

School School of Energy and Power Engineering

Major 14.05.02 Design, Operation and Engineering of Nuclear Power Plants

Department the Butakov Research Center

GRADUATION THESIS

Topic
Design of a power unit of a nuclear power plant with a VVER reactor with an electrical capacity of 1250 MW

UDC 621.311.25:621.039.577.002.5

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Planned learning outcomes

Code	Learning Outcome	Requirements of FSES of HE and (or) interested employers
General by specialty		
	Universal competencies	
O1	To use the methodological foundations of the modern picture of the world for scientific cognition and creativity, to reveal the natural-science essence of problems arising in professional activity	Requirements of FSES OF HE, SSES of TPU (GC-1, PC-10), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O2	Analyze socially significant processes and phenomena, economic problems and social processes, responsibly participate in public and political life, apply methods of social interaction based on accepted moral and legal norms	Requirements of FSES OF HE, SSES OF TPU (GC-2, 5, 9), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O3	To carry out communications in the professional environment and in society as a whole, including in a foreign language, develop documentation, present and publicly defend results, master the methods of propaganda of scientific achievements	Requirements of FSES OF HE, SSES OF TPU (GC-3, 5), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O4	Use a systematic approach in professional activity, set goals and choose ways to achieve them, generalize, analyze, critically comprehend, systematize	Requirements of FSES OF HE, SSES OF TPU (GC-6, PC-1), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS

O5	To realize the need and demonstrate the ability to independently learn throughout life, continuous self-improvement, the development of social and professional competencies, to use the knowledge gained for training and educating new cadres	Requirements of FSES OF HE, SSES OF TPU (GC-7), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O6	To achieve the proper level of physical preparedness for ensuring full-fledged social and professional activity and a proper level of life safety, including protection of personnel and the population from the consequences of accidents, disasters, natural disasters	Requirements of FSES OF HE, SSES OF TPU (GC-8; GPC-1, PC-7, 19), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O7	It is effective to work individually and, in a team, including multinational, to take responsibility for their decisions, including non-standard decisions, to manage the team, to find organizational and managerial solutions in unusual situations	Requirements of FSES OF HE, SSES OF TPU (GC-5, 13, 14, PC-3), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
	Professional competences	
O8	Use information technology to work with information, manage it and create new information; work with information in global computer networks, understand and comply with basic information security requirements	Requirements of FSES OF HE, SSES OF TPU (GPC-1, PC-2, 6, 13, 26), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O9	Understand the importance of their specialty, strive for a responsible attitude to their work activities, demonstrate special competencies	Requirements of FSES OF HE, SSES OF TPU (PC-4), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS

	related to the uniqueness of tasks, facilities in the design and operation of NP	
O10	To use deep mathematical, natural scientific knowledge in professional activity with application of mathematical modeling of objects and processes in the field of design and operation of nuclear reactors	Requirements of FSES OF HE, SSES OF TPU (GC-1, PC-9–11), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O11	Conduct innovative scientific research on the systems and equipment of nuclear power plants and nuclear power plants, participate in the implementation of research results	Requirements of FSES OF HE, SSES OF TPU (GPC-2, PC-5- 16), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O12	Analyze and use scientific and technical information, formulate project goals, set and solve innovative problems of integrated engineering analysis in the design and operation of NPPs	Requirements of FSES OF HE, SSES OF TPU (PC-12; 17, 20), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O13	To select, create and use equipment of nuclear power plants and nuclear power plants, means of measuring thermophysical parameters and automated control, protection and control of technological processes	Requirements of FSES OF HE, SSES OF TPU (GPC-3, PC-18), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O14	Conduct a preliminary feasibility study of design developments of AS systems and nuclear power plants, prepare initial data for the selection and justification of scientific, technical and organizational solutions, carry out innovative engineering projects using	Requirements of FSES OF HE, SSES OF TPU (PC-20 – 25, PSC-1.5, 1.6, 1.8, 1.10), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS

	basic and specialized knowledge, modern design methods to achieve optimal results with taking into account the principles and means of ensuring nuclear and radiation safety	
O15	To develop design and working technical documentation, to complete completed design and engineering work in the field of designing the AS	Requirements of FSES OF HE, SSES OF TPU (PC-22), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O16	Analyze neutron-physical, technological processes and algorithms for monitoring, diagnostics, control and protection, perform neutron-physical, thermal-hydraulic and strength calculations of AS equipment and its elements in stationary and non-stationary operating modes	Requirements of FSES OF HE, SSES OF TPU (PC-6, PSC-1.4), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O17	To make an assessment of nuclear and radiation safety in the operation of nuclear power plants, as well as in handling nuclear fuel and other wastes	Requirements of FSES OF HE, SSES OF TPU (PC-29), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O18	Analyze the technologies of installation, repair and dismantling of AS equipment in relation to the conditions for the construction, operation and decommissioning of power units of NPPs	Requirements of FSES OF HE, SSES OF TPU (PC-13, 14), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
Specialization No. 1 Design and operation of nuclear power plants		
O19	o applies the basics of ensuring optimal operating conditions for a nuclear reactor, thermal mechanical equipment	Requirements of FSES OF HE, SSES OF TPU (PSC-1.14, PSC- 1.15), requirements of international standards EUR-ACE and

	and the power unit of the whole system when starting up, stopping, operating at power and switching from one power level to another in compliance with safety requirements, to perform typical operations for controlling the reactor and the power unit in a functional analytical simulator	FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O20	To carry out and analyze technological activity as an object of management, organize workplaces, provide their technical equipment, place technological equipment, monitor compliance with technological discipline and maintain technological equipment, investigate the causes of its malfunctions, take measures to eliminate them	Requirements of FSES OF HE, SSES OF TPU (PSC-1.9), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O21	To compile technical documentation and organize examination of technical documentation, compile established reports on approved forms, manage small teams of performers, plan personnel work and pay funds	Requirements of FSES OF HE, SSES OF TPU (PSC-1.9), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O22	To carry out work on standardization and preparation for certification of technical means, systems, processes, equipment and materials of nuclear power plants, to conduct an analysis of production costs for ensuring the required quality of products	Requirements of FSES OF HE, SSES OF TPU (PSC-1.11), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O23	To compose and use thermal schemes and mathematical models of processes and apparatuses of nuclear power and	Requirements of FSES OF HE, SSES OF TPU (PSC-1.1, 1.3, 1.7), requirements of international standards EUR-ACE and

	thermal mechanical installations of various types of AS, to prepare initial data for the calculation of thermal schemes	FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O24	To conduct physical experiments at the stages of physical and power start-up of the power unit in order to determine the neutron-physical parameters of the reactor installation and the AS as a whole	Requirements of FSES OF HE, SSES OF TPU (PSC-1.2), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS
O25	To apply in practice the principles of organizing the operation of modern equipment and AS devices, to understand the fundamental features of stationary and transient regimes of reactor plants and power units and the reasons for imposing restrictions in normal operation, in case of violations, repair and overloads	Requirements of FSES OF HE, SSES OF TPU (PC-8, PSC-1.12, 1.13), requirements of international standards EUR-ACE and FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS

The Ministry of Science and Higher Education of the Russian Federation
federal state autonomous educational institution of higher education
«**NATIONAL RESEARCH TOMSK POLYTECHNIC UNIVERSITY**»

School of Energy and Power Engineering

Major **14.05.02 Design, Operation and Engineering of Nuclear Power Plants**

The Butakov Research Center

ESTABLISH:

Head of Educational Program

S.V. Lavrinenko

(Signature)

(Date)

THE ASSIGNMENT
for graduation thesis

In form of:

Graduation project

(bachelor's thesis, master's thesis, graduation work/project)

For student:

Group	Full name
505И	Elsharkawy Abdelrahman Mohamed Amin

Title of the work:

Design of a power unit of a nuclear power plant with a VVER reactor with an electrical capacity of 1250 MW

Established by the order of Director (date, number)

Thesis's accomplishment deadline:

14.01.2021

TECHNICAL ASSIGNMENT:

Basis of the work (project)

(name of the object of research or design, its capacity; operating mode (consistent, periodic, cyclic etc.); type of raw material or product material; requirements to product or process;

The aim of the work is to design a nuclear power plant with a VVER-type reactor with an electrical power of 1250 MW

<p>Objectives of the work (project)</p> <p><i>(review of literature on scientific and technological achievements in the considering field of science/engineering; formulation of aims and objectives of the design or research, list of additional chapters to be developed, discussion and conclusion of the results)</i></p>	<ol style="list-style-type: none"> 1. Description of Power Unit 2. Design Calculation of a Saturated Steam Generator 3. Design NPP with WWER-1250 Type Reactor 4. Design calculation of the turbine condenser 5. Chapter (5) Financial management, resource efficiency and resource saving 6. Social responsibility
<p>List of drawings:</p> <p><i>(with exact indication of the required drawings)</i></p>	<ol style="list-style-type: none"> 1. Thermal diagram of the power unit. 2. The drawing of the steam generator. 3. The drawing of the thermal scheme of the steam turbine installation. 4. The drawing of the condenser. 5. The drawing of Primary circuit. 6. The drawing of Turbine's inlet details.
<p>Consultants on the thesis' additional sections</p>	
<p>Section</p>	<p>Consultant</p>
<p>Financial Management</p>	<p>L.Y. Spicyna, PhD</p>
<p>Social Responsibility</p>	<p>M.V. Gorbenko, PhD</p>

<p>Issue date of the assignment</p>	<p>10.06.2020</p>
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The assignment was issued by the supervisor:

Position	Full name	Degree, academic status	Signature	Date
Associate Professor of The Butakov Research Center	V.E. Gubin	PhD		

The assignment was accepted by the student:

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Student:

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School	School of Energy & Power Engineering	Department	The Butakov Research Center
Educational level	Engineering Physicist	Specialization	14.05.02 Design, Operating and Engineering of Nuclear Power Plants

Initial data for the section “Financial Management, Resource Efficiency and Resource Saving”:

1. <i>The cost of scientific research resources: material, technical, energy, financial, informational and human</i>	<i>Budget of research not higher than 270 000 rubles, salaries of executors not higher than 165 000 rubles</i>
2. <i>Norms and standards for spending resources</i>	<i>Supervisor’ salary – 36 000 rubles per month; engineer’ salary – 18 000 rubles per month</i>
3. <i>The system of taxation used, tax rates, volumes of payments, discounts and loans</i>	<i>Coefficient of incentive bonuses 30%, coefficient of incentives for the manager for conscientious work activity 25%; contributions for social funds are 30,2% totally</i>

Problems to research, calculate and describe:

1. <i>Assessment of the commercial potential of engineering solutions</i>	<i>Comparison of the condensers’ types</i>
2. <i>Planning of research and constructing process and making schedule for all periods of the project</i>	<i>Calendar plan of the project</i>
3. <i>Requirement for investments</i>	<i>Costs calculations</i>
4. <i>Budgeting an engineering project</i>	<i>Creation of the project budget</i>
5. <i>Calculation of resource, financial, social, budgetary efficiency of an engineering project and potential risks</i>	<i>List of resource requirements</i>

Graphic materials

1. <i>Scorecard of competitive advantages</i>
2. <i>Competitive power of the project</i>
3. <i>Gantt diagram</i>
4. <i>The budget for scientific and technical research</i>

Assignment date	
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Consultant:

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Student:

Group	Name	Signature	Date
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Initial data to the section «Social responsibility»:	
1. Characteristics of the object of study (substance, material, device, algorithm, method, working area) and its areas of application	The object of study is a Nuclear Power Plant with 1250 MW capacity with a single stage intermediate reheating of steam.
The list of issues to be investigated, designed and developed:	
1. Legal and organizational safety issues: Special legal norms of labor legislation. Organizational arrangements for the layout of the working area.	1.1 Special legal norms of labor legislation. 1.2 Organizational arrangements for the layout of the working area. These include: 1.2.1. microclimate of the working room; 1.2.2. illumination of the working area; 1.2.3. noise level at the workplace; 1.2.4. increased level of electromagnetic radiation.
2. Industrial safety: 2.1. Analysis of harmful and dangerous factors that can be created by object of study and laboratory during research.	2.1 Analysis of harmful and dangerous factors that can be created by object of study and laboratory during research. These include: 2.1.1 Analysis of identified hazardous factors. 2.1.2 Electrical safety. 2.2 Determination of air exchange in laboratory
3. Ecological safety:	The facility does not affect the environment. Disposal of equipment.
Safety in emergency situations: Analysis of probable emergencies that may occur in the laboratory during research. Justification of measures to prevent emergencies and the development of procedures in case of an emergency.	Fire safety

Abstract

The final qualifying work contains 165 pages, 19 figures, 46 tables, 24 sources.

Keywords: NPP, VVER, Steam generator, Condenser.

The research object of this work is the VVER-1250 power unit and its main equipment.

The purpose of this work is to design a power unit of a nuclear power plant with a VVER reactor with an electrical capacity of 1250 MW.

The work was solved Social responsibility» section and Financial management, resource efficiency and resource saving» section.

The designated goal is achieved by performing the appropriate ones.

Implementation degree: the results of the work are proposed to be used in the developed and reference power units of nuclear power plants.

Scope: energy industry.

The significance of the work lies in the implementation of competitive small and medium-sized NPP power units.

- **List of Abbreviations**

Abbreviation	Definition
NPPs	Nuclear power plants
LWRs	Light water reactors
WWER	water water energetic reactor
FA	Fuel assembly
MCP	Main circulation pipeline
ECCS	emergency core cooling system
SG	Steam generator
PWR	Pressurized water reactor
pp	Perforated plate
LPH	Low-pressure reheaters
HPH	High -pressure reheaters
CP	Condensate pump
FWP	Feed water pump
HPC	High pressure cylinder
LPC	Low pressure cylinder
SH	Super heater
FSS	Federation to the state social insurance bodies
PF	the pension fund
FFOMS	Federal Foundation Compulsory Medical Insurance
CVCS	chemical and volume control system
NCRP	National Council on Radiation Protection
LCA	life cycle analysis
MPD	maximum permissible discharge
H.E.T	Heat exchanger tubes

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Introduction

The world energy demand is growing rapidly, especially in developing countries that are trying to raise the standard of living for billions of people, many of whom do not have access to electricity or clean water. Climate change and the concern for increased emissions of greenhouse gases have brought into question the future primary reliance of fossil fuels.

With the projected worldwide increase in energy demand, concern for the environmental impact of carbon emissions, and the recent price volatility of fossil fuels, nuclear energy is undergoing a rapid resurgence. This nuclear renaissance is broad based, reaching across Asia, North America, Europe, as well as selected countries in Africa and South America.

Many countries have publicly expressed their intentions to pursue the construction of new nuclear energy plants. Some countries that have previously turned away from commercial nuclear energy are reconsidering the advisability of this decision. This renaissance is facilitated by the availability of more advanced reactor designs than are operating today, with improved safety, economy, and operations.

In the early days of nuclear power development, many different reactor types were considered and indeed prototypes were built. These included light water, heavy water, gas reactor and liquid metal-cooled fast reactor systems. The majority of the reactors in operation in the world today are light water reactors (LWRs) but there is also a sizeable fraction of heavy water reactors.

Nuclear power plants are a type of power plant that use the process of nuclear fission in order to generate electricity. They do this by using nuclear reactors in combination with the Rankine cycle, where the heat generated by the reactor converts water into steam, which spins a turbine and a generator.

Nuclear power provides the world with around 11% of its total electricity, with the largest producers being the United States and France.

Aside from the source of heat, nuclear power plants are very similar to coal-fired power plants. However, they require different safety measures since the use of nuclear fuel has vastly different properties from coal or other fossil fuels. They get their thermal power from splitting the nuclei of atoms in their reactor core, with uranium being the dominant choice of fuel in the world today. Thorium also has potential use in nuclear power production, however it is not currently in use.

Electricity was generated by a nuclear reactor for the first time ever on September 3, 1948, at the X-10 Graphite Reactor in Oak Ridge, Tennessee, US which was the first nuclear power station to power a light bulb. The second, larger experiment occurred on December 20, 1951, at the EBR-I experimental station near Arco, Idaho. On June 27, 1954, the world's first nuclear power station to generate electricity for a power grid, the Obninsk Nuclear Power Plant, started operations in Obninsk of the Soviet Union. The world's first full scale power station, Calder Hall in England, opened on October 17, 1956. The world's first full scale power station solely devoted to electricity production Calder Hall was also meant to produce plutonium—the Shipping port Atomic Power Station in Pennsylvania, United States was connected to the grid on December 18, 1957.

Nuclear reactors are very expensive to set-up, however, can provide electricity at very low operational costs as well as with significantly lower CO₂ emissions. These factors, especially the later one, appeals a lot to the governments seeking to reduce greenhouse gas emission owing to worldwide climate change concerns and also diversifying energy assets in wake of depleting fossil fuel resources.

CO₂ emission (kg CO₂-eq./kWh) for nuclear power is on a par with hydro and wind energy sources, and almost negligible as compared to fossil fuel sources such as coal, oil and natural gas.

A major impediment in the growth of the nuclear industry is its high perceived risk, as the high energy density of nuclear reactors (100 times greater than typical fossil fuel-based power) also makes it disastrous in the events of accidents.

- VVER

VVER is one of the widest spread type of reactors in the world using water as heat transfer and moderator. VVER stands for Vodo-Vodyanoi Energetichesky Reactor, which means water water energetic reactor in English. The primary coolant receives heat from the reactor core and supplies this to the secondary circuit. To avoid vaporization of the primary coolant under high temperature; the coolant pressure is kept at 155 Bar.

The name VVER is associated with a wide variety of reactor designs spanning from generation I reactors to modern generation III+ reactor designs. Power output ranges from 70 to 1300 MWe, with designs of up to 1700 MWe in development.

The design concept was oriented to an increase in economic efficiency of the NPP construction and operation, ensuring safety in accordance with the regulatory documents that were valid at the time. As developments were made to attain higher operating power with the accordance of the inherently safe systems, a new VVER design was adopted. The new Russian reactor AES-2006 (VVER-1200) represents the latest model currently offered for construction by Rosatom.

Chapter 1 – Description of Power Unit

1.1 VVER-1250

The VVER-1250 is developed from the VVER-1200 which was developed from VVER-1000. It is aimed at development of typical optimized informative-advanced project of a new generation III+ Power Unit based on VVER technology, which meets a number of target-oriented parameters using modern information and management technologies.

The main improvements from the VVER-1200 are:

- power increased to 1250 MWe gross
- upgraded pressure vessel
- improved core design to improve cooling
- further developments of passive safety systems
- lower construction and operating costs

Table 1.1 shows the main features of VVER-1000 and VVER-1250 reactors. The reactor design has been refined to optimize fuel efficiency. Specifications include a \$1.200 per kW overnight construction cost, 54-month planned construction time, a 60-year design lifetime at 90% capacity factor, and requiring about 35% fewer operational personnel than the VVER-1000.

Table 1.1 VVER-1000 and VVER-1250 main features:

Feature	VVER-1000	VVER-1250
Plant performance rated power	3000 MWe	3300 MWe
Primary pressure	15,7 MPa	16,2 MPa
Secondary pressure	6,3 MPa	7 MPa
Coolant temperature	320 °C	329 °C

VVER-1250 combines the reliability of long-proven engineering solutions with a complex of active and passive safety systems, modified taking into account the "post-Fukushima" requirements.

NPPs based on VVER-1250 are characterized by an increased level of safety, which makes it possible to classify them as "3+" generation. This has been achieved by the introduction of new "passive safety systems", which are able to function without operator intervention even when the station is completely de-energized.

At power unit No. 1 of NVNPP-2 As such systems, a passive heat removal system from the reactor, a passive catalytic hydrogen removal system, and a core melt trap are used. Another feature of the project was a double containment shell, in which the inner shell prevents the leakage of radioactive substances in accidents, and the outer shell resists natural and man-made influences, such as, for example, tornadoes or an aircraft crash.

1.2 Reactor coolant system performance

The Reactor coolant system removes the heat from the reactor core by coolant circulation in a closed circuit and provides heat transfer to the secondary side. The reactor coolant system comprises a reactor, a pressurizer and four circulation loops, each one comprising a steam generator, reactor coolant pump set and main coolant pipelines that provide the loop equipment-to-reactor connection. A steam generator links the primary and the secondary sides. The steam generator headers and heat-exchange tubes are a barrier between the primary coolant and the working medium of the secondary side and prevent the radioactive substance penetration out of the primary to the secondary side.

Table 1.2- Main parameters of VVER-1250 reactor:

Parameter	Value
Reactor nominal thermal power, MW	3300
Coolant inventory in reactor coolant system (PRZ system not considered),	290
Coolant inventory in PRZ at nominal power operation, m ³	55
Primary pressure at the core outlet, absolute, MPa	16,2
Coolant temperature at reactor inlet, °C	298,2
Coolant temperature at reactor outlet, °C	328,9
Coolant flowrate through reactor, m ³ /h	86000

1.3 The reactor

The reactor is a vertical pressure vessel (a vessel and a top head) that houses the internals (protective tube unit, core barrel, and core baffle), the core, control rods and in-core instrumentation sensors. The main joint of the vessel-to-top head that is structurally integrated into the top unit is sealed with the main joint studs.

The drive housings (RCCA nozzles) are installed on the top head nozzles. Electromagnet units designed for RCCA axial motion in the core are fastened outside the housings. The reactor is positioned in the concrete cavity with a biological and thermal shielding and a cooling system. The reactor vessel is supported and fastened by the support ring fixed in the support truss. The thrust ring, installed on the vessel flange keeps the reactor vessel from transverse displacements. Reactor fastening inside the concrete cavity at two levels safely keeps it from displacements at seismic impacts and pipeline breaks. The concrete cavity, electric equipment, in-core instrumentation nozzles and the drives are cooled by the air.

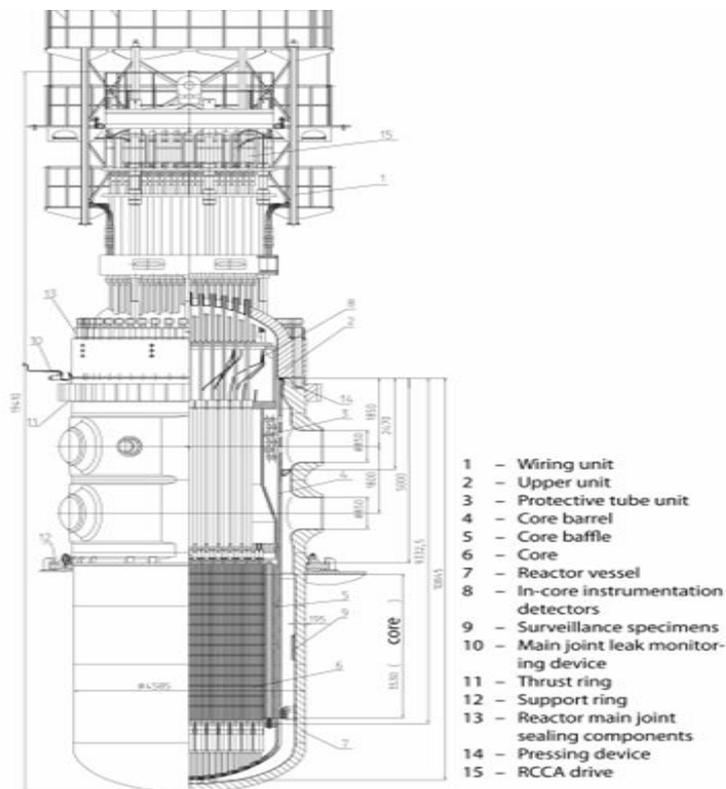


Figure 1.1- Reactor Design

Reactor core and fuel design

The reactor cores contain 163 fuel assemblies (FA). The FAs are intended for heat generation and its transfer from the fuel rod surface to coolant during the design service life without exceeding the permissible design limits of fuel rod damage. The FAs are 4570 mm high (nominal value). When the reactor is in the hot state the height of the power generating part of the fuel rod is 3750 mm. Each FA contains 312 fuel rods. The FA skeleton is assembled of 18 guide channels, 13 spacer grids welded to them, an instrumentation channel and a support grid. The fuel rod cladding is a zirconium alloy tube. Sintered UO₂ pellets with a 5% (4.95 ± 0.05) maximum enrichment are stacked inside the cladding. The average linear heat rate of a fuel rod is 167.8 W/cm.

Main coolant pipeline

The reactor, steam generator and reactor coolant pump are connected by the MCP. The MCP has four circulating loops, where each loop consists of two different parts. The parts are known as hot leg and cold leg. The internal diameter of VVER-1250 MCP is designed to be 850 mm. Fig.1.2 depicts the primary coolant flow path of VVER1250. In normal operational condition, the primary coolant water enters the reactor with an average temperature of 298 °C (cold leg temperature) and exits the Reactor Core with an average temperature of 329 °C (hot leg temperature).

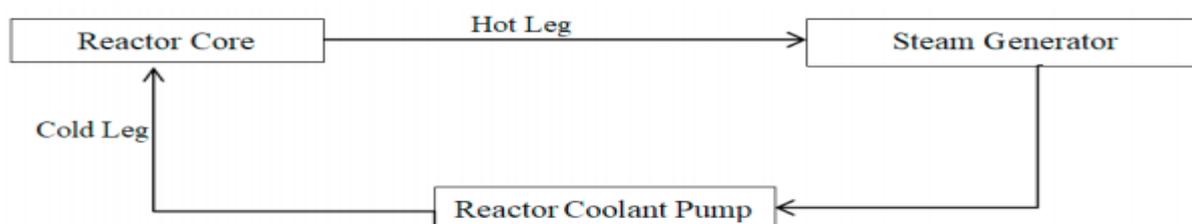


Figure 1.2- Primary Coolant Flow

1.4 Steam generator

VVER-1250 uses a four-circuit nuclear steam generating vessel installation with a thermal neutron reactor, in which ordinary water under pressure is the coolant and moderator. The design includes four cooling loops with a steam generator, a main circulation pump (MCP), a pressure compensator, relief and emergency fittings on steam pipelines, and tanks for the emergency core cooling system (ECCS) of the reactor. The main component of the primary circuit is depicted in Fig.1.1.

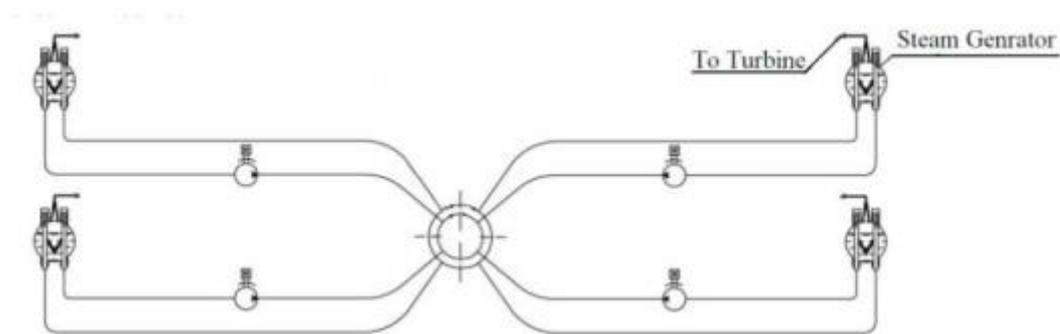


Figure 1.3- Primary Circuit Components of VVER-1250 (for 4 Loops)

Steam generator PGV-1000MKP with supports comprises the following components: steam generator, steam header, supports, shock absorbers, one- and two-chamber surge tanks, embedded components for supports and shock absorbers.

The steam generator itself is a single-vessel heat exchange apparatus of horizontal type with submerged heat-transfer surface and comprises the following components:

- a vessel with different-purpose nozzles;
- a heat-exchange bundle with fastener and spacer components;
- primary coolant collectors;
- feedwater supply and distribution systems;
- emergency feedwater supply and distribution systems;
- distribution perforated plate;
- submerged perforated plate;
- chemicals feeder.

Goal and Tasks of the project

The main goal of this project is to perform all calculations related to Design of a power unit of a nuclear power plant with a VVER reactor with an electrical capacity of 1250 MW.

There are four main categories of tasks associated with the project as stated below;

- Steam generator calculations.
- Calculations of design NPP with VVER-1250 type.
- Design calculation of the turbine condenser.
- Financial management, resource efficiency and resource saving.
- Safety and social responsibility.

Chapter 2 – Design Calculation of a Saturated Steam Generator

2.1 Thermal Calculation of the SG of Saturated Vapor

The purpose of thermal calculation of a steam generator is to determine the main dimensions of the heat exchange surface (heat exchange area, number and average length of pipes).

Table 2.1- Initial data:

Parameter	Denomination, units	Value
Coolant		Water
Thermal power of SG	Q_{sg}, MW	3300/4 = 825
Mass flow of steam	$D_{st} \text{ or } D_2, \text{ kg/s}$	421,45
Coolant flow	$G_1, \text{ kg/s}$	4634,83
Coolant pressure at the inlet to the SG	$p_1, \text{ MPa}$	17,64
Coolant temperature at the inlet to the SG	$t_1', \text{ }^\circ\text{C}$	328,9
Coolant temperature at the outlet of the SG	$t_1'', \text{ }^\circ\text{C}$	298,2
Steam pressure at the SG	$p_{st} \text{ or } p_2, \text{ MPa}$	7
Steam temperature at the outlet of the SG	$t_{st} \text{ or } t_s, \text{ }^\circ\text{C}$	285,8
Feed water temperature	$t_{fw}, \text{ }^\circ\text{C}$	200
Blowdown flow rate, % (as a percentage of mass flow of steam)	$\alpha_{bd}, \%$	0,3

Notes:

- purpose is for the production of saturated steam with natural circulation;
- thermal circuit is evaporator;
- basic type is SG WWER, horizontal, U-shaped tubes.

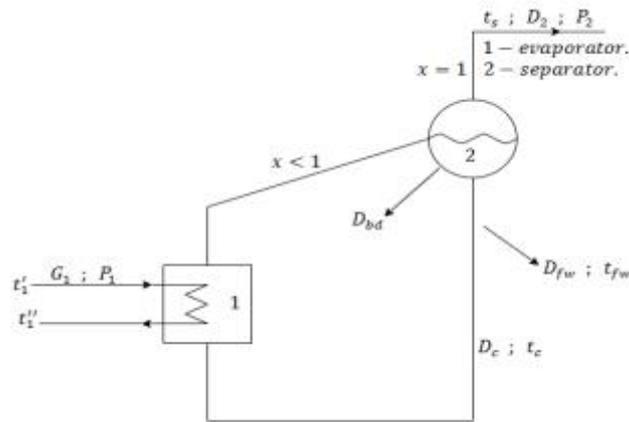


Figure 2.1 Steam generator without economizer

2.1.1 Calculation and Construction of tQ Diagram

2.1.1.1 Determination of Coolant Flow

To do this, use the heat balance equation of the steam generator (from the coolant side).

$$Q_{sg} = G_1 \cdot (h_{1inl} - h_{1out}) ;$$

$$G_1 = \frac{Q_{sg}}{(h_{1inl} - h_{1out})} = \frac{825 \cdot 1000}{(1504 - 1326)} = 4634,83 \text{ kg/s} ;$$

where:

G_1 is coolant flow rate, kg/s;

Q_{sg} is thermal power of the steam generator, kW. It is determined by the thermal power of the reactor, taking into account the number of loops;

$h_{1inl} = f(p_1, t'_1) = f(17.64, 328.9) = 1504 \text{ kJ/kg}$ is coolant enthalpy at the steam generator inlet;

$h_{1out} = f(p_1, t''_1) = f(17.64, 298.2) = 1326 \text{ kJ/kg}$ is coolant enthalpy at the outlet of the steam generator.

