TOMSK POLYTECHNIC UNIVERSITY
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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 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 with WWER for a NPP with electric capacity of 1300MW

Student

Group	Name	Signature	Date
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Head of PEP	Name	Degree, academic status	Signature	Date
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Tomsk 2022

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	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

	the knowledge gained for training and educating new cadres	
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 related to the uniqueness of tasks, facilities in the design and operation of NP	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
O10	To use deep mathematical, natural scientific knowledge in professional activity with application of mathematical modeling of objects and	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

	processes in the field of design and operation of nuclear reactors	
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 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	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
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 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	Requirements of FSES OF HE, SSES OF TPU (PSC-1.14, PSC- 1.15), requirements of international standards EUR-ACE and 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	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

	compliance with technological discipline and maintain technological equipment, investigate the causes of its malfunctions, take measures to eliminate them	
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 thermal mechanical installations of various types of AS, to prepare initial data for the calculation of thermal schemes	Requirements of FSES OF HE, SSES OF TPU (PSC-1.1, 1.3, 1.7), requirements of international standards EUR-ACE and 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	Requirements of FSES OF HE, SSES OF TPU (PC-8, PSC-1.12, 1.13), requirements of international standards EUR-ACE and

	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	FEANI, 24.014 PS, 24.032 PS, 24.036 PS, 24.039 PS

- **List of Abbreviations**

No	Abbreviation	Definition
1	NPPs	Nuclear power plants
2	LWRs	Light water reactors
3	WWER	water water energetic reactor
4	FA	Fuel assembly
5	MCP	Main circulation pipeline
6	ECCS	emergency core cooling system
7	SG	Steam generator
8	PWR	Pressurized water reactor
9	pp	Perforated plate
10	LPH	Low-pressure reheaters
11	HPH	High -pressure reheaters
12	CP	Condensate pump
13	FWP	Feed water pump
14	HPC	High pressure cylinder
15	LPC	Low pressure cylinder
16	SH	Super heater
17	FSS	Federation to the state social insurance bodies
18	PF	the pension fund
19	FFOMS	Federal Foundation Compulsory Medical Insurance
20	CVCS	chemical and volume control system
21	NCRP	National Council on Radiation Protection
22	LCA	life cycle analysis
23	MPD	maximum permissible discharge
24	H.E. T	Heat exchanger tubes

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The Ministry of Science and Higher Education of the Russian Federation
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«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**
506И	Shahin Ahmed Elsayed Abdelsatar Elsayed

Title of the work:

Design of a power unit with WWER for a NPP with electric capacity of 1300MW	
Established by the order of Director (date, number)	

Thesis's accomplishment deadline:	10.01.2021

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 1300 MW

Objectives of the work (project) *(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)*	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
List of drawings: *(with exact indication of the required drawings)*	1. Reactor installation. 2. Turbine installation. 3. Nuclear reactor. 4. Steam generator.

Consultants on the thesis' additional sections

Section	Consultant
Financial Management	N.A. Goncharova, PhD
Social Responsibility	O.A. Antonevich, PhD

Issue date of the assignment	10.06.2021

The assignment was issued by the supervisor:

Position	Full name	Degree, academic status	Signature	Date
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The assignment was accepted by the student:

Group	Full name	Signature	Date
506И	Shahin Ahmed Elsayed Abdelsatar Elsayed		

Contents

Introduction

Today many nations are considering an expanded role for nuclear power in their energy portfolios. This expansion is driven by concerns about global warming, growth in energy demand, and relative costs of alternative energy sources. In 2008, 435 nuclear reactors in 30 countries provided 16% of the world's electricity. In January 2009, 43 reactors were under construction in 11 countries, with several hundred more projected to come on line globally by 2030.

Concerns about the availability of energy resources, climate change, air quality, and energy security point to an important role for nuclear power in future energy supplies. While current second- and third-generation nuclear power plant designs provide a secure, low-cost supply of electricity in many markets, further advances in nuclear power system design could expand opportunities for the use of nuclear power. To explore these opportunities, the International Bureau of Nuclear Energy has engaged governments, industry, and the research community around the world in a wide-ranging discussion on the development of next-generation nuclear power systems known as "fourth generation".

