above}$$

$$P_{vak} = 784,8 \cdot 7,5 \cdot 10^{-3} = 5,88 \text{ mm wire. above}$$

So the absolute pressure in a vacuum is equal to:

$$R_{abs} = R_{atm} - R_{vak} = 740 - 5,88 = 734,1 \text{ mm wire.}$$

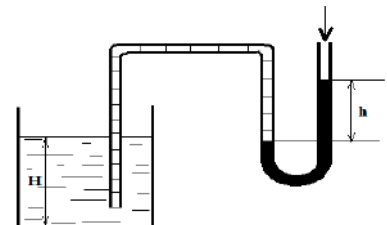
Answer: $R_{abs} = 734,1 \text{ mm wire}$

Issues for independent work.

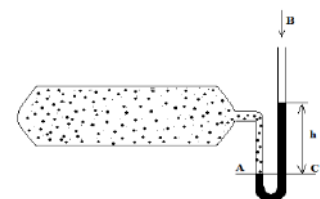
1. Water vapor Δ is heated to $t = 45 \text{ }^\circ\text{C}$. What is this temperature difference in Fahrenheit?

2. If the temperature of the steam in the steam boiler is $950 \text{ }^\circ\text{F}$, express it in $^\circ\text{C}$ (degrees Celsius)?

3. If the mercury manometer reading $P_{atm} = 500 \text{ is mm.sim.ust}$, and the mercury barometer 750 mm.sim.ust has risen to, determine the absolute pressure in the container?



4. To measure rarefaction (vacuum) in the gas pipeline of $\varepsilon 1,2$ -rasm er, a thiagometer with an inclined tube is used (Fig. 1.1). Alcohol was used as a liquid, its density $r = 800 \text{ kg/m}^3$. The slope angle of the pipe $\alpha = 30^\circ$ is, the length of the corridor is $l = 200 \text{ mm}$. If the mercury barometer reading is $P_{atm} = 745 \text{ mm}$ (at $0 \text{ }^\circ\text{C}$), determine the absolute pressure of the gas?



5. Gasoline in a U-shaped container

$P = 220 \text{ mmsim.under pressure}$, density $r = 840 \text{ kg/m}^3$ is equal to. Find the height of the liquid inside the tube?

1.3-rasm

SUBJECT 2. IDEAL GAS MIXTURES.

is known that the working body often consists of a mixture of several gases (components). For example, in internal combustion engines, combustion products, which include hydrogen, carbon dioxide, nitrogen, carbon dioxide, and water vapor, are the working medium. The pressures of gas mixtures are equal to the sum of the partial pressures of individual components (Dalton's law):

$$P_n = \sum P_k \quad (3.1)$$

where P_n — pressure of gas mixture; P_k is the partial pressure of the k -th component in the mixture.

If a mixture with mass M consists of n components, then the mass fractions of some components in the mixture are equal to :

$$g_1 = \frac{m_1}{m_a}; \quad g_2 = \frac{m_2}{m_a}; \quad g_n = \frac{m_n}{m_a} \quad (3.2)$$

Here $m_1, m_2, m_3, \dots, m_n$ — are the mass of individual gases; m_a — the mass of the gas mixture.

The sum of the masses of certain components in a mixture of gases is equal to the mass of the entire mixture:

$$m_1 + m_2 + m_3 + \dots + m_n = m_a \quad (3.3)$$

This equation is called the mass composition equation of the gas mixture. The equation for the relative mass composition of a mixture of gases is as follows:

$$g_1 + g_2 + g_3 + \dots + g_n = 1 \quad (3.4)$$

If a mixture of volume V consists of n components, then the volume fractions of some components in the mixture are equal to :

$$r_1 = \frac{V_1}{V_a}; \quad r_2 = \frac{V_2}{V_a}; \dots \quad r_n = \frac{V_n}{V_a} \quad (3.5)$$

Here $V_1, V_2, V_3, \dots, V_n$ — are the mass of individual gases; V_a — the mass of the gas mixture.

The equation for the volumetric composition of the mixture:

$$V_1 + V_2 + V_3 + \dots + V_n = V_a \quad (3.6)$$

The sum of the volume fractions of the gas mixture components is equal to:

$$r_1 + r_2 + r_3 + \dots + r_n = 1 \quad (3.7)$$

and this equation is called relative volume content equation.

The following relationships exist between mass and volume fractions:

$$r_i = \frac{g_i R_i}{R} \quad (3.8)$$

where: r_i is the volume fraction of the component;

g_i — mass fraction of the component;

R_i is the gas constant of the component;

R is the gas constant of the mixture.

$$r_i = \frac{\frac{m_i}{\mu_i}}{\sum_i^n \frac{m_i}{\mu_i}} \quad (3.9)$$

The density of a gas mixture is the inverse of its specific volume:

$$\rho = \frac{1}{v} = \frac{1}{\sum \frac{m_i}{\rho_i}} \quad (3.10)$$

$$v = \frac{1}{\sum_1^n r_i \rho_i} \quad (3.11)$$

$$v = \sum_1^n \frac{m_i}{\rho_i} \quad (3.12)$$

$$\mu_{ar} = \frac{1}{\sum_{i=1}^n \frac{m_i}{\mu_i}} \quad (3.13)$$

$$R_{ar} = \sum_{i=1}^n g_i \cdot R_i \quad (3.14)$$

Examples of issues related to the topic.

Issue 1. The composition of flue gases is as follows: $CO_2 = 5 \text{ kg}$; $CO = 2 \text{ kg}$; $N_2 = 13 \text{ kg}$. Find the mass fractions of the components?

Everything:

The total mass of the mixture $m = 5 + 2 + 13 = 20 \text{ kg}$. Mass quantities of components :

$$g_{CO_2} = \frac{m_{CO_2}}{m} = \frac{5}{20} = 0,25$$

$$g_{CO} = \frac{m_{CO}}{m} = \frac{2}{20} = 0,1$$

$$g_{N_2} = \frac{m_{N_2}}{m} = \frac{13}{20} = 0,65$$

Issue 2. Mass composition of gas mixture is as follows: $H_2 = 8.4\%$, $CO_2 = 17\%$, $O_2 = 48\%$, $N_2 = 26.6\%$. His gas the constant , the idea molecular mass and volume shares be found

Everything:

1. Don't interfere gas constant the following from the formula we define :

$$R_{ar} = \sum_{i=1}^n g_i \cdot R_i$$

$$R_{ar} = g_{H_2} \cdot R_{H_2} + g_{CO_2} \cdot R_{CO_2} + g_{N_2} \cdot R_{H_2} + g_{O_2} \cdot R_{O_2} =$$

$$= 0,084 \frac{8314}{2} + 0,17 \frac{8314}{44} + 0,48 \frac{8314}{32} + 0,266 \frac{8314}{28} = 584,2 J / kg^{\circ}C$$

$$\mu_{H_2} = 2g / mol, \quad \mu_{CO_2} = 44g / mol, \quad \mu_{O_2} = 32g / mol, \quad \mu_{N_2} = 28g / mol$$

2. We determine the apparent molecular mass of the mixture from the following formula:

$$\mu_{ar} = \frac{1}{\sum_{i=1}^n \frac{g_i}{\mu_i}} = \frac{1}{\frac{g_{H_2}}{\mu_{H_2}} + \frac{g_{CO_2}}{\mu_{CO_2}} + \frac{g_{O_2}}{\mu_{O_2}} + \frac{g_{N_2}}{\mu_{N_2}}} = \frac{1}{\frac{0,084}{2} + \frac{0,17}{44} + \frac{0,84}{32} + \frac{0,266}{28}} = 14,3$$

3. We determine the volume fraction of the mixture from the following formula:

$$r_i = \frac{\frac{g_i}{\mu_i}}{\sum_{i=1}^n \frac{g_i}{\mu_i}}$$

$$r_{H_2} = \frac{\frac{0,084}{2}}{\frac{0,084}{2} + \frac{0,17}{44} + \frac{0,48}{32} + \frac{0,266}{28}} = 0,597$$

$$r_{CO_2} = \frac{\frac{0,17}{44}}{\frac{0,084}{2} + \frac{0,17}{44} + \frac{0,48}{32} + \frac{0,266}{28}} = 0,055$$

$$r_{O_2} = \frac{\frac{0,48}{32}}{\frac{0,084}{2} + \frac{0,17}{44} + \frac{0,48}{32} + \frac{0,266}{28}} = 0,213$$

$$r_{N_2} = \frac{\frac{0,266}{28}}{\frac{0,084}{2} + \frac{0,17}{44} + \frac{0,48}{32} + \frac{0,266}{28}} = 0,135$$

Issue 3. For the non-linear variation of the heat capacity depending on the temperature, under constant pressure, a mixture of $1 m^3$ gases $200^{\circ}C$ with the composition $g_{CO_2} = 0.145$, $g_{O_2} = 0.065$, $g_{N_2} = 79.0\%$ find the amount of heat needed to heat from to $1200^{\circ}C$

Solution:

The amount of heat required for heating is found from the following equation.

$$q_p = \sum_{i=1}^n C_p g_i t_2 - \sum_{i=1}^n C_p g_i \cdot t_1 = (C_{CO_2} g_{CO_2} + C_{O_2} \cdot g_{O_2} + C_{N_2} g_{N_2}) \cdot t_2 - (C_{CO_2} g_{CO_2} + C_{O_2} \cdot g_{O_2} + C_{N_2} g_{N_2}) \cdot t_1$$

If we add the values of heat capacities from tables 2-3-6 given in the appendix to this equation, the amount of heat needed will be found.

$$q_p = (2.2638 \cdot 0.145 + 1.5005 \cdot 0.065 + 1.4202 \cdot 0.79) \cdot 1200 - (1.7373 \cdot 0.145 + 1.3352 \cdot 0.065 + 1.3038 \cdot 0.79) \cdot 200 = 1582 \text{ kJ/m}^3$$

Issue 4 . Atmospheric pressure measured by the barometer at $t=25 \text{ }^\circ\text{C}$ is $P_b = 680 \text{ mm.sim.above}$. If the manometric pressure is equal to $P_m = 1.3 \text{ bar}$, determine the absolute pressure of the steam in the boiler?

Solution:

We write the expression for calculating the absolute pressure of the mixture according to Dalton's law.

$$P_{abs} = P_1 + P_2 + \dots + P_n$$

all pressure values to the *bar* unit.

According to Dalton's law

$$P_{abs} = P_b + P_m = 1,3 + 0,009 = 1,309 \text{ bar}$$

Issue 5. Atmospheric air has approximately the following composition: $g_{O_2} = 23.2\%$; $g_{N_2} = 76.8\%$ volume composition of air, its gas constant, molecular mass and the partial pressure of oxygen and nitrogen if the pressure of the air according to the barometer is $P_{atm} = 101325 \text{ Pa}$ (.sim.ust)?760 mm

Solution:

$$r_i = \frac{\frac{g_i}{\mu_i}}{\sum_{i=1}^n \frac{g_i}{\mu_i}} \text{ using the equation}$$

We determine the volume fraction:

$$r_{O_2} = \frac{\frac{g_{O_2}}{\mu_{O_2}}}{\frac{g_{O_2}}{\mu_{O_2}} + \frac{g_{N_2}}{\mu_{N_2}}} = \frac{\frac{23,2}{32}}{\frac{23,2}{32} + \frac{76,8}{28}} = 0,21;$$

$$r_{N_2} = \frac{\frac{g_{N_2}}{\mu_{N_2}}}{\frac{g_{O_2}}{\mu_{O_2}} + \frac{g_{N_2}}{\mu_{N_2}}} = \frac{\frac{76,8}{28,02}}{\frac{23,2}{32} + \frac{76,8}{28,02}} = 0,79;$$

The gas constant of air is defined as:

$$R_{ar} = \sum_1^n g_i R_i = g_{O_2} R_{O_2} + g_{N_2} R_{N_2} = 0,232 \cdot 260 + 0,768 \cdot 295 = 287 \text{ J/(kg} \cdot \text{K)}$$

The molecular mass of a compound is determined as follows:

$$\mu_{ar} = \sum_1^n r_i \mu_i = r_{O_2} \cdot \mu_{O_2} + r_{N_2} \mu_{N_2} = 0,21 \cdot 32 + 0,79 \cdot 28,02 = 28,9 \quad \text{yoki} \quad R_{ar} = \frac{8314}{\mu_{ar}}$$

$$\text{from the equation: } \mu_{ar} = \frac{8314}{R_{ar}} = \frac{8314}{287} = 28,9$$

We find the partial pressure from the following equation:

$$P_i = r_i \cdot P_n,$$

therefore: $P_{O_2} = r_{O_2} \cdot P_n = 0.21 \cdot 760 = 159.4 \text{ mm wire. above}$

$P_{N_2} = r_{N_2} \cdot P_n = 0.79 \cdot 760 = 600.6 \text{ mm wire. above}$

Issue 6. The mixture of gases consists of hydrogen and carbon monoxide. Mass fraction of hydrogen $g_{H_2} = 6.67\%$. Determine the gas constant of the mixture and its relative volume under normal conditions?

Solution: We use the following equation:

$$R_{ar} = \sum_1^n g_i R_i = g_1 R_1 + g_2 R_2 = 0,0667 \cdot 4124 + 0,9333 \cdot 296,8 = 552 \text{ J}/(\text{kg} \cdot \text{K})$$

$P \nu = RT$:

$$\nu = \frac{RT}{P} = \frac{552 \cdot 273}{\frac{760}{750} \cdot 10^5} = 1,49 \text{ m}^3 / \text{kg}$$

Issues for independent work

Issue 1. 1 m^3 dry air contains approximately $0,232 \text{ m}^3$ oxygen and $0,768 \text{ m}^3$ nitrogen. Determine the composition of air, its gas constant and partial pressures?

Issue 2. If the volumetric composition of the mixture is as follows: Determine the gas constant, specific volume and partial pressure of $H_2O = 6\%$, $CO = 1\%$, $CO_2 = 12\%$, $O_2 = 7\%$, $N_2 = 74\%$? Total pressure $P = 750 \text{ mm.cm.ust}$.

Issue 3. Atmospheric air has the following composition by mass:

$$g_{O_2} = 23,2\%; \quad g_{N_2} = 76,8\%;$$

If the air pressure on the manometer $P_{atm} = 760 \text{ mm.cm.ust}$ is equal to, determine the volume composition of air, gas constant, molecular mass, partial pressures of oxygen and nitrogen?

Issue 4. 1 m^3 air is made up of mostly $0,21 \text{ m}^3$ oxygen and $0,79 \text{ m}^3$ nitrogen. Calculate the mass composition of air, gas constant, partial pressure of oxygen and nitrogen?

Issue 5. The gas mixture consists of hydrogen and carbon monoxide. Mass fraction of hydrogen $g_{H_2} = 6,67\%$. Determine the gas constant and specific volume of the mixture under normal physical conditions?

Issue 6. The composition of the fuel combustion mixture (flue gases) is as follows: $r_{CO_2} = 12,2\%$; $r_{O_2} = 7,1\%$; $r_{CO} = 0,4\%$; $r_{N_2} = 80,3\%$. Determine the mass composition of the gases included in the mixture?

Issue 7. The volume composition of the generator gas is as follows: $H_2 = 7,0\%$; $CH_4 = 2,0\%$; $CO = 27,6\%$; $CO_2 = 4,8\%$; $N_2 = 58,6\%$. Determine the mass fraction, gas constant, density and partial pressure of the gases at a temperature of 15°C and a pressure of 0.1 MPa ?

Issue 8. If atmospheric air is composed of 21% oxygen and 79% nitrogen by volume, determine the average molecular weight of the air?

Issue 9. The mass composition of the mixture is as follows $CO_2 = 18\%$; $O_2 = 12\%$; $N_2 = 70\%$: N.sh. at temperature $t = 180^\circ C$, mass 8 kg and volume 4 m^3 to what pressure is required to compress the mixture?

**TOPIC 3. I Z O B A R, I Z O X O R, ISOTHERMIC PROCESSES,
ADIABATIC AND POLY TROPICAL PROCESSES .**

The purpose of analyzing thermodynamic processes is to determine the laws of change of the state parameters of the working body and to evaluate the characteristics of energy exchange.

For this purpose, the following is determined for each thermodynamic process:

1. The process equation is derived.
2. In the process, the relationship between the thermal parameters of the working body is determined.
3. It is the change in internal energy.
4. The thermodynamic work of the working body is determined.
5. The heat of the process is calculated.
6. Entropy and enthalpy change are calculated.

Therefore, by analyzing thermodynamic processes, all the thermal properties of the working body (p, v, T) and caloric ($\Delta u, c, q, \Delta S, \Delta h$) parameters are determined.

Isochoric process ($V=const$). In this case, the internal energy of the gas changed:

$$du = c_v dT \quad (3.1)$$

$$\text{or } U_2 - U_1 = du = C_v(T_2 - T_1) \quad (3.2)$$

The work done by the gas in the expansion is:

$$dl = PdV$$

$$\text{or } l = \int_1^2 PdV \quad (6.3)$$

Since $V=const$ $PdV=0$ and $l=0$.

Entropy change:

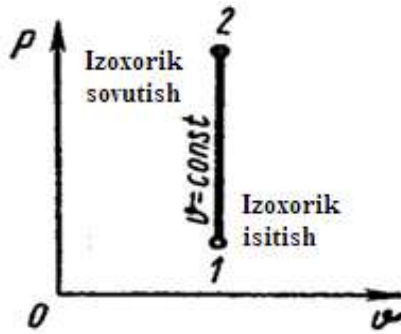
$$dS = dq/T \quad (3.4)$$

or $q = C_v(T_2 - T_1)$

$$dq = C_v dT; dS = \frac{dE}{T} = \frac{C_v dT}{T}; \int_1^2 dS = \int_1^2 C_v \frac{dT}{T};$$

$$S_2 - S_1 = \Delta S = C_v \ln \frac{T_2}{T_1} \quad (3.5)$$

The TS diagram of the isochoretic process is in the form of a logarithmic curve.



6. Figure 1 . Scheme of the isochoric process.

I. Isobaric process (P=const). Change in internal energy:

$$du = C_v dT$$

$$U_2 - U_1 = C_v (T_2 - T_1)$$

The work done by the gas

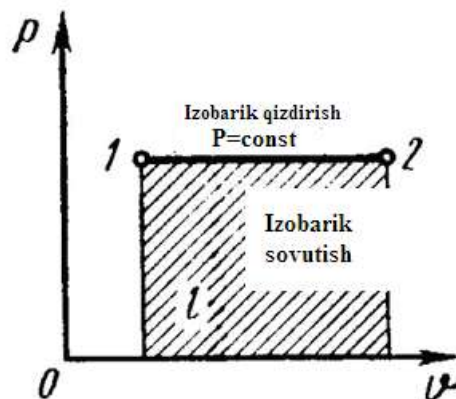
$$dl = p dv$$

$$l = p(V_2 - V_1) \quad (3.6)$$

entropy change:

$$ds = \frac{dq}{T} = \frac{C_p dT}{T} \quad (3.7)$$

$$S_2 - S_1 = \Delta S = C_p \ln \frac{T_2}{T_1} \quad (3.8)$$



5. Figure 2. Scheme of the isobaric process.

II. Isothermal process (T=const) .

Change in internal energy

$$dU = C_v dT,$$

Since $T = const$ $dT = 0$

y ok

$$He \text{ is } 2 - U_1 = 0$$

$$\text{energy change: } dS = \frac{dq}{T} = \frac{dl}{T} = \frac{pdV}{T} \quad (3.9)$$

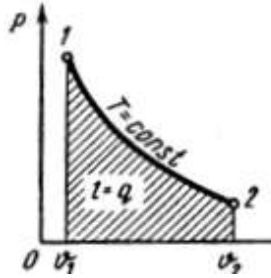


Figure 6.3. Scheme of an isothermal process.

Examples of issues related to the topic.

1st issue. $V=300l$ volume of carbon dioxide (CO_2) with initial parameters $P_1 = 6.8 \text{ MPa}$ and $t_1 = 12^\circ\text{C}$ is heated to $t_2 = 85^\circ\text{C}$?

Determine the subsequent pressure, mass, and heat input of the gas for isochoric and isobaric processes. Assume $c = \text{const}$.