2.1.1.2 Determination of Steam Flow Rate

To do this, use the heat balance equation of the steam generator (from the side of the working fluid).

$$Q_{sg} = k_{hl} \cdot D_2 \cdot ((h' - h_{fw}) + (h'' - h')) + D_{bd} \cdot (h' - h_{fw});$$

$$Q_{sg} = k_{hl} \cdot D_2 \cdot ((h' - h_{fw}) + (h'' - h')) + \frac{\alpha_{bd}}{100} \cdot D_2 \cdot (h' - h_{fw});$$

$$D_2 = \frac{Q_{sg}}{k_{hl} \cdot ((h' - h_{fw}) + (h'' - h')) + \frac{\alpha_{bd}}{100} \cdot (h' - h_{fw})};$$

$$D_2 = \frac{825 \cdot 1000}{1,02 \cdot ((1267 - 855) + (2773 - 1267)) + \frac{0,3}{100} \cdot (12667 - 855)};$$

$$D_2 = 421,45 \text{ kg/s}$$

where:

D_2 is steam flow rate from the steam generator, kg/s;

$k_{hl} = 1.02$ is coefficient that takes into account heat losses in the steam generator;

$h'' = f(p_{st}) = f(7) = 2773 \text{ kJ/kg}$ is steam enthalpy at saturation temperature, kJ/kg;

$h' = f(p_{st}) = f(7) = 1267 \text{ kJ/kg}$ is steam enthalpy at saturation temperature, kJ/kg;

$h_{fw} = f(p_2, t_{fw}) = f(7, 200) = 855 \text{ kJ/kg}$ is enthalpy of feed water, kJ/kg;

$D_{bd} = \left(\frac{\alpha_{bd}}{100}\right) \cdot D_2 = (0,3/100) \cdot 421,45 = 1,26 \text{ kg/s}$ is flow rate of blowdown water.

2.1.1.3 Determination of Feed Water Flow Rate

$$D_{fw} = D_2 + D_{bd} \text{ kg/s} ;$$

$$D_{fw} = 421,45 + 1,26 = 422,71 \text{ kg/s}$$

2.1.1.4 Building a tQ Diagram

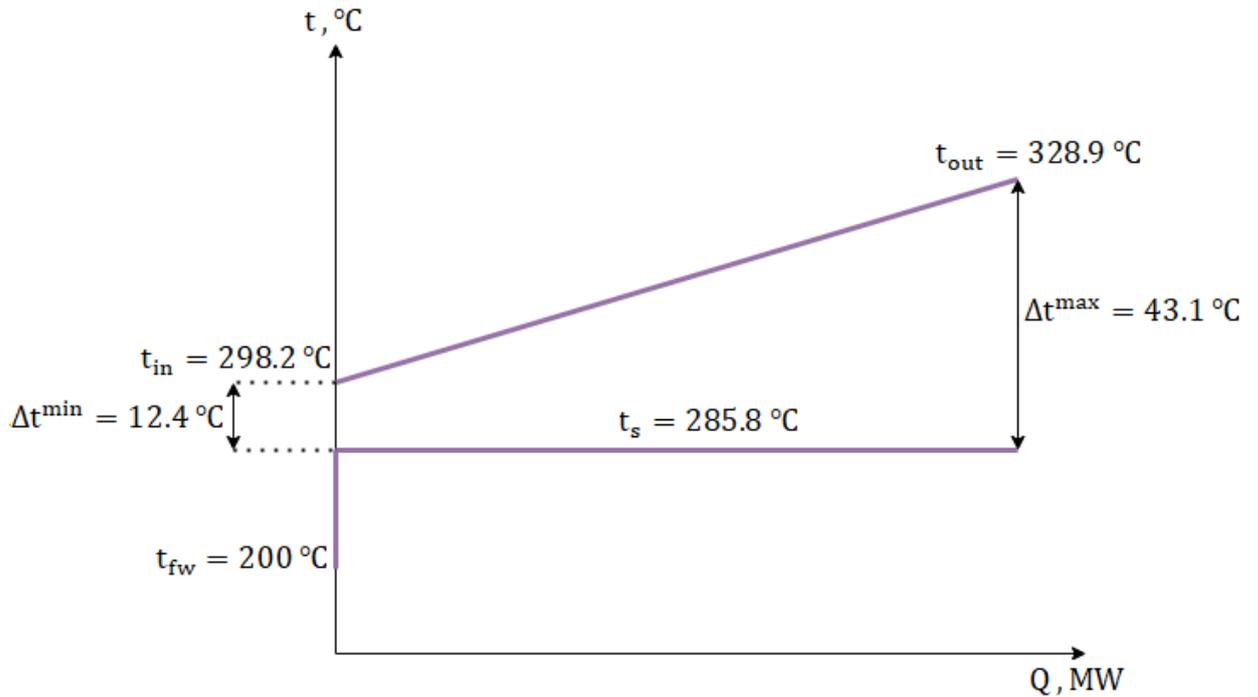


Figure 2.2- tQ-Diagrams of the Steam Generator

2.1.1.5 Choice of Tube Material, Heat Carrier Collector and Vessel

We will focus on the prototype. We accept the following steel grades:

- for heat transfer surface tubes – corrosion-resistant heat-resistant steel 08X18H10T;
- for the heat carrier collector-heat-resistant high-alloy steel 10ГН2МΦА, clad on the side washed by the heat carrier, steel 08X18H10T;
- for vessel elements - 10ГН2МΦА.

2.1.1.6 Calculation of the Wall Thickness of the Tubes of the Heat Transfer Surface of the Steam Generator

The thickness of the tube wall is determined by the conditions of sufficient strength at the maximum operating temperature, taking into account corrosion and technological factors.

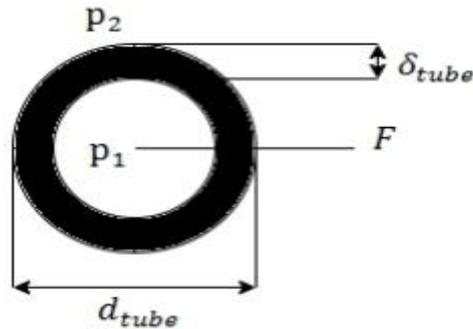


Figure 2.3- Cross Section of Heating Surface

To calculate the nominal wall thickness of tubes, use the formula:

$$\delta_{tube} = \frac{p_{calc} \cdot d_{out}}{2 \cdot \varphi \cdot [\sigma] + p_{calc}} + c ;$$

where:

δ_{tube} is in mm;

$\varphi = 1$ is coefficient of strength (load factor);

$p_{calc} = 0,9 \cdot 1,25 \cdot p_1$ is the rated (design) pressure, MPa;

$p_{calc} = 0,9 \cdot 1,25 \cdot (17,64) = 19,85 \text{ Mpa}$;

$t_{tube.max} = 0,5 \cdot (t'_1 + t_s)$ is maximum operating temperature of the tube wall, °C;

$t_{tube.max} = 0,5 \cdot (328,9 + 285,8) = 307,35 \text{ °C}$.

Where:

d_{out} is the outer diameter of the tubes, mm.

The value of the diameter of the tubes is recommended to take equal:

- 16 mm for horizontal WWER steam generators;
- 14 mm for vertical PWR steam generators.

$[\sigma]$ is nominal stress design, MPa.

$$\delta_{tube} - c = \frac{p_{calc} \cdot d_{out}}{2 \cdot \varphi \cdot [\sigma] + p_{calc}} = \frac{19,85 \cdot 16}{2 \cdot 1 \cdot [91,33] + 19,85} = 1,57 \text{ mm}$$

$$\delta_{tube} = \frac{p_{calc} \cdot d_{out}}{2 \cdot \varphi \cdot [\sigma] + p_{calc}} + c = 1,57 + 0,21 = 1,78 \text{ mm}$$

2.1.1.7 Calculate Nominal Stress Design

This stress design is defined as the minimum of two value

$$[\sigma] = \min \left\{ \frac{\sigma_{sl}}{n_{sl}}; \frac{\sigma_{0,2}}{n_{0,2}} \right\}$$

where:

$n_{sl} = 2,6$ and $n_{0,2} = 1,5$ are relevant safety factors

From Initial Data

$$t_{1,max} = t'_1 = 328,9 \text{ } ^\circ\text{C};$$

$$t_{2,max} = t_s = 285,8 \text{ } ^\circ\text{C};$$

$$t_{tube,max} = \frac{328,9 + 285,8}{2} = 307,35 \text{ } ^\circ\text{C}$$

From table 2.2 at a temperature of 307.35 degrees, selected data

$$\sigma_{sl} = 363 \text{ MPa}$$

$$\sigma_{0,2} = 137 \text{ MPa};$$

We calculate stresses taking into account safety factors

$$\frac{\sigma_{sl}}{n_{sl}} = \frac{363}{2,6} = 139,6 \text{ MPa}$$

$$\frac{\sigma_{0,2}}{n_{0,2}} = \frac{137}{1,5} = 91,33 \text{ MPa};$$

Compare the obtained values.

Nominal voltage tolerance is equal to a lower value $[\sigma] = 91,33 \text{ MPa}$

σ_{sl} is shakedown limit of the tube's material at the design temperature;

$t_{\text{calc}} = t_{\text{tube.max}}$, Mpa;

$\sigma_{0,2}$ is yield point of the tube's material at the design temperature

$t_{\text{calc}} = t_{\text{tube.max}}$, Mpa;

08H18N10T type steel is used for manufacturing steam generator tubes in Russia (Table 2.2).

Table 2.2- Melting point of metals:

$t_{\text{calc}}, ^\circ\text{C}$	100	150	200	250	300	350
σ_{sl}, MPa	412	392	392	373	363	353
$\sigma_{0,2}, \text{MPa}$	177	167	157	147	137	132

C: is an addition to the calculated wall thickness associated with a negative technological tolerance, thinning of tubes during bends and as a result of corrosion, mm

$$C_1 = 0,196 ;$$

$$C_2 = 0 ;$$

$$C_3 = 0 ;$$

$$C_4 = 0,017 ;$$

$$C = C_1 + C_2 + C_3 + C_4$$

$$C = 0,196 + 0 + 0 + 0,017 = 0,21$$

where:

C_1 is minus technological tolerance, mm. Accepted according to the data from Table 2.3 for the precision manufacturing "high accuracy".

Table 2.3- Permissible deviations of tube sizes along wall thickness:

Wall thickness, mm	The deviation value with precision manufacturing		
	Conventional accuracy	high accuracy	very high accuracy
0.5...0.6	± 0.1 mm	± 0.07 mm	
0.7... 1.0	± 0.15 mm	± 0.1 mm	
1.0... 3.0	± 15 %	± 12.5 %	± 12.5 %
> 3.0			- 10 %

C_2 is increasing the calculated wall thickness to compensate for the impact of corrosion processes, taking into account the service life of the steam generator. For austenitic steels this correction is 0;

C_3 is the necessary increase in wall thickness for technological, installation and other considerations of design and production enterprises, mm. for tubes, heating surfaces, this correction is 0;

C_4 is a decrease in the wall thickness of tubes in places of tube bends, mm. It is taken equal to the largest of the two values obtained by the formulas if:

$$[\delta_{\text{tube}} - C] \leq 0,75 \cdot 10^{-2} \cdot a = 0,75 \cdot 10^{-2} \cdot (0.1) = 7,5 \cdot 10^{-4}$$

$$C_4 = (\delta_{tube} - C) \cdot \left[\frac{1.5 \cdot \left(\frac{a}{100} \right) - 2 \cdot \left(\frac{\delta_{tube} - C}{d_{out}} \right)}{1.5 \cdot \left(\frac{a}{100} \right) - \left(\frac{\delta_{tube} - C}{d_{out}} \right)} \right];$$

if $[\delta_{tube} - C] > 0.75 \cdot 10^{-2} \cdot a$

$$C_4 = (\delta_{tube} - C) \cdot \left[1 - 2 \cdot \left(1 - \frac{b}{100} \right) \cdot \frac{2 \cdot \left(\frac{R_b}{d_{out}} \right) + 1}{4 \cdot \left(\frac{R_b}{d_{out}} \right) + 1} \right];$$

$$C_4 = 1,57 \cdot \left[1 - 2 \cdot \left(1 - \frac{11}{100} \right) \cdot \frac{2 \cdot \left(\frac{32}{16} \right) + 1}{4 \cdot \left(\frac{32}{16} \right) + 1} \right] = 0,0174;$$

where:

$R_b = (1,9 \dots 3,5) \cdot d_{out} = 2 \cdot d_{out} = 2 \cdot 16 = 32$ mm is the bending radius of the tube along the neutral line;

a is ovality of the tube in the bent section, %;

b is relative decrease in wall thickness in the stretched part of the bent section, %;

Usually accepted $a = 5 \dots 15$ % = 10 % $b = 10 \dots 30$ % = 11 %.

The tube wall thickness determined by formula is rounded to the nearest higher value available in the tube assortment (Table 2.4). Rounding to the lower side by an amount of not more than 3% is allowed

Table 2.4- Parameters of corrosion-resistant steel tubes:

Outer diameter, mm	12, 13, 14, 15, 16, 17
tube wall thickness, mm	0.8, 1.0, 1.2, 1.4, 1.5, 1.8

Then the internal diameter of the heat exchange tube will be equal:

$$d_{in} = d_{out} - (2 \cdot \delta_{tube}) = 16 - (2 \cdot 1,78) = 12,4 \text{ mm.}$$

2.1.1.8 Determining the Number of Tubes

$$N_{tube} = \frac{G_1}{\rho_{avr} \cdot w \cdot f_{1tube}} = \frac{4634,83}{701,5 \cdot 5 \cdot (1,21 \cdot 10^{-4})} = 10920 \text{ pcs}$$

where:

G_1 is coolant flow, kg/s;

$\rho_{avr} = f(p_1, t_{1avr}) = f(17.64, 313.6) = 701,5 \text{ kg/m}^3$ is the average density of the coolant;

$$t_{1avr} = \frac{328.9 + 298.2}{2} = 313,6 \text{ }^\circ\text{C}$$

w is the speed of the coolant in the tubes, m/s. Accept in the range from 4 to 6 m/s

$w = 5 \text{ m/s}$;

$$f_{1tube} = \frac{\pi \cdot d_{in}^2}{4} = \frac{\pi \cdot 12,4^2}{4} = 120,76 \text{ mm}^2 = 1,21 \cdot 10^{-4} \text{ m}^2$$

is cross-section area of one tube, m^2 .

2.1.1.9 Calculation of Heat Transfer in a Steam Generator

- **Determination of average temperature head in a steam generator**

$$\Delta t_{avr} = \frac{\Delta t_{high} - \Delta t_{low}}{\ln\left(\frac{\Delta t_{high}}{\Delta t_{low}}\right)} = \frac{43,1 - 12,4}{\ln\left(\frac{43,1}{12,4}\right)} = 24,6 \text{ }^\circ\text{C} ;$$

where:

$$\Delta t_{\text{hig}} = t'_1 - t_s = 328,9 - 285,8 = 43,1 \text{ }^\circ\text{C} \text{ is highest temperature head;}$$

$$\Delta t_{\text{low}} = t''_1 - t_s = 298,2 - 285,8 = 12,4 \text{ }^\circ\text{C} \text{ is lowest temperature head.}$$

- **Determination of the heat transfer coefficient from the coolant to the tube walls**

This coefficient can be calculated from the average parameters of the coolant p_1 and t_{1avr} using the following equation

$$\alpha_{1avr} = 0,021 \cdot \left(\frac{\lambda_{1avr}}{d_{in}} \right) \cdot (\text{Re}_{avr})^{0,8} \cdot (\text{Pr}_{avr})^{0,43}$$

$$\alpha_{1avr} = 0,021 \cdot \left(\frac{0,53804}{12,4 \cdot 10^{-3}} \right) \cdot (517788,54)^{0,8} \cdot (0,89839)^{0,43}$$

$$\alpha_{1avr} = 32428,29 \text{ W/(m}^2 \cdot \text{ }^\circ\text{C)} ;$$

where:

$$v_{1avr} = f(p_1, t_{1avr}) = f(17,64, 313,6) = 1,1974 \cdot 10^{-7} \text{ m}^2/\text{s}$$

is average kinematic viscosity of the coolant;

$$\lambda_{1avr} = f(p_1, t_{1avr}) = f(17,64, 313,6) = 0,54 \text{ W/(m} \cdot \text{ }^\circ\text{C)}$$

is the average coefficient of thermal conductivity of the coolant;

$$\text{Pr}_{avr} = f(p_1, t_{1avr}) = f(17,64, 313,6) = 0,898$$

is Prandtl criterion with medium coolant parameters;

$$\text{Re}_{avr} = \frac{w \cdot d_{in}}{v_{1avr}} = 5 \cdot \frac{12,4 \cdot 10^{-3}}{1,1974 \cdot 10^{-7}} = 517788,5$$

is Reynolds criterion with medium coolant parameters.

2.1.1.10 Determination of the heat transfer coefficient from the walls of the tubes to the working fluid

The calculation of the heat transfer coefficient from the tubes to the working fluid is carried out for two sections of the heating surface: inlet and outlet. The procedure for calculating the heat transfer coefficient α_{2in} for the input section is shown below. The calculation of the coefficient α_{1out} for the output section is carried out similarly.

Heat transfer from the wall to the working fluid in a horizontal steam generator occurs under boiling conditions in a large volume. Therefore, the calculation method is interactive and consists of the following steps:

- we accept the initial value of the heat flux $q_{in} = 3 \cdot 10^5 \text{ (W/m}^2\text{)}$ for the output section it is recommended to take $q_{out} = 6 \cdot 10^4 \text{ (W/m}^2\text{)}$;

- calculate the coefficient of heat transfer from the tubes to the working fluid

$$q_{in} = 3 \cdot 10^5 \text{ W/m}^2 ;$$

$$\alpha_{2in} = \frac{10,45}{3,3 - 0,0113 \cdot (t_s - 100)} \cdot q_{in}^{0,7} \left(\frac{\text{W}}{\text{m}^2} \right);$$

- determine the average temperature of the pipe wall in the inlet section, °C

$$t_{\text{tube.in}} = t_s + 0,3 \cdot (t'_1 - t_s), \text{ }^\circ\text{C};$$

- we calculate the average coefficient of thermal conductivity of the pipe wall in the inlet section using the approximation formula for steel 08X18H10T

$$\lambda_{\text{wal.in}} = 14,48 + 0,0156 \cdot t_{\text{tube.in}}, \text{ W/(m}\cdot\text{ }^\circ\text{C)};$$

- calculate the heat transfer coefficient

$$k_{in} = \left[\frac{1}{\alpha_{1avr}} + \frac{\delta_{\text{tube}}}{\lambda_{\text{tube.in}}} + 2 \cdot R_{ox} + \frac{1}{\alpha_2} \right]^{-1}, \text{ W/(m}^2 \cdot \text{ }^\circ\text{C)} ;$$

where:

δ_{tube} , is the wall thickness of the tubes, m;

$R_{ox} = 10^{-5} \text{ m} \cdot \text{°C}/\text{Wt}$. is the thermal resistance of the oxide film on stainless steel tubes;

- calculate the heat flow

$$q'_{in} = k_{in} \cdot (t'_1 - t_s), \text{ W/m}^2;$$

- let's compare the found heat flow q'_{in} with the one set earlier q_{in} .

If the condition $0,95 \leq \frac{q'_{in}}{q_{in}} \leq 1,05$ is met, the calculation ends. If the condition is not met, the calculation continues and the value is taken q'_{in} as the new value q_{in} .
the condition is not met, the calculation continues so must Repeat the calculation and the value is taken q'_{in} as the new value q_{in} .

- **Repeat the calculation of heat transfer ($\alpha_{out} q_{out}, k_{out}$) for the output section of the steam generator**

$$q_{out} = 6 \cdot 10^4 \text{ W/m}^2;$$

$$\alpha_{2out} = \frac{10,45}{3,3 - 0,0113 \cdot (t_s - 100)} \cdot q_{out}^{0,7}, \text{ W}/(\text{m}^2 \cdot \text{°C});$$

- determine the average temperature of the pipe wall in the inlet section, °C

$$t_{\text{tube.in}} = t_s + 0,3 \cdot (t'_1 - t_s), \text{ °C};$$

$$\lambda_{\text{wal.in}} = 14,48 + 0,0156 \cdot t_{\text{tube.in}}, \text{ W}/(\text{m} \cdot \text{°C});$$

- calculate the heat transfer coefficient

$$k_{out} = \left[\frac{1}{\alpha_{1avr}} + \frac{\delta_{tube}}{\lambda_{tube.in}} + 2 \cdot R_{ox} + \frac{1}{\alpha_2} \right]^{-1}, \text{ W}/(\text{m}^2 \cdot \text{°C})$$

- calculate the heat flow

$$q'_{out} = k_{out} \cdot (t''_1 - t_s), \text{ W/m}^2$$

Table 2.5- Results

		First Iteration	Second Iteration
Inlet	$q_{in}, W/m^2$	$3 \cdot 10^5$	266516
	$\alpha_{2in}, W/(m^2 \cdot ^\circ C)$	59395	54673
	$t_{tube}^{in}, ^\circ C$	298,7	298,7
	$\lambda_{wal}^{in}, W/(m \cdot ^\circ C)$	19,14	19,14
	$k_{in}, W/(m^2 \cdot ^\circ C)$	6183,7	6128,6
	$q'_{in}, W/m^2$	266516	264141
	q'_{in}/q_{in}	0,89	0,99
Outlet	$q_{out}, W/m^2$	$6 \cdot 10^4$	62774
	$\alpha_{2out}, W/(m^2 \cdot ^\circ C)$	19252	19871
	$t_{tube}^{out}, ^\circ C$	289,5	290
	$\lambda_{wal}^{out}, W/(m \cdot ^\circ C)$	19	18,997
	$k_{out}, W/(m^2 \cdot ^\circ C)$	5062,4	5104
	$q'_{out}, W/m^2$	62774	63292
	q'_{out}/q_{out}	1,05	1,01

2.1.1.11 Calculation of the average overall heat transfer coefficient

After completing the heat transfer calculations for the input and output sections, you can calculate the average heat transfer coefficient k_{avr} .

For this, the values of k_{in} and k_{out} are compared.

If $\left| \frac{k_{in} - k_{out}}{k_{out}} \right| \leq 0,25$, then $k_{avr} = 0,5 \cdot (k_{in} + k_{out})$;

$$\left| \frac{k_{in} - k_{out}}{k_{out}} \right| = \left| \frac{6183,7 - 5062,4}{5062,4} \right| = 0,22$$

So, we calculate with this formula

$$k_{avr} = 0,5 \cdot (k_{in} + k_{out}) = 0,5 \cdot (6183,7 + 5062,4) = 5623$$

If $\left| \frac{k_{in} - k_{out}}{k_{out}} \right| > 0,25$, then it is necessary to calculate the heat transfer coefficient in

the middle section k_{1-2} , i.e. when $t_{1avr} = 0,5 \cdot (t_1' + t_1'')$. And only then can the average heat transfer coefficient be calculated $k_{avr} = 0,333 \cdot (k_{in} + k_{out} + k_{1-2})$.

2.1.1.12 Determine the area of the heat exchange surface

$$F = \frac{k_{sf} \cdot Q_{sg}}{k_{avr} \cdot \Delta t_{avr}} = \frac{1,05 \cdot 825 \cdot 1000}{(5623 \cdot 10^{-3}) \cdot 24,6} = 6262,4 \text{ m}^2 ;$$

where:

$k_{sf} = 1,05 \dots 1,10$ is the safety factor for taking into account deposits and plugged tubes, and we assumed it by 1,05

k_{avr} is the average heat transfer coefficient $5623 \cdot 10^{-3} \text{ kW}/(\text{m}^2 \cdot ^\circ\text{C})$;

Q_{sg} is thermal power of the steam generator, $825 \cdot 10^3 \text{ kW}$;

Δt_{avr} is average temperature head in the steam generator, $24,6^\circ\text{C}$

2.1.1.13 Calculate the average length of one tube of the steam generator

$$l_{avr} = \frac{F}{\pi \cdot d_{avr} \cdot N_{tube}} = \frac{6262,4}{\pi \cdot (14,2 \cdot 10^{-3}) \cdot 10920} = 12,86 \text{ m} ;$$

Where:

$d_{avr} = 0,5 \cdot (d_{out} + d_{in}) = d_{in} + \delta_{tube}$ is the average diameter of the heat transfer tubes, m;

$$d_{avr} = 0,5 \cdot (16 + 12,4) = 14,2 \text{ mm} = 0,0142 \text{ m}$$

N_{tube} is number of tubes in the steam generator which is = 10920 pcs

Attention! The maximum length of pipes for a horizontal steam generator should not exceed 17 m, for a vertical one - 20 m.

2.2 Design Calculation of Horizontal SG of Saturated Vapor with U-Shaped Tubes

- **Basic Data for the Calculation**

- G_1 and D_2 is mass flow of coolant and working fluid, kg/s;
- p_{1avr} , t_{1avr} - average pressure (MPa) and coolant temperature (°C);
- p_2 is working medium pressure, MPa;
- $D_{col}^{in} = 0,75...1 = 0,75$ m is internal diameter of the collector, m;
- $S_1 = 0,022...0,025 = 0,025$ m is step between the holes along the height (vertical);
- $S_2 = 0,024...0,030 = 0,030$ m is step between holes along the circle (horizontal);
- d_{tube}^{out} - outer diameter of tubes, m;
- l_{tube} is average length of tubes, m;
- arrangement of tubes is corridor;
- collector material is steel 10ГН2МΦА.

2.2.1 Calculation of the Wall Thickness of the Collector, m

$$\delta_{coll} = \frac{P_{1calc} \cdot D_{col}^{in}}{2 \cdot \varphi_{min} \cdot [\sigma] - P_{1calc}}$$

$$\delta_{coll} = \frac{19,85 \cdot 0,75}{2 \cdot 0,36 \cdot (215) - 19,85} = 0,110 \text{ m};$$

where:

$$P_{1calc} = 0,9 \cdot 1,25 \cdot p_{1avr} \approx 0,9 \cdot 1,25 \cdot p_1 \text{ is the rated pressure, MPa};$$

$$P_{1calc} = 0,9 \cdot 1,25 \cdot 17,64 = 19,85 \text{ MPa};$$

$$D_{col}^{in} = 0,75 \text{ m};$$

$$[\sigma] = 215 \text{ MPa is nominal stress design for steel 10ГН2МΦА};$$

φ_{min} is minimum coefficient of strength. Let's accept the smallest value of

$$\varphi_1 = \frac{s_1 - d_{tube}^{out}}{s_1} \text{ and } \varphi_2 = \frac{2 \cdot (s_2 - d_{tube}^{out})}{s_2};$$

$$\varphi_1 = \frac{s_1 - d_{tube}^{out}}{s_1} = \frac{25 - (16 \cdot 10^{-3})}{25} = 0,36;$$

$$\varphi_2 = \frac{2 \cdot (s_2 - d_{tube}^{out})}{s_2} = \frac{2 \cdot (30 - (16 \cdot 10^{-3}))}{30} = 0,93;$$

So $\varphi_1 < \varphi_2$, then $\varphi_{min} = \varphi_1 = 0,36$;

If $\varphi_1 \geq \varphi_2$, then $\varphi_{min} = \varphi_2$, but if $\varphi_1 < \varphi_2$, then $\varphi_1 < \varphi_2$.

2.2.2 Outer Diameter of the Collector, m

$$D_{col}^{out} = D_{col}^{in} + 2 \cdot \delta_{coll};$$

$$D_{col}^{out} = 0,75 + 2 \cdot 0,110 = 0,97 \text{ m.}$$

2.2.3 Recalculation of Step s2 on to the Outer Diameter (Fig. 2.1), m

$$s_{2out} = s_2 \cdot \frac{D_{col}^{out}}{D_{col}^{in}};$$

$$s_{2out} = 0,030 \cdot \left(\frac{0,97}{0,75} \right) = 0,039 \text{ m}$$

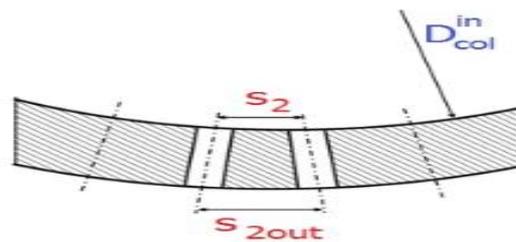


Figure 2.4- Fragment of the wall of the collector

2.2.4 The length of the arc along the Circumference of the Collector Occupied by Tubes of the Upper Row, m

$$L_{c1} = \pi \cdot D_{col}^{out};$$

$$L_{c1} = \pi \cdot 0,97 = 3,048 \text{ m.}$$

2.2.5 Number of Tubes in the Upper Row, pcs.

$$N_{tube1} = \frac{L_{c1}}{s_{2out}} ;$$

$$N_{tube1} = \frac{3,048}{0,039} = 78,5 = 79 \text{ pcs} .$$

2.2.6 The Maximum Width of the Tube Bundle at the Level of the Upper Row of Tubes (Taking into Account 3 Vertical Corridors), m

$$B_{bund}^{max} = N_{tube1} \cdot s_{2out} + 3 \cdot B_{cor} ;$$

$$B_{bund}^{max} = 79 \cdot 0,039 + 3 \cdot 0,15 = 3,5 \text{ m} .$$

where $B_{cor} = (0,15 \dots 0,2)$ assume it as 0,15 m which is width of vertical corridors.