Nuclear reactors produce energy through a controlled chain reaction. While most reactors generate electrical energy. Power reactors use the heat from fission to produce steam that turns turbines to generate electricity. In this respect, they are similar to plants that run on coal and natural gas. Common components of all nuclear reactors include the fuel assembly, control rods, coolant, pressure vessel, containment structure, and an external cooling facility.

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

In a nuclear reactor, neutron interacts with the nuclei of the surrounding atoms. For some nuclei (e.g., U-235), an interaction with a neutron can lead to fission: the nucleus is split into two parts, giving rise to two new nuclei (the so-called fission products), energy, and several new highly energetic neutrons. Other possible interactions are absorption (the neutron is removed from the system) and simple collisions, where the incident neutron transfers energy to the nucleus, either elastically (hard-sphere collision) or inelastically.

The speed of neutrons in a chain reaction determines the type of reactor. Thermal reactors use slow neutrons to maintain the reaction. These reactors require a medium to slow down the neutrons produced by fission.

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.

Water Water Energetic Reactor (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-1300

The VVER-1300 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 1300 MW gross;
- upgraded pressure vessel;
- improved core design to improve cooling;
- further developments of passive safety systems;
- lower construction and operating costs.

VVER-1300 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-1300 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 1.1- Main parameters of VVER-1300 reactor.

Parameter	Value
Reactor nominal thermal power, MW	3718
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	17
Coolant temperature at reactor inlet, °C	297.6
Coolant temperature at reactor outlet, °C	329.1
Coolant flowrate through reactor, m^3/h	73000

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.

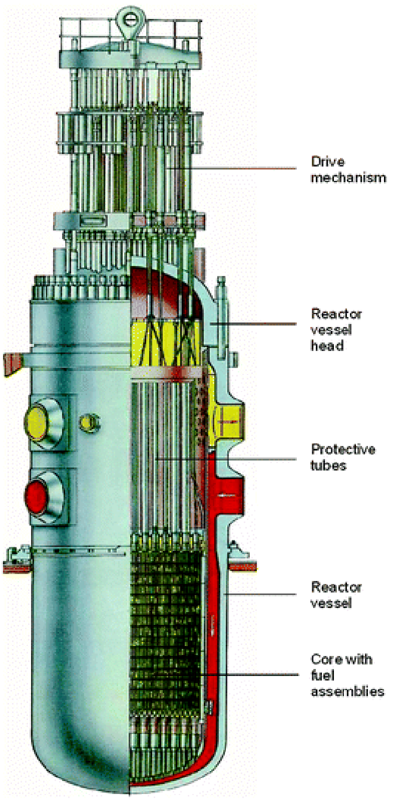


Figure 1.1- Reactor Design.

- **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-1300 MCP is designed to be 850 mm. Fig.1.2 depicts the primary coolant flow path of VVER1300. 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).

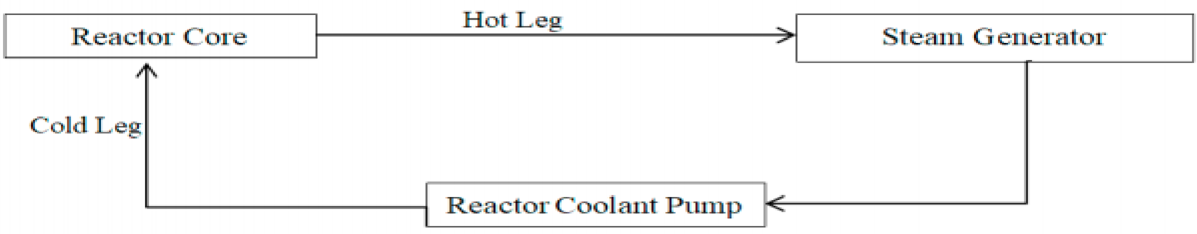


Figure 1.2- Primary Coolant Flow

1.4 Steam generator

VVER-1300 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.