Solution:

a) After gas pressure for an isochoric process.

$$P_2 T_1 = P_1 T_2;$$

$$P_2 = \frac{P_1 T_2}{T_1} = \frac{6,8 \cdot 358}{285} = 8,55 \text{ MPa}$$

We determine the mass of carbonate anhydride from the equation of state of ideal gases.

$$P_1 V_1 = mRT_1$$

$$m = \frac{P_1 V_1}{RT_1} = \frac{6,8 \cdot 10^6 \cdot 300 \cdot 10^{-3}}{189 \cdot 285} = 38 \text{ kg}$$

Amount of heat consumed

$$Q_v = mc_v(t_2 - t_1) = 38 \cdot 0.66(85 - 12) = 1834 \text{ kJ}$$

$$C_v = \frac{\mu C_v}{\mu} = \frac{29,31}{44} = 0,66 \text{ kJ/kg}^\circ\text{S}$$

b) For the isobaric process.

Since $P = \text{const}$ in this process

$$P_2 = P_1 = 6.8 \text{ MPa}$$

the amount of gas does not change either

$$M = 38 \text{ kg.}$$

Amount of heat consumed

$$Q_p = MC_p(t_2 - t_1) = 38 \cdot 0,86(85 - 12) = 2380 \text{ kJ}$$

$$c_p = \frac{\mu C_p}{\mu} = \frac{37,68}{44} = 0,86 \text{ kJ/kg}^\circ\text{S}$$

Issues for independent work.

Issue 1 . An ideal gas of volume $V_1 = 20$ l isothermally compressed until it reaches $V_2 = 15$ l. In this case, the pressure increased by 6 kPa . What was the initial pressure?

Issue 2 . The volume of the gas 6 l was reduced isothermally from 10 l to 4 l . If the initial pressure of the gas is 10 kPa , how much did the pressure increase as a result of the compression?

Issue 3. In an isothermal process, the initial gas pressure $P_1 = 10 \text{ bar}$ and specific volume $V_1 = 0,08 \text{ m}^3/\text{kg}$, construct the isotherm line and determine the remaining parameters?

Issue 4. 6 m^3 air is heated at a constant pressure from $P_1 = 1,3 \text{ bar}$ and $t_1 = 25^\circ\text{C}$ to $t_2 = 130^\circ\text{C}$. Calculate the heat transferred to the air assuming $C = \text{const}$?

Issue 5. The initial pressure of the gas is $P_1 = 10 \text{ bar}$ and temperature $t_1 = 25^\circ\text{C}$. When the gas is heated to $t_2 = 300^\circ\text{C}$ in a constant volume, determine the pressure?

Issue 6. Pressure $P_1 = 2 \text{ bar}$ and volume 2 m^3 . How much heat is consumed when the air is heated from $t_1 = 100^\circ\text{C}$ to $t_2 = 500^\circ\text{C}$ and the work done when the gas expands? Atmospheric pressure 760 mmHg should be considered equal to ?

Adiabatic and polytropic processes.

1. Adiabatic process. In this process, heat is not exchanged with the environment, that is, $q=0$. All rapid processes are conditionally considered as adiabatic processes.

Process equation: $PV^k = \text{const}$, where $K = C_p / C_v$ i.e. K is the adiabatic exponent.

Internal energy change: $q = du + pdV$, where $q = 0$ so $du + pdV = 0$, $du = -pdV$.
 Entropy change: $D S = 0$.

In an adiabatic process, the entropy is constant, or it is called an isentropic process.

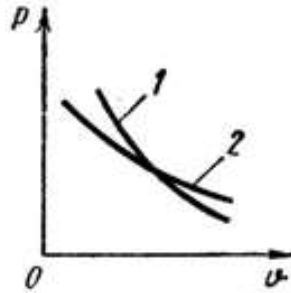


Figure 5.1. Scheme of the adiabatic process.

2. Polytronic process ($PV^n = \text{const}$). Other considered processes are special cases of the polytropic process. For example: at $n=0$, a polytropic process becomes an isobaric process, at $n = \infty$ an isochoric process, at $n=1$ it is isothermal, and at $n=K$ it becomes an adiabatic process.

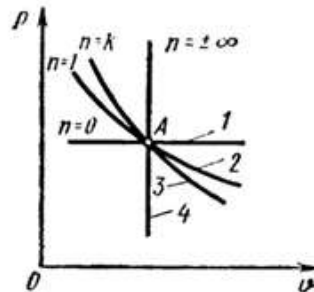


Figure 5.2. Scheme of the polytropic process.

1st isobar, 2nd isotherm, 3rd adiabata, 4th isochore

Examples of issues related to the topic.

Issue 1. Temperature $t = 24^\circ\text{C}$ mass 1 kg of air in polytropic process due to change of state pressure $P_2 = 2.4 \text{ MPa}$ and change of internal energy $\Delta U = 30$ is equal to kJ . $L = -52 \text{ kJ/kg}$ of work was spent.

Determine the polytropic indicator for this process, the previous and subsequent parameters of air entropy and enthalpy change?

Everything:

From the internal energy change equation

$$DU = C_v(T_2 - T_1)$$

We find the temperature of the air at the end of the process.

$$T_2 = \frac{\Delta U}{C_v} + T_1 = \frac{30}{0,72} + 297 = 339 \text{ K}$$

here

$$C_v = \frac{\mu C_v}{\mu} = \frac{20,93}{29} = 0,72 \text{ kJ/kg}^\circ\text{S}$$

$$m C_v = 20,93 \text{ [appendix, table - 2]}$$

From the work equation

$$L = \frac{R}{n-1}(T_1 - T_2)$$

We define a polytropic pointer.

$$n = \frac{R}{L}(T_1 - T_2) + 1 = \frac{287}{-52}(297 - 339) + 1 = 1,23$$

here

$$R = \frac{8314}{\mu} = \frac{8314}{29} = 287 \text{ J/kg}^\circ\text{S} = 0,287 \text{ kJ/kg}^\circ\text{S}$$

We find the previous air pressure from the following equation.

$$\left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}} = \frac{P_2}{P_1}$$

$$P_1 = \frac{P_2}{\left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}}} = \frac{2,4}{\left(\frac{339}{297}\right)^{\frac{1,23}{1,23-1}}} = 1,2 \text{ MPa}$$

Previous specific volume of air

$$V_1 = \frac{RT_1}{P_1} = \frac{287 \cdot 297}{1,2 \cdot 10^6} = 0,081 \text{ m}^3/\text{kg}$$

Next size comparison

$$V_2 = \frac{RT_2}{P_2} = \frac{287 \cdot 339}{2,4 \cdot 10^6} = 0,0411 \text{ m}^3/\text{kg}$$

Entropy change in a polytropic process;

$$\Delta S = C_v \frac{n-k}{n-1} \ln \frac{T_2}{T_1} = 0,72 \frac{1,23-1,4}{1,23-1} \ln \frac{339}{297} = -0,07 \text{ kJ/kg}^\circ\text{S}$$

Enthalpy change

$$\Delta h = C_p (T_2 - T_1) = 1,01(339 - 297) = 42,5 \text{ kJ/kg}$$

here

$$C_p = \frac{\mu C_p}{\mu} = \frac{29,31}{29} = 1,01 \text{ kJ/kg} \cdot \text{S}$$

$$m c_p = 29,31 \text{ [appendix, table - 2]}$$

Issue 2. Hydrogen with mass $M=115 \text{ kg}$, initial parameters $P_1=3.7 \text{ MPa}$ and $t_2=50^\circ\text{C}$ expanded to $P_2=0.25 \text{ MPa}$. Determine the final parameters, amount of heat, work done and change in internal energy of hydrogen for isothermal and adiabatic expansion processes?

Everything:

a) For an isothermal process

Since $T=\text{const}$ in this process

$$T_2 = t_1 = 50^\circ\text{C}$$

We determine the next volume of hydrogen from the equation of state of an ideal gas.

$$V_2 = \frac{MRT_2}{P_2} = \frac{115 \cdot 4157 \cdot 323}{0,25 \cdot 10^6} = 617 \text{ m}^3$$

The amount of heat used to heat hydrogen

$$Q = MRT_2 \cdot \ln \frac{P_1}{P_2} = 115 \cdot 4157 \cdot 323 \ln \frac{3,7}{0,25} = 42,7 \cdot 10^7 \text{ j} = 424 \text{ MJ}$$

Work done

$$L=Q=424 \text{ MJ}$$

Change in internal energy as $T_1=T_2$ in an isothermal process

$$\Delta U = C_v (T_2 - T_1) = 0$$

b) For an adiabatic process

The subsequent temperature of hydrogen

$$T_2 = \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}} = 323 \left(\frac{0,25}{3,7} \right)^{\frac{1,4-1}{1,4}} = 150 \text{ K}$$

Size $V_2 = \frac{MRT_2}{P_2} = \frac{115 \cdot 4157 \cdot 150}{0,25 \cdot 10^6} = 287 \text{ m}^3$

$Q=0$ in an adiabatic process

Change in internal energy

$$\Delta U = -L = -\frac{MR}{k-1}(T_1 - T_2) = \frac{115 \cdot 4157}{1,4-1}(323 - 159) = -20,8 \cdot 10^7 J = -208MJ$$

Issues for independent work.

Issue 1. Temperature $t=45^\circ C$ mass 1 kg of air due to change of state in polytropic process, pressure $P_2=4.2\text{ MPa}$ and change of internal energy $\Delta U = 45$ is equal to kJ . $L = -32\text{ kJ/kg}$ of work was spent.

Determine the polytropic indicator for this process, the previous and subsequent parameters of air entropy and enthalpy change?

Issue 2. Hydrogen with mass $M=95\text{ kg}$, initial parameters $P_1=3.7\text{ MPa}$ and $t_1=55^\circ C$ expanded to $P_2=0.35\text{ MPa}$. Determine the final parameters, amount of heat, work done and change in internal energy of hydrogen for isothermal and adiabatic expansion processes?

Issue 3. 1 kg initial temperature of air is $t_1=30^\circ C$ and pressure is $P_1=1\text{ bar}$. When air is isothermally compressed, its pressure is equal to $P_2=10\text{ bar}$. Calculate the final volume of the air, the work done in the compression, and the heat gained from the gas?

Issue 4. Air with mass 1 kg has an initial temperature of $t_1=15^\circ C$ and a pressure of $P_1=1\text{ bar}$. If $P_2=8\text{ bar}$ when air is compressed adiabatically, Determine the volume, temperature, and work done in the compression of the air after it is compressed?

SUBJECT 4 . CIRCULAR PROCESSES. CARNOT CYCLE.

More information . _

It is known that the state of the body, which is characterized by pressure and volume, is represented by a point on the PV-diagram. In such a diagram, a change in the state of a body is represented by a thermodynamic process curve. A series of successive processes in which the body undergoes several changes and returns to its initial state is called a circular process, in other words, a cycle.

The calculation of modern heat engines is based on ideal circulation processes, i.e. ideal cycles, in which heat is converted into mechanical work. It is necessary to study the ideal cycles to evaluate the perfection of the actual thermal processes that occur in real engines.

Among all the ideal cycles, logically and meaningfully simple is the Carnot cycle. This cycle was discovered in 1824 by French naval officer, engineer-scientist Carnot-Nicolas Léonard Sadi in his book "Observations on the Motive Power of Fire" as a result of correctly solving the problem of the exchange of heat and work. was discovered.

The Carnot cycle is a reversible cycle. It mainly consists of 4 processes , i.e. 2 isothermal and 2 adiabatic processes.

Let us assume that the system (ideal gas) is placed in a perfectly heat-insulating cylinder with walls and a piston. Depending on what process is going on at the bottom of the cylinder, the amount of q -heat from the external heater (heat source) is kept constant due to continuous supply. The process in the system takes place at constant ($T=const$) temperature. Amount of residual (unworked) heat q_2 is continuously removed from the system to the external environment-refrigerator. q_1 amount of heat is also transferred $V = const$. Therefore, its sign is positive, and the sign of q_2 is taken as negative.

When the state of the system changes slowly (when the gas expands or compresses), it is completely isolated from the external environment, that is, it must

be $dq=0$. If this condition is met , the process in the system will be adiabatic as we know (Fig . 8.1). a) PV diagram, b) TS diagram

Let's get acquainted with the processes of the Carnot cycle.

It is known that the parameters of the initial state of the system P_1, V_1, T_1 , are determined by the n 1-point.

The first process is isothermal expansion.

The bottom of the cylinder is in thermal contact with the heat source. The system receives q_1 heat and performs isothermal work on line 1-2. At point 2, the heat source is isolated from the cylinder and the system is thermally insulated. (The bottom of the cylinder is covered with an ideal thermal insulation material) .

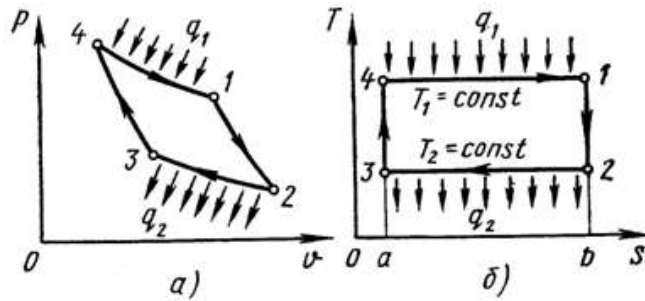


Figure 4.1. Reverse Carnot cycle. p,v- (a) and T,-s- (b) diagram

The second process is adiabatic expansion.

The gas expands along 2-3 lines without exchanging heat with the external environment, the piston moves, and the gas does work at the expense of its internal energy. In this, the temperature and pressure decrease. The temperature of the system is equal to the temperature of the coolant T_2 , the temperature of the piston stops at point 3. After that, the cylinder is brought into thermal contact with the coolant and the third process begins.

The third subregion is isothermal compression.

The piston slowly returns to its original position, so that the gas transfers heat at the refrigerant temperature. It works on external forces. Its volume decreases, its temperature does not change, and the process increases. At point 4, the system is thermally insulated.

The fourth condition is adiabatic compression.

The gas continues to be compressed by external forces, but there is no heat exchange. The volume of the gas decreases, its temperature and pressure increase. When the temperature T of the heat source reaches T_t , the compression process stops and the Kano cycle is closed.

Thus, in the diagram, the Carnot cycle is represented by a closed curve 1-2-3-4-1. In this case, numerically equal work L is performed on the surface bounded by this curve. (Fig. 8.1, a)

8.1 , b, TS of the Carnot cycle is numerically equal to the amount of heat converted into the useful work of the Carnot cycle. In both diagrams, the surfaces are equal to each other.

The coefficient of thermal useful work of the Carnot cycle is found from this formula.

$$\eta = \frac{T_1 - T_2}{T_1} \text{ or } \eta = \frac{Q_1 - Q_2}{Q_1} \quad (4.1)$$

$$A = Q_1 - Q_2 \quad \eta = \frac{A}{Q_1} \quad (4.2)$$

Summary.

1) Carnot cycle thermal factor does not depend on the properties of this body, but is determined only by the value of absolute T_1 and T_2 (Carnot's theorem);

2) The value of the Carnot cycle's thermal function increases as T_1 increases and decreases to T_2 ;

3) The thermal factor of the Carnot cycle is always less than one, because it could be equal to one only when $T_1 = 0$ or, even in an ideal cycle, such a temperature cannot be created. $T_2 = \infty$

Examples of issues related to the topic.

Issue 1. If the temperature of the refrigerator is t_2 , and the temperature of the heat source is given, determine the thermal efficiency of the Carnot cycle ? The temperature of the refrigerator $t_2 = 23^\circ C$, the temperature of the heat source $t_1 = 367^\circ C$

Solution:

The coefficient of thermal (heat) useful work of the Carnot cycle is determined from the following formula.

$$\eta = \frac{T_1 - T_2}{T_1}$$

where T_2 is the temperature of the cooler; T_1 is the temperature of the heat source.

We define absolute temperatures:

$$T_2 = 273 + t_2 = 273 + 23 = 296$$

$$T_1 = 273 + t_1 = 273 + 367 = 640$$

$$\eta = \frac{296}{640} = 0,537$$

Issue 2. If the temperature of the cooler is $t_2 = 27^\circ\text{C}$, and the temperature of the heat source is $T_1 = 327^\circ\text{C}$, determine the thermal FIK of the Carnot cycle?

Solution:

It is known that the coefficient of thermal useful work of the Carnot cycle is found from the following formula:

$$\eta = \frac{T_1 - T_2}{T_1}$$

$$T_2 = 273 + t_2 = 273 + 27 = 300$$

$$T_1 = 273 + t_1 = 273 + 327 = 600$$

$$\eta = 1 - \frac{300}{600} = 0,5$$

Issues for independent work.

Issue 1. During an ideal cycle, the heat engine received 100 J of heat from the heater and gave 60 J of heat to the cooler. Find the FIK of the car?

Issue 2. 1 kg air creates the Carnot cycle. In this case, $t_1 = 627^\circ\text{C}$, $t_2 = 27^\circ\text{C}$. The highest pressure in the cycle is 60 bar, the lowest pressure is 1 bar. Determine the parameters, work, thermal FIK and heats (q_1 , q_2) at the characteristic points of the cycle?

Issue 3. 1 kg Air forms the Carnot cycle in the temperature interval $t_1 = 327^\circ\text{C}$ and $t_2 = 27^\circ\text{C}$. The highest pressure in the cycle is 20 bar, the lowest pressure is 1.2

bar. Determine the parameters of the characteristic points of the cycle, the work, the thermal FIK and the heat supplied to the cycle?

Circular processes.

and expresses the quantitative relationship between the amount of heat, internal energy and mechanical work. The first law does not say anything about the direction of heat processes and the limits of the conversion of heat into work in heat engines.

In 1824, French engineer Sadi Carnot revealed the essence of the second law of thermodynamics, the law that shows the direction of heat processes. There are many definitions of the second law of thermodynamics, the main ones are as follows.

I. To convert heat into mechanical work, there must be a heat source and a cooler whose temperature is lower than the temperature of the heat source, that is, there must be a temperature difference.

II. Not all of the heat supplied to the engine can be completely converted into work, and some of this heat is transferred to the outside body at a lower temperature. (Thomson definition)

III. Heat cannot transfer from a cold body to a hot body without external work. (Definition of Clausius)

IV. A perpetual motion machine of the second type, which operates periodically, cannot be created. (Ostwald definition)

V. Any process that occurs by itself is an irreversible process.

Cyclic thermodynamic processes or cycles.

of the pressure of the gas from r_1 to r_2 was determined as follows:

$$l_{\text{кенг}} = \int_{v_1}^{v_2} p dV \quad (4.1)$$

where V_1 and V_2 are gas volumes at the beginning and end points of the expansion process, respectively. *Repeating* the same process of expansion of the gas, *it is necessary to return* the gas to the initial state 1 with parameters P_1, V_1 , *that is, to compress the gas*. In this case, the gas goes through a circulation process (cycle).

External work must be spent to compress the gas. In compression spent the work

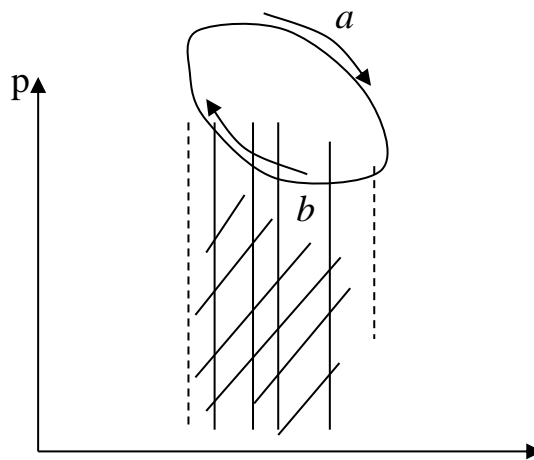
$$l_{cuk} = \int_{v_2}^{v_1} p dV$$

or

$$l_{cuk} = - \int_{v_1}^{v_2} p dV$$

In order to obtain useful work in the cycle, the work done in expansion must always be greater than the work of compression (Figure 9.1), i.e. $l_{kehg} > l_{siq}$. The useful work or cycle work obtained in a circular process is equal to:

$$L_{ts} = l_{kehg} - l_{siq}.$$



4.2-rasm

Cycles in which positive work is obtained are called right cycles or heat engine cycles, and the direction in the $p-v$ diagram is clockwise.