2.2.7 Width of the Heat Exchange Tube Bundle Package, m

$$B_{pack} = \frac{B_{bund}^{max}}{2} ;$$

$$B_{pack} = \frac{3,5 - (3 \cdot 0,15)}{2} = 1,524 \text{ m} .$$

2.2.8 The distance between the axis of the collectors, m

$$B_{dac} = 2 \cdot B_{pack} + 2 \cdot B_{cor} ;$$

$$B_{dac} = (2 \cdot 1,524) + (2 \cdot 0,15) = 3,348 \text{ m} .$$

2.2.9 Width of Submerged Perforated Plate (PP), m

$$B_{pp} = (1,05 \dots 1,1) \cdot B_{bund}^{max} ;$$

$$B_{pp} = 1,1 \cdot (3,5) = 3,85 \text{ m} .$$

2.2.10 SG Vessel Width at Level Perforated Plate, m

$$B_{ves.pp} = B_{pp} + 2 \cdot B_{gap} ;$$

$$B_{ves.pp} = 3,85 + (2 \cdot 0,2) = 4,25 \text{ m} ;$$

where:

$B_{\text{gap}} = (0,15 \dots 0,025)$ assume 0,2 m is the width of the passages (the distance between the PP and the walls of the SG housing) for the flow of water, m.

2.2.11 Height of the location of the submerged perforated plate relative to the horizontal axis of the SG vessel, m

$$h_{pp} = h_0 + h_1 - h_{wl};$$

$$h_{pp} = 0,2 + 0,2 - 0,1 = 0,3 \text{ m};$$

where:

$h_0 = (0,2 \dots 0,35)$ assume 0,2 is height of the arrangement of the upper row of tubes relative to the horizontal axis of the SG;

$h_1 = (0,2 \dots 0,35)$ assume = 0,2 m is the height of the location of the weight level of water above the upper row of tubes;

$h_{wl} = 0,1 \text{ m}$ is height of the weight level above the submerged perforated plate.

2.2.12 The Distance of the Lower Row of Pipes of the Heat Exchange Surface from the Lower Generatrix of the Steam Generator Vessel

$h_{dlr} = 0,08 \dots 0,120 \text{ m}$ and we assumed it equal to 0,1 m.

2.2.13 Internal Diameter of the Steam Generator Vessel, m

$$D_{ves.in} = \sqrt{4 \cdot h_{pp}^2 + B_{ves.pp}^2};$$

$$D_{ves.in} = \sqrt{4 \cdot 0,3^2 + 4,27^2} = 4,29 \text{ m}.$$

2.2.14 Area of the Evaporation Surface, m²

$$F_{es} = B_{ves.pp} \cdot l_{tube};$$

$$F_{es} = 4,25 \cdot 12,86 = 54,66 \text{ m}^2.$$

2.2.15 Superficial Steam Velocity, m/s

$$w_0'' = \frac{D_2}{F_{es} \cdot \rho_2''} ;$$

$$w_0'' = \frac{D_2}{F_{es} \cdot \rho_2''} = \frac{421,45}{54,66 \cdot 36,5} = 0,212 \text{ m/s} ;$$

where:

ρ_2'' is density of saturated vapor at the pressure P_2 of the working fluid, kg/m³;

$$\rho_2'' = f(p_2) = f(7) = 36,5 \text{ kg/m}^3.$$

2.2.16 The True Volumetric Vapor Content in the Water Layer above the Submerged Perforated Plate, m

$$\varphi_{bub} = \frac{w_0''}{w_0'' + (0,65 - 0,039 \cdot p_2)} ;$$

$$\varphi_{bub} = \frac{0,206}{0,206 + (0,65 - 0,039 \cdot 7)} = 0,35 \text{ m}.$$

2.2.17 Actual (real) Water Level above the Submerged Perforated Plate, m

$$h_{real} = \frac{h_{wl}}{(1 - \varphi_{bub})} ;$$

$$h_{real} = \frac{0,1}{(1 - 0,35)} = 0,155 \text{ m}.$$

2.2.18 Height of Steam Volume, m

$$h_{sv} = \frac{D_{ves.in}}{2} - (h_{pp} + h_{real}) ;$$

$$h_{sv} = \frac{4,29}{2} - (0,3 + 0,155) = 1,69 \text{ m}.$$

Attention! The value h_{sv} found should be checked in terms of the effectiveness of precipitation separation.

The minimum permissible height of the vapor volume must correspond to the following condition

$$h_{sv} = 1,69 \gg 0,4 \text{ m} \quad \text{so} \quad h_{sv} \gg 0,4 \text{ m.}$$

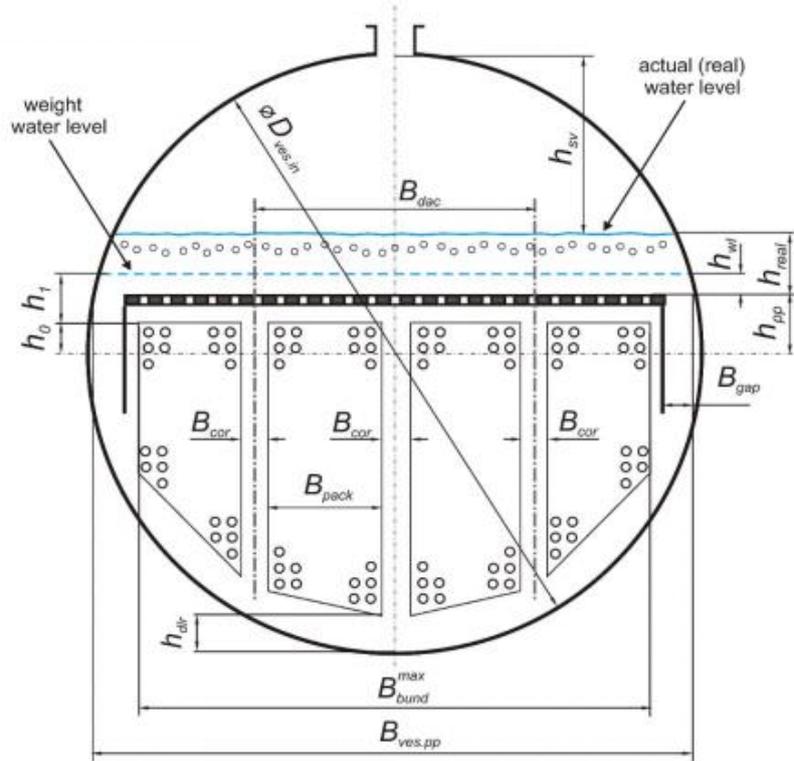


Figure 2.5- To determine the main layout dimensions horizontal SG

2.2.19 Characteristics of steam outlet nozzles

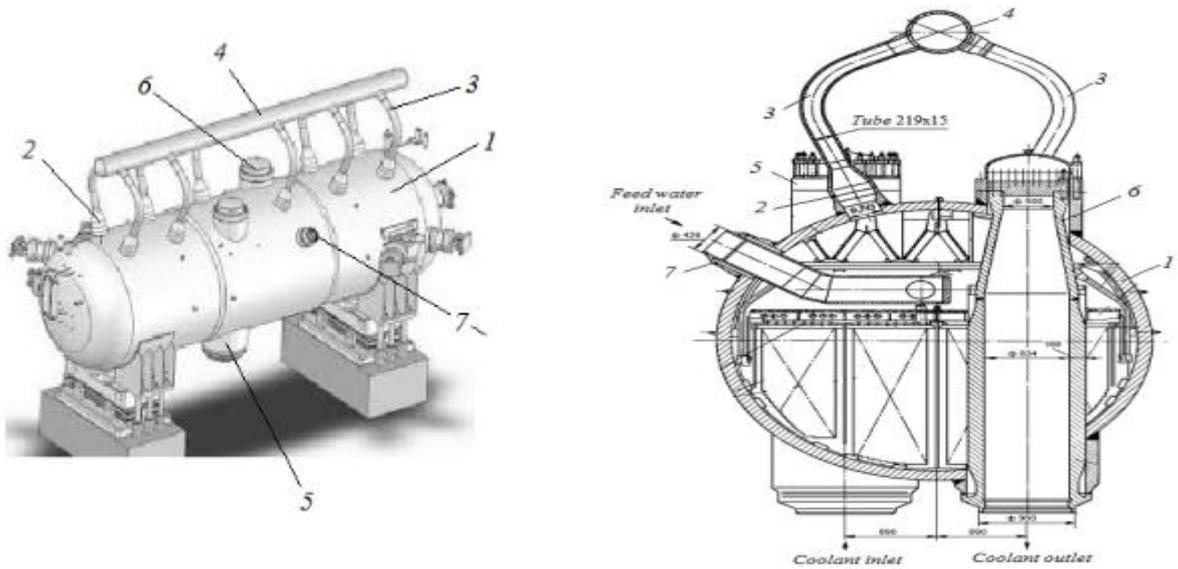


Figure 2.6- Exterior (a) and Cross section (b) of a horizontal steam generator:
 1 - vessel; 2 - steam outlet nozzles; 3 - steam pipes; 4 - steam collector; 5 - input collector of the coolant; 6 - output collector of the coolant; 7 - pipe feed water

Steam outlet nozzles 2 are used to divert the generated steam from the steam generator. They are located in pairs in the upper part of the housing 1. Two nozzles are located in the same sections as the coolant collectors (5 and 6). Steam exhaust nozzles are connected to steam pipes, which are combined by a common steam collector 4.

- **The inner diameter of the steam outlet nozzles**

$d_{noz.in}$ can be determined from the following continuity equation

$$N_{noz} \cdot \frac{\pi \cdot d_{noz.in}^2}{4} \cdot w_{noz} = \frac{D_2}{\rho''},$$

$$N_{noz} = 9 \cdot \frac{\pi \cdot d_{noz.in}^2}{4} \cdot 35 = \frac{421,45}{36,5}.$$

$$d_{noz.in}^2 = 0,047 \text{ m}; \quad d_{noz.in} = 0,216 \text{ m};$$

where:

$N_{noz} = (8...10)$ assume: 9 pc. is number of steam outlet nozzles;

$w_{noz} = 30...40 = 35 \text{ m/s}$. is steam speed in steam outlet nozzles;

D_2 is mass flow of steam, kg/s;

ρ_2'' is density of saturated steam at the pressure P_2 , kg/m³;

$$\rho_2'' = f(p_2) = 36,5 \text{ kg/m}^3.$$

2.2.20 Characteristics of the feed pipe

The inner diameter of the feed $d_{fw.in}$ can be determined from the following continuity equation.

$$\frac{\pi \cdot d_{fw.in}^2}{4} \cdot w_{fw} = \frac{D_{fw}}{\rho_{fw}};$$

$$\frac{\pi \cdot d_{fw.in}^2}{4} \cdot 4 = \frac{422,71}{868,75};$$

$$d_{fw.in}^2 = 0,155 \text{ m};$$

$$d_{fw.in} = 0,394 \text{ m};$$

where:

$w_{fw} = (4...5)$ assume: 4 m/s is feed water speed in feed pipe;

$D_{fw} = D_2 + D_{bd} = 421,45 + 1,26 = 422,71 \text{ kg/s}$ is mass flow of feed water, kg/s;

$\rho_{fw} = f(p_2, t_{fw}) = f(7, 200) = 868,75 \text{ kg/m}^3$ is density of feed water, kg/m³.

2.3 Mechanical Calculation of Horizontal SG of Saturated Vapor with U-Shaped Tubes

The purpose of the mechanical calculation is to calculate the static strength of the main elements of the steam generator and determine the wall thickness of these elements. A full mechanical calculation includes the calculation of the following elements:

- calculation of heat transfer tubes;
- calculation of coolant collectors;
- calculation of the steam generator housing

The mechanical calculation of heat transfer tubes was carried out in section 1 "Thermo-hydraulic calculation". The mechanical calculation of the collectors was carried out in section 2 "Design calculation". The mechanical calculation procedure for the steam generator housing is given below.

- **Calculation of the SG vessel**

The vessel of a horizontal steam generator (Fig. 3.1) is a thick-walled vessel of large diameter. It consists of a central shell 1, two side shells 2 and two bottoms 3. All elements are connected to each other by welding.

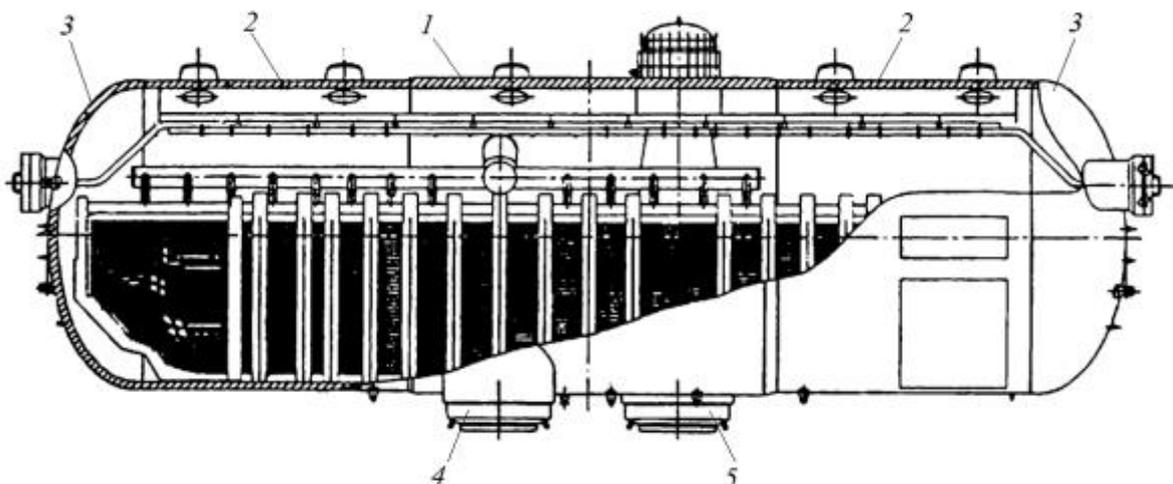


Figure 2.7- Longitudinal section of a horizontal steam generator:

1 is central shell; 2 are side shells; 3 are bottoms; 4 - input collector of the coolant;
5 - output collector of the coolant

2.3.1 Calculation of the Wall Thickness of the Side Shell

The following formula should be used to calculate the nominal wall thickness of the side shell (δ_{vss}).

$$\delta_{vss} = \frac{p_{calc} \cdot D_{ves.in}}{2 \cdot \varphi \cdot [\sigma] - p_{calc}} + C ;$$

$$\delta_{vss} - c = \frac{7,875 \cdot 4,29}{2 \cdot 1 \cdot (181,2) - 7,875} = 0,0953 \text{ m} = 95,3 \text{ mm}.$$

$$\delta_{vss} = 95,3 \text{ mm} \gg 20 \text{ mm} ;$$

So, $C = 0$;

where: δ_{vss} is in m;

$D_{ves.in} = 4,29$ m. is internal diameter of the steam generator vessel, m. It is calculated in the section "Design calculation of the steam generator";

φ is coefficient of strength (load factor). Side shells do not have large diameter holes and therefore this coefficient can be taken $\varphi = 1$;

$p_{calc} = 0,9 \cdot 1,25 \cdot p_2 = 0,9 \cdot 1,25 \cdot 7 = 7,875$ MPa is the rated (design) pressure;

$t_{vss.max} = t_s = 285,8$ °C is maximum operating temperature of the side shell;

C is increase to the nominal thickness of the shell and bottom of the vessel. This increase is assumed to be equal to:

$C = 1$ mm with a wall thickness less than 20 mm;

$C = 0$ with a wall thickness of more than 20 mm.

$[\sigma]$ is nominal stress design, MPa;

Calculate nominal stress design

This stress design is defined as the minimum of two values.

$$[\sigma] = \min \left\{ \frac{\sigma_{sl}}{n_{sl}}; \frac{\sigma_{0,2}}{n_{0,2}} \right\},$$

Where: $n_{sl}=2,6$ and $\sigma_{0,2}=1,5$ are relevant safety factors;

σ_{sl} is shakedown limit of the tube's material at the design temperature $t_{calc} = t_s$, MPa;

$\sigma_{0,2}$ is yield point of the tube's material at the design temperature $t_{calc} = t_s$, MPa;

From initial data

$$t_{calc} = t_s = 285,8 \text{ }^\circ\text{C};$$

From table 2.6 at a temperature of 307,35 °C, select

$$\sigma_{sl} = 471 \text{ MPa} \quad \sigma_{0,2} = 304 \text{ MPa};$$

We calculate stresses taking into account safety factors

$$\frac{\sigma_{sl}}{n_{sl}} = \frac{471}{2,6} = 181,2 \text{ MPa} \quad \frac{\sigma_{0,2}}{n_{0,2}} = \frac{304}{1,5} = 202,7 \text{ MPa};$$

Compare the obtained values. Nominal stress tolerance is equal to a lower value

$$[\sigma] = 181,2 \text{ MPa.}$$

10ГН2МФА type steel is used for manufacturing steam generator vessels in Russia (Table 2.6).

Table 2.6- Mechanical properties of steel 10ГН2МΦА:

$t_{calc}, ^\circ\text{C}$	100	150	200	250	300	350
σ_{sl}, MPa	510	510	510	491	471	491
$\sigma_{0,2}, \text{MPa}$	323	314	304	304	304	294

2.3.2 Calculation of the Wall Thickness of the Central Shell

The following formula should be used to calculate the nominal wall thickness of the central shell (vcs).

$$\delta_{vcs} = \frac{p_{calc} \cdot D_{ves.in}}{2 \cdot \varphi \cdot [\sigma] - p_{calc}} + C ;$$

$$\delta_{vcs} = \frac{7,875 \cdot 4,29}{2 \cdot 0,75 \cdot [181,2] - 7,875} + 0 = 0,128 \text{ m} .$$

The values of all variables in this formula can be taken as for the side shell with the exception of the coefficient of strength φ .

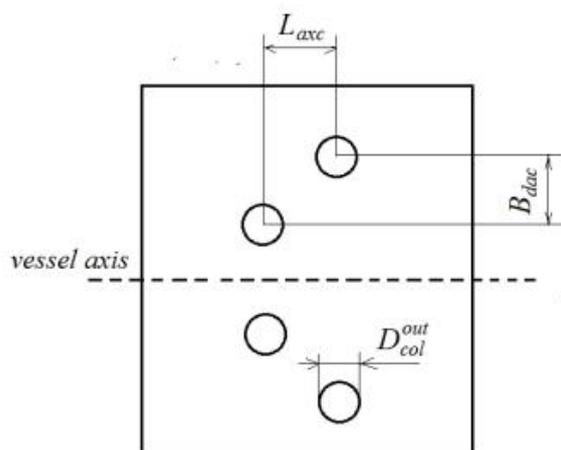


Fig. 2.8- To the calculation of the strength coefficient

In the central shell there are 4 large-diameter holes for the passage of coolant collectors. Therefore, the coefficient $\varphi = \min\{\varphi_1, \varphi_2, \varphi_3\}$ is defined as the smallest $\varphi = \min\{\varphi_1, \varphi_2, \varphi_3\}$ of the three values φ_1, φ_2 and φ_3 . The formulas for calculating these coefficients are given here.

$$\varphi_1 = \frac{2 \cdot L_{axc} - D_{col}^{out}}{2 \cdot L_{axc}} = \frac{2 \cdot 1,94 - 0,97}{2 \cdot 1,94} = 0,75 ;$$

$$\varphi_2 = \frac{2 \cdot (2 \cdot B_{dac} - D_{col}^{out})}{2 \cdot B_{dac}} = \frac{2 \cdot (2 \cdot 3,348 - 0,97)}{2 \cdot 3,348} = 1,71 ;$$

$$\varphi_3 = \frac{1 - \frac{D_{col}^{out}}{L_{axc}} \cdot \frac{1}{\sqrt{1 + m^2}}}{\sqrt{1 - 0,75 \cdot \left(\frac{m^2}{1 + m^2}\right)^2}} = \frac{1 - \frac{0,97}{1,94} \cdot \frac{1}{\sqrt{1 + 1,72^2}}}{\sqrt{1 - 0,75 \cdot \left(\frac{1,72^2}{1 + 1,72^2}\right)^2}} = 0,98 ;$$

$$\varphi_2 > \varphi_3 > \varphi_1 ;$$

because of φ_1 is minimum so we used it.

where:

δ_{vcs} is in m;

$$m = \frac{B_{dac}}{L_{axc}} = \frac{3,348}{1,94} = 1,72 \text{ m} ;$$

$B_{dac} = 3,348$ m. is the radial distance between the axis of the collectors, m. It is calculated in the section "Design calculation of the steam generator".

$L_{axc} \approx 2 \cdot D_{col}^{out} = 2 \cdot 0,97 = 1,94$ m is axial distance between collector axes, m;

$D_{col}^{out} = 0,97$ m is outer diameter of the collector, m. It is calculated in the section

"Design calculation of the steam generator".

2.3.3 Calculation of the Thickness of Bottom

$$\delta_{bot} = \frac{p_{calc} \cdot D_{ves.in}}{4 \cdot \varphi \cdot [\sigma]} \cdot \frac{D_{ves.in}}{2 \cdot h} ;$$

$$\delta_{bot} = \frac{7,875 \cdot 4,29}{4 \cdot 1 \cdot [181,2]} \cdot \frac{4,29}{2 \cdot 0,86} = 0,117 \text{ m.}$$

where:

δ_{bot} , is in m;

h is height of the bottom, m. It can be calculated from relation $\frac{h}{D_{ves.in}} \geq 0,2$

$$\frac{h}{4,29} \geq 0,2;$$

$$h = 0,2 \cdot 4,29 = 0,86 \text{ m};$$

$\varphi = 1$ is coefficient of strength;

The remaining variables in this formula are the same as when calculating the thickness of the central shell.

2.4 Hydraulic Calculation of the Steam Generator

The purpose of hydraulic calculation of the steam generator is to determine the pressure losses when the coolant moves in it. The steam generator is connected to the reactor by main circulation pipelines. The coolant enters the inlet collector from the hot circulation pipeline. Then the coolant is distributed through the heat exchange tubes, passes through them and is collected in the output collector. From the output collector, the coolant goes to the cold circulation pipeline (Figure 2.9.).

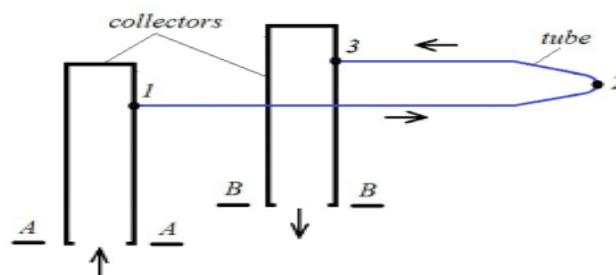


Figure 2.9- Flow diagram of the coolant circulation in a horizontal steam generator

- **The hydraulic resistance of the horizontal steam generator along the coolant path can be represented as follows:**

$$\Delta p_{\Sigma} = \Delta p_{col.in} + \Delta p_{col.out} + \Delta p_{tube};$$

$$\Delta p_{\Sigma} = 2499 + 2499 + 260980 = 265979 \text{ Pa.}$$

Where: $\Delta p_{col.in}$ and $\Delta p_{col.out}$ are hydraulic resistances of the input and output collectors; Each term in the previous equation includes friction pressure losses

Δp_{fr} , local pressure losses Δp_{loc} , static pressure differences Δp_{cpd} and pressure losses due to flow acceleration Δp_{acc} .

$$\Delta p_i = \Delta p_{fr,i} + \Delta p_{loc,i} + \Delta p_{cpd,i} + \Delta p_{acc,i}, \text{ Where: } i \text{ is plot number}$$

$$\Delta p_{total} = 279132 \text{ P.}$$

Static pressure differences and losses from flow acceleration can be ignored, taking into account a small change in the temperature and density of the coolant in a steam generator with a water coolant.

For the calculate the friction pressure losses it is necessary to use

The Altshul's formula:

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{avr} \cdot w^2}{2};$$

where: L is plot length, m;

d_h is characteristic size (hydraulic diameter), m;

$\rho_{avr} = f(p_1, t_{1avr})$ is the average density of the coolant in the SG, kg/m³.

W is the characteristic velocity of the coolant, m/s;

$$w_{col} = \frac{4 \cdot G_{col}}{\rho_{avr} \cdot \pi \cdot (D_{col}^{in})^2};$$

$\xi_{fr} = 0,11 \cdot [(\Delta/d_h) + (68/Re)]^{0,25}$ is coefficient of friction;

Δ is absolute surface roughness, m. For collectors made of perlite steel;

$\Delta_{col} \leq 0,1 \cdot 10^{-3}$ m; for tubes made of austenitic steel $\Delta_{tube} \leq 0,05 \cdot 10^{-3}$ m;

$Re = \frac{w \cdot d_h}{\nu_{avr}}$ is Reynolds number;

$\nu_{avr} = f(p_1, t_{1avr})$ is the average kinematic viscosity of the coolant in the SG.

2.4.1 For the plot lifting movement of the coolant in the inlet collector

(from section A-A to point 1):

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{avr} \cdot w^2}{2};$$

$$D_{col}^{in} = 0,75m;$$

$$\rho_{avr} = f(p_1, t_{1avr}), kg/m^3;$$

$$w_{col} = \frac{4 \cdot G_{col}}{\rho_{avr} \cdot \pi \cdot (D_{col}^{in})^2}, m/s;$$

$$d_h = D_{col}^{in} = 0.75 m;$$

$$L \approx \frac{D_{ves.in}}{2}, m;$$

$$\nu_{avr} = f(p_1, t_{1avr}), m^2/s$$

$$Re = \frac{w_{col} \cdot d_h}{\nu};$$

$$\xi_{fr.col} = 0,11 \left[\left(\frac{\Delta}{d_h} \right) + \left(\frac{68}{Re} \right) \right]^{0,25};$$

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{avr} \cdot w_{col}^2}{2}$$

2.4.2 For the plot movement of the coolant in heat exchange tubes

(from point 1 to point 3)

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{avr} \cdot w^2}{2} ;$$

$$D_{col}^{in} = 0,75 m ;$$

$$\rho_{avr} = f(p_1, t_{1avr}), kg/m^3 ;$$

$$w_{tube} = 5 m/s ;$$

$$d_h = d_{in} = 12,4 mm ;$$

$$L = l_{avr} = 13,2 m ;$$

$$v_{avr} = f(p_1, t_{1avr}), m^2/s$$

$$Re = \frac{w_{tube} \cdot d_h}{\nu} ;$$

$$\xi_{fr.col} = 0,11 \left[\left(\frac{\Delta}{d_h} \right) + \left(\frac{68}{Re} \right) \right]^{0,25} ;$$

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{avr} \cdot w_{tube}^2}{2}, pa$$

2.4.3 Downward movement of the coolant in the output collector

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{avr} \cdot w^2}{2} ;$$

$$D_{col}^{in} = 0,75m ;$$

$$\rho_{avr} = f(p_1, t_{1avr}), kg/m^3 ;$$

$$w_{col} = \frac{4 \cdot G_{col}}{\rho_{avr} \cdot \pi \cdot (D_{col}^{in})^2}, m/s ;$$

$$d_h = D_{col}^{in} = 0,75 m ;$$

$$L \approx \frac{D_{ves.in}}{2}, m ;$$

$$v_{avr} = f(p_1, t_{1avr}), \text{ m}^2/\text{s};$$

$$Re = \frac{w_{col} \cdot d_h}{\nu};$$

$$\xi_{fr.col} = 0,11 \left[\left(\frac{\Delta}{d_h} \right) + \left(\frac{68}{Re} \right) \right]^{0,25};$$

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{L}{d_h} \cdot \frac{\rho_{avr} \cdot w_{col}^2}{2};$$

2.4.4 For the calculate of local pressure losses

It is necessary to use the following formula

$$\Delta p_{loc} = \xi_{loc} \cdot \frac{\rho_{avr} \cdot w^2}{2};$$

where:

ξ_{loc} is local resistance coefficient. The values of this coefficient for some types of local resistances are given in the table 2.7.

Table 2.7- The values of the coefficient of local resistance:

Type of local resistance	Coefficient value ξ_{loc}
Inlet of the coolant to the tubes from the collector	0,5
Output of the coolant from the tubes to the collector	1
Rotation of the coolant in U-shaped tubes	0,5

2.4.4.1 For the Plot Inlet of the Coolant to the Tubes from the Collector (Point 1):

$$\Delta p_{loc} = \xi_{loc.in} \cdot \frac{\rho_{avr} \cdot w_{tube}^2}{2}, Pa .$$

2.4.4.2 For the plot Output of the coolant from the tubes to the collector (point 3):

$$\Delta p_{loc} = \xi_{loc.in} \cdot \frac{\rho_{out} \cdot w_{out}^2}{2}, Pa .$$

Table.2.8- Summarize of the results:

	ρ	w	d_h	ν	Re	ξ_{fr}	L	Δp_{fr}
fr inlet collector	701,5	14,5	0,75	$1,2 \cdot 10^{-7}$	90878925	0,01184	2,14	2499
fr in H.E.T	701,5	5	0,01240	$1,2 \cdot 10^{-7}$	517789	0,02794	13,21	260980
fr outlet collector	701,5	14,5	0,75	$1,2 \cdot 10^{-7}$	90878925	0,01184	2,14	2499
	loc	Δp_{loc}					SUM	265979
ξ_{tube}^{in}	0,5	4384						
ξ_{tube}^{out}	1	8769						
SUM	-	13153						

Then:

$$\Delta p_{total} = 265979 + 13153 = 279132 Pa.$$

The General scheme, characteristic parameters and results of hydraulic calculation of the horizontal steam generator are presented in the Table.2.9.

Table.2.9- Characteristic parameters and results of hydraulic calculation of the horizontal steam generator:

№	Plot name	Type of hydraulic Resistance.	Characteristic coolant velocity, m/s	Characteristic dimensions, m	Pressure losses, Pa
1	Lifting movement of the coolant in the inlet collector (from section A-A to point 1)	Pressure drops due to friction. Friction factor $\xi_{fr.col}$ (Altshul formula)	$W_{col} = 14.5$ m/s (the continuity equation for the collector)	$d_h = D_{col}^{in} = 0.75$ m $L \approx D_{ves.in} / 2 = 4.29 / 2 = 2.145$ m (section 2 "Design calculation")	2499
2	Inlet of the coolant to the tubes from the collector (point 1)	Local pressure drops Local resistance coefficient $\xi_{loc.in}$	$W_{tube} = 5$ m/s (section 1.4. «Thermal calculation»)	$d_h = d_{in} = 0.0124$ m (section 1.3. «Thermal calculation»)	4384
3	Movement of the coolant in heat exchange tubes (from point 1 to point 3)	Pressure drops due to friction. Friction factor $\xi_{fr.tube}$ (Altshul formula)	$W_{tube} = 5$ m/s (section 1.4. «Thermal calculation»)	$d_h = d_{in} = 12.4$ mm $L = l_{avr} = 12.81$ m (section 1.3. «Thermal calculation»)	260980
4	Output of the coolant from the tubes to the collector (point 3)	Local pressure drops Local resistance coefficient $\xi_{loc.out}$	$W_{tube} = 5$ m/s (from section 1.4. «Thermal calculation»)	$d_h = d_{in} = 12.4$ mm (from section 1.3. «Thermal calculation»)	8769
5	Downward movement of the coolant in the output collector (from point 3 to section B-B)	Pressure drops due to friction. Friction factor $\xi_{fr.col}$ (Altshul formula)	$W_{col} = 14.5$ m/s (from the continuity equation for the collector)	$d_h = D_{col}^{in} = 0.75$ m $L \approx D_{ves.in} / 2 = 4.29 / 2 = 2.145$ m (section 2 "Design calculation")	2499

2.5 Calculation of Separation in a Horizontal Saturated Steam Generator

Modern horizontal saturated steam generators do not have louver separators and the main method of steam dehumidification is gravity separation in the steam volume. Therefore, the purpose of calculating separation in a horizontal steam generator is to estimate the humidity of steam in front of the steam receiving ceiling, which is located at the top of the steam volume.