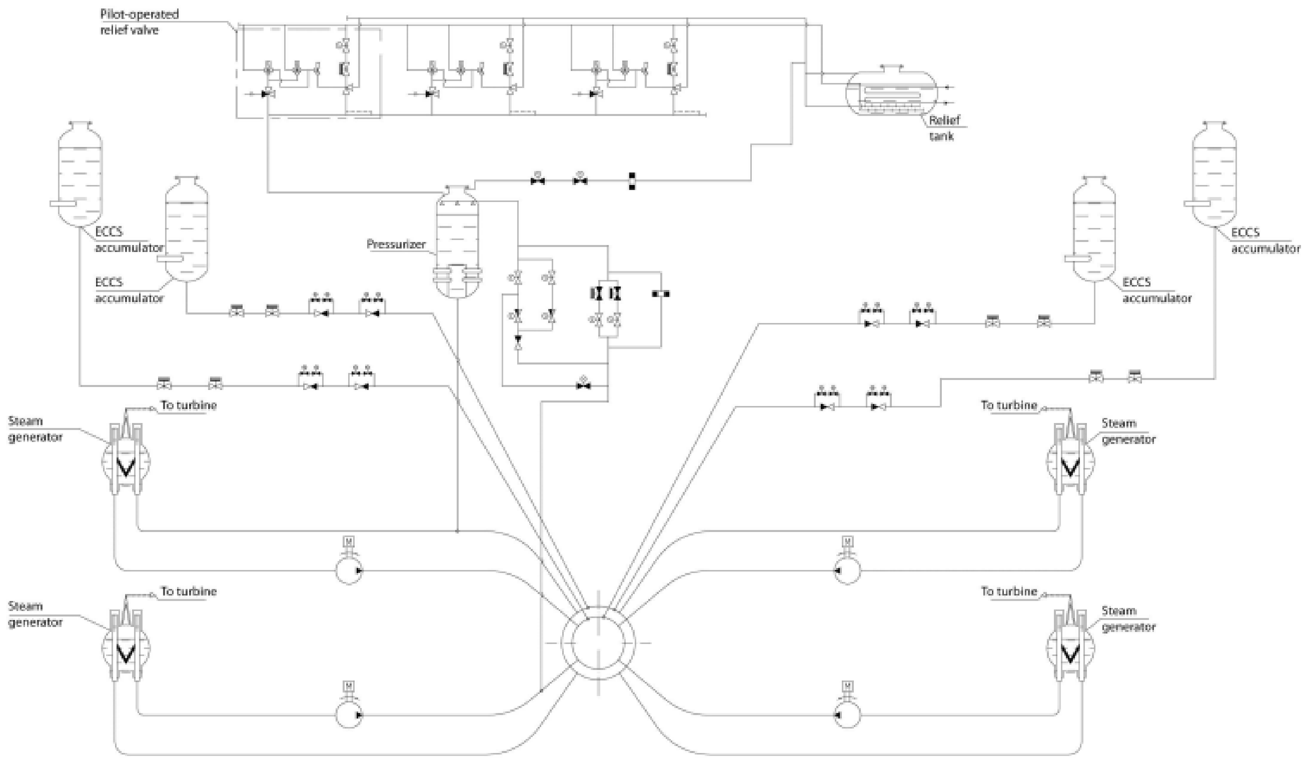


Figure 1.3- Primary Circuit Components of VVER-1300 (for 4 Loops)

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 1300 MW.

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

- ➔ Steam generator calculations.
- ➔ Calculations of design NPP with VVER-1300 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	$\frac{3718}{4} = 929.62$
Mass flow of steam	D_2, kg/s	506.61
Coolant flow	G_1, kg/s	5062.54
Coolant pressure at the inlet to the SG	P_1, MPa	17
Coolant temperature at the inlet to the SG	t_1', °C	329.1
Coolant temperature at the outlet of the SG	t_1'', °C	297.6
Steam pressure at the SG	P_{st} or P_2, MPa	7
Steam temperature at the outlet of the SG	t_{st} or t_s, °C	285.8
Feed water temperature	t_{fw}, °C	225
Blowdown flow rate, % (as a percentage of mass flow of steam)	α_{bd}, %	0.5

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.