A cycle in which work is expended, i.e. the work of compression is greater than the work of expansion, is called the reverse cycle or the cycle of the refrigeration machine. Cycles can be reversible or irreversible. A cycle consisting of balanced feedback processes is reversible, otherwise it is called an irreversible cycle.

For the continuous operation of engines that convert heat into mechanical work, there must be a cooler that takes heat Q_2 from the working medium (gas). Then

$Q = Q_1 - Q_2$ it will be possible to convert heat into work.

It is necessary to try to convert as much heat as possible into work. According to the first law of thermodynamics:

$$Q_1 - Q_2 = \Delta U + L$$

In a cyclic process, $\Delta U = 0$, then

$$Q_1 - Q_2 = L$$

Q_1 given to the working body during the implementation of this cycle is called the thermal useful work coefficient (FIK) of the cycle. Thermal FIK is denoted by η_t and is defined as follows:

$$\eta_t = \frac{L}{Q_1} = \frac{Q_1 - Q_2}{Q_1} \quad (4.2)$$

or

$$\eta_t = 1 - \frac{Q_2}{Q_1} \quad (4.3)$$

1 kg for the working body:

$$\eta_t = \frac{l}{q_1} = \frac{q_1 - q_2}{q_1} \quad \eta_t = 1 - \frac{q_2}{q_1}$$

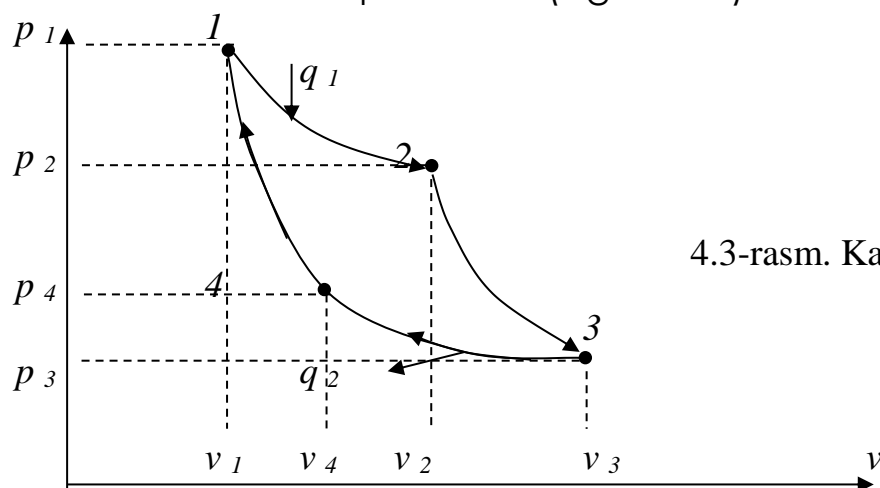
It is known that always $\eta_t < 1$. The greater the value of η_t , the more part of the heat given to the working body is converted into useful work, and the cycle is more perfect.

Carnot cycle (periodicity). Calculation of the cooling coefficient.

Carnot's theorem.

Among all ideal cycles, the cycle proposed by the French scientist Sadi Carnot in 1824 and named after him - the Carnot cycle is the most perfect cycle.

The Carnot cycle is a reversible cycle. It consists of four processes: 2 isothermal and 2 adiabatic processes (Figure 4.3).



4.3-rasm. Karno sikli

The Carnot cycle is illustrated in *the* $r - v$ diagram. We explain the processes that take place in this cycle in the following order:

The initial state of the system is determined by point 1 and the parameters are r_1 , v_1 and T_1 .

1 – 2 isothermal expansion . In this case, the bottom of the cylinder is connected to the heat source. The system receives heat q_1 and expands along the line 1 - 2. At point 2, the system is disconnected from heat.

2-3 adiabatic expansion . The gas expands along 2-3 lines without exchanging heat with the external environment, the piston moves, and the gas does work based on its internal energy. In this case, the temperature and pressure will decrease. When the temperature of the system reaches T_2 , the movement of the piston stops at point 3. After that, the cylinder begins to give q_2 heat to the cooler.

3-4 isothermal compression . The piston returns to its initial position so slowly that the gas remains at coolant temperature. In this case, external forces do work on the gas. Its volume decreases, its pressure increases, and its temperature remains unchanged. Heat extraction q_2 from the working body stops at point 4.

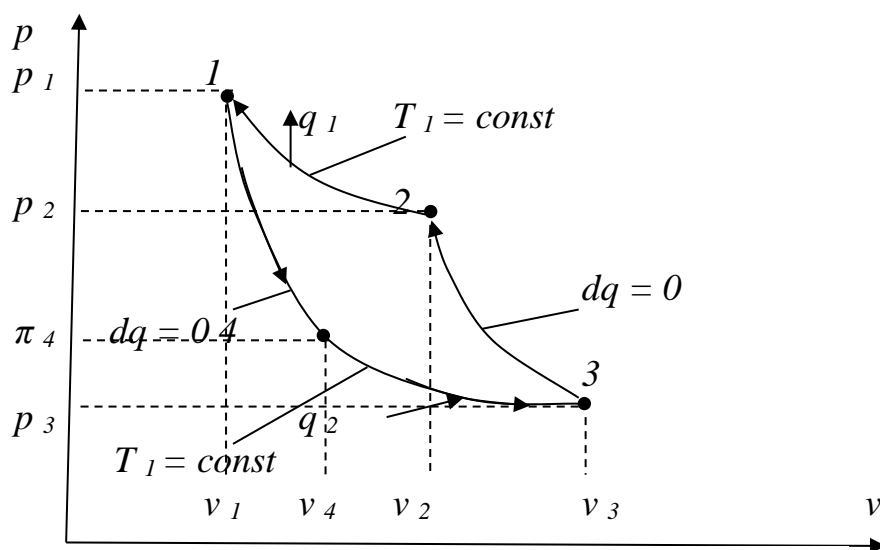
4 – 1 adiabatic compression . The gas continues to be compressed by external forces, but heat exchange does not occur. The volume of the gas decreases, its temperature and pressure increase. Compression stops when the temperature of the heater reaches T_1 .

The thermal FIK of the Carnot cycle is determined using the following formula:

$$\eta_t = \frac{T_1 - T_2}{T_1} = 1 - \frac{T_2}{T_1} \quad (4.3)$$

can occur not only in the forward direction, but also in the reverse direction .

In Figure 4.4, the reversed Carnot cycle is depicted in the $p - v$ diagram.



4.4-rasm. Teskari Karno sikli

The reverse Carnot cycle also results from feedback processes. The working body expands from its initial position by 1-4 adiabats. There is no heat exchange with the environment. The temperature of the working body decreases from T_1 to T_2 . Then the working body begins to expand along the 4 – 3 isotherm and T_2 receives q_2 heat from the heated environment. According to 3 – 2, adiabatic compression of the gas takes place and its temperature increases from T_2 to T_1 . In the isothermal process 2 – 1, heat q_1 is transferred from the gas to the high-temperature environment T_1 .

In the considered reverse cycle, the work done in compression is greater than the work done in expansion by the amount of work equal to 14321 closed area surface. This cycle work is converted into heat and q_2 together with heat is supplied to the heat source at temperature T_1 . Thus, it is possible to transfer heat q_2 from a cold body to a hot body by spending l work in the reverse cycle. In this case, the heat received by the heat source is equal to $q_1 = q_2 + l$.

A machine that works on the reverse cycle is called a refrigeration machine.

Therefore, it is necessary to spend energy to create the reverse cycle or the cooling cycle. The cooling coefficient is used to evaluate the performance of the refrigerator.

$$\varepsilon = \frac{q_2}{q_1 - q_2} = \frac{q_2}{l} \quad (4.4)$$

or

$$\varepsilon = \frac{T_2}{T_1 - T_2} \quad (4.5)$$

Carnot's theorem: The thermal FIK of the Carnot cycle does not depend on the properties of the working body, but only on the temperatures of the heaters and coolers.

Examples of issues related to the topic.

1 . Maximum pressure in the Carnot cycle $P_1 = 40 \text{ kg} \cdot \text{c} / \text{sm}^2$; $t_1 = 400^\circ \text{C}$; $t_2 = 27^\circ \text{C}$; $P_3 = 1 \text{ kg} \cdot \text{c} / \text{cm}^2$ The working substance is nitrogen. Calculate the parameters of the working body at the characteristic points of the cycle and the thermal FIK of the cycle ?

Solution: We calculate the comparison volume at point 1.

$$V_1 = \frac{RT_1}{P_1} = \frac{848 \cdot 637,15}{28 \cdot 40 \cdot 10^4} = 0,05 \quad m^3 / kg \cdot c$$

Comparison volume in 3 points:

$$\frac{V_2}{V_3} = \left(\frac{T_2}{T_1} \right)^{\frac{1}{k-1}} \text{ from the formula}$$

$$V_2 = 0,117 m^3 / kg \cdot c$$

We calculate the pressure at 2 points:

$$P_2 = \frac{PT_1}{V_2} = 17,4 kg \cdot c / cm^2$$

4 – 1 from the adiabatic equation;

$$P_4 = P_1 \left(\frac{T_2}{T_1} \right)^{\frac{k}{k-1}} = 40 \cdot 0,445^{3,5}$$

$$\eta_t = \frac{T_1 - T_2}{T_1} = \frac{673 - 300}{637} = 0,554 \quad (55,4\%)$$

Issues for independent work.

Issue 2. 250 kJ of heat was given to the gas in the circulation process . If the thermal FIK of the cycle is 0.46 , calculate the work done?

Issue 3. Calculate the FIK of the cycle if 80 kJ of useful work is obtained in the cycle, and 50 kJ of heat is given to the refrigerant?

Issue 4. Mass 1 kg forms a Carnot cycle between water vapor $t_1 = 540^0 C$ and temperatures. $t_2 = 30^0 C$ The greatest pressure created in the cycle is 100 bar . The minimum pressure is 10 bar . Determine the work done and the FIK of the thermodynamic parameters of the air at the characteristic points of the cycle?

SUBJECT 5. INTERNAL COMBUSTION ENGINE CYCLES.

Theoretical information.

All modern piston internal combustion engines can be divided into the following three groups:

- 1) fuel that burns at a constant volume;
- 2) fuel that burns at constant pressure;
- 3) mixed fuel: constant volume and constant pressure.

Let us consider an ideal thermodynamic cycle in which heat is supplied under $v = \text{const}$ conditions, consisting of two isochores and two adiabats. 1-2-3-4 and 1-4-5-6. PV and Ts diagrams of this cycle are shown in the 2nd pictures.

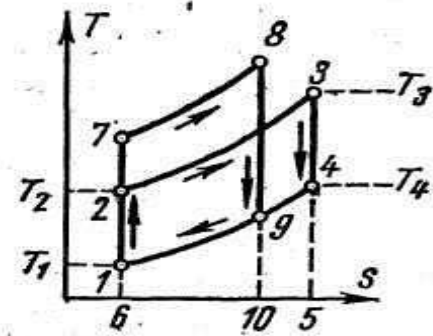
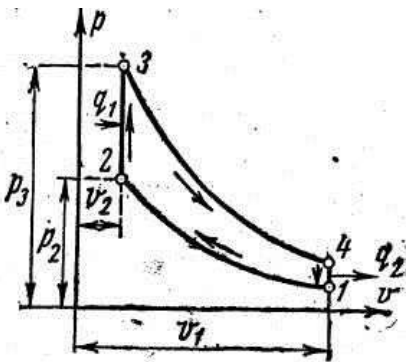


Figure 5.1 Figure 5.2

In the thermodynamic study of ideal cycles of internal combustion engines with pistons, the following quantities are determined: the amount of heat supplied and removed to the cycle; the main parameters of the working body at the characteristic points of the cycle; cycle thermal efficiency. The quantities describing the cycle of any internal combustion engine are:

Compression level:

$$\varepsilon = v_1 / v_2 \quad (5.1)$$

this quantity represents the ratio of the initial specific volume of the working body to the specific volume at the end of compression;

The degree of pressure increase:

$$\lambda = p_3 / p_2 \quad (5.2)$$

this quantity shows the ratio of the initial and final pressures in the isochoric heat transfer process;

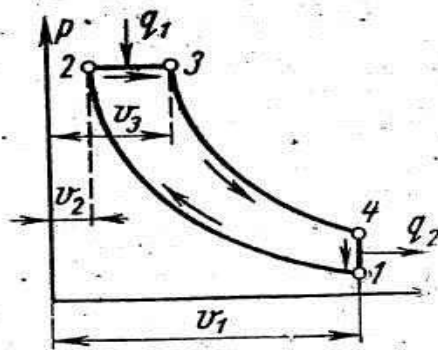
Initial expansion or isobaric expansion rate:

$$\rho = v_3 / v_2 \quad (5.3)$$

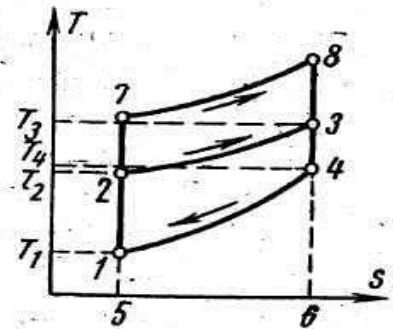
So, the thermal function of the cycle with constant volume of heat is as follows:

$$\eta_t = 1 - \frac{1}{\varepsilon^{k-1}} \quad (5.4)$$

Let's consider an ideal thermodynamic cycle in which heat is produced under $p=\text{const}$ conditions, consisting of two adiabats, one isobar and one isochore. Figures 5.3 and 5.4 show PV- and Ts -diagrams of such a cycle. Initial parameters P_1, V_1, T_1 , a gaseous body is compressed according to equation 1-2. Then q_1 amount of heat is transferred to it according to 2-3 isobars. The working body expands from point 3 to ratio 3-4.



5.3-rasm



5.4-rasm

q_2 is transferred to the environment.

The main characteristics of the cycle are as follows:

$$\text{compression ratio} - \varepsilon = \frac{v_1}{v_2}$$

(5.5)

$$\text{initial expansion rate} - \rho = \frac{v_3}{v_2} \quad (5.6)$$

Amount of heat supplied

$$q_1 = C_p(T_3 - T_2) \quad (5.7)$$

And the amount of heat removed

$$q_2 = C_p(T_4 - T_1) \quad (5.8)$$

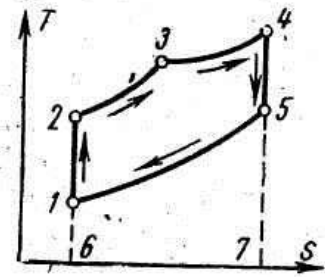
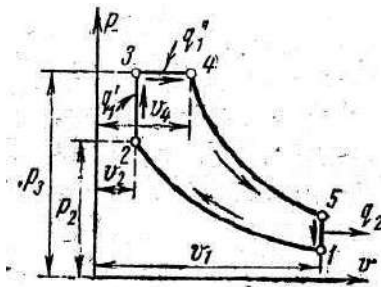
Work done by the cycle:

$$l_0 = q_1 - q_2 \quad (5.9)$$

Thermal FIC of the cycle:

$$\eta_t = 1 - \frac{1}{\varepsilon^{k-1}} \cdot \frac{\rho^{k-1}}{k(\rho-1)} \quad (5.10)$$

v=const and *p=const* heat is mixed under the conditions the given cycle consists of two adiabatas, two isochores and one isobaric line.



5 .Figure 5 5 . Figure 6

The main parameters describing the cycle are:

compression ratio - $\varepsilon = \frac{v_1}{v_2}$

degree of pressure increase - $\lambda = \frac{P_3}{P_2}$

initial expansion rate - $\rho = \frac{v_4}{v_3}$

Amount of heat supplied

$$q_1 = c_v(T_3 - T_2) + c_p(T_4 - T_3)$$

And the amount of heat removed

$$q_2 = c_v(T_5 - T_1)$$

Thermal FIC of the cycle:

$$\eta_t = 1 - \frac{1}{\varepsilon^{k-1}} \cdot \frac{\lambda \rho^k - 1}{\lambda - 1 + k\lambda(\rho - 1)} \quad (5.11)$$

Examples of issues related to the topic.

Issue 1. It is produced by heating at *V=const*. Determine the parameters of the internal combustion engine at the characteristic points for the ideal cycle, the useful

work done, the work supplied and extracted from the cycle and the thermal FIK? The following are given: $P_1 = 1\text{bar}$, $t_1 = 20^\circ\text{C}$, $\varepsilon = 3,6$, $\lambda = 3,33$, $K = 1,4$. The working body is air. Heat capacity is constant.

Solution:

1 kg we calculate for air.

Point 1.

$$v_1 = \frac{RT_1}{P_1} = \frac{287 \cdot 293}{1 \cdot 10^6} = 0,84\text{m}^3 / \text{kg}$$

Point 2: we determine the degree of compression

$$\varepsilon = \frac{v_1}{v_2} = 3,6$$

$$\text{from } v_2 = \frac{v_1}{\varepsilon} = \frac{0,84}{3,6} = 0,233\text{m}^3 / \text{kg}$$

temperature in adiabatic compression:

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1} = 293 \cdot 3,6^{0,4} = 489\text{K};$$

$$t_2 = 216^\circ\text{C}$$

pressure in adiabatic compression:

$$P_2 = \frac{RT_2}{v_2} = \frac{287 \cdot 489}{0,233 \cdot 10^5} = 6,02\text{bar}$$

Point 3: Comparative size $v_3 = v_2 = 0,233\text{m}^3 / \text{kg}$

Parameters in the isochoric process

$$\frac{P_3}{P_2} = \frac{T_3}{T_2} = \lambda = 3,33$$

Here:

$$P_3 = P_2 \cdot \lambda = 6,02 \cdot 3,33 = 20\text{bar}$$

$$T_3 = T_2 \lambda = 489 \cdot 3,33 = 1628^\circ\text{K}; \quad t_3 = 1355^\circ\text{C}$$

Point 4: Comparative size $v_4 = v_1 = 0,84\text{m}^3 / \text{kg}$

temperature in adiabatic expansion:

$$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{k-1} = \left(\frac{v_2}{v_1}\right)^{k-1} = 1628 \cdot \frac{1}{3,6^{0,4}} = 976^\circ K;$$

$$\frac{P_4}{P_1} = \frac{T_4}{T_1} = 1 \cdot \frac{976}{293} = 3,33bar$$

Heat from the cycle

$$q_1 = q_{2-3} = c_v(T_3 - T_2) = \frac{20,93}{28,96}(1628 - 489) = 825kJ/kg$$

Heat supplied to the cycle

$$q_2 = q_{4-1} = c_v(T_4 - T_1) = \frac{20,93}{28,96}(976 - 293) = 495kJ/kg$$

Thermal FIK of the cycle

$$\eta_t = 1 - \frac{q_2}{q_1} = \frac{825 - 495}{825} = 0,4 = 40\%$$

or

$$\eta_t = 1 - \frac{1}{\varepsilon^{k-1}} = 1 - \frac{1}{3,6^{0,4}} = 0,4 = 40\%$$

The work done by the cycle

$$l_0 = q_1 - q_2 = 330kJ/kg$$

Issues for independent work.

Issue 1. A reciprocating IYoD works with heat transfer at $V=\text{const}$. Determine the parameters of the internal combustion engine at the characteristic points for the ideal cycle, the useful work done, the work supplied and extracted from the cycle and the thermal FIK? The following are given: $P_1 = 1bar$, $t_1 = 100^\circ C$, $\varepsilon = 6$, $\lambda = 1,6$, $K = 1,4$. The working medium is air. Heat capacity is constant.

Answer: $v_1 = 1,07m^3/kg$; $v_2 = 0,178m^3/kg$; $T_2 = 761^\circ K$; $T_3 = 1217^\circ K$; $T_4 = 597^\circ K$;
 $P_3 = 19,6bar$; $P_4 = 1,56bar$; $q_1 = 329,7kJ/kg$; $q_2 = 162kJ/kg$; $\eta_t = 0,51$; $l_0 = 167,7kJ/kg$.

Issue 2. Calculate the thermodynamic parameters, useful work, heat input and output from the cycle and thermal FIK at characteristic points for the IYOD cycle operating with heat input at $P=const$? Given the following: $P_1 = 1bar$; $t_1 = 70^\circ C$; $\varepsilon = 12$; $k = 1,4$ $\rho = 1,67$. The working medium is air. Heat capacity is constant.