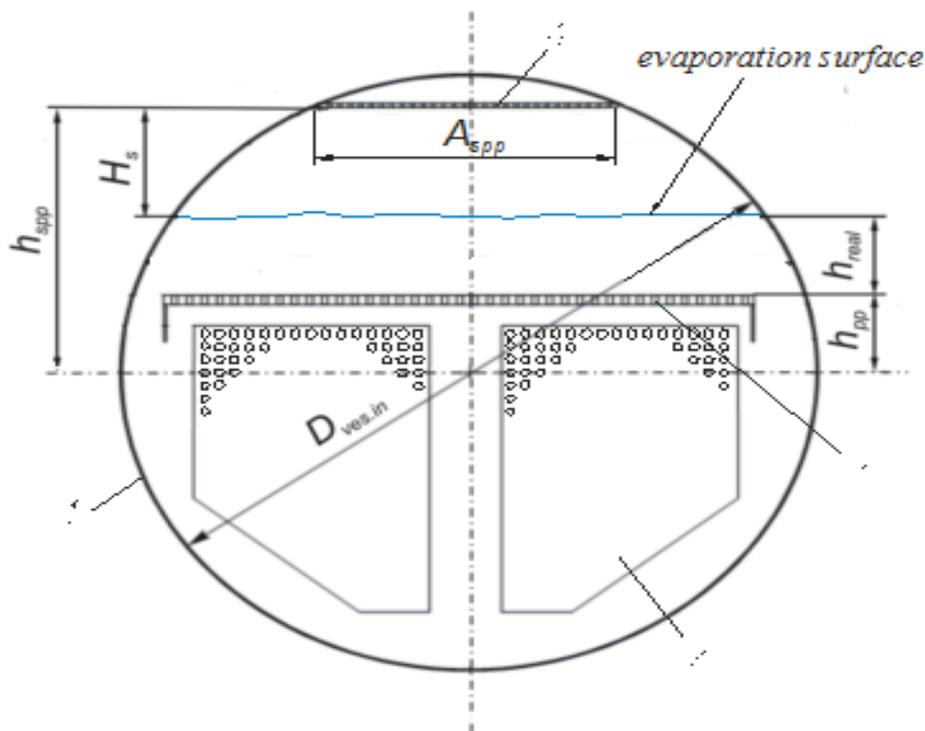


Figure 2.10- To the calculation of separation

1 is vessel; 2 are tubes; 3 is submerged perforated plate; 4 is steam-receiving perforated plate

The procedure for calculating separation in a horizontal steam generator is given below.

- **Basic data for the calculation:**

- $D_2 = 421,45 \text{ kg/s}$ is mass flow of working fluid (steam);
- $p_2 = 7 \text{ MPa}$ is working medium pressure;
- $D_{ves.in} = 4,29 \text{ m}$, is internal diameter of the steam generator vessel, m. It is calculated in the section "Design calculation of the steam generator";
- $F_{es} = 54,66 \text{ m}^2$ is area of the evaporation surface, m^2 . It is calculated in the section "Design calculation of the steam generator";
- $l_{avr} = 12,86 \text{ m}$ is average length of tubes. It is calculated in the section "Thermal calculation of the SG of saturated vapor".
- $w_0'' = 0,212 \text{ m/s}$ is superficial steam velocity. It is calculated in the section "Design calculation of the steam generator".

2.5.1 Determination of the Area Steam-Receiving Perforated Plate

$$F_{spp} = A_{spp} \cdot l_{avr} = 2,574 \cdot 12,86 = 33,1 \text{ m}^2 ;$$

where:

$$A_{spp} = 2 \cdot \sqrt{\left(\frac{D_{ves.in}}{2}\right)^2 - (h_{spp})^2} \text{ is width of the steam-receiving perforated plate;}$$

$$A_{spp} = 2 \cdot \sqrt{\left(\frac{4,29}{2}\right)^2 - (1,716)^2} = 2,574 \text{ m}^2;$$

$$h_{spp} = (0,8 \dots 0,85) \cdot \frac{D_{ves.in}}{2};$$

$$h_{spp} = (0,8) \cdot \frac{4,29}{2} = 1,716 \text{ m. (} h_{spp} \text{ is height of the steam-receiving perforated plate relative to the axis of the SG vessel m).}$$

2.5.2 Distance (height) from the Evaporation Surface to Steam-Receiving Perforated Plate

$$H_s = h_{spp} - h_{pp} - h_{real} = 1,716 - 0,3 - 0,155 = 1,261 \text{ m};$$

where:

$h_{pp} = 0,3 \text{ m}$, is height of the location of the submerged perforated plate relative to the horizontal axis of the PG vessel. It is calculated in the section "Design calculation of the steam generator";

$h_{real} = 0,155 \text{ m}$, is actual (real) water level above the submerged perforated plate. It is calculated in the section "Design calculation of the steam generator".

2.5.3 Steam Velocity before Steam-Receiving Perforated Plate

$$w''_{spp} = \frac{D_2}{\rho'' \cdot F_{spp}} = \frac{421,45}{36,5 \cdot 33,1} = 0,35 \text{ m/s} ;$$

where:

$\rho'' = f(p_2) = 36,5 \text{ kg/m}^3$, is vapor density at saturation at pressure.

2.5.4 Determining the Critical Height of the Steam Volume

$$H_{sv}^{cr} = 0,087 \cdot [w_0'' \cdot F(p)]^{1,3} ;$$

$$H_{sv}^{cr} = 0,087 \cdot [0,206 \cdot 12,37]^{1,3} = 0,29 \text{ m};$$

where:

$$F(p) = 3,45 \cdot 10^3 \cdot \left[\frac{\rho'' \cdot (\rho')^2}{(\rho' - \rho'')^6} \right]^{0,25} ;$$

$$F(p) = 3,45 \cdot 10^3 \cdot \left[\frac{36,5 \cdot (739,7)^2}{(739,7 - 36,5)^6} \right]^{0,25} = 12,37 ;$$

where:

$\rho'' = f(P_2) = 36,5 \text{ kg/m}^3$ is vapor density at saturation at pressure;

$\rho' = f(P_2) = 739,7 \text{ kg/m}^3$ is water density at saturation at pressure.

2.5.5 Steam moisture at the top of the steam volume

Because of $H_s > H_{sv}^{cr}$ we used this formula

If $H_s > H_{sv}^{cr}$, then

$$Y = M \cdot 10^{-4} \cdot \frac{(w_0'')^{2,76}}{H_s^{2,3}} ;$$

$$Y = 27,82 \cdot 10^{-4} \cdot \left(\frac{(0,206)^{2,76}}{1,261^{2,3}} \right) = 0,00207 \% ;$$

where:

M is a pressure dependent coefficient. Determined by the following formula

$$M = 2,05 - (3,049 \cdot p_2) + (0,9614 \cdot p_2^2) ;$$

$$M = 2,05 - (3,049 \cdot 7) + (0,9614 \cdot 7^2) = 27,82 ;$$

The following condition must be met $Y \leq Y_{cr}$.

Attention! The found value Y should be compared with the maximum allowable moisture $Y_{cr} = 0,2 \%$ at the exit of the steam generator.

The following condition must be met $Y \leq Y_{cr}$.

2.6 Calculation of Thermal Insulation of the Steam Generator

Thermal insulation of the steam generator is used to reduce heat loss to the environment during operation of the power unit. Thermal insulation is also necessary to protect personnel from burns in contact with a hot surface.

As a thermal insulation material for the NPP steam generator, you can use mats of the MTP-as brand made of super-thin glass fiber.

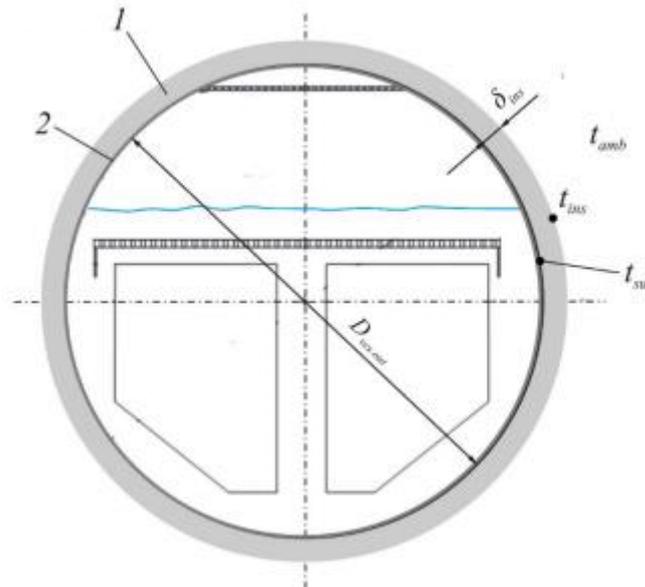


Fig. 2.11- Design scheme of single-layer thermal insulation with a coating layer:

(1- is thermal insulation; 2- is vessel of SG)

Several methods for calculating the thickness of the thermal insulation layer exist depending on the purpose of thermal insulation, namely:

- by the set temperature on the surface of an isolated object;
- for a given heat flux density;
- according to the set speed of cooling or heating of substances in containers, etc.

We will use the first method for calculating the thickness of the insulating layer of a steam generator.

The temperature on the insulation surface t_{ins} is assumed to be equal:

for insulated surfaces located in closed rooms 45 °C; in the open air 60 °C with a plaster protective coating and 50...55 °C with a metal coating.

The thickness of the heat-insulating layer, providing a given temperature on the surface of a single-layer insulation, is determined by the formulas:

for flat and cylindrical surfaces with a diameter of 2 m and more.

$$\delta_{ins} = \frac{\lambda_{ins} \cdot (t_{sur} - t_{ins})}{\alpha_{out} \cdot (t_{ins} - t_{amb})};$$
$$\delta_{ins} = \frac{0,069 \cdot (285,8 - 45)}{6 \cdot (45 - 20)} = 0,111 \text{ m.}$$

For cylindrical objects with a diameter of less than 2 m.

$$\frac{d_{ins}}{d_{out}} \cdot \ln \frac{d_{ins}}{d_{out}} = \frac{2 \cdot \lambda_{ins} \cdot (t_{sur} - t_{ins})}{\alpha_{out} \cdot (t_{ins} - t_{amb})},$$

In this equation:

δ_{ins} is the thickness of the insulation layer, m;

d_{ins} is outer diameter of insulation, m;

$$d_{out} = D_{ves.out} = D_{ves.in} + (2 \cdot \delta_{vss}) = 4,29 + (2 \cdot 0,095) = 4,48 \text{ m}$$

is diameter of the external insulated object, m;

$D_{ves.in} = 4,29$ m is internal diameter of the steam generator vessel, m. It is calculated in the section "Design calculation of the steam generator";

$\delta_{vss} = 0,095$ m is the central shell's wall thickness of the steam generator vessel, m. It is calculated in the section " Mechanical calculation of the steam generator";

$t_{sur} = t_s = 285,8$ °C is surface temperature of the insulated object, °C;

in practical calculations, an equal temperature of the medium (coolant);

$t_{amb} = 20...25$ °C, assume 20 °C is the temperature of the ambient air(environment);

$\alpha_{out} = 6 \dots 10$ W/(m² · k) and we assumed it as 6 W/(m² · k);

- Where:

α_{out} is the coefficient of heat transfer from the insulation surface to the surrounding air;

λ_{ins} is coefficient of thermal conductivity of the insulation layer, W/(m·K). It determined by the formula:

$$\lambda_{ins} = 0,0002 \cdot t_{ins}^{avr} + 0,036 ;$$

$$\lambda_{ins} = 0,0002 \cdot (165,4 + 0,036) = 0,069 .$$

For super-thin fiberglass mats;

$t_{ins}^{avr} = 0,5 \cdot (t_{sur} + t_{ins})$ is average temperature of the insulation layer, °C .

$$t_{ins}^{avr} = 0,5 \cdot (285,8 + 45) = 165,4$$
 °C .

Chapter 3 - The Task is to Design NPP with WWER Type Reactor

The purpose of this task is to determine calculation of process to calculate relative flow rate for every part and determine steam flow a turbine and indicators of energy efficiency of steam turbine installation and power plant and to choose of equipment for the water -steam circuit.

Table 3.1- Initial Data:

Ne, MW	1250	electrical power
p_2 , MPa	7	Steam pressure at the SG
p_0 , MPa	6,58	Initial pressure
t_0 , °C	281,6	Initial temperature
p_c , kPa	6	Pressure of condenser
superheater	1	Number of stages of superheater
t_{fw} , °C	200	Temperature of feedwater
p_d , MPa	0,8	Pressure of deaerator

Notes:

$$p_0 = (0,94 \dots 0,95) p_2 = 0,94 \cdot 7 = 6,58 \text{ Mpa}$$

$$t_0 = f(p_0) = 281,6 \text{ °C}$$

3.1 Determination Of the Composition And Parameters Of The Designed Turbine Installation Of The Power Unit

3.1.1 Feedwater regenerative heater

3.1.1.1 Low pressure regenerative heater

- Main condensate temperature at the inlet to the deaerator t_{mc}

$$t_{mc} = t_d - \Delta t_d ;$$

where:

t_d is temperature in deaerator;

Δt_d is difference temperature and it between $\Delta t_d = 12 \div 15 \text{ }^\circ\text{C}$;

assume $\Delta t_d = 12 \text{ }^\circ\text{C}$;

$$t_d = f(p_d) = f(0,8) = 170,4 \text{ }^\circ\text{C} ;$$

$$t_{mc} = t_d - \Delta t_d = 170,4 - 12 = 158,4 \text{ }^\circ\text{C} .$$

- **Main condensate temperature after seal coolers and ejector temperature**

t_{cse}

$$t_{cse} = t_c + \Delta t_{cse} ;$$

where:

t_c is final temperature;

Δt_{cse} is and it between $\Delta t_{cse} = 3 \div 5^\circ\text{C}$, assume $\Delta t_{cse} = 4 \text{ }^\circ\text{C}$;

$$t_c = f(p_c) = f(0,006) = 36,2 \text{ }^\circ\text{C} ;$$

$$t_{cse} = t_c + \Delta t_{cse} = 36,2 + 4 = 40,2 \text{ }^\circ\text{C} ;$$

$$h_{cse} = f(t_{cse}) = f(40,2) = 168,4 \text{ kJ/kg} .$$

- **Temperature rises after each low-pressure heater**

$\Delta t_{LPH} = 25 \div 35$ assume $\Delta t_{LPH} = 30^\circ\text{C}$

$$\Delta t_{mcs} = \frac{t_{mc} - t_{cse}}{Z_{LPH}} ;$$

where:

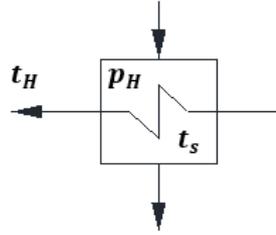
Z_{LPH} number of low-pressure reheaters,

$$Z_{LPH} = \frac{t_{mc} - t_{cse}}{\Delta t_{LPH}} = \frac{158,4 - 40,2}{30} \approx 4 ;$$

Real temperature rises after each heater;

$$\Delta t_{mcs} = \frac{t_{mc} - t_{cse}}{Z_{LPH}} = \frac{158,4 - 40,2}{4} = 29,6 \text{ }^\circ\text{C} .$$

- **Closed type**



$$t_{sj} = t_{mcj} + \theta_{LPH}; p_{Hj} = f(t_{sj})$$

Where: $\theta = (1 \div 2)$ is subcooled temperature in reheater, assume $1,59 \text{ }^\circ\text{C}$

$$t_{Hj} = t_{Hj+1} + \Delta t_{LPH}; p_{exj} = (1,02 \div 1,05)p_{Hj}; \text{ assume } (1,03).$$

- **Closed**

$$t_{mc2} = t_{mc1} - \Delta t_{mcs} = 158,4 - 29,6 = 128,9 \text{ }^\circ\text{C};$$

$$t_{s2} = t_{mc1} + \theta_{LPH} = 158,4 + 1,59 = 160 \text{ }^\circ\text{C};$$

$$p_{H2} = f(t_{s2}) = f(160) = 0,618 \text{ MPa};$$

$$p_{ex2} = 1,03 \cdot (p_{H2}) = 1,03 \cdot (0,618) = 0,637 \text{ MPa}.$$

- **closed**

$$t_{mc3} = t_{mc2} - \Delta t_{mcs} = 128,9 - 29,6 = 99,3 \text{ }^\circ\text{C};$$

$$t_{s3} = t_{mc2} + \theta_{LPH} = 128,9 + 1,59 = 130,4 \text{ }^\circ\text{C};$$

$$p_{H3} = f(t_{s3}) = f(130,4) = 0,274 \text{ MPa};$$

$$p_{ex3} = 1,03 \cdot (p_{H3}) = 1,03 \cdot (0,274) = 0,282 \text{ MPa}.$$

- **closed**

$$t_{mc4} = t_{mc3} - \Delta t_{mcs} = 99,3 - 29,6 = 69,7 \text{ }^\circ\text{C};$$

$$t_{s4} = t_{mc3} + \theta_{LPH} = 99,3 + 1,59 = 100,9 \text{ }^\circ\text{C};$$

$$p_{H4} = f(t_{s4}) = f(100,9) = 0,105 \text{ MPa};$$

$$p_{ex4} = 1,03 \cdot (p_{H4}) = 1,03 \cdot (0,105) = 0,108 \text{ MPa}.$$

- **closed**

$$t_{mc5} = t_{mc4} - \Delta t_{mcs} = 69,7 - 29,6 = 40,2 \text{ }^\circ\text{C};$$

$$t_{s5} = t_{mc4} + \theta_{LPH} = 69,7 + 1,59 = 71,3 \text{ }^\circ\text{C};$$

$$p_{H5} = f(t_{s5}) = f(71,3) = 0,033 \text{ MPa};$$

$$p_{ex5} = 1,03 \cdot (p_{H5}) = 1,03 \cdot (0,033) = 0,034 \text{ MPa}.$$

Table 3.2- Low pressure heater parameters:

Type	NO	$t_{Hj}, ^\circ\text{C}$	$t_{sj}, ^\circ\text{C}$	p_{Hj}, MPa	p_{exj}, MPa
CL	2~mc	158,4	160	0,618	0,637
CL	3	128,9	130,4	0,274	0,282
CL	4	99,3	100,9	0,105	0,108
CL	5	69,7	71,3	0,033	0,034
-	cse	40,2	-	-	-

- **Condensate pumps pressure p_{cp}**

$$p_{cp} = (1,1 \div 1,4)p_d ;$$

$$p_{cp} = 1,2(p_d) = 1,2(0,8) = 0,96 \text{ MPa} .$$

3.1.1.2 High pressure feedwater regenerative heater

- **Temperature of feed water pump t_{fwp}**

$$t_{fwp} = 171,4 \text{ } ^\circ\text{C} ;$$

where:

$$p_{fwp} \text{ is pressure of feed water, } p_{fwp} = (1,2 \div 1,3)p_0 ,$$

$$h_{fwp} \text{ is enthalpy of feed water, } h_{fwp} = h'_d + \Delta h_{fwp} .$$

- **Pressure of feed water pump**

$$p_{fwp} = 1,3(p_0) = 1,3 \cdot (6,58) = 8,6 \text{ MPa} .$$

- **Enthalpy of feed water pump**

$$h_{fwp} = h'_d + \Delta h_{fwp} ;$$

Where:

- h'_d is enthalpy of water in deaerator

$$h'_d = f(p_d) = f(0,8) = 721 \text{ kJ/kg};$$

$$\Delta h_{fwp} = v(p_{fwp} - p_d), \text{ where } v \text{ is specific volume;}$$

$$v = f(p_d) = f(0,8) = 0,0011 \text{ m}^3/\text{kg};$$

$$\Delta h_{fwp} = v(p_{fwp} - p_d) = 0,0011(8,6 - 0,8) \cdot 10^3 = 8,7 \text{ kJ/kg};$$

$$h_{fwp} = h'_d + \Delta h_{fwp} = 721 + 8,7 = 729,7 \text{ kJ/kg};$$

$$t_{fwp} = f(p_{fwp}, h_{fwp}) = 171,4 \text{ }^\circ\text{C}.$$

- **Temperature rises after each high-pressure heater**

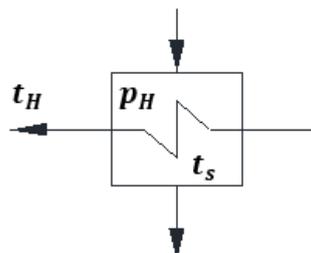
$$\Delta t_{HPH} = 25 \div 35$$

$$t_{fwh} = 200 - 2 = 198 \text{ }^\circ\text{C};$$

$$\Delta t_{HPH} = \frac{t_{fwh} - t_{fwp}}{Z_{HPH}} = \frac{198 - 171,4}{1} = 26,6 \text{ }^\circ\text{C}.$$

Real temperature rises after each heater

- **Closed type**



$$t_s = t_H + \theta_{HPH}; p_H = f(t_s)$$

where: $\theta_{HPH} = (3 \div 5)$ is subcooled temperature in reheater, assume it 3°C

$$t_{Hj} = t_{Hj+1} + \Delta t_{HPH}; p_{exj} = (1,02 \div 1,05)p_{Hj}; \text{ assume } (1,03)$$

- **closed**

$$t_{H1} = t_{fwp} + \Delta t_{HPH} = 171,4 + 26,6 = 198 \text{ }^\circ\text{C};$$

$$t_{s1} = t_{H1} + \theta_{HPH} = 198 + 3 = 201 \text{ }^\circ\text{C};$$

$$p_{H1} = f(t_{s1}) = f(201) = 1,59 \text{ MPa};$$

$$p_{ex1} = 1,03(p_{H1}) = 1,03 \cdot (1,59) = 1,64 \text{ MPa}.$$

Table 3.3- High pressure heater parameters:

Type	NO	$t_{Hj}, ^\circ\text{C}$	$t_{sj}, ^\circ\text{C}$	p_{Hj}, MPa	p_{exj}, MPa
CL	1~fw	198	201	1,59	1,64
fwp	fwp	171,4	-	-	-

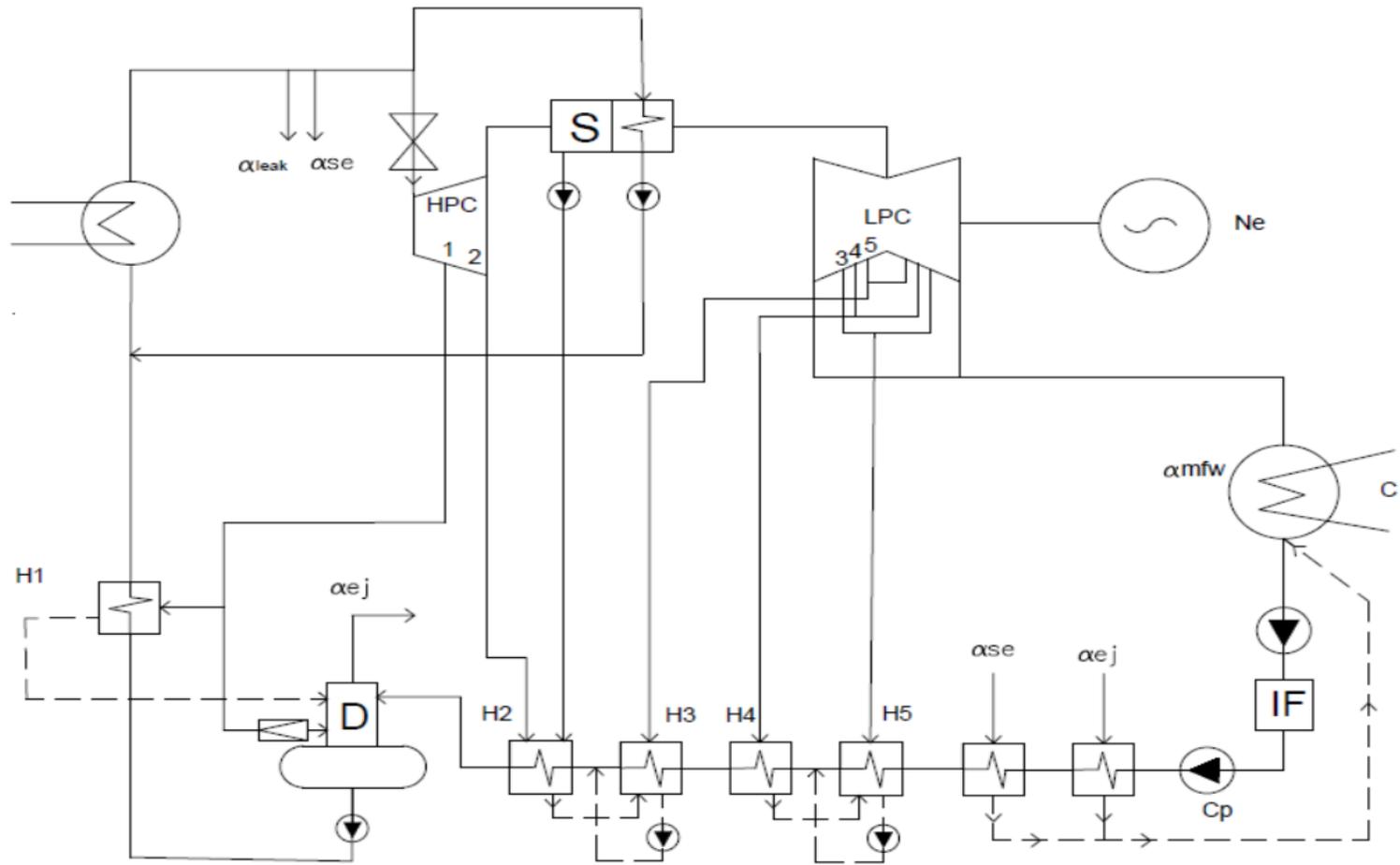


Figure 3.1- Designed Scheme

- Isentropic process 1st extraction where $p_1 = p_{ex1} = 1,64 \text{ MPa}$,

$$h_0 = h_{0'} = 2778 \text{ kJ/kg};$$

$$s_{0'} = s_{1t} = f(p_{0'}, h_0) = 5,8527 \text{ kJ}/(\text{kg} \cdot ^\circ\text{C});$$

$$h_{1t} = f(p_1, s_{0'}) = f(1,64, 5,8527) = 2528 \text{ kJ/kg};$$

$$h_1 = h_0 - 0,862 \cdot (h_0 - h_{1t}) = 2778 - 0,862 \cdot (2778 - 2528) = 2563 \text{ kJ/kg};$$

$$s_1 = f(p_1, h_1) = f(1,64, 2563) = 5,9265 \text{ kJ}/(\text{kg}^\circ\text{C});$$

$$t_1 = f(p_1, s_1) = f(1,64, 5,9265) = 202,6 \text{ }^\circ\text{C}.$$

- Isentropic process 2nd extraction where $p_2 = p_{ex2} = 0,637 \text{ MPa}$,

$$s_{0'} = s_{2t} = 5,8527 \text{ kJ}/(\text{kg}^\circ\text{C});$$

$$h_{2t} = f(p_2, s_{0'}) = f(0,637, 5,8527) = 2374 \text{ kJ/kg};$$

$$h_2 = h_0 - 0,862 \cdot (h_0 - h_{2t}) = 2778 - 0,862 \cdot (2778 - 2374) = 2430 \text{ kJ/kg};$$

$$s_2 = f(p_2, h_2) = f(0,637, 2430) = 5,9821 \text{ kJ}/(\text{kg}^\circ\text{C});$$

$$t_2 = f(p_2, s_2) = f(0,637, 5,9821) = 161,2 \text{ }^\circ\text{C}.$$

Exhaust steam quality from HPC, $x^{HPC} = f(p_2, h_2) = f(0,637, 2430) = 0,842$

which is allowable range.

- **Properties of superheating system**

- For Separator

$p_s = \text{constant line};$

$$p_s = p_2 = 0,637 \text{ MPa}.$$

So, the loses of pressure after separator is

$$p'_s = (0,94 \div 0,95)p_s = (0,95) \cdot p_s;$$

$$p'_s = 0,605 \text{ MPa}.$$

- So, the enthalpy of separator h_s ;

$$h_s = f(p'_s) = 2757 \text{ kJ/kg} .$$

- For Super HEATER 'SH'

So, the loses of pressure in SH.

$$p_{sh} = (0,94 \div 0,95) \cdot p'_s = (0,95) \cdot P'_s;$$

$$p_{sh} = 0,573 \text{ MPa}.$$

$$t_{sh} = t_0 - \Delta t_r ;$$

- So, for one stage SH $\Delta t_r = 11,6 \text{ }^\circ\text{C} ;$

$$t_r = 281,6 - 11,6 = 270 \text{ }^\circ\text{C} .$$

$$h_{sh} = f(P_{sh}, t_{sh}) = f(0,573 , 270) = 3000 \text{ kJ/kg} ;$$

$$s_{sh} = f(p_{sh} , h_{sh}) = 7,2837 \text{ kJ}/(\text{kg} \cdot \text{ }^\circ\text{C}) .$$

3.3.2 For LPC (Low Pressure Cylinder)

- **Parameters at the LPC entry**

The steam pressure before the nozzles of the LPC is less than after superheater: Throttle valve which keeps enthalpy constant but make some pressure losses 3÷5% of p_0 .

$$P_{sh} = 0,9 \cdot (P_2) = 0,9 \cdot (0,637) = 0,573 \text{ MPa} .$$

Table 3.5- Steam parameters (SH):

p_{sh}, MPa	0,573
$h_{sh} = f(p_{sh}, t_{sh}), kJ/kg$	3000
$t_{sh}; ^\circ C$	270
$s_{sh} = f(p_{sh}, h_{sh}) =, kJ/(kg \cdot ^\circ C)$	7,2837

- with absolute internal efficiency $\eta_{oi}^{LPC} = 0,831$.