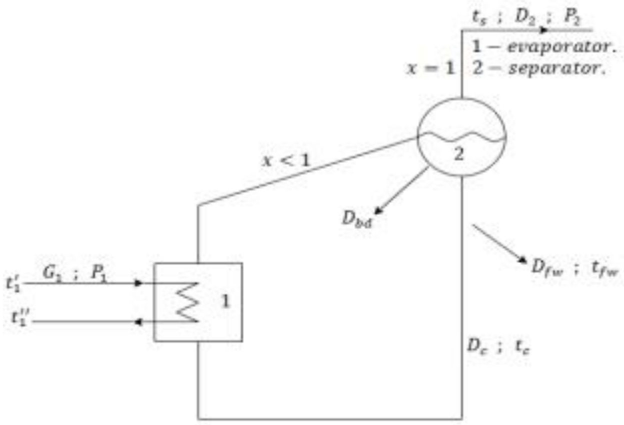


Figure 2.1 Steam generator without economizer

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).

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

$$G_1 = \frac{Q_{sg}}{(h_{1inl} - h_{1out})} = \frac{929.62 \cdot 10^3}{(1507 - 1323)} = 5062.54 \;{}^{kg}/_{s} \,;$$

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;

$h_{1inl} = f(p_1,\ t_1')$ is coolant enthalpy at the steam generator inlet;

$$h_{1inl} = f(17, 329.1) = 1507 \;{}^{kJ}/_{kg} \;;$$

$h_{1out} = f(p_1,\ t_1'')$is coolant enthalpy at the outlet of the steam generator;

$$h_{1out} = f(17, 297.6) = 1323 \;{}^{kJ}/_{kg}.$$

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).

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

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

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

$$D_2 = \frac{929.62 \cdot 10^3}{1{,}02 \cdot \left((1267 - 975) + (2773 - 1267)\right) + \frac{0{,}5}{100} \cdot (1267 - 975)} \text{ ;}$$

$$D_2 = 506.61 \ {}^{kg}/_{s}.$$

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;

$h'' = f(p_{st})$ is steam enthalpy at saturation temperature, ${}^{kJ}/_{kg}$;

$$h'' = f\,(7) = 2773 \ {}^{kJ}/_{kg};$$

$h' = f(p_{st})$is steam enthalpy at saturation temperature, ${}^{kJ}/_{kg}$;

$$h' = f\,(7) = 1267 \ {}^{kJ}/_{kg};$$

$h_{fw} = 975 \ {}^{kJ}/_{kg}$is enthalpy of feed water, ${}^{kJ}/_{kg}$;

$D_{bd} = \left(\frac{\alpha_{bd}}{100}\right) \cdot D_2$ is flow rate of blowdown water;