3 . Draw a graph of thermal FIK of IYOD operating with heat supplied at $P=const$ versus degree of expansion. Between 3.5 and 1.5 $\varepsilon = 16$; $k = 1,4$.

SUBJECT 6. HEAT CONDUCTIVITY OF FLAT WALL AND CYLINDRICAL WALL.

Theoretical information.

Thickness made of homogeneous material δ The temperatures on the outer surfaces of the flat single-layer wall are kept unchanged. The temperature changes only in *the X direction* , which is perpendicular to the wall surface . The figure shows the scheme of a flat single-layer wall.

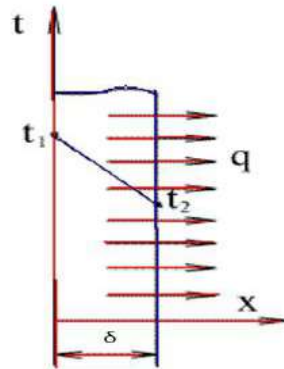


Figure 6.1. Scheme of a flat single-layer wall.

The Fure equation for the elementary layer is as follows.

$$q = -\lambda \frac{dt}{dx} \text{ from } dt = -\frac{q}{\lambda} dx \quad (6.1)$$

if we integrate, at $x=0$ it is equal to $t=t_1$

$$t = -\frac{q}{\lambda} x + C$$

or

$$t = -\frac{q}{\lambda} x + t_1 \quad \int_{t_1}^{t_2} dt = -\int_0^{\delta} \frac{q}{\lambda} dx \quad (6.2)$$

$$t_2 - t_1 = -\frac{q}{\lambda} \cdot \delta \quad q = \frac{t_1 - t_2}{\delta / \lambda} \quad (6.3)$$

$\frac{\delta}{\lambda}$ - thermal resistance of the wall,

$$Q = q \cdot F \cdot \tau = \frac{\lambda}{\delta} \cdot \Delta t \cdot F \cdot \tau \quad (6.4)$$

Examples of issues related to the topic.

Issue 1. Thickness $d = 50$ mm, thermal conductivity coefficient $\lambda = 40$ W/(m·°C), $\lambda = 1.1$ W/(m·°C), $\lambda = 0.11$ W/(m·°C) Determine the heat flux density lost through a single-layer (steel, concrete, diatomite brick) wall? Temperatures $t_1 = 100$ °C and $t_2 = 90$ °C

Everything:

We calculate the heat flux density.

$$q = \frac{Q}{F}$$

We write the formula for the amount of heat.

$$Q = \lambda \frac{F \Delta t}{\delta}$$

We put the amount of heat in the expression of the flux density and simplify.

$$q = \lambda \frac{\Delta t}{\delta}$$

We calculate the heat flux density separately for each wall material.

$$q_{pol} = \lambda \frac{\Delta t}{\delta} = \frac{40 \cdot 10}{5 \cdot 10^{-2}} = 0.8 \text{ Vt} / m^2$$

$$q_{bet} = \lambda \frac{\Delta t}{\delta} = \frac{1.1 \cdot 10}{5 \cdot 10^{-2}} = 0.022 \text{ Vt} / m^2$$

$$q_{dit} = \lambda \frac{\Delta t}{\delta} = \frac{0.11 \cdot 10}{5 \cdot 10^{-2}} = 0.0022 \text{ Vt} / m^2$$

Issues for independent work.

Issue 2. A red brick wall with a thickness of $d=250$ mm has a length of $l=5$ m and a height of $h=4$ is equal to m . The temperature of the inner surface of the wall is $t_1=110$ °C and the temperature of the outer surface is $t_2=40$ °C. Calculate the heat loss through the wall if the heat transfer coefficient of the red brick is $\lambda=0.70$ W/(m·°C). W/m²

Issue 3. $q=145$ W/m² when the temperature difference is $\Delta t=20$ °C through a wall with a thickness of $d =40$ mm equal heat loss. Determine the coefficient of thermal conductivity of the wall material?

Issue 4 . What is the heat flux through a brick wall of height 5 m, width, 4 mand thickness ? 250 mm Wall surface temperatures $t_{S1} = 27^0C$ and $t_{S2} = -23^0C$. The heat transfer coefficient of the brick is equal to $\lambda= 0.77 \frac{vt}{m.^0C}$.

Examples of issues related to the topic.

Issue 1. Thickness $d =50$ mm, thermal conductivity coefficient $l_1 =40$ W/(m·°C), $l_2=1.1$ W/(m·°C), $l_3=0.11$ W/(m· °C) determine the heat flux density lost

through a single-layer (steel, concrete, diatomite brick) wall? Temperatures $t_1=100$ °C and $t_2=90$ °C.

Everything:

We calculate the heat flux density:

$$q = \frac{Q}{F}$$

We write the formula for the amount of heat:

$$Q = \lambda \frac{F\Delta t}{\delta}$$

We put the amount of heat in the flux density expression and simplify:

$$q = \lambda \frac{\Delta t}{\delta}$$

We calculate the heat flux density separately for each wall material:

$$q_{pol} = \lambda \frac{\Delta t}{\delta} = \frac{40 \cdot 10}{5 \cdot 10^{-2}} = 0,8 \text{ Vt} / m^2$$

$$q_{bet} = \lambda \frac{\Delta t}{\delta} = \frac{1,1 \cdot 10}{5 \cdot 10^{-2}} = 0,022 \text{ Vt} / m^2$$

$$q_{dit} = \lambda \frac{\Delta t}{\delta} = \frac{0,11 \cdot 10}{5 \cdot 10^{-2}} = 0,0022 \text{ Vt} / m^2$$

Issue 2. An aluminum ball of thickness 180 mm is compressed on one side by a heater $t_{s1}=400$ °C and on the other side by a cooler $t_{s2}=10$ °C. If the heat flux $Q=176,8$ W, the heat transfer coefficient $l=204$ W/m·°C and there is no heat loss from the side surfaces, the thermal resistance, temperature gradient and cross-sectional surface of the pipe find

Solution:

Conditions for one-dimensionality:

- 1) flat, layer 1, δ ;
- 2) 1?
- 3) $\frac{\partial t}{\partial \tau}=0$; $q_v=0$;
- 4) $x=0$; $t=t_{c1}$
 $x = \delta$; $t=t_{c2}$.

- 1) Heat transfer: $q_s = \frac{\lambda}{\delta} (t_{c1} - t_{c2})$;

$$q = \frac{204}{0,18} (400-10) = 442 \cdot 10^3 \text{ W} / m^2 ;$$

- 2) Thermal resistance: $R = \frac{\delta}{\lambda}$;

$$R = \frac{0,18}{204} = 0,88 \cdot 10^{-3} \text{ m}^2 \cdot \text{K} / \text{W}$$

- 3) Temperature gradient:

$$\text{degree } t = \frac{q}{\lambda} = \frac{442000}{204} = 2166.7 \text{ K/m};$$

$$\text{degree } t = \frac{t_{c1} - t_{c2}}{\delta} = \frac{390}{0,18} = 2166.7 \text{ K/m};$$

4) Cross-sectional area: $F = \frac{Q}{q}$

$$F = \frac{176.8}{442000} = 0.4 \cdot 10^{-3} = 400 \text{ mm}^2$$

Issues for independent work.

Issue 1. A red brick wall with a thickness of $d = 250 \text{ mm}$ has a length of $l = 5 \text{ m}$ and a height of $h = 4 \text{ m}$. The temperature of the inner surface of the wall is $t_1 = 110^\circ\text{C}$ and the temperature of the outer surface is $t_2 = 40^\circ\text{C}$. Calculate the heat loss through the wall if the heat transfer coefficient of the red brick is equal to $\lambda = 0.70 \text{ W/m}\cdot^\circ\text{C}$?

Issue 2. $q = 145 \text{ W/m}^2$ when the temperature difference is $\Delta t = 20^\circ\text{C}$ through a wall with a thickness of $d = 40 \text{ mm}$ equal heat loss. Determine the coefficient of thermal conductivity of the wall material?

Issue 3. What is the heat flux through a brick wall of height 5 m , width, 4 m and thickness 250 mm Wall surface temperatures $t_{s1} = 27^\circ\text{C}$ and $t_{s2} = -23^\circ\text{C}$. The heat transfer coefficient of the brick is equal to $\lambda = 0.77 \frac{\text{Wt}}{\text{m}\cdot^\circ\text{C}}$.

Multi-layer flat wall heat transfer

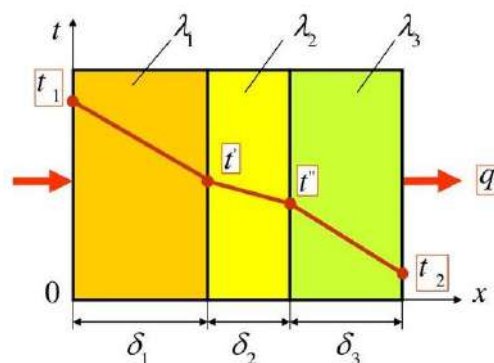
The walls of heat exchange devices, steam and hot water devices and other energy devices consist of layers made of different materials. We derive the thermal conductivity of a multi-layer flat wall using the formulas of the thermal conductivity of each layer for the stable mode. Let a flat wall operating in a three-layer stable thermal regime be given. For example, to solve, we introduce notation as follows.

δ_1, δ_2 and δ_3 - thickness of layers;

λ_1, λ_2 and λ_3 – thermal conductivity coefficients of materials of each layer;

t_1 and t_4 are the temperatures of the outer surfaces of the wall;

t_2 and t_3 are temperatures at the boundary of the layers (Fig. 6.2).



6.2 - picture. Thermal conductivity of a multilayer flat wall.

We determine the heat passing through each layer using the Fourier equation:

$$\begin{aligned} q &= \frac{\lambda_1}{\delta_1}(t_1 - t') \\ q &= \frac{\lambda_2}{\delta_2}(t' - t'') \\ q &= \frac{\lambda_3}{\delta_3}(t'' - t_2) \end{aligned} \quad (6.5)$$

or

$$\left. \begin{aligned} t_1 - t' &= q \frac{\delta_1}{\lambda_1} \\ t' - t'' &= q \frac{\delta_2}{\lambda_2} \\ t'' - t_2 &= q \frac{\delta_3}{\lambda_3} \end{aligned} \right\} \quad (6.6)$$

We add the equation (21.2) step by step:

$$t_1 - t_4 = \Delta t = q \left(\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3} \right) \quad (6.7)$$

From this

$$q = \frac{\Delta t}{\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}} \quad (6.8)$$

for n-layer:

$$q = \frac{\Delta t}{\sum_{i=1}^n \frac{\delta_i}{\lambda_i}} = \frac{\Delta t}{R} \quad (6.9)$$

R is called the complete thermal resistance of a multi-layer wall.

$$R = R_1 + R_2 + R_3 \dots + R_n = \sum_{i=1}^n \frac{\delta_i}{\lambda_i}; \quad (6.10)$$

The total heat flux is equal to:

$$Q = \frac{F \cdot \Delta t}{R} = \frac{F \cdot \Delta t}{\sum_{i=1}^n \frac{\delta_i}{\lambda_i}}; \quad (6.11)$$

In some cases, the equivalent heat transfer coefficient for a multilayer wall is calculated as for a homogeneous wall by entering:

$$\lambda_i = \frac{\sum_{i=1}^n \delta_i}{\sum_{i=1}^n \frac{\delta_i}{\lambda_i}} \quad (6.12)$$

λ Given i:

$$Q = \frac{\lambda_i F \cdot \Delta t}{\sum_{i=1}^n \delta_i} \quad (6.13)$$

Examples of issues related to the topic.

Issue 1. The thickness of the wall of the combustion chamber of the steam boiler (foam chamber) $\delta_1 = 125mm$ and the thickness of the red brick $\delta_2 = 500mm$. The temperature of the inner surface of the combustion chamber $t_{s1} = 1100^\circ C$, the temperature of the outer surface $t_{s3} = 50^\circ C$, $\lambda_1 = 0,28 + 0,000236t$, $\lambda_2 = 0,7Vt / m^\circ C$. If the thickness of the brick is reduced, diatomite compounds are placed between the layers, how will the temperature of the outer surface change and what will be the thickness of the inserted layer?

Solution:

$$t_{d3} = t_{d4} + q \frac{\delta_2}{\lambda_2} = 50 + 1090 \cdot \frac{0,25}{0,7} = 439^\circ C$$

Average heat transfer coefficient:

$$\lambda_{o'rt} = a + b \frac{t_{d3} + t_{d2}}{2} = 0,113 + 0,00023 \left(\frac{828 + 439}{2} \right) = 0,259Vt / m^\circ C$$

Inserted material layer thickness:

$$\delta = \frac{\Delta t_d}{q} \lambda_{o'rt} = \frac{828 - 439}{1090} \cdot 0,259 = 0,0936m; \delta = 94mm$$

Issues for independent work.

Issue 1. The plant is made of devoir building bricks, brick thickness $\delta_1 = 250mm$, thermal conductivity coefficient $\lambda_1 = 0,25Vt / m^\circ C$. The wall is covered from the outside with a layer of sand plaster thickness $\delta_2 = 20mm$ and heat transfer coefficient $\lambda_2 = 0,25Vt / m^\circ C$. On the inside, $\delta_2 = 60mm$ it is covered with a heat insulation plate with a thickness and a heat transfer coefficient $\lambda_3 = 0,018Vt / m^\circ C$. The temperature of the outer surface of the wall $-20^\circ C$ and the temperature of the inner surface $-20^\circ C$ are equal to. Calculate the heat flux through the wall?

Single-layer cylindrical wall thermal conductivity

The difference between a cylindrical wall and a flat wall is that in a cylindrical wall, the surface of the inner surface is always smaller than the surface of the outer surface. If the wall is thick, this difference will be big. The heat flow is directed

normal to the pipe surface. For the elemental surface of the wall, we apply the Fourier equation.

Assuming that the surface of the inner surface of the cylindrical wall is F and the length of the pipe is $F=2\pi r l$, the specific heat flow obtained for 1 meter of the pipe is q_1 we find .

$$q = -\lambda \frac{dt}{dx} 2\pi r \quad (6.14)$$

from this

$$dt = -\frac{qt}{2\pi\lambda} \frac{dr}{r}$$

q by integration .

$$q = \frac{\pi(t_1 - t_2)}{\frac{1}{2\lambda} \ln \frac{r_1}{r_2}} = \frac{\pi(t_1 - t_2)}{\frac{1}{2\lambda} \ln \frac{d_2}{d_1}} \quad (6.15)$$

q_1 - linear heat flux density.

$$R = \frac{1}{2\lambda} \ln \frac{d_2}{d_1} \quad (6.16)$$

R - linear thermal resistance.

the ratio of diameters is small $\frac{d_2}{d_1}$, formulas used for a flat wall can be used. $R_{e\lambda} = \frac{\delta}{\lambda}$

Issues for independent work.

Issue 1. The inner diameter of the steel pipe is 60 mm and the thickness is 5 mm. The coefficient of thermal conductivity of steel $\lambda = 50 \text{ Wt/m}^\circ\text{C}$ is equal to. If the temperature of the inner surface of the pipe $t_1 = 100^\circ\text{C}$ and the temperature of the outer surface $t_2 = 20^\circ\text{C}$ are equal to. Find the linear heat flux density lost from the pipe?

Issue 2. The inner diameter of the aluminum pipe is 100 mm and the thickness is 10 mm. The thermal conductivity coefficient of aluminum $\lambda = 250 \text{ Wt/m}^\circ\text{C}$ is equal to . If the temperature of the inner surface of the pipe $t_1 = 150^\circ\text{C}$ and the temperature of the outer surface $t_2 = 40^\circ\text{C}$ are equal to. Find the linear heat flux density lost from the pipe?

Issue 3. The internal diameter of the pipe made of reinforced concrete is 500 mm, and the thickness is 100 mm. The heat transfer coefficient of reinforced concrete $\lambda = 1,7 \text{ Wt/m}^\circ\text{C}$ is equal to. If the temperature of the inner surface of the pipe $t_1 = 80^\circ\text{C}$ and the temperature of the outer surface $t_2 = 15^\circ\text{C}$ are equal to. Find the linear heat flux density lost from the pipe?

Multilayer s cylindrical wall thermal conductivity

In practice, single-layer cylindrical walls are very rare. Because the surface of pipes is covered with metal oxide, oil, thermal insulation or some chukmas (nakip, saji). Such cylindrical walls are called multi-layered cylindrical walls. The thermal

conductivity of a multi-layer wall is calculated based on the formulas of a single-layer cylindrical wall. Let's consider a wall with thermal conductivity of three-layer cylindrical walls $\lambda_1, \lambda_2, \lambda_3$.

In this case, the temperature of the inner surface of the wall is t_1 , the temperature of the outer surface is t_4 , at the boundary of the layers t_2 ; Let t_3 be t_3 .

In the steady heat mode, the heat passing through each layer is the same and constant.

consider the case $t_1 > t_2 > t_3 > t_4$:

For the first layer:

$$q_l = \frac{2\pi\lambda_1}{\ln \frac{d_2}{d_1}} (t_1 - t_2) \quad (6.17)$$

For the second layer:

$$q_l = \frac{2\pi\lambda_2}{\ln \frac{d_3}{d_2}} (t_2 - t_3) \quad (6.18)$$

For the third layer:

$$q_l = \frac{2\pi\lambda_3}{\ln \frac{d_4}{d_3}} (t_3 - t_4) \quad (6.19)$$

The temperature change can be found from this formula:

$$t_1 - t_2 = \frac{q_l}{2\pi\lambda_1} \ln \frac{d_2}{d_1} \quad (6.20)$$

$$t_2 - t_3 = \frac{q_l}{2\pi\lambda_2} \ln \frac{d_3}{d_2} \quad (6.21)$$

$$t_3 - t_4 = \frac{q_l}{2\pi\lambda_3} \ln \frac{d_4}{d_3} \quad (6.22)$$

Adding (23.4), (23.5), (23.6) we find the total temperature pressure:

$$t_1 - t_4 = \Delta t = q_l \left[\frac{1}{2\pi\lambda_1} \ln \frac{d_2}{d_1} + \frac{1}{2\pi\lambda_2} \ln \frac{d_3}{d_2} + \frac{1}{2\pi\lambda_3} \ln \frac{d_4}{d_3} \right]$$

The linear density of the heat flux, which is sought from this:

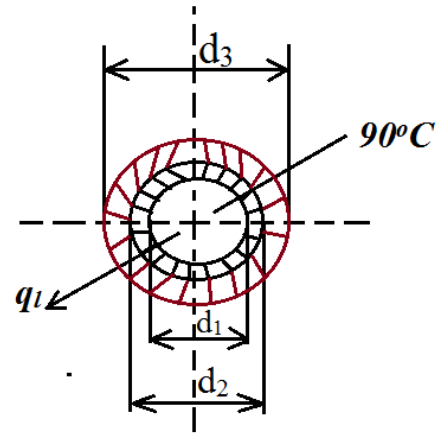
$$q_l = \frac{\Delta t}{\frac{1}{2\pi\lambda_1} \ln \frac{d_2}{d_1} + \frac{1}{2\pi\lambda_2} \ln \frac{d_3}{d_2} + \frac{1}{2\pi\lambda_3} \ln \frac{d_4}{d_3}} \quad (6.23)$$

for an n-layer cylindrical wall:

$$q_l = \frac{\Delta t}{\sum_{i=1}^n \frac{1}{2\pi\lambda_i} \ln \frac{d_{i+1}}{d_i}} \quad (6.24)$$

Examples of issues related to the topic.

Issue 1. Calculate the heat loss from a pipe 1 meter long with a diameter of $\frac{d_1}{d_2} = \frac{150}{165} mm$ Insulation thickness $\delta = 60mm$, heat transfer coefficient of pipe material $\lambda_1 = 50Vt/m \cdot ^\circ C$, for insulation material $\lambda_2 = 0,15Vt/m \cdot ^\circ C$. The temperature of the water in the pipe $t_s = 90^\circ C$, the heat transfer coefficient from the water to the surface of the pipe $\alpha_1 = 1000Vt/m^2 \cdot ^\circ C$. The temperature of the environment is equal to $t_{s2} = -15^\circ C$ the coefficient of heat transfer from the surface of the insulation to the air $\alpha_2 = 8Vt/m^2 \cdot ^\circ C$. Determine the temperature of the surface of the insulating material.