Isentropic process 3rd extraction where $p_3 = p_{ex3} = 0,282 MPa$,

$$s_{SH'} = s_{3t} = 7,2837 kJ/(kg \cdot ^\circ C) ;$$

$$h_{3t} = f(p_3, s_{SH'}) = f(0.282, 7.2837) = 2839 kJ/kg ;$$

$$h_3 = h_{sh} - 0,831 \cdot (h_{sh} - h_{3t}) = 3000 - 0,831 \cdot (3000 - 2839) = 2866 \frac{kJ}{kg} ;$$

$$s_3 = f(p_3, h_3) = f(0.282, 2866) = 7,3414 kJ/(kg^\circ C);$$

$$t_3 = f(p_3, s_3) = f(0.282, 7.3414) = 199,6 ^\circ C .$$

- Isentropic process 4th extraction where $p_4 = p_{ex4} = 0,108 MPa$,

$$s_{SH'} = s_{4t} = 7,2837 kJ/(kg \cdot ^\circ C) ;$$

$$h_{4t} = f(p_4, s_{SH'}) = f(0.108, 7.2837) = 2660 kJ/kg ;$$

$$h_4 = h_{sh} - 0,831 \cdot (h_{sh} - h_{4t}) = 3000 - 0,831 \cdot (3000 - 2660) = 2717 \frac{kJ}{kg} ;$$

$$s_4 = f(p_4, h_4) = f(0.108, 2717) = 7,4335 kJ/(kg \cdot ^\circ C) ;$$

$$t_4 = f(p_4, s_4) = f(0.108, 7.4335) = 120,6 ^\circ C .$$

- Isentropic process 5th extraction where $p_5 = p_{ex5} = 0,034 \text{ MPa}$,

$$s_{SH'} = s_{5t} = 7,2837 \text{ kJ}/(\text{kg} \cdot ^\circ\text{C}) ;$$

$$h_{5t} = f(p_5, s_{SH'}) = f(0.034, 7.2837) = 2477 \text{ kJ}/\text{kg} ;$$

$$h_5 = h_{sh} - 0,831 \cdot (h_{sh} - h_{5t}) = 3000 - 0,831 \cdot (3000 - 2477) = 2656 \frac{\text{kJ}}{\text{kg}} ;$$

$$s_5 = f(p_5, h_5) = f(0.034, 2656) = 7.7998 \text{ kJ}/(\text{kg} \cdot ^\circ\text{C}) ;$$

$$t_5 = f(p_5, s_5) = f(0.034, 7.7998) = 85,4 \text{ } ^\circ\text{C} .$$

- Isentropic process C' point

when $p_c = 0,006 \text{ MPa}$;

$$s_{SH'} = s_{c't} = 7,2837 \text{ kJ}/(\text{kg} \cdot ^\circ\text{C}) ;$$

$$h_{ct} = f(p_c, s_{sh}) = f(0.006, 7.2837) = 2243 \text{ kJ}/\text{kg} ;$$

$$H_0^{LPC} = h_{sh} - h_{ct} = 3000 - 2243 = 757 \text{ kJ}/\text{kg} ;$$

$$H_i^{LPC} = H_0^{LPC} - \eta_{LPC} = 757 \cdot 0,831 = 629 \text{ kJ}/\text{kg} ;$$

$$h_c = h_{sh} - (H_i^{LPC}) = 3000 - 629 = 2371 \text{ kJ}/\text{kg} ;$$

$$s_c = f(p_c, h_c) = f(0.006, 2371) = 7,6966 \text{ kJ}/(\text{kg} \cdot ^\circ\text{C}) ;$$

$$t_c = f(p_c, s_c) = f(0.006, 7.6966) = 36,2 \text{ } ^\circ\text{C} .$$

Exhaust steam quality from LPC, $x^{LPC} = f(p_c, h_c) = f(0.006, 2371) = 0,9189$

it is allowable dryness factor for low-speed turbine (25Hz).

3.4 The factor of reduced power generation by the j –th extraction

$$y_j = \frac{H_i - H_j}{H_i} ;$$

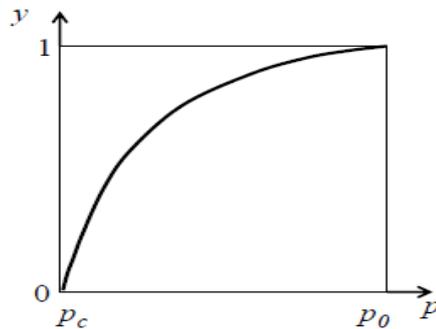


Fig 3.3- Show relation between y and p

$$0 \leq y_j \leq 1$$

Where:

- $H_j = (h_o - h_j)$ work steam by the j –th extraction
- H_i is the internal energy

➤ First for HPC:

$$H_j = (h_o - h_j);$$

$$H_1 = (h_o - h_1) = (2778 - 2563) = 215 \text{ kJ/kg} ;$$

$$H_2 = (h_o - h_2) = (2778 - 2430) = 348 \text{ kJ/kg} ;$$

$$H_i^{HPC} = H_2 = 348 \text{ kJ/kg}.$$

➤ For LPC:

$$H_3 = (h_{sh} - h_3) + H_i^{HPC} = (3000 - 2866) + 348 = 482 \text{ kJ/kg} ;$$

$$H_4 = (h_{sh} - h_4) + H_i^{HPC} = (3000 - 2717) + 348 = 631 \text{ kJ/kg} ;$$

$$H_5 = (h_{sh} - h_5) + H_i^{HPC} = (3000 - 2655) + 348 = 693 \text{ kJ/kg} ;$$

$$H_c = (h_{sh} - h_c) + H_i^{HPC} = (3000 - 2371) + 348 = 977 \text{ kJ/kg} .$$

➤ Total heat drops:

$$H_i^{total} = 977 \text{ kJ/kg} .$$

3.5 Calculation the factor of reduced power generation by the j –th extraction

$$y_1 = \frac{H_i - H_1}{H_i} = \frac{977 - 215}{977} = 0,7799 ;$$

$$y_2 = \frac{H_i - H_2}{H_i} = \frac{977 - 348}{977} = 0,6438 ;$$

$$y_3 = \frac{H_i - H_3}{H_i} = \frac{977 - 482}{977} = 0,5067 ;$$

$$y_4 = \frac{H_i - H_4}{H_i} = \frac{977 - 631}{977} = 0,3541 ;$$

$$y_5 = \frac{H_i - H_5}{H_i} = \frac{977 - 693}{977} = 0,2907 ;$$

$$y_{c'} = \frac{H_i - H_6}{H_i} = \frac{977 - 977}{977} = 0 .$$

Table 3.6- All parameters:

No.	Extracted steam			Steam in heaters (drain)			Heater's outlet water			Extracted steam work in cylinder	Underproduction factor
	pj	tj	hj	PHj	Tsj	h'j	pwj	twj	hwj	Hi	yi
	MPa	°C	kJ/kg	MPa	°C	kJ/kg	MPa	°C	kJ/kg	kJ/kg	
0	6,58	281,6	2778	-	-	-	-	-	-		
0'	6,45	280,3	2778	-	-	-	-	-	-	0	1
1	1,64	202,6	2563	1,59	201	857	8,6	198	846	215	0,7799
D	1,64		2563	0,80	170,4	721	0,80	170,4	721	-	-
Sep	0,637		2759	0,637	159,2	681	-	-	-	-	-
SH1	0,573	270	3000	-	-	-	-	-	-	-	-
2	0,637	161,2	2430	0,618	160	676	0,96	158,4	669	348	0,6438
3	0,282	199,6	2866	0,274	130,4	548	0,96	128,9	542	482	0,5067
4	0,108	120,6	2717	0,105	100,9	423	0,96	99,3	417	631	0,3541
5	0,034	85,4	2655	0,033	71,3	299	0,96	69,7	293	693	0,2907
C	0,006	36,2	2371	0,0058	35,6	149	0,0058	149	806	-	-

3.6 Material and thermal balance equations calculation & Feedwater

$$\alpha_{SG} = \alpha_0 + \alpha_{se} + \alpha_{leak} + \alpha_{SH} ;$$

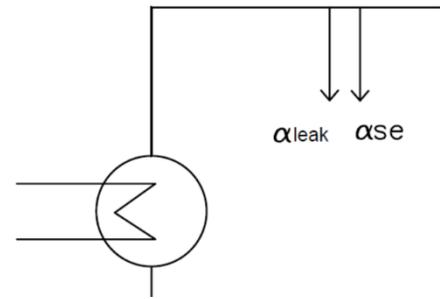
$$\alpha_{SG} = 1 + 0,005 + 0,002 + 0,1189 = 1,1259 .$$

$$\alpha_{leak} = 0,002 \quad \alpha_{se} = 0,005 \quad \alpha_{bd} = 0 ;$$

$$\alpha_{fw1} = \alpha_{SG} + \alpha_{bd} = 1,1259 .$$

$$\alpha_{tu} = \alpha_0 + \alpha_{SH} ;$$

$$\alpha_{tu} = 1 + 0,1189 = 1,1189 .$$



- **For Heater (1)**

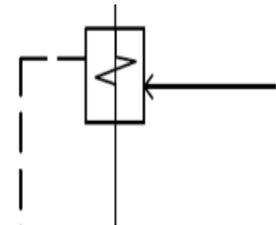
$$\alpha_{fw} = \alpha_{leak} + \alpha_{se} + \alpha_0 = 1 + 0,002 + 0,005 = 1,007 ;$$

$$\alpha_{dr1} = \alpha_{H1} = 0,0699 ;$$

$$\alpha_1 = \alpha_{H1} + \alpha_D ;$$

$$\alpha_{H1}(h_1 - h'_1) = \alpha_{fw}(h_{fw1} - h_{fwp}) \cdot \frac{1}{\eta_H} ;$$

$$\alpha_{H1}(2563 - 857) = 1,007(846 - 729,7) \cdot \frac{1}{0,98} .$$



- **For Deaerator**

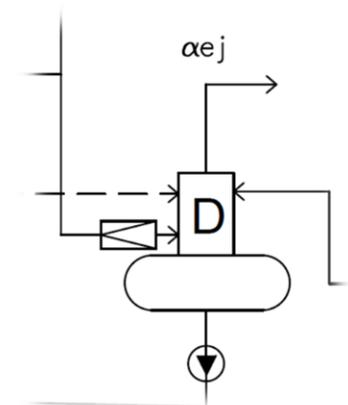
$$\alpha_{ej} = 0,002 ;$$

$$\alpha_{mc} + \alpha_{dr1} + \alpha_D = \alpha_{fw} + \alpha_{ej} ;$$

$$\alpha_{mc} \cdot h_{mc2} + \alpha_{dr1} \cdot h'_1 + \alpha_D \cdot h_1 = \alpha_{fw} \cdot h'_D + \alpha_{ej} \cdot h''_D ;$$

$$\alpha_{mc} \cdot 669 + 0,0699 \cdot 857 + \alpha_D \cdot 2563 = 1,007 \cdot 721 + 0,002 \cdot 2768 ;$$

$$h'_D = f(p_d) = 721 \text{ kJ/kg} ;$$



$$h_D'' = f(p_d) = 2768 \text{ kJ/kg};$$

$$h_{mc2} = h_{fw2} = 669 \text{ kJ/kg}.$$

- **For separator**

$$\alpha_1 = \alpha_{H1} + \alpha_D;$$

$$\alpha_s^{in} = 1 - \alpha_1 - \alpha_2;$$

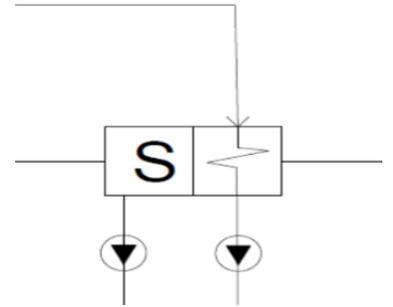
$$\alpha_s^{in} = \alpha_{RH} + \alpha_s;$$

$$\alpha_s^{in} \cdot h_2 = \alpha_{RH}^{in} \cdot h_s + \alpha_s \cdot h_s';$$

$$\alpha_s^{in} \cdot 2430 = \alpha_{RH}^{in} \cdot 681 + \alpha_s \cdot 681;$$

$$h_s' = f(p_s) = f(0,637) = 681 \text{ kJ/kg};$$

$$h_s = f(p_s, x = 0,995) = f(0,637, x = 0,995) = 2748 \text{ kJ/kg}.$$



- **For Super heater**

$$\alpha_{SH}(h_0 - h_0') = \alpha_{SH}^{in}(h_{SH} - h_s) \frac{1}{\eta_H};$$

$$h_0' = 1245 \text{ kJ/kg};$$

$$h_0 = 2778 \text{ kJ/kg};$$

$$h_{SH} = 3000 \text{ kJ/kg};$$

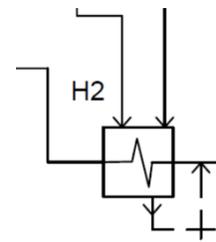
$$\alpha_{SH}^{in} = 1 - \alpha_1 - \alpha_2 - \alpha_s.$$

- **For Heater (2)**

$$\alpha_{dr2} = \alpha_{H2} + \alpha_s;$$

$$\alpha_{H2}(h_2 - h_2') + \alpha_s(h_s' - h_2') = \alpha_{mc}(h_{mc2} - h_{mix1}) \cdot \frac{1}{\eta_H};$$

$$\alpha_{H2}(2430 - 676) + \alpha_s(681 - 676) = \alpha_{mc}(669 - h_{mix1}) \cdot \frac{1}{0,98}.$$

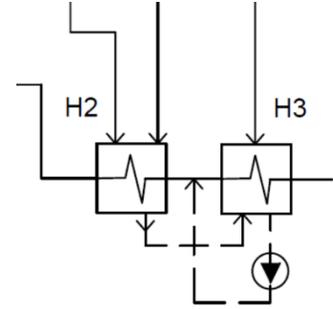


- **Mixing Point (1)**

$$\alpha_{mc} = \alpha_{mc3} + \alpha_{dr3} ;$$

$$\alpha_{mc3} \cdot h_{mc3} + \alpha_{dr3} \cdot h'_3 = \alpha_{mc} \cdot h_{mix1} \cdot \frac{1}{\eta_H} ;$$

$$\alpha_{mc3} \cdot 542 + \alpha_{dr3} \cdot 548 = \alpha_{mc} \cdot h_{mix1} \cdot \frac{1}{0,99} .$$

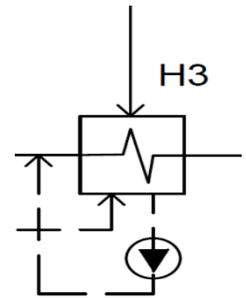


- **For Heater (3)**

$$\alpha_{dr3} = \alpha_{H3} + \alpha_{dr2} ;$$

$$\alpha_{H3}(h_3 - h'_3) + \alpha_{dr2}(h'_2 - h'_3) = \alpha_{mc3}(h_{mc3} - h_{mc4}) \cdot \frac{1}{\eta_H} ;$$

$$\alpha_{H3}(2866 - 548) + \alpha_{dr2}(676 - 548) = \alpha_{mc3}(542 - 417) \cdot \frac{1}{0,98} .$$

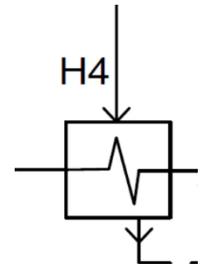


- **For Heater (4)**

$$\alpha_{dr4} = \alpha_{H4} = \alpha_4 ;$$

$$\alpha_{H4}(h_4 - h'_4) = \alpha_{mc3}(h_{mc4} - h_{mix2}) \cdot \frac{1}{\eta_H} ;$$

$$\alpha_{H4}(2717 - 423) = \alpha_{mc3}(417 - h_{mix2}) \cdot \frac{1}{0,98} .$$

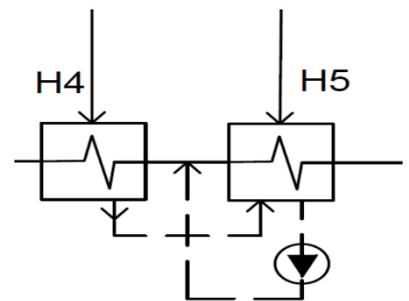


- **Mixing Point (2)**

$$\alpha_{mc3} = \alpha_{dr5} + \alpha_{mc5} ;$$

$$\alpha_{mc5} \cdot h_{mc5} + \alpha_{dr5} \cdot h'_5 = \alpha_{mc3} \cdot h_{mix2} \cdot \frac{1}{\eta_H} ;$$

$$\alpha_{mc5} \cdot 293 + \alpha_{dr5} \cdot 299 = \alpha_{mc3} \cdot h_{mix2} \cdot \frac{1}{0,99} .$$



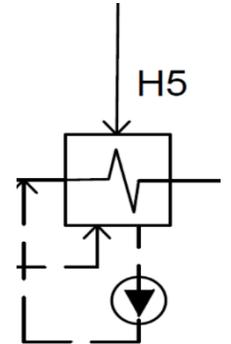
- **For Heater (5)**

$$\alpha_{dr5} = \alpha_{H5} + \alpha_{dr4} ;$$

$$\alpha_{H5}(h_5 - h'_5) + \alpha_{dr4}(h'_4 - h'_5) = \alpha_{mc5}(h_{mc5} - h_{cse}) \cdot \frac{1}{\eta_H} ;$$

$$\alpha_{H5}(2655 - 299) + \alpha_{dr4}(423 - 299) = \alpha_{mc5}(293 - 169) \cdot \frac{1}{0,98} ;$$

$$h_{cse} = f(p_{cp}, t_{cse}) = f(0.96, 40.2) = 169 \text{ kJ/kg}.$$

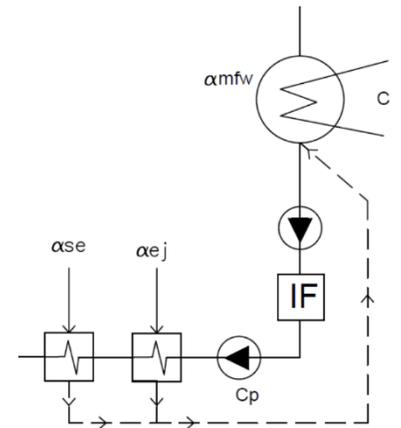


- **For Condenser**

$$\alpha_c^* = \alpha_{mc5} - \alpha_{mfw} - \alpha_{se} - \alpha_{ej};$$

$$\alpha_c^* = \alpha_{mc5} - 0,002 - 0,005 - 0,002 = 0,6105 ;$$

$$\alpha_c = \alpha_0 - \alpha_1 - \alpha_2 - \alpha_3 - \alpha_4 - \alpha_5 - \alpha_s = 0,6105 ;$$



$$\delta_{\alpha_c} = \frac{\alpha_c^* - \alpha_c}{\alpha_c^*} \cdot 100 = \frac{0,6105 - 0,6105}{0,6105} \cdot 100 = 0 \leq 0,05 .$$

Table 3.7- Relative flowrate:

$\alpha_{h1} = 0,0699$	$\alpha_{dr4} = 0,0388$
$\alpha_1 = 0,0928$	$\alpha_{h5} = 0,0325$
$\alpha_{dr1} = 0,0699$	$\alpha_5 = 0,0325$
$\alpha_{h2} = 0,0694$	$\alpha_{dr5} = 0,0713$
$\alpha_2 = 0,0694$	$\alpha_D = 0,0229$
$\alpha_{dr2} = 0,1983$	$\alpha_{mc} = 0,9162$
$\alpha_{h3} = 0,0271$	$\alpha_{mc3} = 0,6908$
$\alpha_3 = 0,0271$	$\alpha_s = 0,1289$
$\alpha_{dr3} = 0,2254$	$\alpha_s^{in} = 0,8377$
$\alpha_{h4} = 0,0388$	$\alpha_{Rh}^{in} = 0,7089$
$\alpha_4 = 0,0388$	$\alpha_{mc5} = 0,6195$
$\alpha_{SH} = 0,1189$	$h_{mix1} = 538$
$\alpha_{fw1} = 1,1259$	$h_{mix2} = 291$
$\alpha_{SG} = 1,1259$	$\alpha_{fw} = 1,007$
$\alpha_{leak} = 0,002$	$\alpha_{se} = 0,005$
$\alpha_{ej} = 0,002$	$\alpha_c = 0,6105$
$\alpha_{tu} = 1,1189$	

3.7 Determining Steam Flow To The Turbine

$$G_0 = \frac{N_e \cdot 10^3}{H_i^{total} \cdot \eta_M \cdot \eta_g \cdot (1 - \sum(\alpha_j \cdot y_j) - \alpha_s \cdot y_s)};$$

$$G_0 = \frac{(1250 \cdot 10^3)}{977 \cdot 0,98 \cdot 0,99 \cdot (1 - 0,1539 - 0,0830)} = 1728,12 \text{ kg/s} .$$

Where:

η_M is mechanical efficiency of a steam turbine installation = 0,98;

η_g is efficiency of the generator = 0,985 ÷ 0,99 assume it = 0,99;

α_j is relative steam consumption in the jth selection;

y_j is reproduction factor in each extraction;

N_e is electric power of NPP;

H_i is total internal heat drops in turbine, kJ/kg;

$$H_i = (h_{sh} - h_c) + H_i^{HPC} = (3000 - 2371) + 348 = 977 \text{ kJ/kg} .$$

- Total heat drops = 977 kJ/kg .

3.8 Power for a turbine is determined by the formula

$$N_e = \frac{G_0 H_i \cdot \eta_M \cdot \eta_g \cdot [1 - \sum(\alpha_j \cdot y_j) - \alpha_s \cdot y_s]}{10^3} ;$$

$$N_e = \frac{1728,12 \cdot 977 \cdot 0,98 \cdot 0,99 \cdot (1 - 0,1539 - 0,0830)}{10^3} = 1250,003 \text{ MW} .$$

Table 3.8- Relative flow rate and under production factor:

NO j	α_j	y_j	$(\alpha_j \cdot y_j)$
1	0,0928	0,7799	0,0724
2	0,0694	0,6438	0,0447
3	0,0271	0,5067	0,0137
4	0,0388	0,3541	0,0137
5	0,0325	0,2907	0,0094
$\sum (\alpha_j \cdot y_j)$	-	-	0,1539
Separator (s)	0,1289	0,6438	0,0830

- **Values of flow rate at the part of NPP**

$$G_i = G_0 \cdot \alpha_i, kg/s$$

Table 3.9- Values of flow rate at the part of NPP:

$G_{h1} = 120,80$	$G_D = 39,57$
$G_1 = 160,37$	$G_{mc} = 1583,30$
$G_{dr1} = 120,80$	$G_{mc3} = 1193,79$
$G_2 = 119,93$	$G_{mc5} = 1070,57$
$G_{dr2} = 342,69$	$G_s = 222,75$
$G_3 = 46,83$	$G_s^{in} = 1447,65$
$G_{dr3} = 389,52$	$G_{SH} = 205,47$
$G_4 = 67,05$	$G_{Rh}^{in} = 1225,06$
$G_{dr4} = 67,05$	$G_{fw} = 1740,22$
$G_5 = 56,16$	$G_{fw1} = 1945,69$
$G_{dr5} = 123,21$	$G_{SG} = 1945,69$
$G_{leak} = 3,46$	$G_{se} = 8,64$
$G_{ej} = 3,46$	$G_c = 1055,02$
$G_{tu} = 1933,59$	

3.9 Indicators of energy efficiency of steam turbine installation and power plant

3.9.1 Thermal loading of a steam generating unit, Q_{SG} , kW (MW)

$$Q_{SG} = G_0 [(\alpha_{TU} + \alpha_{leak} + \alpha_{cs})(h_0 - h_{fw}) + \alpha_{bd}(h'_{bd} - h_{fw})] ;$$

$$Q_{SG} = 1728,12 \cdot ((1,1189 + 0,002 + 0,005) \cdot (2778 - 1115) + 0,3 \cdot (1245 - 1115)) ;$$

$$Q_{SG} = 3303 \text{ MW} ;$$

where:

$G_0 = 1728,12$ kg/s, is steam flow to a turbine;

$\alpha_{TU} = 1,1189$, is the relative flow rate for turbine installation;

$\alpha_{bd} = 0$, is the relative flow rate of blowdown water;

$\alpha_{leak} = 0,002$, is a relative leakage flow rate;

$\alpha_{se} = 0,005$, is a relative steam flow rate out of the turbine seals;

$h_0 = 2778$ kJ / kg, is enthalpy of steam at the turbine inlet;

$h'_{bd} = 1245$ kJ/kg, is enthalpy of blowdown water, it is the enthalpy of saturated water at a pressure of p_0 .

3.9.2 Thermal loading of turbine Q_{ts} , kW (MW)

$$Q_{ts} = G_0 \left((\alpha_{TU} + \alpha_{cs})(h_0 - h_{fw}) + \alpha_{leak}(h_c - h_{fw}) + \alpha_{bd}(h'_{bd} - h_{fw}) \right) ;$$

$$Q_{ts} = 1728,12 \cdot (1869 + 0,002(149 - 1115) + 0,3(1245 - 1115)) ;$$

$$Q_{ts} = 3294 \text{ MW}.$$

3.9.3 Electrical efficiency of turbo-generator

$$\eta_e = \eta_{ts} = \frac{N_e}{Q_{ts}} = \frac{1250}{3294} = 0,37 .$$

3.9.4 Steam turbine plant (STP) heat rate, for generating electricity

$$q_{ts} = \frac{3600}{\eta_{ts}} = \frac{3600}{0,37} = 9729,73 \text{ kJ}/(\text{kW} \cdot \text{h}) .$$

3.9.5 NPP efficiency

$$\eta_{npp} = \eta_{rs} \cdot \eta_{pip}^I \cdot \eta_{pip}^{II} \cdot \eta_{sg} \cdot \eta_e ;$$

$$\eta_{npp} = 0,99 \cdot 0,995 \cdot 0,995 \cdot 0,985 \cdot 0,37 = 0,36 = 36 \% ;$$

where:

$\eta_{rs} = 0,99$ is the efficiency of the reactor system;

$\eta_{pi}^I = 0,995$ is the efficiency of heat transport of the 1st circuit.

$\eta_{pip}^{II} = 0,995$ is the efficiency of heat transport of the 2nd circuit;

$\eta_{sg} = 0,985$ is the efficiency of the steam generator.

3.9.6 Burnup fuel rate, ton/year

$$b_{nf} = \frac{Q_r \cdot T_{eff}}{24 \cdot \bar{B} \cdot 10^3} = \frac{3300 \cdot 6000}{24 * 35 * 10^3} = 23,57 \text{ ton/year} ;$$

where:

$T_{eff} = 6000$ hr/year is full load hours;

$\bar{B} = 35 \cdot 10^3$ (MW · day/ton), is average burn up fraction for reactor WWER.

3.10 Choice of equipment for the water-steam circuit

- **The regenerative closed heaters**

We will choose heaters according to the area of the heat exchange surface and the water consumption. In this case, the steam and water pressure in the heater must be taken into account.

The characteristics of existing heaters are available in the handbook.

Evaluate heat transfer area $F \text{ m}^2$

$$F = \frac{Q}{k \cdot \bar{\Delta t}} ;$$

where:

$Q = G \cdot \Delta h$, is heat load of the heater, kW;

Δh is difference enthalpy between outlet and inlet, kJ/kg;

G mass flow rate of water, kg/s;

$k = 3500 \rightarrow 4000$ is heat transfer coefficient, $\text{W}/(\text{m}^2 \cdot \text{k})$;

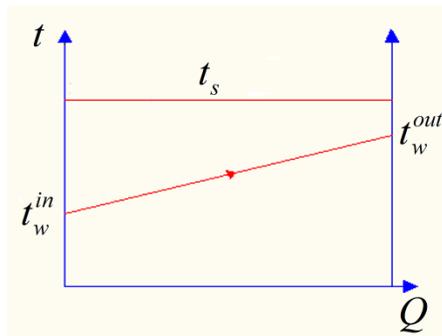


Figure 3.4- To the calculation of the logarithmic temperature difference

$\bar{\Delta t}$ is logarithmic temperature difference, °C

$$\bar{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} ;$$

where:

$$\Delta t_{big} = t_s - t_w^{in} ;$$

$$\Delta t_{small} = t_s - t_w^{out} .$$

We will show the selection of one heater in detail. The results of the selection of all heaters are placed in the table.