$$D_{bd} = \left(\frac{0{,}5}{100}\right) \cdot 506.62 = 2.53 \ {}^{kg}/_{s}.$$

2.1.1.3 Determination of Feed Water Flow Rate.

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

$$D_{fw} = 506.61 + 2.53 = 509.14 \ {}^{kg}/_{s}.$$

2.1.1.4 Building a tQ Diagram.

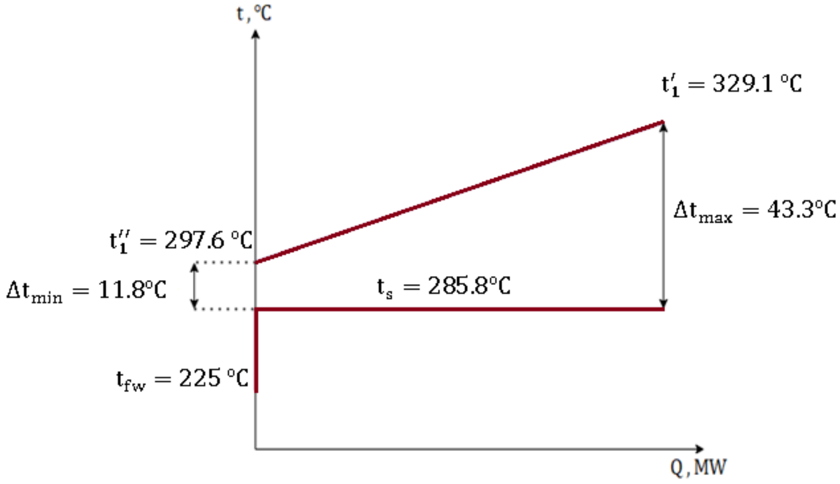


Figure 2.2- tQ-Diagrams of the Steam Generator

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 10ГН2МФА, clad on the side washed by the heat carrier, steel 08X18H10T;
- for vessel elements - 10ГН2МФА.

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.

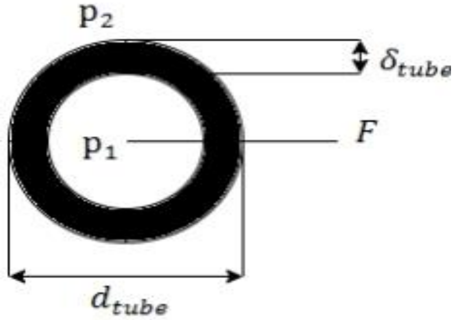


Figure2.3- Cross Section of Heating Surface

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;

$$p_{calc} = 0{,}9 \cdot 1{,}25 \cdot (17) = 19{,}125 \text{ Mpa;}$$

$t_{tube.max} = 0{,}5 \cdot (t_1' + t_s)$ is maximum operating temperature of the tube wall, °C;

$$t_{tube.max} = 0{,}5 \cdot (329.1 + 285{,}8) = 307{,}45 \text{ °C} .$$

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.

$$\delta_{tube} - c = \frac{p_{calc} \cdot d_{out}}{2 \cdot \varphi \cdot [\sigma] + p_{calc}} = \frac{19.125 \cdot 16}{2 \cdot 1 \cdot [91] + 19.125} = 1{,}521 \text{ mm;}$$

$$\delta_{tube} = \frac{p_{calc} \cdot d_{out}}{2 \cdot \varphi \cdot [\sigma] + p_{calc}} + c = 1.521 + 0{,}1967 = 1{,}718 \text{ mm.}$$

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

$$t_{1.max} = t_1' = 329.1\ ℃;$$

$$t_{2.max} = t_s = 285.8\ ℃;$$

$$t_{tube.max} = \frac{329.1 + 285.8}{2} = 307.45\ ℃;$$

From table 2.2 at a temperature of 307.45 degrees, selected data

$$\sigma_{sl} = 363\ \text{MPa} \qquad \sigma_{0.2} = 137\ \text{MPa};$$

We calculate stresses taking into account safety factors

$$\frac{\sigma_{sl}}{n_{sl}} = \frac{363}{2.6} = 140\ \text{MPa}; \qquad \frac{\sigma_{0,2}}{n_{0,2}} = \frac{137}{1.5} = 91\ \text{MPa};$$

Compare the obtained values.

Nominal voltage tolerance is equal to a lower value $[\sigma] = 91$ MPa;

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

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

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

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

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

Table 2.2- Melting point of metals

t_{calc}, °C	100	150	200	250	300	350
σ_{sl}, MPa	412	392	392	373	363	353
$\sigma_{0,2}$, 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;

$$C_1 = 0.1902;$$

$$C_2 = 0;$$

$$C_3 = 0\ ;$$

$$C_4 = 0.0065\ ;$$

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

$$C = 0.1902 + 0 + 0 + 0.0067 = 0.196.$$

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:

$$[\delta_{tube} - C] \le 0{,}75 \cdot 10^{-2} \cdot a = 0{,}75 \cdot 10^{-2} \cdot (0.05) = 3{,}75 \cdot 10^{-4};$$