Solution:

We calculate the heat transfer coefficient for a multilayer cylindrical wall using the following formula:

$$k_l = \frac{1}{\frac{1}{\alpha_1 \cdot d_1} + \frac{1}{2\lambda_1} \ln \frac{d_2}{d_1} + \frac{1}{2\lambda_2} \ln \frac{d_3}{d_2} + \frac{1}{\alpha_2 \cdot d_3}} = \frac{1}{\frac{1}{1000 \cdot 0,15} + \frac{1}{2 \cdot 50} \ln \frac{165}{150} + \frac{1}{2 \cdot 0,15} \ln \frac{285}{165} + \frac{1}{8 \cdot 0,285}} = 0,53Vt/m \cdot ^\circ C$$

Linear heat flux density:

$$q_l = k_l \pi (t_{s1} - t_{s2}) = 0,53 \cdot 3,14 (90 - (-15)) = 174,7Vt/m$$

The temperature of the outer surface of the insulation:

$$t_{s3} = t_{s2} + \frac{q_l}{\alpha_2 \pi d_3} = -15 + \frac{174,7}{8 \cdot 3,14 \cdot 0,285} = 27^\circ C$$

Issue 2. A steam pipe with an internal diameter of 140 mm is insulated with 2 layers of thickness $d_2 = 20 mm$ and $d_3 = 40 mm$. Heat transfer coefficients of pipes and insulation layers: $1_1 = 55 W/(m \cdot ^\circ C)$, $1_2 = 0.037 W/(m \cdot ^\circ C)$, $1_3 = 0.14 W/(m \cdot ^\circ C)$. The temperature on the inner surface of the pipe is $t_1 = 300^\circ C$ and the temperature on the outer surface is $t_4 = 55^\circ C$. The thickness of the steam pipe is $d = 5 mm$. Find the heat flux through a 1 m steam pipe?

Solution: Heat flux through 1 m of steam

$$q_\ell = \frac{2\pi(t_1 - t_4)}{\frac{1}{\lambda_1 \cdot \ln(d_2/d_1)} + \frac{1}{\lambda_2 \cdot \ln(d_3/d_2)} + \frac{1}{\lambda_3 \cdot \ln(d_4/d_3)}} = \frac{2 \cdot 3,14(300 - 55)}{\frac{1}{55 \ln(150/140)} + \frac{1}{0,037 \ln(130/150)} + \frac{1}{0,14 \ln(270/190)}} = 172,5 Vt/m$$

Issue 3. The steel pipe has a diameter of 108x5 mm and has 3 layers of insulation. In line $\lambda_1 = 50,3Vt/m \cdot ^\circ C$ $\delta_2 = 25mm$, $\lambda_2 = 0,038Vt/m \cdot ^\circ C$ $\delta_3 = 35mm$, $\lambda_3 = 0,052Vt/m \cdot ^\circ C$ $\delta_4 = 35mm$, $\lambda_4 = 0,116Vt/m \cdot ^\circ C$. The temperature of the inner

surface of the pipe $t^I = 218^\circ C$, the temperature of the surface of the outer layer $t^{IV} = 76^\circ C$ Determine the unknown temperatures between each layer?

Solution:

$$R_1 + R_2 + R_3 = \frac{1}{2\lambda_1} \ln \frac{d_2}{d_1} + \frac{1}{2\lambda_2} \ln \frac{d_3}{d_2} + \frac{1}{2\lambda_3} \ln \frac{d_4}{d_3}$$

$$q_l = \frac{\pi(t^I - t^{IV})}{R_1 + R_2 + R_3} = \frac{\pi(t^I - t^V)}{R_1 + R_2 + R_3 + R_4}$$

$$q_l = \frac{3,14 \cdot (218 - 76)}{\frac{1 \cdot 2,303}{2 \cdot 50,3} \lg \frac{108}{98} + \frac{1 \cdot 2,303}{0,038} \lg \frac{158}{108} + \frac{1 \cdot 2,303}{2 \cdot 0,052} \lg \frac{228}{158}}$$

$$q_l = 52,24 \text{ Wt/m}$$

$$q_l = \frac{\pi(t^I - t^{II})}{R_1}; \quad t^{II} = t^I - \frac{q_l}{\pi} R_1$$

$$t^{II} = 218 - \frac{52,24 \cdot 0,001}{3,14} = 217,98^\circ C;$$

$$t^{III} = t^{II} = \frac{q_l}{\pi} R_2 = 217,98 - \frac{52,24}{3,14} 5,0073 = 134,67^\circ C$$

$$t^{IV} = 76^\circ C$$

$$t^{IV} = 134,67 - \frac{52,24 \cdot 3,5269}{3,14} = 75,99 \approx 76^\circ C$$

$$t^{IV} - t^{IV} - \frac{q_l}{\pi} R_4;$$

$$R_4 = \frac{1}{2\lambda_4} \ln \frac{d_5}{d_4} = \frac{1 \cdot 2,303}{2 \cdot 0,016} \lg \frac{236}{228} = 0,148 \text{ m} \cdot K / \text{Vt}$$

$$t^V = 76 - \frac{52,24 \cdot 0,148}{3,14} = 73,54^\circ C;$$

$$q_l = \frac{\pi(t^I - t^{III})}{R_1 + R_2}$$

$$52,24 = \frac{3,14(218 - t^{III})}{0,001 + 5,0073}$$

$$t^{III} = 218 - 83,32 = 134,68^\circ C .$$

Issues for independent work.

Issue 1. The wall of the steam boiler combustion chamber consists of fireclay with a thickness of $\delta_1 = 150$ mm, diatomite with a thickness of $\delta_2 = 50$ mm and red brick with a thickness of $\delta_3 = 250$ mm. The heat transfer coefficients of the materials are $\lambda_1 = 0.93$, λ_2 respectively ; $\lambda_2 = 0.13$ and $\lambda_3 = 0.7$ W/m \cdot $^\circ C$. The temperature on the inner surface of the combustion chamber is $t_1 = 1200$ $^\circ C$ and the temperature on the outer surface is $t_4 = 50$ $^\circ C$. Determine the density of the heat flux passing through the

wall of the combustion chamber and the temperatures on the surfaces where the layers adhere?

Issue 2. A steam pipe of length 3 m, inner diameter 140 mm consists of an insulating layer with a thickness of $\delta_2 = 20$ mm and $\delta_3 = 40$ mm. Heat transfer coefficients of the pipe and insulation layers are $h_1 = 55$ W/m²°C, respectively $\lambda_1 = 0.037$ W/m°C and $\lambda_3 = 0.14$ W/m°C. The temperature on the inner surface of the pipe is $t_1 = 300$ °C and the temperature on the outer surface of the insulation is $t_4 = 55$ °C. Steam pipe thickness $\delta = 5$ mm. Determine the heat flow through the steam pipe.

SUBJECT 7. HEAT RESISTANCE.

Theoretical information .

As mentioned above, the process of heat transfer in the movement of gas and liquid macroparticles from one place to another is called **convection**. Heat exchange

due to the combined effect of convection and molecular transfer of heat is called convective heat exchange.

Convective heat exchange between the moving medium and its boundary surface with a solid body is called **heat transfer**.

The main task of the theory of convective heat transfer is to determine the amount of heat that passes through a solid body that is swept by the current. The final flow of heat is always in the direction of decreasing temperature. When the liquid is in laminar motion along the pipe, the heat exchange is less due to the boundary layer formed, when the turbulent motion occurs, the thickness of the boundary layer decreases due to the increase in the movement speed of the immobilized liquid particles. As a result, heat exchange increases. The Newton-Richmann law is used to calculate the heat transfer process:

$$Q = \alpha F(t_s - t_{dev}) \quad (7.1)$$

where: Q - heat flow, [W];

α - heat transfer coefficient, $W/m^2 K$;

t_s - ambient temperature, °C ,

t_{dev} - wall surface temperature. °C ;

F - heat exchange surface, m^2 .

This equation was obtained by I. Newton in 1701 and is called Newton's law of convective heat transfer. According to this law, the amount of heat transferred from the liquid to the wall or from the wall to the liquid Q is proportional to the surface F involved in heat exchange, the temperature drop $t_c - t_{dev}$ and the time of heat exchange τ . Here t_{dev} is the temperature of the wall surface; t_c is the temperature of the medium that washes the wall surface. The coefficient of proportionality, which takes into account the specific conditions of heat exchange between a liquid and a solid body, is called **α the heat transfer coefficient**.

we take $F= 1 \text{ m}^2$ and $\tau=1 \text{ sec}$ in the formula, we get the heat flux density in Watts passing through one square meter of surface:

$$q = \alpha(t_s - t_{dev}) \quad (7.2)$$

or

$$q = \frac{t_s - t_{dev}}{\frac{1}{\alpha}} \quad (7.3)$$

The value $1/\alpha$ is called the thermal resistance of heat transfer.

$$\alpha = \frac{q}{t_s - t_{dev}} \quad (7.4)$$

Heating is a complex process.

α - Heat transfer coefficient depends on the following factors :

- a) causes of fluid leakage,
- b) liquid flow mode (laminar or turbulent),
- c) physical properties of liquid,
- g) shape and dimensions of the heating surface.

In laminar flow, fluid particles move without mixing. In this case, the heat transfer normal to the flow direction is carried out mainly by heat conduction. Since the thermal conductivity of the liquid is very small, the intensity of heat exchange in the laminar flow is not high (**In the laminar flow, the particles of the liquid move without mixture**).

In turbulent flow, heat is distributed in the flow by heat conduction, as well as by the mixing of almost the entire mass of the liquid, in which the viscous part of the liquid under the layer does not participate, since the molecular transfer of heat dominates the turbulent transfer. Therefore, the intensity of heat exchange in a turbulent flow is much greater than in a laminar flow (in **a turbulent flow, heat spreads through the mixing of almost the entire mass of the liquid**).

free and forced movement , depending on the reasons for its occurrence .

Free movement occurs in unevenly heated liquids and gases. **The forced movement of liquid** is due to the influence of external influences: fans, pumps and the like.

Currently, the theory of similarities is used to investigate convective heat transfer.

Examples of issues related to the topic.

Issue 1. If the amount of heat transferred from a solid surface to the environment is equal to $\Delta Q = 100 \frac{Vt}{m^2}$ what is the coefficient of heat transfer on the surface for a temperature of $1 \text{ m}^2 t = 10^\circ \text{C}$?

Solution:

We write the Newton-Richmann law.

$$Q = \alpha \cdot F(t_1 - t_2)$$

If the surface 1 m^2 is equal, the formula will look like this.

$$Q = \alpha \cdot (t_1 - t_2)$$

We calculate the heat transfer coefficient.

$$\alpha = \frac{Q}{\Delta t} = \frac{100}{10} = 10 \text{ Vt} / \text{m}^2 \cdot \text{K}$$

Issues for independent work.

Issue 1. If the heat flow density from a solid surface to the environment is equal to $\Delta Q = 200 \frac{vt}{m^2}$ what is the coefficient of heat

transfer on the surface for a temperature 1 m^2 of $t = 40^\circ \text{C}$?

2 . If the heat flux density $q = 100 \frac{vt}{m^2}$ through a single-layer brick wall at $\Delta t = 20^\circ \text{C}$, what is the heat transfer coefficient?

Issue 3 . If $\alpha_1 = 30 \text{ W/m}^2 \cdot \text{K}$, $\alpha_2 = 100 \text{ W/m}^2 \cdot \text{K}$ and the thickness of the wall $\delta = 50 \text{ mm}$, determine the heat transfer coefficient for a single-layer flat wall. $\lambda = 0.7 \text{ W/m} \cdot \text{K}$.

SUBJECT 8. HEAT EXCHANGE DEVICES.

Theoretical information.

A device designed to heat or cool a heat carrier is called **a heat exchanger (IAA)** . A liquid or gas is used as a heat carrier. Heat carriers are divided into heating and heated carriers. For example, the heated gas in the boiler is the heating heat carrier, and the water in the boiler is the heated heat carrier. The water in the heating radiator is the carrier of heating heat, and the air that distributes heat to the room is the carrier of heated heat.

Examples of IAAs are boilers, condensers, steam heaters, air heaters, central heating appliances, radiators, and the like.

IAAs differ greatly in their shape and size, as well as the working body used. Although IAAs are very different, the basic rules of heat calculation remain common to them. IAAs are extremely common in technology, currently there is no clear classification of them. The following classification refers to the most commonly used IAAs.

IAAs can be classified as follows:

With a mixer . In such IAAs, hot and cold heat carriers directly touch each other and then mix. For example, high-temperature steam from the boiler unit is mixed with cold or warm water, and then transferred to consumers. Such IAAs include coolers, deaerators, scrubbers, and other devices.

Recuperative . In such IAAs, heat is transferred through a separating wall (usually metal). Such appliances include steam generators, steam heaters, water heaters, air heaters and various types of vaporizers.

Currently, recuperative devices are the most common. Their structure is very simple, compact and ensures constant temperature of heat carriers.

Recuperative devices are mainly made of metal. For heat carriers with a temperature of 400-450 °C, pipes are made of carbon steel, and for heat carriers with a temperature of 500-700 °C, they are made of alloy steel.

Regenerative . In such IAAs, the heating (or cooling) surface itself is washed from time to time with a hot, sometimes cold heat carrier.

First, the heat carrier heated from the regenerator panels - combustion products from blast furnaces and marten furnaces, boilers, etc. are sent.

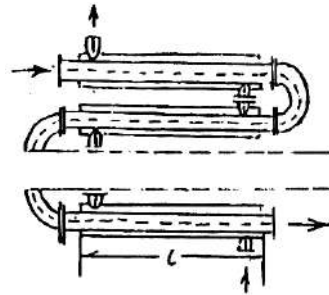
The heating surface of the regenerator takes heat from the heated gases and then transfers this heat to the cold heat carrier. Examples of such IAAs are air heaters of modern boiler units.

Examples of issues related to the topic.

Issue 1. "We determine the heating surface and the number of sections of the tubular heat exchanger inside the pipe. Both heat carriers are water.

The heating water $\frac{d_2}{d_1} = \frac{35}{32}$ moves to the mm internal pipe and the temperature at the entrance to the pipe $t_1' = 95^\circ S$, the temperature of the heating water at the exit from the device, $t_1'' = 47^\circ S$ consumption. $G_1 = 2130 \text{ kg/soat}$

Warming (cold water) water moves in the opposite direction and heats $t_2' = 18^\circ S$ up $t_2'' = 45^\circ S$. The diameter of the outer pipe $D=48 \text{ mm}$, the consumption of heated water, $G_2 = 3200 \text{ kg/soat}$ the length of one section of the heat exchanger device $l = 1.75 \text{ m}$



Solution : Heat capacity of water $C_{suv} \approx 4.19 \text{ kJ/kg} \cdot K$

Amount of heat transferred:

$$Q = G_2 C_{suv} (t_2'' - t_2') = \frac{3200}{3600} \cdot 4.19 \cdot 10^3 (45 - 18) = 100.56 \text{ kWt}$$

We determine the average arithmetic value of the temperatures of heat carriers and, accordingly, the physical properties of water:

$$t_1 = 0.5(t_1' + t_1'') = 0.5(95 + 47) = 48^\circ S$$

At this temperature:

$$\rho_1 = 1.029 \text{ kg/m}^3, \nu_1 = 20.02 \cdot 10^{-6} \text{ m}^2/\text{s}, \lambda_1 = 2.96 \cdot 10^{-2} \text{ Wt/m} \cdot K, Pr_1 = 0.694$$

$$t_2 = 0.5(t_2' + t_2'') = 0.5(18 + 45) = 31.5^\circ S \approx 30^\circ S$$

That is

$$\rho_2 = 1.165 \text{ kg/m}^3, \nu_2 = 16.00 \cdot 10^{-6} \text{ m}^2/\text{s}, \lambda_2 = 2.67 \cdot 10^{-2} \text{ Wt/m} \cdot K, Pr_2 = 0.701$$

The speed of the heat carrier is equal to:

$$\omega_1 = \frac{4G_1}{\rho_1 \pi d_1^2 \cdot 3600} = \frac{4 \cdot 2130}{1.029 \cdot 3.14 \cdot (32 \cdot 10^{-3})^2 \cdot 3600} = 715.31 \text{ m/s}$$

$$\omega_2 = \frac{4G_2}{\rho_2 \pi (D^2 - d_1^2) \cdot 3600} = \frac{4 \cdot 3200}{1.167 \cdot 3.14 \cdot (48^2 - 35^2) \cdot 3600} = 901 \text{ m/s}$$

$$\text{Reynolds number for superheated water } \text{Re}_1 = \frac{\omega_1 d_1}{\nu_1} = \frac{715.31 \cdot 32 \cdot 10^{-3}}{20.02 \cdot 10^{-6}} = 1143353$$

So, the movement of water is turbulent. We calculate the Nussel number and heat transfer coefficient using the following formula:

$$\text{Nu}_1 = 0.021 \cdot \text{Re}_1^{0.8} \cdot \text{Pr}_1^{0.43} \left(\frac{\text{Pr}_1}{\text{Pr}_2} \right)^{0.25}$$

The temperature of the pipe wall is unknown, so we take it as a first approximation.

$$t_{s1} \approx 0.5(t_1 + t_2) = 0.5(70 + 30) = 50^\circ \text{S}$$

In that case $\text{Pr}_{s1} \approx 3.5$

$$\text{Nu}_1 = 0.021 \cdot (1143353)^{0.8} \cdot (0.694)^{0.43} \left(\frac{0.694}{3.5} \right)^{0.25} = 853.78$$

Coefficient of heat transfer from water to pipe surface:

$$\alpha_1 = \text{Nu}_1 \frac{\lambda_1}{d_1} = 853.78 \cdot \frac{2.96 \cdot 10^{-2}}{32 \cdot 10^{-3}} = 789.7465 \text{ Wt} / \text{m}^2 \cdot \text{K}$$

Now Re_2 we find for the water to be heated.

$$d_e = D - d_2 = (48 - 35) \cdot 10^{-3} = 13 \cdot 10^{-3} \text{ m}$$

$$\text{Re}_2 = \frac{\omega_2 d_e}{\nu_2} = \frac{901 \cdot 13 \cdot 10^{-3}}{16 \cdot 10^{-6}} = 73206265$$

a first approximation $t_{s2} \approx t_{s1}$,

$\text{Pr}_{s2} \approx \text{Pr}_{s1}$ will be In that case

$$\text{Nu}_2 = 0.021 \cdot \text{Re}_2^{0.8} \cdot \text{Pr}_2^{0.43} \left(\frac{\text{Pr}_2}{\text{Pr}_1} \right)^{0.25}$$

$$\text{Nu}_1 = 0.021 \cdot (732062.5)^{0.8} \cdot (0.701)^{0.43} \left(\frac{0.701}{3.5} \right)^{0.25} = 592.6$$

Coefficient of heat transfer from the pipe wall to the heated water:

$$\alpha_2 = \text{Nu}_2 \frac{\lambda_2}{d_e} = 592.6 \cdot \frac{2.67 \cdot 10^{-2}}{13 \cdot 10^{-3}} = 1217 \text{ Wt} / \text{m}^2 \cdot \text{K}$$

Heat transfer coefficient

$$K = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}} = \frac{1}{\frac{1}{789.7465} + \frac{1.5 \cdot 10^{-3}}{45} + \frac{1}{1217}} = 471.42$$

$$K = 471.42 \text{ Vt} / \text{m} \cdot \text{K}$$

$$\text{Heat flux density: } q = K \cdot \Delta t_a = 471.42 \cdot 40 = 18856.8 \text{ Vt} / \text{m}^2$$

$$\text{Heating surface: } F = \frac{Q}{q} = \frac{100.56 \cdot 10^{-3}}{18856.8} = 5.33 \text{ m}^2$$

$$\text{Number of sections: } n = \frac{F}{\pi d_1 l} = \frac{5.33}{3.14 \cdot 3.2 \cdot 10^{-2} \cdot 1.75} = 30$$

Issues for independent work.