For RGFW 5 ‘IPH’

$$\Delta h = h_{w5} - h_{cse} = 293 - 168 = 125 \text{ kJ/kg} ;$$

$$Q = G_{mc5} \cdot \Delta h = 1070,57 \cdot 125 = 133,8 \cdot 10^3 \text{ kW} ;$$

$$\Delta t_{big} = t_{s5} - t_{cse} = 71,3 - 40,2 = 31,1 \text{ }^\circ\text{C} ;$$

$$\Delta t_{small} = t_{s5} - t_{w5} = 71,3 - 69,7 = 1,6 \text{ }^\circ\text{C} ;$$

$$\bar{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{31,1 - 1,6}{\ln\left(\frac{31,1}{1,6}\right)} = 9,9 \text{ }^\circ\text{C} ;$$

$$F = \frac{Q}{k\bar{\Delta t}} = \frac{133,8 \cdot 10^3 \cdot 10^3}{4000 \cdot 9,9} = 3378,8 \text{ m}^2 .$$

For RGFW 4 ‘IPH’

$$\Delta h = h_{w4} - h_{w5} = 417 - 293 = 124 \text{ kJ/kg} ;$$

$$Q = G_{mc3} \cdot \Delta h = 1193,79 \cdot 124 = 148,01 \cdot 10^3 \text{ kW} ;$$

$$\Delta t_{big} = t_{s4} - t_{w5} = 100,9 - 69,7 = 31,2 \text{ }^\circ\text{C} ;$$

$$\Delta t_{small} = t_{s4} - t_{w4} = 100,9 - 99,3 = 1,6 \text{ }^\circ\text{C} ;$$

$$\bar{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{31,2 - 1,6}{\ln\left(\frac{31,2}{1,6}\right)} = 9,97 \text{ }^\circ\text{C} ;$$

$$F = \frac{Q}{k\bar{\Delta t}} = \frac{148,01 \cdot 10^3 \cdot 10^3}{4000 \cdot 9,97} = 3711,4 \text{ m}^2 .$$

For RGFW 3 ‘IPH’

$$\Delta h = h_{w3} - h_{w4} = 542 - 417 = 125 \text{ kJ/kg};$$

$$Q = G_{mc3} \cdot \Delta h = 1193,79 \cdot 125 = 149,22 \cdot 10^3 \text{ kW};$$

$$\Delta t_{big} = t_{s3} - t_{w4} = 130,4 - 99,3 = 31,1 \text{ }^\circ\text{C};$$

$$\Delta t_{small} = t_{s3} - t_{w3} = 130,4 - 128,9 = 1,5 \text{ }^\circ\text{C};$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{31,1 - 1,5}{\ln\left(\frac{31,1}{1,5}\right)} = 9,8 \text{ }^\circ\text{C};$$

$$F = \frac{Q}{k\overline{\Delta t}} = \frac{149,22 \cdot 10^3 \cdot 10^3}{4000 \cdot 9,8} = 3806,6 \text{ m}^2.$$

For RGFW 2 ‘IPH’

$$\Delta h = h_{w2} - h_{mix1} = 669 - 538 = 131 \text{ kJ/kg};$$

$$Q = G_{mc} \cdot \Delta h = 1583,3 \cdot 131 = 207,41 \cdot 10^3 \text{ kW};$$

$$\Delta t_{big} = t_{s2} - t_{w3} = 160 - 128,9 = 31,1 \text{ }^\circ\text{C};$$

$$\Delta t_{small} = t_{s2} - t_{w2} = 160 - 158,4 = 1,6 \text{ }^\circ\text{C};$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{31,1 - 1,6}{\ln\left(\frac{31,1}{1,6}\right)} = 9,9 \text{ }^\circ\text{C};$$

$$F = \frac{Q}{k\overline{\Delta t}} = \frac{207,41 \cdot 10^3 \cdot 10^3}{4000 \cdot 9,9} = 5237,6 \text{ m}^2.$$

For RGFW 1 ‘HPH’

$$\Delta h = h_{w1} - h_{fwp} = 846 - 730 = 116 \text{ kJ/kg};$$

$$Q = G_{fw} \cdot \Delta h = 1740,22 \cdot 116 = 201,9 \cdot 10^3 \text{ kW};$$

$$\Delta t_{big} = t_{s1} - t_{fwp} = 201 - 171,4 = 29,6 \text{ }^\circ\text{C};$$

$$\Delta t_{small} = t_{s1} - t_{w1} = 201 - 198 = 3 \text{ }^\circ\text{C};$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{29,6 - 3}{\ln\left(\frac{29,6}{3}\right)} = 11,6 \text{ }^\circ\text{C};$$

$$F = \frac{Q}{k\overline{\Delta t}} = \frac{201,9 \cdot 10^3 \cdot 10^3}{4000 \cdot 11,6} = 4351,3 \text{ m}^2.$$

Table 3.10- Characteristic of closed RFWH in NPP:

RFW H No	G, kg/s	p_w , MPa	p_{st} , MPa	Δh , kJ/kg	Q, MW	$\bar{\Delta t}$, °C	F, m ²	Selected Type	G kg/s	F, m ²	n
HPH (1)	1740,22	8,6	1,59	116	201,9	11,6	4351,3	ПВД-К-2470-11.9- 2.84	860	2470	2
LPH (2)	1583,3	0,96	0,618	131	207,4	9,9	5237,6	ПН-3000-25-16- IIIA	1112,5	3000	2
LPH (3)	1193,79	0,96	0,274	125	149,2	9,8	3806,6	ПН-1800-42-8-IVA	700	1800	2
LPH (4)	1193,79	0,96	0,105	124	148,01	9,97	3711,4	ПН-1800-42-8-IVA	700	1800	2
LPH (5)	1070,57	0,96	0,033	125	138,8	9,9	3378,8	ПН-3200-30-16- IIA	1430,6	3200	1

- **The Feed Water Deaerator**

Thermal feed water deaerator is used at nuclear power plants to remove oxygen, carbon dioxide and other corrosive gases from feed water, as well as for regenerative heating of the main condensate; it is a place for collecting and storing a supply of feed water. The feed water deaerator usually consists of one or two columns and a deaerator tank. The total capacity of the deaerators is selected based on the maximum feed water consumption. One or two deaerators with a working pressure of 0,6 to 1,2 MPa are installed on each NPP power unit

The deaeration tank is designed to collect deaeration water and create its emergency reserve. The geometric capacity of the deaerator tanks must be 15% more than the emergency reserve. This reserve is calculated for at least 3 minutes of operation of the turbine unit in emergency situations.

The characteristics of the existing deaerators are in the reference book.

Example of selecting a deaerator

Initial data for selecting a high-pressure deaerator:

- maximum feed water consumption $G_{fw} = 1740,22 \text{ kg/s}$;
- deaerator pressure $p_d = 0,8 \text{ MPa}$.

The minimum geometric capacity (capacity) of deaerator tanks can be determined by the formula

$$V_{dt} = 1,15 \cdot \tau \cdot v \cdot 60 \cdot G_{fw} = 1,15 \cdot 3 \cdot 0,0011 \cdot 60 \cdot 1740,22 = 396,2 \text{ m}^3 ;$$

where: $\tau = 3 \text{ min}$ is the time for calculating the total volume of feed water in the NPP deaerator tanks;

$v = 0,0011 \text{ m}^3/\text{kg}$ – specific volume of water in the state of saturation at a pressure $p_d = 0,8 \text{ MPa}$ in the deaerator.

Deaerator is selected: two columns of the ДП-2800 type (feed water flow rate $2 \times 777.7 \text{ kg/s}$) with a deaerator tank БД-185-1 (geometric capacity 217.6 m^3).

Chapter (4) Design calculation of the turbine condenser

The purpose of calculating a condenser is to determine its geometric dimensions and operational characteristics.

Modern powerful steam turbines of nuclear power plants have usually several double-flow low-pressure cylinders. Steam from each cylinder is sent to a separate condenser. So first you need to determine the number of exhaust steam outputs of the turbine.

4.1 Calculation of the Number of Flows in the Low-Pressure Cylinder of Turbine

4.1.1 Maximum power of a single-flow turbine, MW

$$N_i^{max} = \frac{m1}{2 \cdot 10^{-3} \cdot \pi} \cdot k_{unl} \cdot H_i \cdot \frac{[\sigma] \cdot c_2}{\rho_{mat} \cdot n^2 \cdot v_2} ;$$

$$N_i^{max} = \frac{1,2}{2 \cdot 10^{-3} \cdot \pi} \cdot 2,3 \cdot 977 \cdot \frac{[450] \cdot 223,6}{7800 \cdot 25^2 \cdot 21,811} = 406,12 \text{ MW} ;$$

where: $m1 = 1,1 \rightarrow 1,3$ is coefficient that takes into account power generation by steam streams of regenerative bleed-offs, assume it 1,2;

$k_{unl} = 2,3 \rightarrow 2,4$ is unloading coefficient, which depends on the geometric characteristics of the blades of the last stage of the turbine; assume it 2,3;

H_i is extracted steam work in turbine, 977 kJ/kg;

$[\sigma]$ is allowable tensile stress for the material of the blades. For stainless steel $[\sigma] = 450$ MPa; for titanium alloy BT6 $[\sigma] = 950 \div 1000$ MPa;

$\rho_{mat} = 7800$ kg/m³ is density of the blade material (stainless steel); for titanium alloy BT6 $\rho_{mat} = 4300$ kg/m³;

n is rotor's rotation frequency, 25 rev/s;

$v_2 = f(p_c, h_c) = f(0.006, 2371) = 21,811$ m³/kg is specific volume of steam at the outlet of the last stage of the turbine, m³/kg.

It is determined by the known parameters of the steam p_c and h_c at the outlet of the turbine.

c_2 is output steam speed, m/s. Depends on the allowable power loss at the output speed;

$\Delta h_{os} = 20 \div 35$ kJ/kg. assume it 25.

4.1.2 Number of Flows of Spent Steam going to the Condenser

$$i = \frac{N_e}{\eta_m \cdot \eta_g \cdot N_i^{max}} ;$$

$$i = \frac{1250}{0,98 \cdot 0,99 \cdot 406,12} = 3,15 = 4 ;$$

So, we'll have two condensers;

where:

N_i^{max} is the maximum power of a single-flow turbine, 406,12 MW;

N_e is total electric power of the turbine unit, 1250 MW;

η_m is mechanical efficiency of the turbine unit. 0,98;

η_g is the efficiency of the generator. 0,99

4.1.3 The output speed of steam is determined from the following equation

$$\Delta h_{os} = \frac{c_2^2}{2000} ;$$

$$c_2^2 = \Delta h_{os} \cdot 2000 = 25 \cdot 2000 = 50000 ;$$

$$c_2 = 223,6 \text{ m/s} ;$$

The resulting number of flows i must be rounded up to the nearest even integer.

4.1.4 Exhaust steam flow per condenser

$$G_{c1} = \frac{2 \cdot G_c}{i} ;$$

$$G_{c1} = \frac{2 \cdot 1055,02}{4} = 527,51 \text{ kg/s} ;$$

where:

$$G_c = \alpha_c \cdot G_0 = 0,6105 \cdot 1728,12 = 1055,02 \text{ kg/s}$$

is total exhaust steam flow;

$i = 4$ is Number of flows of spent steam going to the condenser.

- **Initial data for the calculation of the condenser**

Table 4.1- Initial data:

Parameter	Denomination, units	Value
Exhaust steam flow per condenser	G_{c1} , kg/s	527,51
Condenser pressure	p_c , MPa	0,006
Number of tube-side passes for cooling water	z	2
Coolant temperature at the inlet to the condenser	t_{w1} , °C	20
Speed of the cooling water in the tubes of the condenser	w_w , m/s	2,2
Condenser tube sizes	$d_{out} \times \delta_{wall}$, mm	28 × 1
Tube material		stainless steel;

Notes:

- take the cooling water density equal to $\rho_w = 1000 \text{ kg / m}^3$;
- take the average heat capacity of cooling water equal to $c_w = 4,19 \text{ kJ/kg}$;
- the coefficient that takes into account the contamination of pipes is equal to $a_0 = 0,65 \dots 0,85$, assume it 0,85.

4.2 Determining the characteristics of a condenser**4.2.1 Flow rate of cooling water per condenser**

$$W_1 = m \cdot G_{c1} ;$$

$$W_1 = 60 \cdot 527,51 = 31650,6 \text{ kg/s}$$

where:

$m = 60$ is the cooling ratio for two-way condensers ($z = 2$), kg/s.

4.2.2 The number of heat transfer tubes, pieces

$$n_{tube} = \frac{4 \cdot W_1 \cdot z}{\pi \cdot d_{inn}^2 \cdot \rho_w \cdot w_w} ;$$

$$n_{tube} = \frac{4 \cdot 31650,6 \cdot 2}{\pi \cdot (0,026)^2 \cdot 1000 \cdot 2,2} = 54195 \text{ pcs} ;$$

where:

z is number of tube-side passes for cooling water;

$$d_{inn} = d_{out} - (2 \cdot \delta_{wall}) ;$$

$d_{inn} = 28 - (2 \cdot 1) = 26 \text{ mm}$, is the inner diameter of the tubes;

w_w is speed of water in tubes, m / s.

4.2.3 Cooling water heating in the condenser, °C

$$\Delta t_w = \frac{r}{c_w \cdot m} ;$$

$$\Delta t_w = \frac{2415}{4,19 \cdot 60} = 9,6 \text{ °C} ;$$

where:

$$r = h'' - h' = 2567 - 152 = 2415 \text{ kJ/kg} ;$$

$$h'' = f(P_c) = 2567 \text{ kJ/kg} ;$$

$$h' = f(P_c) = 152 \text{ kJ/kg} \text{ is latent heat of vaporization under pressure } P_c, \text{ kJ/kg} ;$$

$c_w = 4,19$ is heat capacity of cooling water, kJ/ (kg °C).

4.2.4 Temperature of the cooling water at the condenser outlet, °C

$$t_{w2} = t_{w1} + \Delta t_w ;$$

$$t_{w2} = 20 + 9,6 = 29,6 \text{ °C} .$$

4.2.5 The Heat power that is transferred to the cooling water in the condenser, kW

$$Q_{w1} = W_1 \cdot c_w \cdot \Delta t_w ;$$

$$Q_{w1} = 31650,6 \cdot 4,19 \cdot 9,6 = 1,273 \cdot 10^6 \text{ kW} .$$

4.2.6 The average temperature difference, °C

$$\Delta t_{avr} = \frac{\Delta t_w}{\ln \left(\frac{t_s - t_{w1}}{t_s - t_{w2}} \right)} ;$$

$$\Delta t_{avr} = \frac{9,6}{\ln \left(\frac{36,2 - 20}{36,2 - 29,6} \right)} = 10,7 \text{ °C} ;$$

where:

$t_s = f(p_c) = 36,2$ °C, is saturation temperature at condenser pressure p_c .

4.2.7 Specific vapor load of the condenser d_c . Initially set in the range of 40 ... 60 kg / (m² · h), and then must be checked

$d_c = 43$ kg / (m² · h);

The overall heat transfer coefficient (BTI formula) is calculated using one of two expressions. $t_{w1} = 20$ °C. So, we will use the following expression:

If $t_{w1} \leq 35$ °C

$$k = 4070 \cdot a \cdot \left(\frac{1,1 \cdot w_w}{d_{inn}^{0,25}} \right)^x \cdot \left[1 - \frac{0,52 - 0,002 \cdot d_c \cdot \sqrt{a}}{1000} \cdot (35 - t_{w1})^2 \right] \\ \cdot \left[1 - \frac{z - 2}{10} \cdot \left(1 - \frac{t_{w1}}{35} \right) \right] \cdot \Phi_d ;$$
$$k = 4070 \cdot 0,5525 \cdot \left(\frac{1,1 \cdot 2,2}{0,026^{0,25}} \right)^{0,265} \cdot \left[1 - \frac{0,52 - 0,002 \cdot 43 \cdot \sqrt{0,5525}}{1000} \cdot (15)^2 \right] \\ \cdot \left[1 - \frac{2 - 2}{10} \cdot \left(1 - \frac{20}{35} \right) \right] \cdot 1 = 3249,2 \text{ W}/(\text{m}^2 \cdot \text{°C}) ;$$

where:

k - in W/(m²·°C);

$x = 0,12 \cdot a \cdot (1 + 0,15 \cdot t_{w1}) = 0,12 \cdot 0,5525 \cdot (1 + 0,15 \cdot 20) = 0,265$

$a = a_0 \cdot a_m = 0,65 \cdot 0,85 = 0,5525$

is coefficient taking into account pollution of tubes and tube material;

$a_0 = 0,65 \dots 0,85$ is coefficient that takes into account tube contamination;

Assume it 0,65;

a_m is correction factor that takes into account the tube material,

For stainless steel = 0,85;

d_{inn} is the inner diameter of the tubes = 26 mm;

w_w is speed of water in tubes 2,2 m / s;

t_{w1} is the temperature of the cooling water at the inlet to the condenser, 20 °C;

$z = 2$ is number of tube-side passes for cooling water;

$\Phi_d = 1$ When designing condensers, this coefficient is taken equal to 1.

- **Heat transfer surface area, m²**

$$F = \frac{Q_w}{k \cdot \Delta t_{avr}} ;$$

$$F = \frac{1,273 \cdot 10^6 \cdot 10^3}{3249,2 \cdot 10,7} = 36615,77 \text{ m}^2.$$

- **The length of the heat transfer tubes, m**

$$L = \frac{F}{n_{tube} \cdot \pi \cdot d_{out}} ;$$

$$L = \frac{36615,77}{54195 \cdot \pi \cdot 0,028} = 7,68 \text{ m} < 16 \text{ m} .$$

Where: $d_{out} = 0,028 \text{ m}$, is outer diameter of the tubes,

The length of the tubes must be less than 16 m.

- **The calculated value of the specific steam load of the condenser, kg / (m²·h)**

$$d_c^{calc} = \frac{3600 \cdot G_{c1}}{F} ;$$

$$d_c^{calc} = \frac{3600 \cdot 527,51}{36615,77} = 51,86 \text{ kg}/(\text{m}^2 \cdot \text{h}).$$

- The obtained value d_c^{calc} must be compared with the specified in paragraph

$$\frac{d_c^{calc}}{d_c} = \frac{51,86}{43} = 1,50 ;$$

$$\left| \frac{d_c^{calc} - d_c}{d_c^{calc}} \right| \cdot 100 = \left| \frac{51,86 - 43}{51,86} \right| \cdot 100 = 17,08 \% .$$

The obtained value d_c^{calc} must be compared with the specified in paragraph (4.2.7). If there is a significant (more than 2%) discrepancy, it is necessary to assign $d_c = d_c^{calc}$ and repeat the calculation, starting with paragraph (4.2.7).

By repeating the calculation, in (4.2.7) with new $d_c = d_c^{calc}$, we obtain

$d_c, \text{kg}/(\text{m}^2 \cdot \text{h})$	43	51,86
$k, \text{W}/(\text{m}^2 \cdot ^\circ\text{C})$	3249,2	3259,6
F, m^2	36615,77	36721
L, m	7,68	7,70
ERROR %	17,08	0,32

The condition is met, so the calculation ended.

4.2.8 Mass of condenser tubes

$$M_{tube} = n_{tube} \cdot L \cdot \frac{\pi \cdot (d_{out}^2 - d_{inn}^2)}{4} \cdot \rho_{mat} , \text{kg} ;$$

where:

L, d_{out} and d_{inn} are in m ;

$$M_{tube} = 54195 \cdot 7,70 \cdot \frac{\pi \cdot (0,028^2 - 0,026^2)}{4} \cdot 7800 = 276094,77 \text{ kg} ;$$

ρ_{mat} is density of the pipe material, kg/m^3 . For brass tubes $\rho_{mat} = 8750 \text{ kg}/\text{m}^3$; for cupronickel tubes $\rho_{mat} = 8900 \text{ kg}/\text{m}^3$; for stainless steel tubes $\rho_{mat} = 7800 \text{ kg}/\text{m}^3$; for titanium tubes $\rho_{mat} = 4500 \text{ kg}/\text{m}^3$.

4.2.9 Cost of condenser tubes

$$C_{tube} = \frac{M_{tube} \cdot c_{mat}}{10^6}, \text{ million rubles ;}$$

$$C_{tube} = \frac{276094,77 \cdot 350}{10^6} = 96,6 \text{ million rubles ;}$$

where: c_{mat} is price 1 kg of tubes, rub/kg. For brass tubes $c_{mat} = 675 \dots 700$ rub/kg; for cupronickel tubes $c_{mat} = 2400 \dots 2500$ rub/kg; for stainless steel tubes $c_{mat} = 350 \dots 400$ rub/kg; for titanium tubes $c_{mat} = 1900 \dots 2100$ rub/kg.

4.2.10 Cost of the condenser

$$C_{cond} = K_c \cdot C_{tube}, \text{ million rubles ;}$$

$$C_{cond} = K_c \cdot C_{tube} = 1,75 \cdot 96,6 = 169,1 \text{ million rubles.}$$

where:

$K_c = 1,75 \dots 2$ is empirical coefficient.

4.3 Hydraulic calculation of the condenser

4.3.1 Pressure losses in the condenser along the cooling water path

The purpose of the hydraulic calculation of a condenser is to determine the pressure loss during the movement of cooling water in it.

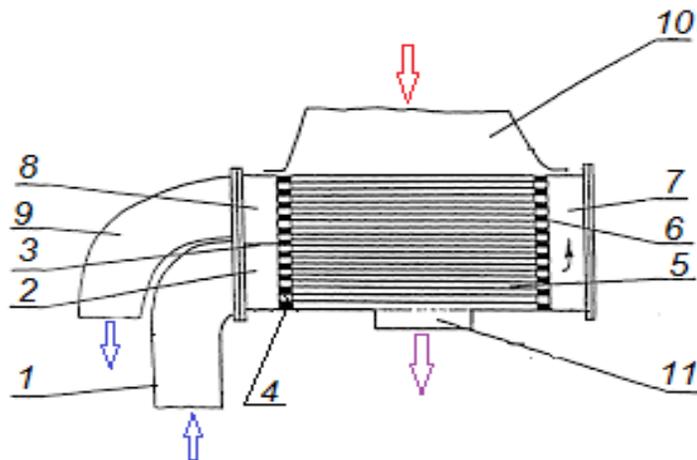


Figure 4.1- To the hydraulic calculation of the condenser

The hydraulic resistance of a two-way condenser with straight tubes can be represented as follows

$$\Delta p_{\Sigma} = \Delta p_{loc} + \Delta p_{fr} = 8470 + 50168,5 = 58638,5 \text{ Pa} ;$$

where:

Δp_{loc} are local pressure losses;

Δp_{fr} are friction losses in the condenser tubes;

$\Delta p_{wch.in}$ is local hydraulic resistance at the water inlet to the tubes from the water chamber;

$\Delta p_{wch.out}$ is local hydraulic resistance at the water outlet from the pipes to the water chamber;

Δp_{turn} is local hydraulic resistance from turning the water in the water chamber;

For the calculate of local pressure losses it is necessary to use the following formula

$$\Delta p_{loc} = \xi_{loc} \cdot \frac{\rho_w \cdot w_w^2}{2} , \text{ pa} ;$$

where:

$\rho_w \approx 1000 \text{ kg/m}^3$ is the average density of the cooling water;

w_w is speed of the cooling water in the tubes of the condenser, m/s;

ξ_{loc} is local resistance coefficient. The values of this coefficient for some types of local

resistances are given in the table 4.2.

$$\Delta p_{loc} = 2 \cdot \Delta p_{wch.in} + 2 \cdot \Delta p_{wch.out} + \Delta p_{turn} ;$$

$$\Delta p_{loc} = (2 \cdot \xi_{in} + 2 \cdot \xi_{out} + \xi_{turn}) \cdot \frac{\rho_w \cdot w_w^2}{2} ;$$

$$\Delta p_{loc} = ((2 \cdot 0,5) + (2 \cdot 1) + 0,5) \cdot \left(\frac{1000 \cdot 2,2^2}{2} \right) = 8470 \text{ Pa} .$$

Table 4.2- The values of the coefficient of local resistance:

Type of local resistance	Coefficient value ξ_{loc}
Inlet to the tubes from the water chamber	0,5
Outlet from the pipes to the water chamber	1
Turning the water in the water chamber	0,5

For the calculate the friction pressure losses it is necessary to use the Altshul formula

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{2 \cdot L}{d_h} \cdot \frac{\rho_w \cdot w_w^2}{2}, pa$$

$$\Delta p_{fr} = 0,035 \cdot \frac{2 \cdot 7,70}{0,026} \cdot \frac{1000 \cdot 2,2^2}{2} = 50168,5 Pa ;$$

where:

L is length of the heat transfer tubes, 9,21 m;

$d_h = d_{inn} = 0,026$ is characteristic size (hydraulic diameter), m;

$\xi_{fr} = 0,035 \dots 0,037$ is coefficient of friction. Assume it 0,035.

4.3.2 Power of the pump for pumping water through the condenser

$$N_p = \Delta p_{\Sigma} \cdot \frac{W}{\rho_w \cdot \eta_p \cdot 1000}, kW ;$$

$$N_p = 58638,5 \cdot \frac{31650,6}{1000 \cdot 0,86 \cdot 1000} = 2158,1 kW.$$

where:

Δp_{Σ} is total hydraulic resistance of a two-way condenser, Pa;

$\eta_p = 0,86 \dots 0,88$ is the efficiency of the pump, assume it 0,86 .

4.3.3 Electric power consumption for the circulation pump drive

$$E_p = N_p \cdot \tau_{rp}, (kW \cdot h) ;$$

$$E_p = 2158,1 \cdot 6500 = 14027650 (kW \cdot h) ;$$

where: $\tau_{rp} = 6500 \dots 7000 h$, is number of hours of use of rated power.

4.3.4 The cost of electricity for pumping water through the condenser

$$C_{el} = \frac{E_p \cdot T_{el}}{10^6}, \text{ million rubles ;}$$

$$C_{el} = \frac{14027650 \cdot 14}{10^6} = 196,4 \text{ million rubles ;}$$

where: $T_{el} = 14 \dots 16 \text{ rub}/(\text{kW} \cdot \text{h})$, is electricity tariff for nuclear power plants.

4.4 Design calculation of the turbine condenser No (2)

- **Initial data for the calculation of the second condenser**

Table 4.3- Initial data:

Parameter	Denomination, units	Value
Exhaust steam flow per condenser	G_{c1} , kg/s	527,51
Condenser pressure	p_c , MPa	0,006
Number of tube-side passes for cooling water	z	2
Coolant temperature at the inlet to the condenser	t_{w1} , °C	20
Speed of the cooling water in the tubes of the condenser	w_w , m/s	2,2
Condenser tube sizes	$d_{out} \times \delta_{wall}$, mm	28×2
Tube material		stainless steel;

- **Determining the characteristics of a condenser**

4.4.1 Flow rate of cooling water per condenser

$$W_1 = m \cdot G_{c1} ;$$

$$W_1 = 60 \cdot 527,51 = 31650,6 \text{ kg/s} .$$

4.4.2 The number of heat transfer tubes, pieces

$$n_{tube} = \frac{4 \cdot W_1 \cdot z}{\pi \cdot d_{inn}^2 \cdot \rho_w \cdot w_w} ;$$

$$n_{tube} = \frac{4 \cdot 31650,6 \cdot 2}{\pi \cdot (26 \cdot 10^{-3})^2 \cdot 1000 \cdot 2,2} = 54195 \text{ pcs} ;$$

where:

z is number of tube-side passes for cooling water;

$$d_{inn} = d_{out} - (2 \cdot \delta_{wall}) ;$$

$d_{inn} = 28 - (2 \cdot 1) = 26 \text{ mm}$, is the inner diameter of the tubes;

4.4.3 Cooling water heating in the condenser, °C

$$\Delta t_w = \frac{r}{c_w \cdot m} ;$$

$$\Delta t_w = \frac{2415}{4,19 \cdot 60} = 9,6 \text{ °C} ;$$

where:

$$r = h'' - h' = 2567 - 152 = 2415 \text{ kJ/kg} ;$$

$$h'' = f(P_c) = 2567 \text{ kJ/kg};$$

$h' = f(P_c) = 152 \text{ kJ/kg}$ is latent heat of vaporization under pressure P_c , kJ/kg;

$c_w = 4,19$ is heat capacity of cooling water, kJ/ (kg °C).

4.4.4 Temperature of the cooling water at the condenser outlet, °C

$$t_{w2} = t_{w1} + \Delta t_w ;$$

$$t_{w2} = 20 + 9,6 = 29,6 \text{ °C} .$$

4.4.5 The Heat power that is transferred to the cooling water in the condenser, kW

$$Q_{w2} = W_1 \cdot c_w \cdot \Delta t_w ;$$

$$Q_{w2} = 31650,6 \cdot 4,19 \cdot 9,6 = 1,273 \cdot 10^6 \text{ kW} .$$

4.4.6 The average temperature difference, °C

$$\Delta t_{avr} = \frac{\Delta t_w}{\ln \left(\frac{t_s - t_{w1}}{t_s - t_{w2}} \right)} ;$$

$$\Delta t_{avr} = \frac{9,6}{\ln \left(\frac{36,2 - 20}{36,2 - 29,6} \right)} = 10,7 \text{ °C} ;$$

where:

$$t_s = f(p_c) = 36,2 \text{ °C}, \text{ is saturation temperature at condenser pressure } p_c.$$

4.4.7 Specific vapor load of the condenser d_c . Initially set in the range of 40 ... 60 kg / (m² · h), and then must be checked

$$d_c = 48 \text{ kg} / (\text{m}^2 \cdot \text{h});$$

- The overall heat transfer coefficient (BTH formula) is calculated using one of two expressions

$t_{w1} = 20 \text{ °C}$. So, I will use the following expression:

If $t_{w1} \leq 35 \text{ °C}$

$$k = 4070 \cdot a \cdot \left(\frac{1,1 \cdot w_w}{d_{inn}^{0,25}} \right)^x \cdot \left[1 - \frac{0,52 - 0,002 \cdot d_c \cdot \sqrt{a}}{1000} \cdot (35 - t_{w1})^2 \right] \cdot \left[1 - \frac{z - 2}{10} \cdot \left(1 - \frac{t_{w1}}{35} \right) \right] \cdot \Phi_d ;$$

$$k = 4070 \cdot 0,5525 \cdot \left(\frac{1,1 \cdot 2,2}{24^{0,25}} \right)^{0,265} \cdot \left[1 - \frac{0,52 - 0,002 \cdot 48 \cdot \sqrt{0,5525}}{1000} \cdot (15)^2 \right] \left[1 - \frac{2 - 2}{10} \cdot \left(1 - \frac{20}{35} \right) \right] \cdot 1$$

$$= 3272,6 \text{ W}/(\text{m}^2 \cdot \text{°C}) ;$$

where:

k - in $\text{W}/(\text{m}^2 \cdot \text{°C})$;

$$x = 0,12 \cdot a \cdot (1 + 0,15 \cdot t_{w1}) = 0,265$$

$a = a_0 \cdot a_m = 0,65 \cdot 0,85 = 0,5525$ is coefficient taking into account pollution of tubes and tube material;

$a_0 = 0,65 \dots 0,85$ is coefficient that takes into account tube contamination;

Assume it 0,65.

a_m is correction factor that takes into account the tube material:

for stainless steel = 0,85;

d_{inn} is the inner diameter of the tubes = 24 mm ;

w_w is speed of water in tubes 2,2 m / s;

t_{w1} is the temperature of the cooling water at the inlet to the condenser; 20 °C;

$z = 2$ is number of tube-side passes for cooling water;

$\Phi_d = 1$ When designing condensers, this coefficient is taken equal to 1.

- **Heat transfer surface area, m^2**

$$F = \frac{Q_{w2}}{k \cdot \Delta t_{avr}} ;$$

$$F = \frac{(1,273 \cdot 10^6) \cdot 10^3}{3272,6 \cdot 10,7} = 36354 \text{ m}^2 ;$$

- **The length of the heat transfer tubes, m**

$$L = \frac{F}{n_{tube} \cdot \pi \cdot d_{out}} ;$$

$$L = \frac{36354}{54195 \cdot \pi \cdot 0,028} = 7,63 \text{ m} < 16 \text{ m} .$$

- **The calculated value of the specific steam load of the condenser, kg / (m²·h)**

$$d_c^{calc} = \frac{3600 \cdot G_{c1}}{F} ;$$

$$d_c^{calc} = \frac{3600 \cdot 527,51}{36354} = 52,24 \text{ kg}/(\text{m}^2 \cdot \text{h}) .$$

- **The obtained value d_c^{calc} must be compared with the specified in paragraph**

$$\frac{d_c^{calc}}{d_c} = \frac{52,24}{48} = 1,09 ;$$

$$\left| \frac{d_c^{calc} - d_c}{d_c^{calc}} \right| \cdot 100 = \left| \frac{52,24 - 48}{52,24} \right| \cdot 100 = 8,12 \% .$$

The obtained value d_c^{calc} must be compared with the specified in paragraph (4.4.7). If there is a significant (more than 2%) discrepancy, it is necessary to assign $d_c = d_c^{calc}$ and repeat the calculation, starting with paragraph (4.4.7).