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

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

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

$$C_4 = 1.521 \cdot \left[1 - 2 \cdot \left(1 - \frac{10}{100}\right) \cdot \frac{2 \cdot \left(\frac{33.6}{16}\right) + 1}{4 \cdot \left(\frac{33.6}{16}\right) + 1}\right] = 0.0065;$$

where:

$R_b = (1,9 \ldots 3,5) \cdot d_{out} = 2,1 \cdot d_{out} = 2.1 \cdot 16 = 33.6$ 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 $a = 5 \ldots 15\ \% = 5\%$ $b = 10 \ldots 30\ \% = 10\ \%$.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:

$$d_{in} = d_{out} - (2 \cdot \delta_{tube}) = 16 - (2 \cdot 1.718) = 12.56 \text{ mm}.$$

2.1.1.8 Determining the Number of Tubes

$$N_{tube} = \frac{G_1}{\rho_{avr} \cdot w \cdot f_{1tube}} = \frac{5062.54}{700.49 \cdot 5 \cdot (1,24 \cdot 10^{-4})} = 11654 \text{ pcs};$$

where:

G_1 is coolant flow, $^{kg}/_{s}$;

$\rho_{avr} = f(p_1,\ t_{1avr})$ is the average density of the coolant;

$$\rho_{avr} = f(17, 313.4) = 700.49\ {}^{kg}/_{m^3};$$

$$t_{1av} = \frac{329.1 + 297.6}{2} = 313,4\ ℃;$$

w is the speed of the coolant in the tubes, ${}^{m}/_{s}$. Accept in the range from 4 to 6 ${}^{m}/_{s}$

$w = 5\ {}^{m}/_{s}$;

$$f_{1tube} = \frac{\pi \cdot d_{in}^2}{4} = \frac{\pi \cdot 12{,}56^2}{4} = 124.01\ mm^2 = 1{,}24 \cdot 10^{-4}\ m^2;$$

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**

$$\Delta t_{avr} = \frac{\Delta t_{hig} - \Delta t_{low}}{\ln\left(\frac{\Delta t_{hig}}{\Delta t_{low}}\right)} = \frac{43.3 - 11.8}{\ln\left(\frac{43.3}{11.8}\right)} = 24.2\ ℃;$$

where:

$\Delta t_{hig} = t_1' - t_s$ is highest temperature head;

$$\Delta t_{hig} = 329.1 - 285.8 = 43.3\ ℃;$$

$\Delta t_{low} = t_1'' - t_s$is lowest temperature head.

$$\Delta t_{low} = 297.6 - 285.8 = 11.8\ ℃.$$

- **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

$$\alpha_{1avr} = 0{,}021 \cdot \left(\frac{\lambda_{1avr}}{d_{in}}\right) \cdot (Re_{avr})^{0,8} \cdot (Pr_{avr})^{0,43};$$

$$\alpha_{1avr} = 0{,}021 \cdot \left(\frac{0{,}537}{12{,}44 \cdot 10^{-3}}\right) \cdot (524804)^{0,8} \cdot (0.902)^{0,43}$$

$$\alpha_{1avr} = 32350.97\ {}^{W}/_{(m^2 \cdot ℃)};$$

where:

$$\nu_{1avr} = f(p_1,\ t_{1avr}) = f(17, 313.4) = 1.197 \cdot 10^{-7}\ {m^2}/{s}\ ;$$

is average kinematic viscosity of the coolant;

$\lambda_{1avr} = f(p_1,\ t_{1avr})$is the average coefficient of thermal conductivity of the coolant;

$$\lambda_{1avr} = f\,(17, 313.4) = 0.5370\, {W}/{(m \cdot {}^{\circ}C)}\ ;$$

$Pr_{avr} = f(p_1,\ t_{1avr})$is Prandtl criterion with medium coolant parameters;

$$Pr_{avr} = f\,(17, 313.4) = 0.902\ ;$$

$$Re_{avr} = \frac{w\ \cdot\ d_{in}}{\nu_{1avr}} = 5 \cdot \frac{12.56\ \cdot\ 10^{-3}}{1{,}197\ \cdot\ 10^{-7}} = 524804\ ;$$

is Reynold’s 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 $q_{in} = 3 \cdot 10^5$ (W/m^2) for the output section it is recommended to take $q_{out} = 6 \cdot 10^4$ (W/m^2);