1 . In a tube-in-tube type heat exchanger, hot transformer oil is cooled using cold water. Transformer oil moves at a speed of 4 m/s in a brass tube with a diameter of $d_2/d_1=14/12 \text{ mm}$. The temperature of the oil at the entrance to the heat exchanger is $t'_{s1} = 100^\circ \text{C}$. Water flows through the annular gap in opposite direction to the oil at a speed of 2.5 m/s . The temperature of water at the entrance to the device is $t'_{s2} = 20^\circ \text{C}$, the inner diameter of the outer pipe is $d_3 = 22 \text{ mm}$. Determine the total length of the heat exchange surface corresponding to the temperature of the oil at the outlet of the device $t''_{s1} = 60^\circ \text{C}$.

List of used literature.

1. Zohidov RA, Avezov RR, Vardiyashvili AB, Alimova MM "Theoretical foundations of thermal engineering", textbook, part 1, TGTU, 2005.
2. Zohidov RA, Alimova MM, Mazhodova Sh.S. A collection of technical thermodynamics and heat transfer problems, TDTU, Tashkent, 2006.
3. G'.N.Uzokov, DN Mamedova, Sh.K.Yakhshiboyev, HA Almardanov. A collection of experiments on "Thermodynamics and heat engineering". Study guide. - Against: Intellect, 2021.
4. G'.N.Uzokov, DN Mamedova, Sh.K.Yakhshiboyev, HA Almardanov. Instruction manual for conducting practical training in "Thermodynamics and heat engineering". Study guide. - Against: Intellect, 2021.
3. Svetkov F. _ F. , Grigorev B. _ A. _ Teplomassoobmen , MEI , 2001.
4. Kudinov VA, EM Kartashov. Technical thermodynamics. - M.: Vsshaya school. 2005
5. Alimova MM, Mazhudova Sh.S., Isakhodjayev XS, Rakhimjonov RT, Umarjonova F.Sh. A collection of experiments on the subject "Theoretical foundations of heat engineering". Methodological guide, part 1. Tashkent, TashDTU. 2006.
6. Alimova MM, Mazhudova Sh.S., Isakhodjaev XS, Rakhimjonov RT, Umarjonova F.Sh. Methodical guide to the collection of experimental works on the subject "Theoretical foundations of heat engineering". Part 1 . ToshDTU , 2004

7. Poliuk GS, Gurovich BM, Taktaeva LN, Koroli MA Sbornik laboratornx rabot po discipline: "Teoreticheskie osnov teplotekhniki". Chast I. TashGTU. Tashkent, 2004.
8. Alimova MM, Mazhudova Sh.S., Isakhodjaev XS, Rakhimjonov RT, Umarjonova F.Sh. Methodical guide to the collection of experimental works on the subject "Theoretical foundations of heat engineering". Part 2 . ToshDTU , 2007.
9. Poliuk GS, Gurovich BM, Taktaeva LN, Koroli MA Sbornik laboratornx rabot po discipline: "Teoreticheskie osnov teplotekhniki". Chast II. TashGTU. Tashkent, 2007.
10. Koroli MA Metodicheskaya razrabotka po self-standing work po discipline "Teplotekhnika", Tashkent, 2006
11. Zohidov RA, Alimova MM, Mazhudova Sh.S., Isakhodjaev XS. Heat technique. Study guide for vocational colleges, Tashkent. Cholpon-2006.
12. Andrianova TN and dr. Sbornik zadach po tekhnicheskoy termodinamike, M.: 2000
13. Pod ed. Zakharovoy AA Tekhnicheskaya thermodynamics and temperature engineering. -M: Academy, 2006
14. Taktaeva LN, Koroli MA, Alimova MM, Mazhudova Sh.S. Test tasks for assessment of mastery results. Tosh.dav.tex.un-ti. 2004
15. Taktaeva LN, Koroli MA Thermal and hydraulic raschet recuperativnx teploobmennx apparatus. Methodological instruction. Tashkent, TGTU, 2006
16. Taktaeva LN, Rakhimjonov RT, Alimova MM, Mazhudova Sh.S. Thermal and hydraulic calculation of recuperative heat exchangers. Methodical guide for independent work. TDTU, Tashkent, 2006

Electronic textbooks

1. www.Ziyo.net
2. http://dhes.ime.mrsu.ru/studies/tot/tot_lit.htm;
3. http://rbip.bookchamber.ru/description.aspx?product_no=854;
4. <http://energy-mgn.nm.ru/progr36.htm>

Applications

Table 1

SI system of international units

Bigness	Unit of measure	Unit writing
Basic units		
length	meter	m
mass	kilogram	kg
time	second	s
power of electricity	Ampere	A
Kelvin thermodynamic temperature	Kelvin	K
amount of substance	mol	mol
surface	meter square	m^2
volume	cubic meter	m^3
speed	meters per second	m/s
acceleration	meters per sec.sq	m/s^2
density	kilograms per cubic meter	kg/m^3
strength	Newton	N
pressure	Pascal	Pa
amount of work, energy, heat	Joule	J
power, heat flow	Watt	W
specific heat capacity	Joules per kilogram Kelvin	J/kgK
enthalpy	joules per kilogram	J/kg
heat flux density	Watts per square meter	W/m^2
heat transfer coefficient	Watts per meter Kelvin	$W/(m \cdot K)$
heat transfer coefficient	Watts per square meter Kelvin	$W/(m^2 \cdot K)$
radiation coefficient	Watts per meter Kelvin 4 degrees	$W/(m^2 \cdot K^4)$

Table 2

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Energy	1 kcal=4.187 kJ
Strength	1 kgs=9.81 N
Relative weight	$1 kg/cm^3 = 9.81 N/m^3$
Density	$1 kg \cdot s^2/m^4 = 9.81 kg/m^3$
Pressure	$1 kg/cm^2 = 0.981 \cdot 10^5 Pa$
Dynamic viscosity coefficient	$1 kg \cdot s/m^2 = 9.81 Pa \cdot s$

Heat capacity	1kcal/(kg · °C)=4.187 kJ/(kg · °C)
Enthalpy	1kcal/kg=4.187kJ/kg
Heat flow	1 kcal/hour=1.163 W
heat flux density	1 kcal/(m ² · h)=1.163 W/m ²
heat flow volume density	1 kcal/(m ³ · h)=1.163 W/m ³
heat transfer coefficient	1 kcal/(m · h · °C)=1.163 W/m · °C
heat transfer coefficient	1 kcal/(m ² · h · °C)=1.163 W/m ² · °C
radiation coefficient	1 kcal/(m ² · h · K ⁴) =1.163 W/(m ² · K ⁴)

Table 3

Important gases and molecular mass, density and kilomolar volumes and gas constants under normal conditions

Substance	Chemical writing	molecular mass, μ	Density ρ, kg/m ³	kilomole volumes μ _v , m ³ /kg	Gas constant J/(kg · K)
Air	-	28.96	1,239	22.40	287.0
Oxygen	O ₂	32.00	1,429	22.39	259.8
Nitrogen	N ₂	28,026	1,251	22.40	296.8
Atmospheric nitrogen	N ₂	28,16	(1,257)	(22.40)	(295.3)
Helium	Hey	4,003	0.179	22.42	2078.0
Argon	Ar	39,994	1,783	22.39	208.2
Hydrogen	H ₂	2,016	0.090	22.43	4124.0
Carbon monoxide	SO	28.01	1,250	22.40	296.8
Carbon-(IV) -oxide	SO ₂	44.01	1,977	22,26	188.9
sulfur-(IV) -oxide	SO ₂	64.06	2,926	21.89	129.8
Methane	SN ₄	16,032	0.717	22.39	518.8
Ethylene	S ₂ N ₄	28,052	1,251	22.41	296.6
Coke gas	-	11.50	0.515	22,33	721.0
Ammonia	NH ₃	17,032	0.771	22.08	488.3
Water vapor	N ₂ O	18,016	(0.804)	(22.40)	(461)

Table 4

Heat capacity of oxygen

Temperature t, °S	Molar heat capacity, J/(kmol · K)				Mass heat capacity, J/(kg · K)		Volumetric heat capacity, J/(m ³ · K)	
	μ _{s r}	μ _{s v}	μ _{p.m}	μ _{etc}	μ _{p.m}	μ _{etc}	μ _{p.m}	μ _{etc}
0	29,274	20,959	29,274	20,959	0.9148	0.6548	1.3059	0.9349

100	29,877	21,562	29,538	21,223	0.9232	0.6632	1.3176	0.9466
200	30,815	22,500	29,931	21,616	0.9353	0.6753	1.3352	0.9642
300	31,832	23,517	30,400	22,085	0.9500	0.6900	1.3561	0.9852
400	32,758	24,443	30,878	22,563	0.9651	0.7051	1.3775	1.0065
500	33,549	25,234	31,334	23,019	0.9793	0.7193	1.3980	1.0270
600	34,202	25,887	31,761	23,446	0.9927	0.7327	1.4168	1.0459
700	34,746	26,431	32,150	23,835	0.0048	0.7448	1.4344	1.0634
800	35,203	26,888	32,502	24,187	1.0157	0.7557	1.4499	1.0789
900	35,584	27,269	32,825	24,510	0.0258	0.7658	1.4645	1.0936
1000	35,914	27,599	33,118	24,803	1.0350	0.7750	1.4775	1.1066
1100	36,216	27,901	33,386	25,071	1.0434	0.7834	1.4892	1.1183
1200	36,488	28,173	33,633	25,318	1.0509	0.7913	1.5005	1.1296
1300	36,752	28,437	33,863	25,548	1.0580	0.7984	1.5106	1.1396
1400	36,999	28,684	34,076	25,761	1.0647	0.8051	1.5202	1.1493
1500	37,242	28,927	34,282	25,967	1.0714	0.8114	1.5294	1.1585
1600	37,480	29,165	34,474	26,159	1.0773	0.8173	1.5378	1.1669
1700	37,715	29,400	34,658	26,343	1.0831	0.8231	1.5462	1.1752

Table 5
Heat capacity of nitrogen

Temperature $t, ^\circ\text{S}$	Molar heat capacity, $\text{J}/(\text{kmol} \cdot \text{K})$				Mass heat capacity, $\text{J}/(\text{kg} \cdot \text{K})$		Volumetric heat capacity, $\text{J}/(\text{m}^3 \cdot \text{K})$	
	μ_{s_r}	μ_{s_v}	$\mu_{p.m}_-$	μ_{etc}_-	$\mu_{p.m}_-$	μ_{etc}_-	$\mu_{p.m}'_-$	$\mu_{etc}'_-$
0	29,115	20,800	29,115	20,800	1.0392	0.7423	1.2987	0.9278
100	29,199	20,884	29,144	20,829	1.0404	0.7427	1.3004	0.9295
200	29,471	21,156	29,228	20,913	1.0434	0.7465	1.3038	0.9328
300	29,952	21,637	29,383	21,068	1.0488	0.7519	1.3109	0.9399
400	30,576	22,261	29,601	21,286	1.0567	0.7599	1.3205	0.9496
500	31,250	22,935	29,864	21,549	1.0660	0.7691	1.3322	0.9613
600	31,920	23,605	30,149	21,834	1.0760	0.7792	1.3452	0.9743
700	32,540	24,225	30,451	22,136	1.0869	0.7900	1.3586	0.9877
800	33,101	24,786	30,748	22,433	1.0974	0.8005	1.3716	1.0006
900	33,599	25,284	31,037	22,722	1.1078	0.8110	1.3845	1.0136
1000	34,039	25,724	31,313	22,998	1.1179	0.8210	1.3971	1.0178
1100	34,424	26,109	31,577	23,262	1.1271	0.8302	1.4089	1.0379
1200	34,773	26,448	31,828	23,513	1.1359	0.8395	1.4202	1.0492
1300	35,070	26,745	32,067	23,752	1.1447	0.8478	1.4306	1.0597
1400	35,330	27,005	32,293	23,978	1.1526	0.8558	1.4407	1.0697
1500	35,556	27,231	32,502	24,187	1.1602	0.8633	1.4499	1.0789
1600	35,757	27,432	32,699	24,384	1.1673	0.8704	1.4587	1.0877
1700	35,937	27,612	32,883	24,568	1.1736	0.8771	1.4671	1.0961

Table 6
Heat capacity of carbon(II)-oxide

Temperature	Molar heat capacity, $\text{J}/(\text{kmol} \cdot \text{K})$	Mass heat capacity, $\text{J}/(\text{kg} \cdot \text{K})$	Volumetric heat capacity, $\text{J}/(\text{m}^3 \cdot \text{K})$
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$t, ^\circ\text{S}$	μs_r	μs_v	$\mu p.m_-$	μetc_-	$\mu p.m_-$	μetc_-	$\mu p.m'_-$	$\mu etc'_-$
0	35,860	27,545	35,860	27,545	0.8148	0.6259	1.5998	1.2288
100	40,206	31,891	38,112	29,797	0.8658	0.6770	1.7003	1.3293
200	43,689	35,374	40,059	31,744	0.9102	0.7214	1.7373	1.4164
300	46,515	38,200	41,755	33,440	0.9487	0.7599	1.8627	1.4918
400	48,860	40,515	43,250	34,935	0.9826	0.7938	1.9297	1.5587
500	50,825	42,500	44,573	36,258	1.0128	0.8240	1.9887	1.6178
600	52,452	44,137	45,753	37,438	1.03	0.8508	2.0411	1.6701
700	53,826	45,511	46,813	38,498	1.0639	0.8746	2.0884	1.7174
800	54,977	46,662	47,763	39,448	1.0852	0.8964	2.1311	1.7601
900	55,952	47,637	48,617	40,302	1.1045	0.9157	2.1692	1.7982
1000	56,773	48,458	49,392	41,077	1.1225	0.9332	2.2035	1.8326
1100	57,472	49,157	50,099	41,784	1.1384	0.9496	2.2349	1.8640
1200	58,071	49,756	50,740	42,425	1.1530	0.9638	2.2638	1.8929
1300	58,586	50,271	51,322	43,007	1.1660	0.9772	2.2898	1.9188
1400	59,030	50,715	51,858	43,543	1.1782	0.9893	2.3136	1.9427
1500	59,411	51,096	52,348	44,033	1,1895	1.0006	2.3354	1.9644
1600	59,737	51,422	52,800	44,485	1,1995	1.0107	2.3555	1.9845
1700	60,022	51,707	53,218	44,903	1.2091	1.0203	2.3743	2.0034

Table 7
Heat capacity of water vapor

Temperature	Molar heat capacity, J/(kmol · K)				Mass heat capacity, J/(kg · K)		Volumetric heat capacity, J/(m ³ · K)	
$t, ^\circ\text{S}$	μs_r	μs_v	$\mu p.m_-$	μetc_-	$\mu p.m_-$	μetc_-	$\mu p.m'_-$	$\mu etc'_-$
0	33,499	25,184	33,499	25,184	1.8594	1.3980	1.4943	1.1237
100	34,055	25,740	33,741	25,426	1.8728	1.4114	1.5052	1.1342
200	34,964	26,649	34,118	25,803	1.8937	1.4323	1.5223	1.1514
300	36,036	27,721	34,575	26,260	1.9192	1.4574	1.5424	1.1715
400	37,191	28,876	35,090	26,775	1.9477	1.4863	1.5654	1,1945
500	38,406	30,091	35,630	27,315	1.9778	1.5160	1.5897	1.2188
600	39,662	31,347	36,195	27,880	2.0092	1.5474	1.6148	1.2439
700	40,951	32,636	36,789	28,474	2.0419	1.5805	1.6412	1.2703
800	42,249	33,934	37,392	29,077	2.0754	1.6140	1.6680	1.2971
900	43,513	35,198	38,008	29,693	2.1097	1.6483	1.6957	1.3247
1000	44,723	36,408	38,619	30,304	2.1436	1.6823	1.7229	1.3519
1100	45,858	37,543	39,226	30,911	2.1771	1.7158	1.7501	1.3791
1200	46,913	38,598	39,825	31,510	2.2106	1.7488	1.7769	1.4059
1300	47,897	39,582	40,407	32,092	2.2429	1.7815	1.8028	1.4319
1400	48,801	40,486	40,976	32,661	2.2743	1.8129	1.8280	1.4570
1500	49,639	41,324	41,525	33,210	2.3048	1.8434	1.8527	1.4817
1600	50,409	42,094	42,056	33,741	2.3346	1.8728	1.8761	1.5052
1700	51,133	42,818	42,576	34,261	2.3630	1.9016	1.8996	1.5286

Table 8
Heat capacity of air

Temperature	Molar heat capacity, J/(kmol · K)				Mass heat capacity, J/(kg · K)		Volumetric heat capacity, J/(m ³ · K)	
	μs_r	μs_v	$\mu p.m_-$	μetc_-	$\mu p.m_-$	μetc_-	$\mu p.m'_-$	$\mu etc'_-$
0	29,073	20,758	29,073	20,758	1.0036	0.7164	1.2971	0.9261
100	29,266	20,951	29,152	20,758	1.0061	0.7193	1.3004	0.9295
200	29,676	21,361	29,299	20,984	1.0115	0.7243	1.3071	0.9362
300	30,266	21,951	29,521	21,206	1.0191	0.7319	1.3172	0.9462
400	30,949	22,634	29,789	21,474	1.0283	0.7415	1.3289	0.9579
500	31,640	23,325	30,095	21,780	1.0387	0.7519	1.3427	0.9718
600	32,301	23,986	30,405	22,090	1.0496	0.7624	1.3565	0.9856
700	32,900	24,585	30,723	22,408	1.0605	0.7733	1.3708	0.9998
800	33,432	25,117	31,028	22,713	1.0710	0.7842	1.3842	1.0312
900	33,905	25,590	31,321	23,006	1.0815	0.7942	1.3976	1.0262
1000	34,315	26,00	31,598	23,283	1.0907	0.8039	1.4097	1.0387
1100	34,679	26,394	31,862	23,547	1.0999	0.8127	1.4214	1.0505
1200	35,002	26,687	32,109	23,794	1.1082	0.8215	1.4327	1.0618
1300	35,291	26,976	32,343	24,028	1.1166	0.8294	1.4432	1.0722
1400	35,546	27,231	32,565	24,250	1.1242	0.8369	1.4528	1.0819
1500	35,772	27,457	32,774	24,259	1.1313	0.8441	1.4620	1.0911
1600	35,977	27,662	32,967	24,652	1.1380	0.8508	1.4708	1.0999
1700	36,170	27,855	33,151	24,836	1.1443	0.8570	1.4788	1.1078

Table 9
Physical properties of dry steam ($V=760$ mm sim.ust $\approx 1.01 \cdot 10^5$ Pa)

$t,$ $^{\circ}S$	$\rho,$ kg/m^3	$s,$ $kJ/(kg \cdot ^{\circ}C)$	$\lambda,$ $W/m \cdot ^{\circ}C$	$a \cdot 10^6,$ m^2/s	$\mu \cdot 10^6,$ $Pa \cdot s$	$\nu \cdot 10^6,$ m^2/s	Pr
-50	1,584	1,013	2.04	12.7	14.6	9.23	0.728
-40	1,515	1,013	2.12	13.8	15.2	10.04	0.728
-30	1,453	1,013	2.20	14.9	15.7	10.80	0.723
-20	1,395	1,009	2.28	16.2	16.2	12.79	0.716
-10	1,342	1,009	2.36	17.4	16.7	12.43	0.712
0	1,293	1,005	2.44	18.8	17.2	13,28	0.707
10	1,247	1,005	2.51	20.0	17.6	14,16	0.705
20	1,205	1,005	2.59	21.4	18.1	15.06	0.703
30	1,165	1,005	2.63	22.9	18.6	16.00	0.701
40	1,128	1,005	2.76	24.3	19.1	16.96	0.699
50	1,093	1,005	2.83	25.7	19.6	17.95	0.698

60	1,060	1,005	2.90	26.2	20.1	18.97	0.696
70	1,029	1,009	2.96	28.6	20.6	20.02	0.694
80	1,000	1,009	3.05	30.2	21.1	21.09	0.692
23,90	0.972	1,009	3.13	31.9	21.5	22.10	0.690
100	0.946	1,009	3.21	33.6	21.9	23.13	0.688
120	0.898	1,009	3.34	36.8	22.8	25.45	0.686
140	0.854	1,013	3.49	40.3	23.7	27.80	0.684
160	0.815	1,017	3.64	43.9	24.5	30.09	0.682
180	0.779	1,022	3.78	47.5	25.3	32.49	0.682