By repeating the calculation, in (4.4.7) with new $d_c = d_c^{calc}$, we obtain

d_c , kg/(m ² · h)	48	52,24
k , W/(m ² ·°C)	3272,6	3277,4
F , m ²	36354	36522
L , m	7,63	6,53
ERROR %	8,12	0,15

The condition is met, So the calculation ended.

4.4.7 Mass of condenser tubes

$$M_{tube} = n_{tube} \cdot L \cdot \frac{\pi \cdot (d_{out}^2 - d_{inn}^2)}{4} \cdot \rho_{mat}, kg$$

$$M_{tube} = 54195 \cdot 6,53 \cdot \frac{\pi \cdot (0,028^2 - 0,024^2)}{4} \cdot 7800 = 450941,5 kg .$$

4.4.8 Cost of condenser tubes

$$C_{tube} = \frac{M_{tube} \cdot c_{mat}}{10^6}, million rubles ;$$

$$C_{tube} = \frac{450941,5 \cdot 350}{10^6} = 157,8 million rubles .$$

4.4.9 Cost of the condenser

$$C_{cond} = K_c \cdot C_{tube}, million rubles ;$$

$$C_{cond} = K_c \cdot C_{tube} = 1,75 \cdot 157,8 = 276,2 million rubles .$$

4.4.10 Hydraulic calculation of the condenser

The hydraulic resistance of a two-way condenser with straight tubes can be represented as follows

$$\Delta p_{\Sigma} = \Delta p_{loc} + \Delta p_{fr} ;$$

$$\Delta p_{\Sigma} = 8470 + 46091 = 54561 Pa .$$

For the calculate of local pressure losses it is necessary to use the following formula

$$\Delta p_{loc} = \xi_{loc} \cdot \frac{\rho_w \cdot w_w^2}{2}, pa ;$$

$$\Delta p_{loc} = 2 \cdot \Delta p_{wch.in} + 2 \cdot \Delta p_{wch.out} + \Delta p_{turn}$$

$$\Delta p_{loc} = (2 \cdot \xi_{in} + 2 \cdot \xi_{out} + \xi_{turn}) \cdot \frac{\rho_w \cdot w_w^2}{2}$$

$$\Delta p_{loc} = ((2 \cdot 0,5) + (2 \cdot 1) + 0,5) \cdot \frac{1000 \cdot 2,2^2}{2} = 8470 Pa .$$

For the calculate the friction pressure losses it is necessary to use the Altshul's formula

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{2 \cdot L}{d_h} \cdot \frac{\rho_w \cdot w_w^2}{2}, pa;$$

$$\Delta p_{fr} = 0,035 \cdot \left(\frac{2 \cdot 6,53}{0,024} \right) \cdot \left(\frac{1000 \cdot 2,2^2}{2} \right) = 46091 Pa .$$

4.4.11 Power of the pump for pumping water through the condenser

$$N_p = \Delta p_{\Sigma} \cdot \frac{W}{\rho_w \cdot \eta_p \cdot 1000}, kW;$$

$$N_p = 54561 \cdot \left(\frac{31650,6}{1000 \cdot 0,86 \cdot 1000} \right) = 2008 kW.$$

4.4.12 Electric power consumption for the circulation pump drive

$$E_p = N_p \cdot \tau_{rp}, (kW \cdot h);$$

$$E_p = 2008 \cdot 6500 = 13052000 (kW \cdot h) .$$

4.4.13 The cost of electricity for pumping water through the condenser

$$C_{el} = \frac{E_p \cdot T_{el}}{10^6}, million rubles;$$

$$C_{el} = \frac{13052000 \cdot 14}{10^6} = 182,7 million rubles;$$

where:

$T_{el} = 14 \dots 16 rub/kW \cdot h$, is electricity tariff for nuclear power plants.

Table 4.4- Results of variant calculations of the condenser:

	Option 1	Option 2
	$d_{out} = 28 \text{ mm}$ $\delta_{wall} = 1 \text{ mm}$	$d_{out} = 28 \text{ mm}$ $\delta_{wall} = 2 \text{ mm}$
G_{c1} , kg/s	527,51	527,51
W_1 , kg/s	31650,6	31650,6
M_{tube} , kg	276094,77	292801,23
C_{tube} , million rubles	96,6	157,8
C_{cond} , million rubles	169,1	276,2
N_p , kW	2158,1	2008
E_p , kW·h	14027650	13052000
C_{el} , million rubles	196,4	182,7

Chapter (5) Financial management, resource efficiency and resource saving
ASSIGNMENT FOR THR DIPLOMA PROJECT SECTION

5.1 Analysis of competitive technical solutions

The condenser is designed for circulating water supply systems for steam turbines. The steam turbine condenser consists of a body with a steam intake unit, condenser tubes fixed in tube sheets and adjacent to the body, front and rear water chambers with an additional unit for introducing a cooling medium. An additional input unit is connected to the inlet part of the front water chamber, and the upper part of the rear water chamber is equipped with a unit for connection to the ejection system. This technical solution allows for reliable filling of the upper tubes of the condenser with a cooling medium with minimal energy and labor costs. A decrease in the thermal power of the turbine leads to a decrease in the electrical power generation and an increase in the cost of electricity.

Using this analysis, the scientific project where modified to improve the designs and make it withstand successfully. in order to study this modification, the strengths and weaknesses of the comparative structures needed to be evaluated. All available information on competitive developments is used (Table 5.1).

Table 5.1 – The results of calculations of the competitive structures of the condenser

	Design options	
	Condenser (1)	Condenser (2)
	1000-KIIC -1	1000-KIIC -1
	<i>d_{out} = 28 mm ; δ_{wall} = 1 mm</i>	<i>d_{out} = 28 mm ; δ_{wall} = 2 mm</i>
<i>C_{cond} , million RUB</i>	169,1	276,2
<i>C_{el} , million RUB</i>	196,4	182,7

Notes:

- C_{cond} is cost of the condenser;
- C_{el} is the cost of electricity for pumping water through the condenser.

The analysis is carried out using a scorecard. The scorecard is shown in table 5.2.

The object of research is a steam turbine condenser, which uses two types of heat exchange tubes. Therefore, the comparison will be made on the basis of data on two options for the design of the condenser with different sizes of heat exchange tubes.

Condensers for NPP turbines are manufactured at Leningrad Metal Plant.

Table 5.2 - Scorecard for comparing competitive technical solutions

Items to assess	Value of criteria C_i	Points		Competitiveness	
		B_1	B_2	K_1	K_2
Technical criteria for evaluating resource efficiency					
1. Energy efficiency	0,2	3	4	0,6	0,8
2. Dimensions and weight	0,15	4	2	0,6	0,3
3. Environmental safety	0,05	4	3	0,2	0,15
4. Lifetime	0,2	3	4	0,6	0,8
5. Reliability	0,2	2	4	0,4	0,8
Economic performance indicators					
1. Price	0,15	4	2	0,6	0,3
2. Maintenance	0,02	3	3	0,06	0,06
3. The competitiveness of the product	0,03	3	3	0,09	0,09
Total	1			3,15	3,3

The analysis of competitive technical solutions is defined as follows:

$$K_i = \sum_{i=1}^2 C \cdot B_i ;$$

where:

K - competitiveness of scientific research;

C_i - indicator weight (in unit fractions);

B_i - score of the i^{th} indicator.

Indices for indicators "1" - first type 1000-KIQC -1 with $d_{out} = 28$ mm; $\delta_{wall} = 1$ mm;

"2" - second type 1000-KIQC -1 with $d_{out} = 28$ mm; $\delta_{wall} = 2$ mm.

Calculation example:

$$K_1 = \sum C_i \cdot B_{1i} = (0,2 \cdot 3) + (0,15 \cdot 4) + \dots + (0,03 \cdot 3) = 3,15 .$$

The results show that the competitiveness of option 1 was 3,15, while that of option 2 was equal to 3,3 .

Thus, the investigated scientific development (condenser design), which uses tubes with $d_{out} = 28$ mm; $\delta_{wall} = 2$ mm, is competitive and has a number of advantages in terms of technical and economic indicators of resource efficiency.

5.2 Project initiation

Initiation processes define initial goals and content and fix initial financial resources. The internal and external stakeholders of the project are determined, which will interact and influence the overall result of the scientific project.

5.2.1 Project goals and results

Information about the stakeholders of the project, the hierarchy of project goals and criteria for achieving goals is presented in table below.

Table 5.3 – Stakeholders of the project

Stakeholders of the project	Stakeholders of the project expectations
TPU, NPP operation, design and engineering, project executor	High efficiency equipment (condenser)

Information about the hierarchy of project goals and criteria for achieving goals is given in the table below.

Table 5.4 – Project goals and results

Project goals	Provide reliable condensers for the turbine installation of a nuclear power plant, reduce energy costs for driving circulation pumps, and increase the efficiency of using the condenser
Expected results of the project	Based on the conducted research, analyze the sensitivity, find shortcomings, suggest the necessary measures to improve these indicators.
Acceptance criteria of the project result	Improving efficiency in relation to the proposed measures to improve the reliability of the equipment.
Requirements to the project results	Project completion on time
	Stability of technological equipment
	The efficiency of the equipment used
	Convenience in usage

5.2.2 Organizational structure of the project

The organizational structure of the project is presented in the table 5.5.

Table 5.5 – Project Working Group

№	Name	Position	Functions	Hours spent
1	Elsharkawy. A.M	Project Executor	Work on project implementation	150
2	Gubin. V.E	Project Manager	Coordination of work activities and assistance in project implementation	35
Total:				185

So, the time spent for my research is equal:

for my Supervisor (Project Manager) → $35 \cdot 4 = 140$ hours;

for me as an Engineer (Project Executor) → $150 \cdot 4 = 600$ hours.

5.2.3 Assumptions and constraints

Limitations and assumptions are summarized in table 5.6.

Table 5.6 – Limitations and assumptions

Factor	Limitations/assumptions
1. Project budget	270 000 RUB
1.1 Source of budgeting	Own funds / Rosatom scholarship
2. Project timeline:	10 July 2020 – 15 January 2021
2.1 Date of approval of the project management plan	10 July 2020
2.2 Project completion date	25 December 2020
3. Other	-

As a result of the initialization of the project, the goals and expected results were formulated, the stakeholders of the project and the financial framework were identified, which is very important for the successful completion of the project and its implementation.

5.2.4 Project planning

The main way to develop a design implementation schedule is called a Gantt chart. A Gantt chart is a horizontal graph that depicts work on a topic in long time periods, described by completion dates and start dates for the assigned work (tables 5.7 and 5.8).

Note:

$t_{o\omega k} = (3 \cdot t_{max_{min}} \cdot 0,2)$, is expected labor intensity of performing one job, person-days;

$T_p = \frac{t_{o\omega k}}{U}$, is the duration of the execution of one job, working days;

where $U = 1$, is number of performers performing the same job, person.

$T_k = T_p \cdot k_k$ - duration of one job, calendar days,

where $k_k = 1,65$, is calendar factor.

Table 5.7 – Design and research timing

№	Task	The laboriousness of the task						Duration of the task in working days, T_{pi}		Duration of the task in calendar days, T_{ki}	
		t_{min} , person-days		t_{max} , person-days		$t_{ожи}$, person-days		S.V	Eng	S.V	Eng
		S.V	Eng	S.V	Eng	S.V	Eng				
1	Drawing up the technical assignment	10,8		12,5		11,5		11,5		18,9	
2	Literature review		14,5		13		13,6		13,6		22,4
3	Selection of the research field		12,5		10,7		15		15		24,8
4	Calendar planning	8,8		13		10,5		10,5		17,3	
5	Description of the design object		15,6		12,1		13,5		13,5		22,3
6	Statement of the design problem		22,8		19,8		21		21		34,7
7	Development of the calculation model		24,8		16,8		20		20		33
8	Variational calculations of the object		27,4		23,4		25		25		41,3
9	Evaluation of calculation results	10		17,5		13		13		21,5	
10	Comparative calculations of economic efficiency object		19,5		9,5		13,5		13,5		22,3
11	Choosing the optimal design		15,7		10,2		12,4		12,4		20,5
12	Drawing up a final report		20,5		13		16		16		26,4

- Where:

S.V means Supervisor;

Eng means Engineer.

Table 5.8 – Schedule of the project design

№	Task	Executors	T _{ki} days	Duration of the task																			
				July		August				September				October				November				December	
				3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
1	Drawing up the technical assignment	Supervisor	18,9																				
2	Literature review	Engineer	22,4																				
3	Selection of the research field	Supervisor	24,8																				
4	Calendar planning	Supervisor	17,3																				
5	Description of the design object	Engineer	22,3																				
6	Statement of the design problem	Engineer	34,7																				
7	Development of the calculation model	Engineer	33																				
8	Variational calculations of the object	Engineer	41,3																				
9	Evaluation of calculation results	Supervisor	21,5																				
10	Comparative calculations of economic	Engineer	22,3																				
11	Choosing the optimal design	Supervisor	20,5																				
12	Drawing up a final report	Engineer	26,4																				
	-Engineer																					-Supervisor	

5.2.5 Project budgeting

The project budget must display reliable values for all types of costs associated with its implementation. The costs of this project include:

- costs of purchasing equipment;
- costs for materials and other products;
- expenses for the main and additional salaries of the theme performers;
- costs for special equipment;
- costs of social security contributions;
- overhead costs.

5.2.5.1 Costs for materials and other products

These costs include office supplies, printing costs, and various equipment required for paperwork.

Table 5.9 – Costs for materials for the project

Name	Unit of measurement	Number	Price per unit, RUB	Expenses (E_M), RUB
Paper	Pack	1	250	250
Pens	Unit	2	50	100
Pencils	Unit	1	50	50
Ruler	Unit	1	40	40
Printing	Page	200	2	400
Folder	Unit	2	5	10
Stapler	Unit	1	150	150
Staples	Pack	1	40	40
Hole puncher	Unit	1	250	250
Total				1 290

5.2.5.2 Costs for specialized equipment

This item includes all costs that are associated with the purchase of special equipment (for example, instruments, instrumentation, stands, devices and mechanisms) necessary for the project.

Table 5.10 – Costs for specialized equipment

№	Name	Number	Price per unit, RUB	Total price of equipment, RUB
1	Laptop	1	30 000	30 000
2	Microsoft-Windows 10-Professional x64	1	4 000	4 000
3	Kaspersky Anti-Virus	1	1 320	1 320
4	Microsoft-Office 2019-Home	1	2 500	2 500
Total, RUB				37 820

The cost of specialized equipment is recorded in the form of depreciation charges.

Depreciation is the gradual transfer of costs incurred to purchase or build property, plant and equipment to the cost of the finished product. With its help, money spent on the construction or purchase of property is compensated. Depreciation deductions are paid during the entire period of property exploitation.

Let's calculate the amount of monthly depreciation deductions in a linear way. Equipment costs are 37 820 RUB. The operating life of the computer is 7 years, the Microsoft Windows 10 license is 4 years, the rest of the software is a year. Then the annual depreciation rate for them, respectively:

$$N_{DL} = \frac{1}{7} \cdot 100\% = 14.29\% ;$$

$$N_{DWin} = \frac{1}{4} \cdot 100\% = 25\% ;$$

$$N_{DSS} = \frac{1}{1} \cdot 100\% = 100\% .$$

Academic year depreciation (9 months) for Laptop, Microsoft Windows 10 License, and Supporting Software:

$$D_L = 30000 \cdot \frac{N_{DL}}{100\%} \cdot \frac{T}{365} = 30000 \cdot \frac{14.29\%}{100\%} \cdot \frac{90}{365} = 1057 \text{ RUB},$$

$$D_{Win10} = 4000 \cdot \frac{N_{DWin}}{100\%} \cdot \frac{T}{365} = 4000 \cdot \frac{25\%}{100\%} \cdot \frac{90}{365} = 246,6 \text{ RUB},$$

$$D_{SS} = 3820 \cdot \frac{N_{DSS}}{100\%} \cdot \frac{T}{365} = 3820 \cdot \frac{100\%}{100\%} \cdot \frac{90}{365} = 941,9 \text{ RUB},$$

where T – number of working days

Total depreciation for a year:

$$D = D_L + D_{Win10} + D_{SS} = 2245,2 \text{ RUB}$$

5.2.5.3 Basic salary

The amount of expenses for wages of employees is determined based on the labor intensity of the work performed and the current system of salaries and tariff rates.

The calculation of the basic salary of the head of a scientific project is based on the sectoral wage system. The branch system of remuneration at TPU assumes the following composition of wages:

- 1) Salary - determined by the enterprise. In TPU, salaries are distributed in accordance with the positions held, for example, assistant, art. lecturer, associate professor, professor (see "Regulations on remuneration" given on the website of the Planning and Finance Department of TPU).
- 2) Incentive payments - set by the head of departments for effective work, performance of additional duties, etc.
- 3) Other payments; district coefficient.

Since incentive bonuses, other payments and incentives depend on the activities of the manager in particular, we will take the coefficient of incentive bonuses equal to 30%, and the coefficient of incentives for the manager for conscientious work activity is 25%.

The basic salary of a manager is determined by the formula:

$$S_b = S_r \cdot T_w ;$$

where:

S_r is worker's regular salary;

T_p is duration of work, work days.

Additional salary:

$$S_{add} = 0,15 \cdot S_b ;$$

Average daily salary for a 5-day working week:

$$S_d = \frac{S_m \cdot M}{F_d} ;$$

where:

S_m is worker's monthly salary, RUB;

F_d is number of working days in a month, days,

$M = 11,2$ is number of months of work without vacation during the year

Full salary can be defined as:

$$S_F = S_b + S_{add} ;$$

Taking into account the document "Regulations on wages", associate professor, candidate of technical sciences, working at TPU has a salary equal to $S_r = 36\,000$ rubles (senior teacher – 30000 rubles, professor, doctor of technical sciences – 45000 rubles). A design engineer with no experience in Tomsk has an average salary of 18,000 rubles. With this in mind, we calculate the size of the total salary of the project manager and design engineer during the study.

Monthly salaries:

- For project supervisor:

$$S_{b.sup} = S_r \cdot (1 + k_{pr} + k_d) \cdot k_r = 36000 \cdot (1 + 0,3 + 0,25) \cdot 1,3 = 72540 \text{ RUB} ,$$

$$S_{F.sup} = S_{b.sup} + S_{add} = 72540 + (0,15 \cdot 72540) = 83421 \text{ RUB} .$$

- For engineer developer:

$$S_{b.eng} = S_r \cdot (1 + k_{pr} + k_d) \cdot k_r = 18000 \cdot (1 + 0,3 + 0,25) \cdot 1,3 = 36\,270 \text{ RUB} ;$$

$$S_{F.eng} = S_{b.eng} + S_{add} = 36270 + 0,15 \cdot 36270 = 41711 \text{ RUB} .$$

Average daily salary:

$$S_{D.sup.} = \frac{S_{b.sup.}}{F_d} = \frac{72540}{20.58} = 3524,1 \text{ RUB},$$

$$S_{D.eng.} = \frac{S_{b.eng.}}{F_d} = \frac{36270}{20.58} = 1762.4 \text{ RUB};$$

where the average number of working days in a month was determined as:

$$F_d = \frac{T_w}{12} = \frac{247}{12} = 20,58 ;$$

Let's assume that the project manager spent 35 working hours on it, then the design engineer was engaged in the rest of the time (150 hours). Salaries of project participants for the period of work:

$$S_{sup} = S_{D.sup.} \cdot t_{sup} = 3524,1 \cdot 35 = 123347 \text{ RUB};$$

$$S_{eng} = S_{D.eng.} \cdot t_{eng} = 1762.4 \cdot 150 = 264315 \text{ RUB}.$$

Additional salaries of project participants:

$$S_{add.sup.} = 0,15 \cdot 72540 = 10881 \text{ RUB};$$

$$S_{add.eng.} = 0,15 \cdot 36270 = 5440,5 \text{ RUB}.$$

Daily additional salaries:

$$S_{D.add.sup.} = \frac{10880.3}{20,58} = 528,63 \text{ RUB},$$

$$S_{D.add.eng.} = \frac{5440.5}{20,58} = 264,4 \text{ RUB},$$

Additional salary for the entire project period:

$$S_{Padd.sup} = S_{D.add.sup.} \cdot t_{sup} = 528,63 \cdot 35 = 18502 \text{ RUB};$$

$$S_{Padd.eng} = S_{D.add.eng.} \cdot t_{eng} = 264,4 \cdot 150 = 39648 \text{ RUB}.$$

Full salary for the period of the project:

$$S_{F.sup} = S_{b.sup} + S_{Padd.sup} = 72540 + 18502 = 91042 \text{ RUB};$$

$$S_{F.eng} = S_{b.eng} + S_{Padd.eng} = 36270 + 39648 = 75918 \text{ RUB}.$$

5.2.5.4 Contributions to social funds

Here I will consider the obligatory contributions according to the norms established by the legislation of the Russian Federation to the state social insurance bodies (FSS), the pension fund (PF) and medical insurance (FFOMS) from the costs of wages of employees. The number of contributions to extra-budgetary funds is determined by the formula:

$$S_{exb} = k_{exb}(S_{F.sup} + S_{F.eng}) ;$$

Where: k_{exb} – contribution rate to extrabudgetary funds.

To date, the following contributions must be made from the amount provided as payment for labor:

- 22% towards the accrual of future pension;
- 5,1% to the Mandatory Health Insurance Fund;
- 2,9% to the Social Insurance Fund;
- from 0,2 to 8,5% for insurance against accidents that may occur at work (the exact amount depends on the risk class, which includes the profession and position of the employee).

The work of a manager and a design engineer belongs to the 1 risk class. Thus, the total deductions amount to 30,2%.

$$S_{exb} = 0,302 \cdot (91042 + 75918) = 50422 \text{ RUB} .$$

5.2.5.5 Organization of research costs budget

In the previous subchapters, the values of the main costs of the research were calculated. Let us take them all in one table 5.11.

Table 5.11 – Research cost budgeting

Name	Cost, RUB.	Cost, %
Costs for materials and other products	1290	0,51
Costs for specialized equipment	2245,2	0,88
Supervisor salary costs	91042,1	35,71
Design engineer salary costs	75917,4	29,77
Contributions to social funds	50421,8	19,77
Overheads	34065,7	13,36
Research budget	254982,2	100

Conclusion

In the course of the completed project, a condenser-refrigerator was calculated for the implementation of the condenser types depending on the thickness that is 1 and 2 mm, length and number of the tube.

In the literature review, advanced condenser designs were considered. The technological scheme was justified connected by a pipeline.

Depending on all these variants we found that it affects the cost of condenser if we use a less metal during designing the condenser so the cost of the condenser lower but the electrical cost of pumping to condenser will be higher than the condenser that uses higher thickness of tube with more metal and more cost value of condenser

So, it is preferred to get condenser with low thickness as the cost will be so small like the first variant of condenser with 1 mm thickness and 28 mm diameter and taking into account that pumping cost will not be affected too much, that is why I suggest to choose the variant which has these parameters; $d_{out} = 28$ mm; $\delta_{wall} = 2$ mm.

Chapter – 6 Social responsibility

6.0 Introduction

In this work, we developed a software package for the rehabilitation and assessment of motor disorders of the central nervous system in augmented reality. The work was carried out in the laboratory of the Department of Biomedical Cybernetics of the Biomedical Faculty of Siberian State Medical University. This laboratory is equipped with tools that allow you to study finger movements for assessing motor impairment “Leep Motion” and glasses “Epson Moveiro BT-300” as well as personal computers for managing, processing information and rehabilitating patients. To ensure the safety of workers and the environment, it is necessary to develop a set of technical and organizational measures that minimize the negative consequences of system design actions.

The purpose of this section is to analyze and evaluate harmful and hazardous labor factors that may affect project development personnel. Development of protective measures against these factors, assessment of working conditions. This section also discusses issues related to safety, fire protection and environmental protection, recommendations for creating optimal working conditions.

The potential risk is the use of equipment based on energy consumption

GOST 12.1.030-81

When working with equipment should be guided by the following document:

GOST R 12.1.019-2009

Collective protective equipment includes the use of a special research room.

Personal protective equipment includes: when working with the equipment, hands should be clean and dry, the room temperature must correspond to the data specified in table №3, in order to avoid high or too low humidity of the room. At the end of the work, it is necessary to turn off all equipment and check the room in order to avoid dangerous situations.

6.1 Legal and organizational safety issues

6.1.1 Special legal norms of labor legislation

Most of the work that is carried out in production is directly related to the presence of dangerous and harmful production factors.

When hiring, the applicant is informed about this, and also indicated in the employment contract. And, accordingly, the employer is also obliged to familiarize not only with such working conditions, but also to teach safety measures, safe work practices, conduct internships at the workplace, provide training on labor protection, and periodically check the employee's knowledge of labor protection requirements.

In accordance with Art. 221 - 225 of the Labor Code of the Russian Federation in the conditions of dangerous and (or) harmful production factors, it should be provided by the employer of workers with personal protective equipment, special clothing, disinfecting or rinsing agents, all necessary share of first aid, etc. Also, at his own expense, the employer must ensure the issuance of special shoes and clothes, as well as other personal protective equipment. In addition, according to part 3 of article 221 of the Labor Code of the Russian Federation, the employer must provide care for special clothing (i.e. storage, repair, replacement, washing, drying).

It is also envisaged to undergo a medical examination for workers who perform work in conditions with dangerous and (or) harmful production factors, which is indicated in Article 213 of the Labor Code of the Russian Federation. Moreover, both during employment and in the process of work. In the order of the Ministry of Health and Social Development of the Russian Federation dated 12.04.2011 № 302n. The procedure for conducting a medical examination is indicated. The requirements of this document stipulate that a medical examination should be carried out once a year, or twice a year. It depends on the type of activity of the employee in the workplace, as well as on the presence of specific harmful factors.

According to part 6 of article 213 of the Labor Code of the Russian Federation, for workers whose work is associated with sources of increased danger (for example, the influence of adverse production factors and harmful substances), as well as for

those working under conditions of increased danger, a mandatory psychiatric examination should be performed at least once every 5 years. According to the Decree of the Ministry of Labor of the Russian Federation and the Ministry of

Education of the Russian Federation of 13.01.2003 No. 1/29 “On approving the procedure for training on labor protection and testing knowledge of labor protection requirements for employees of organizations”, a production worker must, in addition to a medical examination at least once every 3 years, pass his knowledge test occupational safety, as well as first aid training for injured people.

6.2 Organizational arrangements for the layout of the working area

6.2.1 Microclimate of the working room

During work in the laboratory, it is necessary to create favorable conditions for the microclimate of the workplace. Prolonged exposure of a person to adverse weather conditions can dramatically worsen his well-being, reduce labor productivity and lead to diseases. The microclimate is determined by combinations of temperature, humidity, air velocity and thermal radiation acting on the human body.

High air temperature contributes to rapid fatigue of the worker, and can lead to overheating of the body, cause a violation of thermoregulation, poor health, decreased attention, heat stroke, increased stress on the heart. Low air temperature can cause local or general hypothermia, cause colds, and lead to diseases of the peripheral nervous system (radiculitis, bronchitis, rheumatism). Low humidity can cause the mucous membranes of the respiratory tract to dry out. Air mobility effectively contributes to the heat transfer of the human body and is positively manifested at high temperatures and negatively at low.

According to SanPin 2.2.4.548–96, work in the laboratory belongs to category 1b in terms of energy consumption - this is light physical work, which does not require lifting and carrying heavy loads, is performed while sitting or is connected with walking.

We give the optimal and permissible microclimate indicators of industrial premises in accordance with SanPin 2.2.4.548–96.

Table 6.1- Optimum microclimate indicators:

Period of the year	Temperature, degrees, °C	Relative humidity, %	Air speed, m / s
Cold	21–23	40–60	0.1
Warm	22–24	40–60	0.1

Table 6.2- Permissible indicators microclimate:

Period of the year	Temperature, degrees, °C		Surface temperature, °C	Relative humidity, %	Air speed, m / s	
	Range below r.h.	Range above r.h.			for air temperature range below (relative humidity), no more	for air temperature range above (relative humidity), no more
Cold	19.0 – 20.9	23.1 – 24.0	18.0 – 25.0	15 - 75	0.1	0.2
Warm	20.0 – 21.9	24.1 – 28.0	19.0 – 29.0	15 - 75	0.1	0.3

Laboratory and housing water heating using radiators.

The measured microclimate indicators of the laboratory correspond to acceptable indicators: air temperature and surface temperature are 20°C and 21°C with a relative humidity of 50% in the cold season; 23°C and 24°C with a relative humidity of 55% in the warm season, which complies with SanPin N 2.2.4.548-96.

6.2.2 Work area illumination

Not only eye health and human performance, but also his physical and psych emotional state directly depends on the degree of illumination. Moreover, in premises for various purposes, the lighting requirements should vary. Also, when calculating the

illumination, it is reasonable to take into account the characteristics of the working process carried out by a person in such a room, its frequency and duration.

In practice, two types of lighting are used: natural and artificial. Natural lateral and artificial working, as well as combined, which consists of local lighting of workplaces and general lighting of the room. These types of lighting are standardized by Set of rules 52.13330.2011.

In this laboratory, work is carried out on personal computers. According to SanPin 2.2.2 / 2.4.1340–03 “Hygienic requirements for personal electronic computers and organization of work”, artificial lighting in premises for the operation of a personal computer should be carried out by a general uniform lighting system.

Illumination on the table surface in the area of the working document should be 300 - 500 lux. Lighting should not create glare on the surface of the screen. Illumination of the screen surface should not be more than 300 lux.

In the laboratory, medium-precision work is carried out with the smallest size of the object of discrimination 0.5 - 1.0 mm, the contrast of the object of discrimination with the background is medium. The category of visual work is IV, subdischarge b, thus the illumination of the working surface from general lighting systems is 200 lux (Set of rules 52.13330.2011 “Natural and artificial lighting”).

Table 6.3- Lighting requirements for residential and public buildings:

Artificial lighting		Natural lighting, DLR, %, at	
Illumination on the working surface from the general lighting system, lux	Coefficient of pulsation of illumination CP, %, no more	Top lighting or combined	Side
300	20	2.5	0.7

Thus, there are no violations of the lighting standards in the laboratory.