Table 10
Physical properties of water at the saturation line

$t, ^\circ\text{S}$	$r \cdot 10^{-5}, \text{Pa}$	$\rho, \text{kg/m}^3$	$h, \text{kJ/kg}$	$s_r, \text{kJ}/(\text{kg} \cdot ^\circ\text{C})$	$\lambda \cdot 10^{-2}, \text{W}/\text{m} \cdot ^\circ\text{C}$	$a \cdot 10^{-8}, \text{m}^2/\text{s}$	$\mu \cdot 10^{-6}, \text{Pa} \cdot \text{s}$	$\nu \cdot 10^{-6}, \text{m}^2/\text{s}$	$\beta \cdot 10^{-4}, \text{K}^{-1}$	$\sigma \cdot 10^{-4}, \text{N}/\text{m}$	Pr
0	1,013	999.9	0.00	4,212	55.1	13.1	1788	1,789	-0.63	756.4	13.67
10	1,013	999.7	42.04	4,191	57.4	13.7	13.06	1,306	+0.70	741.6	9.52
20	1,013	998.2	83.91	4,183	59.9	14.3	1004	1,006	1.82	726.9	7.02
30	1,013	995.7	125.7	4,174	61.8	14.9	801.5	0.805	3.21	712.2	5.42
40	1,013	992.2	167.5	4,174	63.5	15.3	653.3	0.659	3.87	696.5	4.31
50	1,013	988.1	209.3	4,174	64.8	15.7	549.4	0.556	4.49	676.9	3.54
60	1,013	983.2	251.1	4,179	65.9	16.0	469.9	0.478	5.11	662.2	2.98
70	1,013	977.8	293.0	4,187	66.8	16.3	406.1	0.415	5.70	643.5	2.55
80	1,013	971.8	335.0	4,195	67.4	16.6	355.1	0.365	6.32	625.9	2.21
90	1,013	965.3	377.0	4,208	68.0	16.8	314.9	0.326	6.95	607.2	1.95
100	1,013	958.4	419.1	4,220	68.3	16.9	282.5	0.295	7.52	588.6	1.75
110	1.43	951.0	461.4	4,233	68.5	17.0	259.0	0.272	8.08	569.0	1.60
120	1.98	943.1	503.7	4,250	68.6	17.1	237.4	0.252	8.64	548.4	1.47
130	2.70	934.8	546.4	4,266	68.6	17.2	217.8	0.233	9.19	528.8	1.36
140	3.61	926.1	589.1	4,287	68.5	17.2	201.1	0.217	9.72	507.2	1.26
150	4.76	917.0	632.2	4,313	68.4	17.3	186.4	0.203	10.3	486.6	1.17
160	6.18	907.4	675.4	4,346	68.3	17.3	173.6	0.191	10.7	466.0	1.10
170	7.92	897.3	719.3	4,380	67.9	17.3	162.8	0.181	11.3	443.4	1.05
180	10.03	886.9	763.3	4,417	67.4	17.2	153.0	0.173	11.9	422.8	1.00
190	12.55	876.0	807.8	4,459	67.0	17.1	144.2	0.165	12.6	400.2	0.96
200	15.55	863.0	852.5	4,505	66.3	17.0	136.4	0.158	13.3	376.7	0.93
210	19.08	852.8	897.7	4,555	65.5	16.9	130.5	0.153	14.1	354.1	0.91
220	23,20	840.3	943.7	4,614	64.5	16.6	124.6	0.148	14.8	331.6	0.89
230	27.98	827.3	990.2	4,681	63.7	16.4	119.7	0.145	15.9	310.0	0.88

Table 11
Physical properties of water vapor at the saturation line

t, °S	$r \cdot 10^{-5}, \text{Pa}$	$\rho'', \text{kg/m}^3$	h'', kJ/kg	r, kJ/kg	$s_r, \text{kJ}/(\text{kg} \cdot ^\circ\text{C})$	$\lambda \cdot 10^{-2}, \text{W}/\text{m} \cdot ^\circ\text{C}$	$a \cdot 10^{-8}, \text{m}^2/\text{s}$	$\mu \cdot 10^{-6}, \text{Pa} \cdot \text{s}$	$\nu \cdot 10^{-6}, \text{m}^2/\text{s}$	Pr
100	1,013	0.598	2675.9	2256.8	2,135	2,372	18.58	11.97	20.02	1.08
110	1.43	0.826	2691.4	2230.8	2,177	2,489	13.83	12.46	15.07	1.09
120	1.98	1,121	2706.5	2230.0	2,206	2,593	10.50	12.85	11.46	1.09
130	2.70	1,496	2720.7	2202.8	2,257	2,686	7,972	13,24	8.85	1.11
140	3.61	1,966	2734.1	2174.3	2,315	2,791	6,130	13.54	6.89	1.12
150	4.76	2,547	2746.7	2145.0	2,395	2,884	4,728	13.93	5.47	1.16
160	6.18	3,258	2758.0	2114.4	2,479	3,012	3,722	14.32	4.39	1.18
170	7.92	4,122	2768.0	2082.6	2,583	3,128	2,939	14.72	3.57	1.21
180	10.03	5,157	2778.5	2049.5	2,709	3,268	2,339	15.11	2.93	1.25
190	12.55	6,394	2786.4	2015.2	2,856	3,419	1,872	15.60	2.44	1.30
200	15.55	7,862	2793.1	1978.8	3,023	3,547	1,492	15.99	2.03	1.36
210	19.08	9,588	2798.2	1940.7	3,199	3,722	1,214	16.38	1.71	1.41
220	23,20	11.62	2801.5	1900.5	3,408	3,896	0.983	16.87	1.45	1.47
230	27.98	13.99	2803.2	1857.8	3,634	4,094	0.806	17.36	1.24	1.54
240	33,48	16.76	2803.2	1813.0	3,881	4,291	0.658	17.76	1.06	1.61

Table 12
Temperature-dependent physical properties of transformer oil

t, °S	$\rho, \text{kg}/\text{m}^3$	$s_r, \text{kJ}/(\text{kg} \cdot ^\circ\text{C})$	$\lambda, \text{W}/\text{m} \cdot ^\circ\text{C}$	$\mu \cdot 10^{-6}, \text{Pa} \cdot \text{s}$	$\nu \cdot 10^{-6}, \text{m}^2/\text{s}$	$a \cdot 10^{-6}, \text{m}^2/\text{s}$	$\beta \cdot 10^{-4}, \text{K}^{-1}$	Pr
0.0	892.5	1,549	0.1123	629.8	70.5	8.14	6.80	846
10	886.4	1,620	0.1115	335.5	37.9	7.83	6.85	484
20	880.3	1,666	0.1106	198.2	22.5	7.56	6.90	298
30	874.2	1,729	0.1008	128.5	14.7	7.28	6.95	202
40	868.2	1,788	0.1090	89.4	10.3	7.03	7.00	146
50	862.1	1,846	0.1082	65.3	7.58	6.80	7.05	111
60	856.0	1,905	0.1072	49.5	5.78	6.58	7,10	87.8
70	850.0	1,964	0.1064	38.6	4.54	6.36	7.15	71.3
80	843.9	2,026	0.1056	30.8	3.66	6.17	7.20	59.3
90	837.8	2,085	0.1047	25.4	3.03	6.00	7.25	50.5
100	831.8	2,144	0.1038	21.3	2.56	5.83	7.30	43.9
110	825.7	2,202	0.1030	18.1	2.20	5.67	7.35	38.8
120	819.6	2,261	0.1022	15.7	1.92	5.50	7.40	34.9

Table 13
Temperature dependent physical properties of MS-20 oil

t, °S	$\rho, \text{kg}/\text{m}^3$	$s_r, \text{kJ}/(\text{kg} \cdot ^\circ\text{C})$	$\lambda, \text{W}/\text{m} \cdot ^\circ\text{C}$	$\mu \cdot 10^{-6}, \text{Pa} \cdot \text{s}$	$\nu \cdot 10^{-6}, \text{m}^2/\text{s}$	$a \cdot 10^{-6}, \text{m}^2/\text{s}$	$\beta \cdot 10^{-4}, \text{K}^{-1}$	Pr
-10	990.3	1,951	0.136	-	-	7.75	6.24	-
0	903.6	1,980	0.135	-	-	7.58	6.24	-

+10	897.9	2,010	0.135	-	-	7.44	6.31	-
20	892.3	2,043	0.134	10026	1125	7.30	6.35	15400
30	886.6	2,072	0.132	4670	526	7.19	6.38	7310
40	881.0	2,106	0.131	2433	276	7.08	6.42	3890
50	875.3	2,135	0.130	1334	153	7.00	6.46	2180
60	869.6	2,165	0.129	798.5	91.9	6.86	6.51	1340
70	864.0	2,198	0.128	498.3	58.4	6.75	6.55	865
80	858.3	2,227	0.127	336.5	39.2	6.67	6.60	588
90	852.7	2,261	0.126	234.4	27.5	6.56	6.64	420
100	847.0	2,290	0.126	171.7	20.3	6.44	6.69	315
110	841.3	2,320	0.124	132.4	15.7	6.36	6.73	247
120	835.7	2,353	0.23	101.0	12.1	6.25	6.77	193
130	830.0	2,382	0.122	79.76	9.61	6.17	6.82	156
140	824.4	2,420	0.121	61.80	7.50	6.08	6.87	123
150	818.7	2,445	0.120	53.17	6.50	6.00	6.92	108

Table 14
Temperature-dependent physical properties of MK oil

t, °S	ρ , kg/m ³	s_r , kJ/(kg·°C)	λ , W/m·°C	$\mu \cdot 10^6$, Pa·s	$\nu \cdot 10^6$, m ² /s	$\alpha \cdot 10^6$, m ² /s	$\beta \cdot 10^4$, K ⁻¹	Pr
10	911.0	1,645	0.1510	35414	3883	9.94	8.56	39000
20	903.0	1,712	0.1485	18560	1514	9.58	8.64	15800
30	894.5	1,758	0.1461	6180	691.2	9.28	8.71	7450
40	887.5	1,804	0.1437	3031	342.0	8.97	8.79	3810
50	879.0	1,851	0.1413	1638	186.2	8.69	8.86	2140
60	871.5	1,897	0.1389	961.4	110.6	8.39	8.95	1320
70	864.0	1,943	0.1363	603.3	69.3	8.14	9.03	858
80	856.0	1,989	0.1340	399.3	46.6	7.89	9.12	591
90	848.2	2,035	0.1314	273.7	32.3	7.61	9.20	424
100	840.7	2,081	0.1290	202.1	24.0	7.33	9.28	327
110	838.0	2,127	0.1264	145.2	17.4	7.11	9.37	245
120	825.0	2,173	0.1240	110.4	13.4	6.92	9.46	193.5
130	817.0	2,219	0.1214	87.31	10.7	6.69	9.54	160.0
140	809.2	2,265	0.1188	70.34	8.70	6.53	9.65	133.3
150	801.6	2,311	0.1168	56.90	7.10	6.25	9.73	113.5

Books

1. Zohidov RA, Avezov RR, Vardiyashvili AB, Alimova MM Heat technique. i.q.kol., part 1, Tashkent, TDTU, 2005.
2. Baskakov AP Thermotechnics. M.: Energoatomizdat, 1999.
3. Isachenko VP, Osipova VA, Sukomel AS Teploperedacha. M.: - Energy, 1981.
4. Andrianova TN and dr. Sbornik zadach po tekhnicheskoy thermodynamics. M.: MEI, 2000.
5. Krasno shch ekov KA, Sukomel AS Sbornik zadach po teploperedache. M.: Energy, 1991.
6. http://dhes.ime.mrsu.ru/studies/tot/tot_lit.htm

Subject.	Enter
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1.1. Teaching technology of lecture training.

Time-2 hours	number of students is 12
The form of training	Introduction, visual lecture

the lecture session:	<ol style="list-style-type: none"> 1. The purpose of the science of heat engineering and its place in other specialized sciences. 2. Recognition of technical thermodynamics as a science 3. The main essence and purpose of the heat transfer section
<i>The purpose of the training session:</i> to form knowledge, information and imagination about the purpose, essence, history of development of ITNA science, its connection with other sciences.	
<p style="text-align: center;"><i>Pedagogical tasks:</i></p> <p>Educator:</p> <ul style="list-style-type: none"> - The purpose of the science of heat engineering and its place in other specialized sciences. - Recognition of technical thermodynamics as a science - The main essence and purpose of the heat transfer section 	<p style="text-align: center;"><i>Learning outcomes:</i></p> <p>Student:</p> <ul style="list-style-type: none"> - explains the reasons for the emergence of ITNA science; - descriptions of what science is; - explains the laws of science related to physics, mathematics and social sciences
Teaching methods and techniques	– blis-request, statement.
Teaching tools	- Text of lectures, posters, blackboard, chalk.
Teaching form	- Team, group and pair work.
Teaching conditions	- equipped auditorium.

Technological card of the lecture session

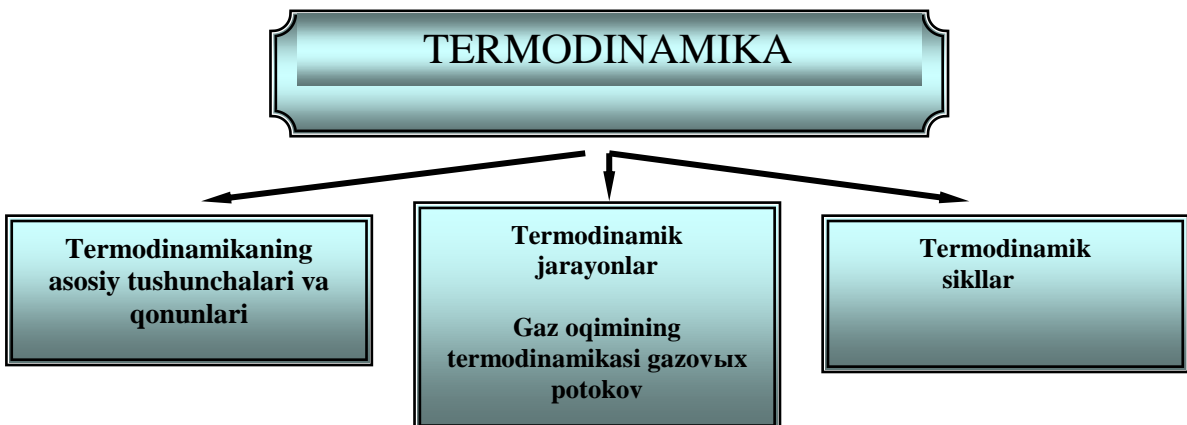
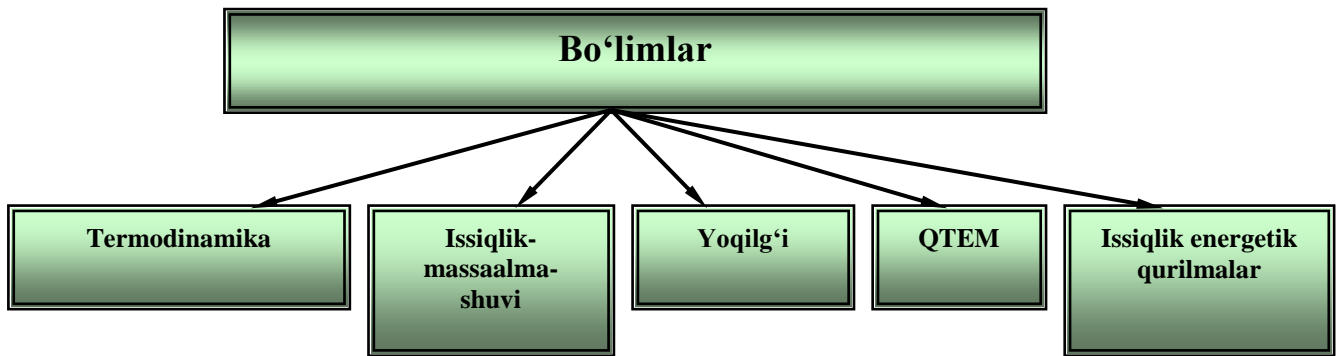
steps, time	Activity content	
	Teacher	A student

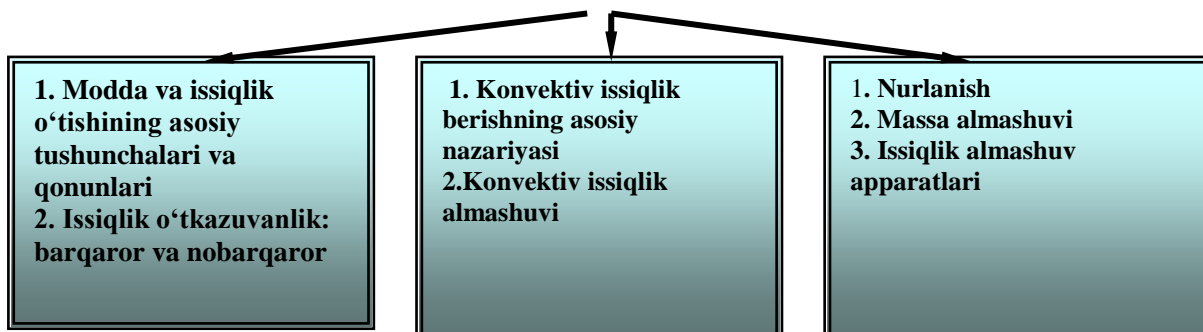
1 . Introduction (10 min.)	1.1 The topic and plan of the training session and the expected results will be announced.	1.1. They listen and record.
Stage 2. Main (60 min.)	2.1. Focuses students' attention on the questions in the outline and the concepts in them and conducts quick question-and-answer. 2.2. The teacher continues the lecture . speaks and raises questions about the purpose, essence, history of development of ITNA science, its knowledge about its relationship with other sciences; a) What are the reasons for the emergence of ITNA science as a science ? b) What is the main content of technical thermodynamics ? c) Are the quantities in the heat transfer part met in the previous subjects? 2.3. Emphasizes that students focus on and record the main concepts of the topic.	2.1. Students answer. 2.2. He remembers , makes suggestions and writes down the main points. They think about the questions and try to answer them gradually. 2. 3 . He hears, remembers , brings.
3rd stage. Final (10 min.)	3.1. Concludes the topic and draws students' attention to the main issues. Actively participating students are encouraged .	3.1. Listens and clarifies.

the 1st exercise.

1. The essence of ITNA science and its approach with other sciences
2. Quantities involved in technical thermodynamics

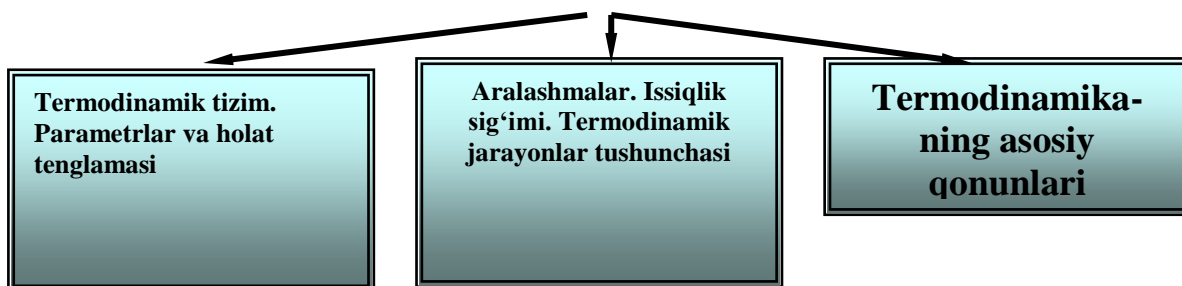
Logical structure diagram of "Heat technique" and "Heat technique" science





TERMODINAMIKA

Termodinamikaning asosiy tushunchalari va qonunlari



Termodinamik jarayonlar

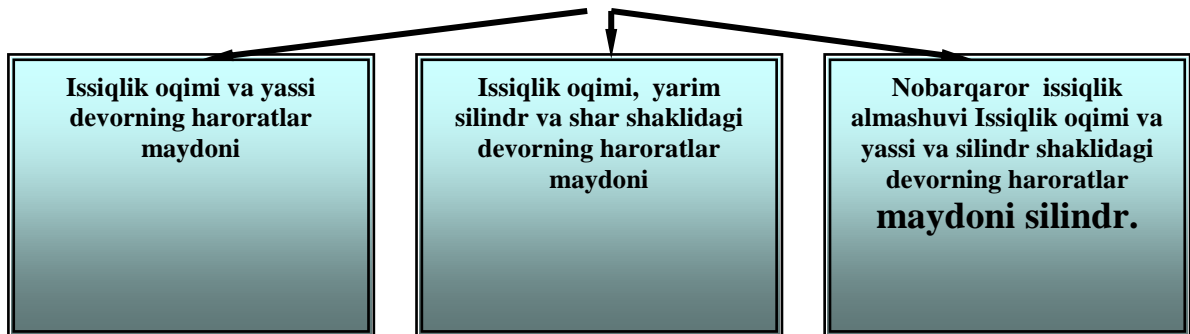


Termodinamik sikllar

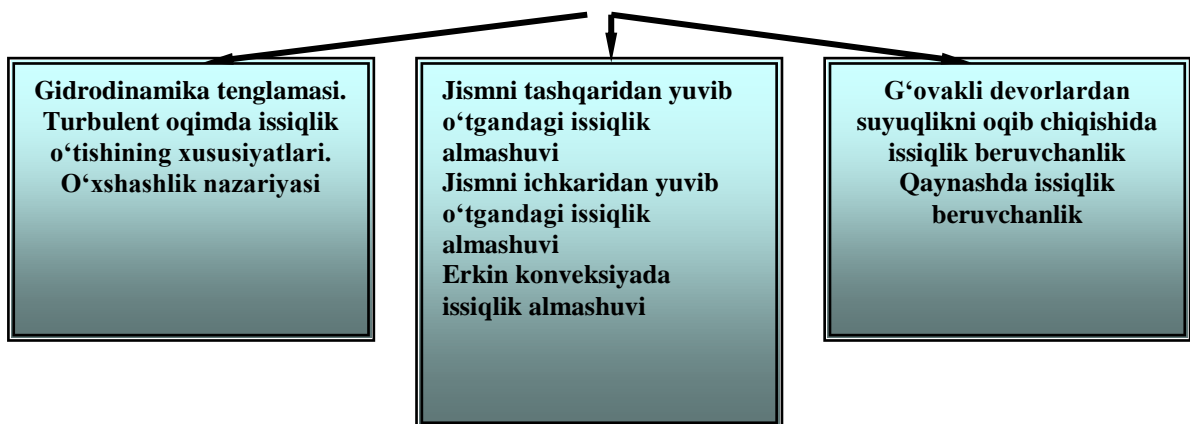


Issiqlik-massa almashuvi

Modda va issiqlik o'tishining asosiy tushunchalari va qonunlari. Issiqlik o'tkazuvchanlik



**Konvektiv issiqlik berishning nazariyasining asosiy tamoyili
КОНВЕКТИВНЫЙ ТЕПЛОБМЕН**



**Nurlanish
Massa almashuvi
Issiqlik almashuv apparatlari**



Tests on "Heat technique".

What is pressure ?	pressure at absolute zero	Pressure corresponding to sea level at $T=273.15K$	* $1 M^2$ force acting normal to the surface	pressure above atmospheric pressure
What is excess pressure?	less than atmospheric pressure	index of atmospheric and rarefaction pressures	absolute and manometric pressure difference	*difference between absolute and atmospheric pressures
What is barometric pressure?	A pressure equal to 1 kg/cm	*atmospheric pressure	pressure measured with a micromanometer	pressure measured with a manometer
Which of the following pressures is a thermodynamic parameter?	P_{opm}	$P_{\delta ap}$	$P_{\delta ak}$	* P_{mym}
What does a spring gauge measure?	*excess and dilution pressure;	barometric pressure;	pressure in kg/m;	absolute pressure
Which of these pressures is the least?	*10 kg/ m^2	1 bar	1 atm	1kg/ cm^2
What pressure is measured with a micromanometer?	excess pressure	*small overpressure, dilution and pressure difference	small absolute pressure	small barometric pressure
A barometer is:	overpressure gauge	vacuum pressure gauge	a device that measures pressure differences	*a device that measures atmospheric pressure
What is measured in a U-shaped manometer:	* excess pressure, rarefaction, pressure difference	absolute pressure dilution, pressure difference	absolute pressure;	barometric pressure
Show the unit of pressure in the SI system	g/cm	*N/ m^2	kg/cm	1kg/m
Temperature is:	*body temperature	the amount of energy released when an electric current passes through a conductor	form of energy transfer	micromolecular form of energy transfer
What is absolute temperature?	*temperature proportional to the average kinetic energy of forward rotational movement of molecules	temperature corresponding to a given absolute pressure	Temperature corresponding to $273^{\circ}C$	temperature of the body

manometric thermometer measure?	pressure and temperature	pressure	*temperature	temperature difference
are the measurement ranges of liquid glass thermometers ?	to the structure of the thermometer	* to the physical properties of the thermometric substance	to capillary thickness	to the properties of the glass
What kind of working body is used in liquid glass thermometers?	* mercury, ethyl alcohol	Water, oil	helium, water	Acetone, water
What measuring instrument is used to measure the EEC of a thermocouple?	*millivolt-meter	ammeter	voltmeter	frequency meter
What temperature should the cold end of the thermocouple have?	20 ⁰ C	0 ⁰ C	373 ⁰ C	100 ⁰ C
What is the heat-sensing element of resistance thermometers:	*pure metal wire	junction of two conductive electrodes	quartz plate	hot pot
What is formed in a thermocouple?	temperature difference	tension	*EU	amperage
Find the measuring ranges of "lossy fiber" optical pyrometers?	from * 700 ⁰ C to 6000 ⁰ C	50 ⁰ C from 600 ⁰ C to	small positive temperatures	0 ⁰ C temperatures close to
Method of operation Find a thermometer based on the comparison of the light intensity of 2 objects:	glass thermometer	*optical thermometer	manometer thermometer	thermocouple
Which of the following quantities is not a thermodynamic state parameter?	T	V	*L	P
Show the equation of state of the working body?	$pV = mRT$	* $F(p, v, T) = 0$	$pV = RT$	$pV = const$
Show the equation of state for 1 kg of substance?	$P = f(T, V)$	$PV = mRT$	$P = \frac{RT}{V}$	* $PV = RT$
What is heat capacity?	* the heat required to heat a substance to one degree	supplied heat	heat taken away	the ratio of heat to temperature
$\mu c_{pm} \Big _{t_1}^{t_2}$ what heat capacity	medium mass	average volume	* average molar	true molar

Q = mc(t ₂ - t ₁) what heat capacity is used in the expression	molar	volume	*massive	isobar
In which of the isochoric and isobaric processes is the heat greater?	isochoric	* isobaric	polytropic	depending on the atom of the gas
Q = c'(t ₂ - t ₁)V ₀ In what unit should the volume of the body in the expression be	M ³	* HM ³	MM ³	M
c _p - c _v = x what quantity is substituted for x in the expression	* R	k	μc _p	μc _v
$\frac{C_p}{x} = \kappa$ what quantity is substituted for x in the expression	R	k	* c _v	μc _v
What is the value of heat capacity in an adiabatic process?	1κЖ/κг p	4,19κЖ/κг p	+ ∞	* 0
c Specify the unit of measurement of p _m	* κЖ/κг ⁰ C	κЖ/κмоль ⁰ C	κЖ/м ³ ⁰ C	κЖ/гp
Which of the following expressions is the specific heat capacity of the body?	c _x = $\frac{Q}{\Delta T}$	* c _x = $\frac{q}{\Delta T}$	c _x = $\frac{dq}{\Delta T}$	c _x = $\sum_{i=1}^n c_i q_i$
Which of the following expressions corresponds to the concept of the real heat capacity of a body?	c _x = $\frac{Q}{m\Delta T}$	* c _x = $\frac{dq}{dt}$	c _x = $\frac{q}{\Delta T}$	c _x = $\frac{Q}{\mu \Delta T}$
Show the Mayer equation	* c _p - c _v = R	$\frac{PV}{T} = R$	$\frac{c_p}{c_v} = K$	c _n = $\frac{c_p - c_v}{c_n - c_v}$
Heat capacity for which process c _x = c _p	isochoric	isothermal	* isobaric	adiabatic
What process is T=const	isochoric	* isothermal	isobaric	adiabatic
What process is r=const	isochoric	isothermal	* isobaric	adiabatic
What process is v=const	* isochoric	isothermal	isobaric	adiabatic
What process is q=0 ?	isochoric	isothermal	isobaric	* adiabatic
What process is PV ⁿ =const	* polytropic	isothermal	isobaric	adiabatic
Show the equation of Dalton's law for a gas mixture	R _{CM} = $\sum_{i=1}^n g_i R_i$	$\sum_{i=1}^n g_i = 1$	* P _{CM} = $\sum_{i=1}^n p_i$	m _{CM} = $\sum_{i=1}^n g_i m_i$

Show the expression of the first law of thermodynamics	* $dq = du + d\ell$	$dq = dh$	$dq = C_v dT$	$dq = C_p dT$
What is the work done by 1 kg of ideal gas in an isobaric process?	$\ell = 0$	$\ell = RT \ln \left(\frac{v_2}{v_1} \right)$	* $\ell = p (v_2 - v_1)$	$\ell = \frac{1}{k-1} (p_1 v_1 - p_2 v_2)$
What is the specific heat in an isobaric process?	$q = c_v (T_2 - T_1)$	$dq = C_v dT$	* $q = c_p (T_2 - T_1)$	$dq = C_p dT$
What is the work done by 1 kg of ideal gas in isochoric process?	* $\ell = 0$	$\ell = RT \ln \left(\frac{v_2}{v_1} \right)$	$\ell = \frac{R}{k-1} (T_1 - T_2)$	$\ell = R(T_2 - T_1)$
What is the specific heat in an isochoric process?	* $q = c_v (T_2 - T_1)$	$dq = C_v dT$	$q = c_p (T_2 - T_1)$	$dq = C_p dT$
In which process $q = 0$	isochoric	isothermal	isobaric	* adiabatic
What are the processes of the Carnot cycle?	From 2 isochore and 2 isobaric processes	From 2 isobaric and 2 polytropic processes	* From 2 isotherm and 2 adiabatic processes	From 2 isobars and 2 isotherm processes
Show the useful work coefficient of the Carnot cycle	* $\eta_t = 1 - \frac{T_2}{T_1}$	$\eta_t = \frac{Q_1 - Q_2}{Q_1}$	$\eta_t = 1 - \frac{Q_2}{Q_1}$	$\eta_t = \frac{L_y}{Q_1}$
What is the work done by 1 kg of ideal gas in isothermal expansion?	$\ell = 0$	* $\ell = RT \ln \frac{V_2}{V_1}$	$\ell = P(V_2 - V_1)$	$\ell = \frac{1}{k-1} (P_1 V_1 - P_2 V_2)$
What is the work done by 1 kg of ideal gas in adiabatic expansion?	$\ell = 0$	$\ell = RT \ln \frac{V_2}{V_1}$	$\ell = R(T_2 - T_1)$	* $\ell = \frac{1}{k-1} (T_1 - T_2)$
Show the equation of a thermodynamic process with a polytropic exponent $n = \pm \infty$	$P = \text{const}$	* $V = \text{const}$	$PV^k = \text{const}$	$PV = \text{const}$
How is average heat capacity calculated in engineering calculations?	$c_m = \frac{q}{t_2 - t_1}$	$c_m = \frac{dq}{dt}$	* $C_m \Big _{t_1}^{t_2} = \frac{C_m \Big _0^{t_2} - C_m \Big _0^{t_1}}{t_2 - t_1}$	$c' = \frac{q}{V(t_2 - t_1)}$
What kind of compressor is the SO-7A compressor?	*piston, two cylinder, single cylinder	membrane, two cylinders	single cylinder with piston	membrane, single cylinder
What are the parts of a compressor?	piston, crankshaft, receiver, suction valve	cylinder, flywheel, drive valve, filter	* cylinder, piston, crankshaft, flywheel, receiver, exhaust, intake and exhaust valves, filter	piston, generator, receiver, filter

What is gas compressed in a compressor?	*when the piston moves from bottom to top	when the number of revolutions increases	when the piston moves forward	I do not know
What is called a compressor?	a machine that produces work in compressing air	*A machine that compresses air at a pressure higher than 3 atm	A machine that consumes work when compressing air at a pressure higher than 3 atm	a machine that converts heat energy into mechanical energy
State Four's law	$grad t = \bar{n}_0 \frac{\partial t}{\partial n}$	* $dQ = -\lambda \frac{\partial t}{\partial n} dF \cdot dt$	$\lambda = A \frac{c_p \rho^{\frac{4}{3}}}{\mu^{\frac{1}{3}}}$	$\lambda = \frac{\bar{w} \bar{c}_v \rho}{3}$
The heat transfer coefficient is -	* The amount of heat transferred M^2 from the surface when the temperature difference 0C is equal to 1 per unit of time	amount of heat passing through the wall	the amount of heat removed from the main heater	The amount of heat transferred from a solid to a liquid
What does the heat transfer coefficient depend on?	viscosity, moisture	to the temperature of the liquid	* to the nature, density, humidity, temperature of the body	To the amount of heat
Indicate the criterion that characterizes the buoyancy force created by the density difference in liquids	$Nu = \frac{\alpha l}{\lambda}$	$Pr = \frac{\nu}{a}$	$Re = \frac{w \ell}{\lambda}$	* $Gr = \frac{g l^3}{\nu^2} \beta \Delta t$
What is convection due to the difference in density of hot and cold particles called?	*free	mandatory	mixed up	I do not know
Describe the physical meaning of Nu= Nusselt's criterion $\frac{\alpha l}{\lambda}$	Similarity of the field of velocities	Similarity of the field of temperatures	Action status	*Convective heat transfer at the wall fluid boundary
Show the expression of Peckle's criterion	$\frac{g l^3}{\nu^2} \beta \Delta t$	$\frac{\nu}{a}$	* $\frac{w \ell}{a}$	$\frac{\alpha l}{\lambda}$
Which of the following criteria represents the relationship between buoyancy and	Re	* Gr	Pr	Well

viscosity in a fluid flow?				
Which equation is used to calculate heat transfer in free movement of fluid	$Nu = c Re^n$	$Nu = c Pr^n$	* $Nu = c(Gr \cdot Pr)^n$	$Nu = c Re \cdot Pr^n$
Show the expression of the Pho criterion	* $\frac{a \tau}{\ell_0^2}$	$\frac{\alpha l_0}{\lambda_c}$	$\frac{\alpha l_0}{\lambda_\partial}$	$\frac{w \ell}{a}$
What quantity should be substituted for x in the expression $Nu = \frac{x l}{\lambda}$	g	* a	C_v	C_p
What is the K coefficient called?	heat transfer coefficient	heat transfer coefficient	heat transfer coefficient	radiation
l called?	heat transfer coefficient	*heat transfer coefficient	heat transfer coefficient	radiation
a called?	*heat transfer coefficient	heat transfer coefficient	heat transfer coefficient	radiation
S_0 is called	heat transfer coefficient	heat transfer coefficient	heat transfer coefficient	* radiation
Show the heat transfer equation	* $Q = K(t_{\text{жс1}} - t_{\text{жс2}})$	$Q = \frac{\lambda}{\delta} (t_1 - t_2) F$	$Q = \frac{\lambda}{\delta} (t_1 - t_2)$	$Q = a(t_1 - t_2)$
Find the Grasgoff criterion	$\frac{\alpha l}{\lambda}$	$\frac{w l \rho}{\mu}$	$\frac{\mu C_p g}{\lambda}$	* $\frac{g l^3}{\nu^2} \beta \Delta t$
State the Prandtl criterion	$q = -\lambda \frac{dt}{dx}$	$q = \alpha_k (t_{\text{жс}} - t_c)$	* $q_{1-2} = C_{np} \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right]$	$Q = KF(t_{\text{жс1}} - t_{\text{жс2}})$
What characterizes the Prandtl criterion	Flow state	* the relationship between the coefficient of thermal conductivity and viscosity	of fluid through the wall	change in flow rate
$q = -\lambda \frac{dt}{\partial n}$ this is an equation	*heat conduction (Fure's law)	radiation (Stephan-Bolsman law)	convection (Newton's law)	Nusselt's criterion equation
Which equation corresponds to the two-dimensional constant temperature field equation?	* $t = f(x, y)$	$t = f(x, \tau)$	$t = f(x, y, z)$	$t = f(x, y, z, \tau)$
What does the radiation coefficient characterize?	* property of absorbing and scattering light from the body itself	thermal conductivity	heating	amount of heat

Heat exchangers are divided into several types	regenerative, recuperative, mixed	regenerative	recuperative	mixed up
Find the error?	$Q = \frac{\lambda}{\delta} \Delta t F$	$q = -\lambda \frac{\partial t}{\partial n} dF d\tau$	$\frac{\partial t}{\partial \tau} = a \frac{\partial^2 t}{\partial x^2}$	* $q = \alpha_1 (t_{c_1} - t_{c_2})$
Which expression is used to determine the heat flux density for a flat wall under the third-order boundary condition?	$q = -\lambda grad t$	* $q = \frac{t_{c_1} - t_{c_2}}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}}$	$q = \frac{\lambda}{\delta} \Delta t$	$q_{\ell} = k_{\ell} \pi (t_{c_1} - t_{c_2})$
corresponds to a 3-dimensional stable temperature field ?	$t = f(x, y, \tau)$	* $t = f(x, y, z)$	$t = f(x, z, \tau)$	$t = f(x, y, z, \tau)$
Convective heat transfer is	*heat exchange between the liquid flow and the surface of the solid body touching it	heat exchange due to hot and cold particle densities	heat exchange using a fan or pump	heat transfer between solid bodies
From what expression is the coefficient of heat transfer determined?	$Q = \frac{\lambda}{\delta} (t_1 - t_2) F$	$Q = I \cdot \Delta U$	$Q_k = Q - Q_{\text{h}}$	* $\alpha = \frac{Q_k}{F(t_{\text{o}} - t_c)}$
What does the heat transfer coefficient depend on ?	heat transfer coefficient and temperature difference	* density difference, viscosity, temperature difference, surface, amount of heat	to the temperature and humidity of the liquid	to the density and ambient temperature
horizontal pipe in which the electric heater is installed insulated?	to evenly distribute the air	to evenly distribute the air	* so that the temperature is evenly distributed over the surface	to reduce heat loss to the environment
$x = C_{np} [(\frac{T_1}{100})^4 - (\frac{T_2}{100})^4] F$ What quantity should be substituted for x in the expression?	* Q_{h}	Q_k	α	Q
Which criterion is decisive in solving problems in the case of convection?	* Nu	Re	Pr	Gr
What is a steady state?	with the thermocouple display	*with all gauge displays unchanged	by keeping the ammeter reading unchanged	without changing the reading of the voltmeter

	remaining unchanged			
$\alpha = \frac{Q_k}{F(t_c - x)}$ What quantity should be substituted for x in the expression?	\bar{t}_d	$20^0 C$	$* t_c$	$293^0 C$
$C_{np}[(\frac{T_1}{100})^4 - (\frac{T_2}{100})^4] F$ What is defined by the expression?	Q_k	$* Q_H$	Q	α
What expression determines the amount of heat released from the main heater?	$Q = Q_k - Q_H$	$Q = mc(t_1 - t_2)$	$Q = \frac{\lambda}{\delta}(t_1 - t_2) F$	$* Q = I \cdot \Delta U$
Does $g = 9.81 \text{ m/s}$ affect the heat transfer coefficient in free convection?	no	*valid in all conditions	if so, it has no effect	if so, it has an effect
How does forced convection change with increasing speed?	* increases	does not change	decreases	first decreases, then increases
Forced convection is -	convection caused by the difference in density of hot and cold particles	*fan, pump-assisted convection	convection that occurs due to the acceleration of free fall	convection that occurs due to temperature differences
Does the coefficient of viscosity affect the coefficient of heat transfer in free convection?	no effect	*has an effect	has an effect in all cases	not effective in all cases
temperature difference affect the heat transfer coefficient?	* increases	does not change	first increases, then decreases	decreases