6.2.3 Noise level at the workplace

Noise pollution of the environment at the workplace adversely affects workers: attention is reduced, energy consumption increases with the same physical activity, the speed of mental reactions slows down, etc. As a result, labor productivity and the quality of the work performed are reduced.

The main sources of noise in rooms equipped with computer technology are printers, plotters, copying equipment and equipment for air conditioning, fans of cooling systems.

In accordance with SanPin 2.2.2 / 2.4.1340–03 “Hygienic requirements for personal electronic computers and organization of work”, the noise level at workplaces should not exceed 50 dBA.

6.2.4 Elevated electromagnetic radiation

PCs are sources of broadband electromagnetic radiation:

- soft x-ray;
- ultraviolet 200-400 nm;
- visible 400–750 nm;
- near infrared 750–2000 nm;
- kHz radio frequency range;
- electrostatic fields.

Table 6.4- Temporary permissible levels of EMF created by PC in the workplace:

Name of parameters	Temporary Permissible Levels	
Electric field strength	In the frequency range 5 Hz - 2 kHz	25 V/m
	In the frequency range 2 kHz - 400 kHz	2.5 V/m
Magnetic flux density	In the frequency range 5 Hz - 2 kHz	250 nT
	In the frequency range 2 kHz - 400 kHz	25 nT
Electrostatic field strength	15 kV/m	

If at the surveyed workplace equipped with a PC, the intensity of the electric and / or magnetic field in the range of 5 - 2000 Hz exceeds the values given above, it is necessary to measure the background EMF levels of industrial frequency (with the equipment turned off). The background level of the electric field with a frequency of 50 Hz should not exceed 500 V / m.

The background levels of the magnetic field induction should not exceed the values causing violations of the requirements for the visual parameters of the VDT. As a precaution, you should limit the duration of work with the PC, do not place them concentrated in the work area and turn them off if they are not working. Along with this, it is necessary to install air ionizers in the room, ventilate the room more often and, at least once during the work shift, clean the screen of dust (SanPin 2.2.2 / 2.4.1340–03).

6.3 Industrial safety

Industrial safety is understood as a system of organizational measures and technical means that prevent or reduce the likelihood of exposure to working personnel of dangerous traumatic production factors that arise in the work area during the course of labor activity. In our work, it is necessary to find out dangerous and harmful factors that may arise when working with an information system. Subsequent selection is made using GOST 12.0.003–2015 "Dangerous and harmful production factors. Classification". The selection results are shown in the table below.

Table 6.5- Harmful and dangerous factors when working with a computer:

Source of factor, name of the type of work	List of factors (according to GOST12.0.003–2015)		Relevant regulatory documents
	Harmful	Dangerous	
1) Computer work	1) The microclimate of the working room; 2) increased or decreased humidity of the air of the working area 3) Illumination of the working area; 4) Increased noise in the workplace; 5) Increased level of electromagnetic radiation	1) Exposure to electrical current	1) SanPin 2.2.4.548–96; 2) GOST R 12.1.019–2009; 3) GOST 12.1.030–81; 4) SP 52.13330.2011; 5) SanPin 2.2.2/2.4.1340–03; 6) GOST 12.1.003–83; 7) SanPin 2.2.2/2.4.1340–03

6.3.1 Analysis of harmful and dangerous factors that can be created by object of study and laboratory during research

6.3.1.1 Analysis of identified hazardous factors

The laboratory room where the work was carried out belongs to category B.

The causes of the fire may be:

1. Short circuit currents.
2. Malfunction of electric networks.
3. Ignorance of fire safety rules or negligence of staff.
4. Smoking in the wrong places.

In this regard, the following fire safety standards must be observed in the laboratory:

1. To protect the network from overloads, it is forbidden to include additional non-intended consumers.
2. Carry out work in the laboratory only when the equipment and electrical wiring are in good condition.
3. For extinguish a fire (fire extinguisher).
4. Have a plan of evacuation of people, which should hang in a conspicuous place.
5. Place the equipment so that there is sufficient passageway to the exit.

The building of the Siberian State Medical University, in which the laboratory is located, meets the fire safety requirements.

6.3.1.2 Electrical safety

Electrical safety is a system of organizational and technical measures aimed at protecting people from the harmful and dangerous effects of electric current.

There is a danger of electric shock in all cases where electrical installations and equipment are used. Electrical installations are classified by voltage - with a rated voltage of up to 1000 V (rooms without increased danger), up to 1000 V with the presence of an aggressive environment (rooms with increased danger) and over 1000 V (rooms especially dangerous) (according to the Rules for the Installation of Electrical Installations).

To ensure safe operation, it is necessary to exclude possible sources of electric shock: Accidental contact with live parts under voltage. The appearance of voltage on the mechanical parts of electrical equipment (cases, covers, etc.) due to insulation damage or other reasons. The occurrence of stress on the ground or supporting surface.

According to the degree of danger of electric shock, this laboratory belongs to rooms without increased danger, it is a dry room without increased dusting, the air temperature is normal, the floor is covered with insulating material.

All electrical equipment and devices are in place and have protective grounding with a resistance of not more than 4 ohms (GOST 12.1.030-81.) All employees undergo initial electrical safety training.

Before starting work, it is necessary to check the serviceability of conductive wires. It is forbidden to use wires with damaged insulation or without insulation, as well as wires that are not equipped with plugs or soldered terminals, to connect electrical appliances.

Instruments must be kept clean. At the end of the work, disconnect the equipment from the network.

Electric shock during GQW can occur during careless handling of the connecting wires or in the event of an emergency - shorting of live parts to the equipment case in the absence of grounding and grounding. This can happen when working with electrical laboratory equipment.

Table 6.6- Permissible levels of touch voltages and currents:

Mode	Type of Current					
	Variable, 50 Hz			Constant		
	U, V	I, mA	Duration, min	U, V	I, mA	Duration, min
Normal	2	0,3	<10	8	1	<10

First aid to the victim should consist in immediately disconnecting the current that caused the injury, disconnecting (in rubber gloves) the victim from the leads and calling the doctor. If the victim is conscious, but before that he was swooning or has been under current for a long time, he needs to ensure peace before the doctor arrives. If the victim lost consciousness, but breathing persists, it is necessary to put him in comfortably, evenly, unfasten his tight clothes, create an influx of fresh air, remove unnecessary people from the room, breathe ammonia, spray with water, rub and warm the body. With convulsive and rare breathing, artificial respiration is necessary.

In the absence of signs of life (lack of pulse and breathing), the victim cannot be considered dead. It is necessary immediately, without wasting time, before the arrival of the doctor to do artificial respiration.

6.3.1.3 Air exchange in laboratory

Air exchange in public buildings is necessary to clean the air of harmful substances: to remove harmful substances (emitted harmful gases, vapors and dust), to remove water vapor and excess heat.

In residential and public buildings, carbon dioxide (CO₂) exhaled by people is a constant harmful emission. The required air exchange is determined by the amount of carbon dioxide exhaled by a person and by its permissible concentration. The amount of carbon dioxide, depending on the age of the person and the work performed, as well as the permissible concentration of carbon dioxide for different rooms. The carbon dioxide content in the air can be determined by the chemical composition of the air. However, given the increased carbon dioxide content in the atmosphere of settlements, the CO₂ content should be taken into account when calculating:

- for large cities (over 300 thousand inhabitants)– 0,5 l/m³.

Determine the required rate of air exchange in a laboratory for two people, if the volume of the room is V=68 m³. The laboratory is located in 603 office of the laboratory building SibSMU. The amount of carbon dioxide exhaled by an adult with light work in an institution is 18 l/h. The maximum permissible concentration of carbon dioxide for institutions is 1,25 l/m³. The required air exchange in the laboratory is determined by the formula:

$$L = \frac{G \cdot p}{x_v - x_n} ;$$

where:

L – air exchange required, m³/h;

G – the amount of harmful substances released into the room air, g/h;

P – number of people working in the laboratory; x_v – maximum permissible concentration of harmfulness in the air of the working area of the room, mg/m^3 ;
 x_n – the maximum possible concentration of the same harmfulness in the air of populated areas, mg/m^3 .

The rate of air exchange (n), which shows how many times in one hour the air is completely replaced in the room, which is determined by the formula.

$$n = \frac{L}{V_n}, h^{-1};$$

where: V_n is the internal volume of the room, m^3

According to, the permissible air exchange rate should be in the range from 3 to $10 h^{-1}$.

Required air exchange in the laboratory, according to 1:

$$L = \frac{18 \cdot 2}{1,25 - 0,5} = 48 m^3/h$$

The required air exchange rate is:

$$n = \frac{48}{68} = 0,7 h^{-1}$$

Thus, the calculated consumed air exchange in the laboratory should be $48 \text{ m}^3/\text{h}$ but it is not enough to perform the permissible air exchange rate because it should be in the range from 3 to $10 h^{-1}$.

6.4 Safety in emergency situations

In case of emergency, you must immediately call the fire department at number “01” from your business phone or “101” from your mobile phone.

The notification of civil defense alerts in the event of an emergency to the personnel of the objects is carried out using voice information through broadcasting channels, radio broadcast networks and communication networks.

On the territory of the Siberian State Medical University they do not use, do not produce, do not process, do not store radioactive, fire hazardous, and also explosive substances that create a real threat of an emergency source. As the most probable technological emergencies, the project considers: Fire at the territory object. Fire hazards for humans include toxic combustion products, low oxygen concentration, open flames, smoke, and high air temperatures. The following measures must be observed to prevent fire:

- Reducing the determining size of the combustible medium.
- Prevention of the formation of a combustible medium.

In case of overheating, short circuits, etc. possible ignition of electrical installations, wiring. To extinguish the fire, it is necessary to use special means, it is impossible to use water and other conductive substances. Therefore, the premises should be equipped with means for extinguishing electrical installations and electrical wiring under voltage.

6.5 Ecological safety

6.5.1 Environmental impact of nuclear power

The environmental impact of nuclear power results from the nuclear fuel cycle, operation, and the effects of nuclear accidents.

The greenhouse gas emissions from nuclear fission power are much smaller than those associated with coal, oil and gas, and the routine health risks are much smaller than those associated with coal. However, there is a "catastrophic risk" potential if containment fails, which in nuclear reactors can be brought about by overheated fuels melting and releasing large quantities of fission products into the environment.

The most long-lived radioactive wastes, including spent nuclear fuel, must be contained and isolated from the environment for a long period of time. On the other side, spent nuclear fuel could be reused, yielding even more energy, and reducing the amount of waste to be contained.

- **Other waste**

Moderate amounts of low-level waste are through chemical and volume control system (CVCS). This includes gas, liquid, and solid waste produced through the process of purifying the water through evaporation. Liquid waste is reprocessed continuously, and gas waste is filtered, compressed, stored to allow decay, diluted, and then discharged. The rate at which this is allowed is regulated and studies must prove that such discharge does not violate dose limits to a member of the public (see radioactive effluent emissions).

Solid waste can be disposed of simply by placing it where it will not be disturbed for a few years.

- **Power plant emission**
- **Radioactive gases and effluents**

Most commercial nuclear power plants release gaseous and liquid radiological effluents into the environment as a byproduct of the Chemical Volume Control System.

Civilians living within 50 miles (80 km) of a nuclear power plant typically receive about 0,1 μSv per year. For comparison, the average person living at or above sea level receives at least 260 μSv from cosmic radiation.

All reactors are to have a containment building. The walls of containment buildings are several feet thick and made of concrete and therefore can stop the release of any radiation emitted by the reactor into the environment. If a person is to worry about an energy source that releases large amounts of radiation into the environment, they should worry about coal-fired plants. "The waste produced by coal plants is actually more radioactive than that generated by their nuclear counterparts. In fact, the fly ash emitted by a [coal] power plant—a by-product from burning coal for electricity—carries into the surrounding environment 100 times more radiation than a nuclear power plant producing the same amount of energy." Coal-fired plants are much more hazardous to people's health than nuclear power plants as they release much more radioactive elements into the environment and subsequently expose people to greater levels of radiation than nuclear plants do.

Estimated radiation doses ingested by people living near the coal plants were equal to or higher than doses for people living around the nuclear facilities.

At one extreme, the scientists estimated fly ash radiation in individuals' bones at around 18 millirems (thousandths of a rem, a unit for measuring doses of ionizing radiation) a year. Doses for the two nuclear plants, by contrast, ranged from between three and six millirems for the same period. And when all food was grown in the area, radiation doses were 50 to 200 percent higher around the coal plants."

The total amount of radioactivity released through this method depends on the power plant, the regulatory requirements, and the plant's performance. Atmospheric dispersion models combined with pathway models are employed to accurately approximate the dose to a member of the public from the effluents emitted. Effluent monitoring is conducted continuously at the plant.

- **Comparison to coal-fired generation**

In terms of net radioactive release, the National Council on Radiation Protection and Measurements (NCRP) estimated the average radioactivity per short ton of coal is 17,100 millicuries/4,000,000 tons.

In terms of dose to a human living nearby, it is sometimes cited that coal plants release 100 times the radioactivity of nuclear plants. This comes from NCRP Reports No. 92 and No. 95 which estimated the dose to the population from 1000 MWe coal and nuclear plants at 4,9 man-Sv/year and 0,048 man-Sv/year respectively (a typical Chest x-ray gives a dose of about 0.06 mSv for comparison). The Environmental Protection Agency estimates an added dose of 0,3 μ Sv per year for living within 50 miles (80 km) of a coal plant and 0,009 milli-rem for a nuclear plant for yearly radiation dose estimation. Nuclear power plants in normal operation emit less radioactivity than coal power plants.

Unlike coal-fired or oil-fired generation, nuclear power generation does not directly produce any sulfur dioxide, nitrogen oxides, or mercury (pollution from fossil fuels is blamed for 24,000 early deaths each year in the U.S. alone). However, as with all energy sources, there is some pollution associated with support activities such as mining, manufacturing and transportation.

A major European Union-funded research study known as External, or Externalities of Energy, undertaken over the period of 1995 to 2005 found that the environmental and health costs of nuclear power, per unit of energy delivered, was €0,0019/kWh. This is lower than that of many renewable sources including the environmental impact caused by biomass use and the manufacture of photovoltaic solar panels, and was over thirty times lower than coals impact of €0,06/kWh, or 6 cents/kWh. However, the energy source of the lowest external costs associated with it was found to be wind power at €0,0009/kWh, which is an environmental and health impact just under half the price of Nuclear power.

- **Waste heat**

As with all thermoelectric plants, nuclear power plants need cooling systems. The most common systems for thermal power plants, including nuclear, are:

- Once-through cooling, in which water is drawn from a large body, passes through the cooling system, and then flows back into the water body.
- Cooling pond, in which water is drawn from a pond dedicated to the purpose, passes through the cooling system, then returns to the pond.
- Cooling towers, in which water recirculates through the cooling system until it evaporates from the tower.

Nuclear plants exchange 60 to 70% of their thermal energy by cycling with a body of water or by evaporating water through a cooling tower. This thermal efficiency is somewhat lower than that of coal-fired power plants, thus creating more waste heat.

It is possible to use waste heat in cogeneration applications such as district heating. The principles of cogeneration and district heating with nuclear power are the same as any other form of thermal power production. One use of nuclear heat generation was with the Ågesta Nuclear Power Plant in Sweden. In Switzerland, the Beznau Nuclear Power Plant provides heat to about 20,000 people. However, district heating with nuclear power plants is less common than with other modes of waste heat generation. A number of thermal stations use indirect seawater cooling or cooling towers that in comparison use little to no freshwater.

- **Water consumption and risks**

During the process of nuclear power generation, large volumes of water are used. The uranium fuel inside reactors undergoes induced nuclear fission which releases great amounts of energy that is used to heat water. The water turns into steam and rotates a turbine, creating electricity. When intaking water for cooling, nuclear plants, like all thermal power plants including coal, geothermal and biomass power plants, use special structures. Water is often drawn through screens to minimize to entry of debris. The problem is that many aquatic organisms are trapped and killed against the screens, through a process known as impingement. Aquatic organisms small enough to pass through the screens are subject to toxic stress in a process known as entrainment. Billions of marine organisms are sucked into the cooling systems and destroyed.

- **Greenhouse gas emissions**

Many stages of the nuclear fuel chain — mining, milling, transport, fuel fabrication, enrichment, reactor construction, decommissioning and waste management — use fossil fuels, or involve changes to land use, and hence emit carbon dioxide and conventional pollutants.

Nuclear energy contributes a very small amount of emissions into the atmosphere which can cause many environmental problems such as global warming. Uranium is not burned in a nuclear power plant as coal is so there are no emissions from it. All of the waste that comes from the fission of uranium stays in the plant and is therefore able to be disposed of in a safe way in which the uranium is kept out of the environment.

Nuclear energy produces far less carbon dioxide than coal, 9 grams per kilowatt hour compared with 790–1017 grams per kilowatt hour for coal. Also, nuclear energy produces the same amount if not less greenhouse gasses than renewable resources. Like all energy sources, various life cycle analysis (LCA) studies have led to a range of estimates on the median value for nuclear power, with most comparisons of carbon dioxide emissions show nuclear power as comparable to renewable energy sources.

Nuclear power, primarily from ~1970 to 2013, is estimated to have prevented the atmospheric emission of 64 gigatons of CO₂-equivalent.

6.5.2 Calculation of the maximum permissible discharge

It is required to calculate maximum permissible discharge (MPD) of radionuclides for a NPP designed specifically for given region. Calculation has to be carried out for normal operation mode and repair period, if electrical capacity, N_e , of the NPP is known.

Emission goes through the chimney consisting of the main chimney and internal one. The internal one has diameter d , and it is used during normal operation mode, when the gas mixture is being vented with the volumetric flow rate V_1 . The main chimney is needed to emit the gas mixture during repair period, when the volumetric flow rate is V_2 . The diameter of the main tube is D .

NPP's normal operation mode time assumed equal to t_{no} . Temperature difference of the gas mixture and the air, where the mixture is emitted, is ΔT .

Capacity expansion limit and buffer area sizes are needed to be determined either.

Table 6.7- Initial data:

Parameter	Variant
	13
N_e, MW	1250
H, m	145
d, m	1,5
D, m	3
$V_1, \frac{m^3}{c}$	35
$V_2, \frac{m^3}{c}$	90
$\Delta T, ^\circ C$	17

Notes:

- Critical groups of population are exposed to external and internal irradiations; internal one includes irradiation due to breathing and with dietary intake (all of the possible ways).

- **Maximum Permissible Discharge**

If the value of C_{ni} is unknown, the evaluation of MPD_i can be done via the formula below:

$$MPD_i = \frac{1}{\gamma} K_d TC_i = \frac{1}{10} \cdot K_d \cdot TC_i \frac{Bq}{s} ;$$

where:

is γ is a factor; $\gamma = 30$ for operating NPP and, if the following capacity expansion is planned; $\gamma = 10$ at the stage of NPP design.

Tolerable concentrations are calculated according to the algorithm represented in the formula.

$$TC_i = \frac{\eta_i}{\sum_k \frac{\eta_k}{TC_k}} ;$$

Table 6.8- Permissible concentration and maximum permissible emission of radionuclides from the designed NPP during its normal operation and in the repair mode:

Radionuclide	Blowout η_k , rel. units	TC_i Bq/m ³	TC_i Bq/m ³	MPD_i op ($\frac{Bq}{s}$)	MPD_i re ($\frac{Bq}{s}$)	$\sum MPD_i$ op ($\frac{Bq}{s}$)	$\sum MPD_i$ re ($\frac{Bq}{s}$)
⁴¹ Ar	$7.4 \cdot 10^7$	1813	833.24	1789799520	2814684720	$1.5464 \cdot 10^{14}$	$2.43189 \cdot 10^{14}$
^{85m} Kr	$1.2 \cdot 10^7$	14800	135.12	290237760	456435360	$2.5077 \cdot 10^{13}$	$3.9436 \cdot 10^{13}$
⁸⁵ Kr	$1.2 \cdot 10^6$	96200	13.512	29023776	45643536	$2.5077 \cdot 10^{12}$	$3.9436 \cdot 10^{12}$
⁸⁷ Kr	$2.5 \cdot 10^7$	2997	281.5	604662000	950907000	$5.2243 \cdot 10^{13}$	$8.21584 \cdot 10^{13}$
⁸⁸ Kr	$3.4 \cdot 10^7$	1147	382.84	822340320	1293233520	$7.105 \cdot 10^{13}$	$1.11735 \cdot 10^{14}$
¹³³ Xe	$6.7 \cdot 10^7$	51800	754.42	1620494160	2548430760	$1.4001 \cdot 10^{14}$	$2.20184 \cdot 10^{14}$
¹³⁵ Xe	$4.8 \cdot 10^7$	62900	540.48	1160951040	1825741440	$1.0031 \cdot 10^{14}$	$1.57744 \cdot 10^{14}$
⁸⁹ Sr	$4.0 \cdot 10^{-1}$	35	$4.504 \cdot 10^{-6}$	9.674592	15.214512	835884.749	1314533.837
⁹⁰ Sr	1.0	1.5	$1.126 \cdot 10^{-6}$	2.418648	3.803628	208971.187	328633.4592
¹³¹ I	$1.2 \cdot 10^3$	5	0.013512	29023.776	45643.536	2507654246	3943601510
¹³⁴ Cs	$1.0 \cdot 10^{-1}$	0.023	$1.38 \cdot 10^{-6}$	2.96424	4.66164	256110.336	402765.696

If the value of C_{ni} is unknown, the evaluation of MPD_i can be done via the formula below:

$$MPD_i = \frac{1}{\gamma} K_d T C_i = \frac{1}{10} \cdot K_d \cdot T C_i \frac{Bq}{s},$$

Where:

γ is a factor; $\gamma = 30$ for operating NPP and, if the following capacity expansion is planned;

$\gamma = 10$ at the stage of NPP design.

Tolerable concentrations are calculated according to the algorithm represented in the task 1.

Coefficient of meteorological dilution of component in the atmosphere is calculated with the

Formula:

$$K_d = \frac{H^2 \sqrt{V \Delta T}}{A \cdot F \cdot m \cdot n \cdot \alpha \cdot c \cdot \left(\frac{v}{v_0}\right)};$$

where:

H is height of the tube, m;

V is volumetric flow rate of the gas mixture, $\frac{m^3}{s}$;

A is a factor depending on temperature stratification of the atmosphere and defining the conditions of vertical or horizontal dissipation at an intensive turbulent exchange in the atmosphere $s^{\frac{2}{3}} \cdot ^\circ C^{\frac{1}{3}}$;

F is a factor taking account of component settling capability;

m and n are dimensionless correcting factors;

α is factor of temporal settling, it is taken equal to $\frac{1}{13}$;

$\left(\frac{v}{v_0}\right)$ is wind rose factor;

c is wind rose correction factor.

Table 6.9- F factor values:

F = 1	Gases and aerosol
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$$m = \frac{1}{0,67 + 0,1\sqrt{f} + 0,34\sqrt[3]{f}} ;$$

$$f = \frac{10^3 w_0^2 D}{H^2 \Delta T} ;$$

where

w_0 is outlet velocity of gases, $\frac{m}{s}$;

D is chimney diameter ($D \equiv d$ in case repair period).

$$w_0 = \frac{v_1}{A} ;$$

$$A = \frac{\pi}{4} \cdot d_0^2 = \frac{\pi}{4} \cdot (1,5)^2 = 1,77 \text{ m}^2$$

$$w_0 = 19,82 \frac{m}{s}$$

$$f = \frac{10^3 w_0^2 D}{H^2 \Delta T} = \frac{10^3 \cdot (19,82)^2 \cdot 3}{145^2 \cdot 17} = 3,3$$

$$m = \frac{1}{0,67 + 0,1\sqrt{f} + 0,34\sqrt[3]{f}} = \frac{1}{0,67 + 0,1\sqrt{3,3} + 0,34\sqrt[3]{3,3}} = 0,83$$

The factor n depends on parameter V_m :

$$V_m = 0,65 \sqrt[3]{\frac{V \Delta T}{H}} = 0,65 \sqrt[3]{\frac{35 \cdot 17}{145}} = 1,04$$

Table 6.10- n Factor values:

$n = 3 - \sqrt{(V_m - 0,3)(4,36 - V_m)}$	$V_m \in (0,3 ; 2]$
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$$n = 3 - \sqrt{(1,04 - 0,3)(4,36 - 1,04)} = 1,77$$

$$K_d = \frac{(145)^2 \cdot \sqrt{90 \cdot 17}}{0,2 \cdot 1 \cdot 0,83 \cdot 1,77 \cdot \frac{1}{13} \cdot 3 \cdot \left(\frac{4}{1}\right)} = 210543854,4 \text{ m}^3/s$$

$$MPD_i = \frac{1}{30} \cdot 210543854,4 \cdot 7618364 = 2,67333 \cdot 10^{13} \frac{Bq}{s}$$

Annual discharge of radioactive noble gases of an NPP is calculated with the following formula:

$$B_{an} = B_n N_e, \frac{Ci}{year}$$

Where:

B_n is normalized discharge of radioactive noble gases, B_n is assumed equal to $20 \frac{Ci}{MW \cdot year}$;

$$B_{an} = 20 \cdot 1200 = 24000 \frac{Ci}{year}$$

Capacity expansion limit is calculated with the formula

$$N_e^{lim} = N_e \frac{\sum_i MPD_i^{RNG} \cdot t_{no}}{B_{an}} ;$$

Where:

$\sum_i MPD_i^{RNG}$ is maximum permissible discharge of radioactive noble gases only.

$$t_{no} = 320 \cdot 24 \cdot 60 \cdot 60 = 27648000 \text{ s/years}$$

$$B_{an} = 24000 \cdot (3,7 \cdot 10^{10}) = 8,88 \cdot 10^{14} \text{ Bq/years}$$

$$MPD_{RNG} = \frac{1}{\gamma} K_d T C_{RNG}, \frac{Bq}{s}$$

$$MPD_{RNG} = \frac{1}{30} \cdot 210543854,4 \cdot 7618300 = 2,67331 \cdot 10^{13} \frac{Bq}{s}$$

$$N_e^{lim} = 1250 MW \cdot \frac{\left(2,67331 \cdot 10^{13} \frac{Bq}{s}\right) \cdot \left(27648000 \frac{s}{years}\right)}{8,88 \cdot 10^{14} \frac{Bq}{years}} = 1,04 \cdot 10^9 \text{ MW}$$

- Buffer area size

Size of the buffer area is calculated by the formula

$$X = 2\beta H ;$$

where:

β is a factor depending on V_m :

$$\beta = 4,95V_m \left(1 + 0,28f^{\frac{1}{3}} \right), \text{ if } V_m \leq 2 ;$$

$$\beta = 5,26$$

$$X = 2 \cdot (5,26) \cdot (145) = 1524,22 .$$

- **Conclusion**

In conclusion according to the calculations that have been done, the calculations showed the following:

For steam generator calculations, we obtained the following results:

- Coolant flow rate = 4634,83 kg/s;
- Steam flow rate = 421,45 kg/s;
- Wall thickness of tube = 1,57 mm;
- Number of tubes = 10920 pcs;
- Average temperature head in SG = 24,6 °C;
- Heat transfer coefficient = 32428,29 W/(m²·°C);
- Area of heat exchange surface = 6262,4 m²;
- Average length of one tube of SG = 12,86 m;
- Wall thickness of the collector = 0,110 m;
- Internal diameter of SG vessel = 4,29 m;
- Height of steam volume = 1,69 m;
- Wall thickness of the side shell = 95,3 mm;
- Wall thickness of the central shell = 0,128 m;
- Thickness of the bottom = 0,117 m;
- Steam moisture at the top of the steam volume = 0,00207;
- Thickness of the heat insulating layer = 0,111 m.

For calculations of NPP with a VVER-1250 and saturated steam turbine with low speed that was divided into high pressure part and low-pressure part which drives an electrical generator of 25Hz, and by following steam flow after condensing and the stages of reheating the water before reaching the NPP steam generator, we obtained the design with the following parameters:

- Thermal power of Steam generator unit is $Q_{SG} = 3303$ MW;
- Thermal power of Turbine unit is $Q_{ts} = 3294$ MW;
- Overall NPP efficiency is $\eta_{npp} = 33$ % ;
- Number of High-Pressure Heater $n_{HPH} = 1$;
- Steam flow rate from steam generator to the turbine unit is $G_{SG} = 1728,12$ kg/s ;
- Feedwater flow rate $G_{fw} = 1740,22$ kg/s ;
- Burn up fuel rate $b_{nf} = 23,57$ ton/year.

For turbine condenser calculations, we obtained the following results:

	Option 1	Option 2
	$d_{out} = 28 \text{ mm}$ $\delta_{wall} = 1 \text{ mm}$	$d_{out} = 28 \text{ mm}$ $\delta_{wall} = 2 \text{ mm}$
G_{c1} , kg/s	527,51	527,51
W_1 , kg/s	31650,6	31650,6
M_{tube} , kg	276094,77	292801,23
C_{tube} , million rubles	96,6	157,8
C_{cond} , million rubles	169,1	276,2
N_p , kW	2158,1	2008
E_p , kW·h	14027650	13052000
C_{el} , million rubles	196,4	182,7

From economic point of view, the turbine condenser in option number 1 is much cheaper than the other option.

According to the part of financial management calculations:

I calculated two options of turbine condensers first option has out diameter of tube = 28 mm and the thickness of wall = 1 mm, and the second option has the same out diameter = 28 mm but the different between them is the thickness of wall, the second thickness = 2 mm and the first option one is better from economic because it cheaper than second option and has a number of advantages in terms of technical and economic indicators of resource efficiency. It is no overpaying about the budget limitation.

According to the part of social responsibility:

such items as industrial and environmental safety were examined, various harmful and dangerous factors and methods of dealing with them were identified, a list of measures to reduce the threat from the possibility of emergency situations was identified, legal and organizational safety issues were studied. We calculated the average values maximum allowable emissions of radioactive materials into the atmosphere from the designed nuclear power station with the possibility of further expansion. We obtained the $\sum_i MPD_i^{RNG}$ values in the normal operation mode and repair mode and we noticed that in the repair mode emission limit values higher than during normal operation of the planned power plant. And this was due to the dilution factor meteorological, namely repair mode uses primary vent stack, where in the diameter of the mouth 2 times the inner tube, and also increases an average volumetric flow of air-gas mixture, to a larger volume of air necessary to lower the concentration of radioactive substances.

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- **Applications**

Graphic material:

ФЮРА.693100.001 P1 Reactor installation. Structural energy diagram.

ФЮРА.31 1115.004 P3 Turbine installation. Energy schematic diagram.

assembly drawings:

ФЮРА.693100.002 СБ Nuclear reactor. Assembly drawing.

ФЮРА.693410.003 СБ Steam generator. Assembly drawing.