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

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

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

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

$$t_{tube.in} = t_s + 0{,}3 \cdot (t_1' - t_s), ℃;$$

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

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

- calculate the heat transfer coefficient

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

where:

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

$R_{ox} = 10^{-5}\ {}^{m \cdot ℃}/_{W}$ t is the thermal resistance of the oxide film on stainless steel tubes;

- calculate the heat flow:

$$q_{in}' = K_{in} \cdot (t_1' - t_s), {}^{W}/_{m^2};$$

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

If the condition $0{,}95 \le \frac{q_{in}'}{q_{in}} \le 1{,}05$ 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 (α_{out} q_{out}, k_{out}) for the output section of the steam generator.**

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

$$\alpha_{2out} = \frac{10{,}45}{3{,}3 - 0.0113 \cdot (t_s - 100)} \cdot q_{out}{}^{0,7}, {}^{W}/_{(m^2 \cdot ℃)};$$

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

$$t_{tube.in} = t_s + 0{,}3 \cdot (t_1' - t_s), \text{°C};$$

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

- calculate the heat transfer coefficient

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

- calculate the heat flow

$$q'_{out} = k_{out} \cdot (t_1'' - t_s), \ {}^{W}/_{m^2}.$$

Table 2.5- Results

		First Iteration	Second Iteration
Inlet	q_{in}, W/m^2	$3 \cdot 10^5$	274729
	α_{2in}, $W/(m^2 \cdot °C)$	59412.28	55863.08
	t_{tube}^{in}, °C	298.8	298.8
	λ_{wal}^{in}, $W/(m \cdot °C)$	19.14	19.14
	k_{in}, $W/(m^2 \cdot °C)$	6349.19	6306.37
	q'_{in}, W/m^2	274729	272877
	q'_{in}/q_{in}	0.91	0.99
Outlet	q_{out}, W/m^2	$6 \cdot 10^4$	
	α_{2out}, $W/(m^2 \cdot °C)$	19257.38	
	t_{tube}^{out}, °C	289.4	
	λ_{wal}^{out}, $W/(m \cdot °C)$	18.994	
	k_{out}, $W/(m^2 \cdot °C)$	5173.48	
	q'_{out}, W/m^2	60891.69	
	q'_{out}/q_{out}	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 $k_{avr} = 0{,}5 \cdot (k_{in} + k_{out})$;

$$\left|\frac{k_{in} - k_{out}}{k_{out}}\right| = \left|\frac{6306.37 - 5173.48}{5173.48}\right| = 0{,}218\,;$$

So, we calculate with this formula

$$k_{avr} = 0.5 \cdot (k_{in} + k_{out}) = 0.5 \cdot (6306.67 + 5173.48) = 5739.92 \approx 5740;$$

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.

$$F = \frac{k_{sf} \cdot Q_{sg}}{k_{avr} \cdot \Delta t_{avr}} = \frac{1.05 \cdot 929.62 \cdot 10^3}{(5740 \cdot 10^{-3}) \cdot 24.2} = 7208.41\ m^2;$$

where:

$k_{sf} = 1{,}05 \ldots 1{,}10$ 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 5740$\cdot 10^{-3}$ $kW/(m^2 \cdot °C)$;

Q_{sg} is thermal power of the steam generator, $929.62 \cdot 10^3$ kW;

Δt_{avr} is average temperature head in the steam generator, 24.2°C.

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

$$l_{avr} = \frac{F}{\pi \cdot d_{avr} \cdot N_{tube}} = \frac{7028.41}{\pi \cdot (14.28 \cdot 10^{-3}) \cdot 11654} = 13.43\ m\,;$$

Where:

$d_{avr} = 0.5 \cdot (d_{out} + d_{in}) = d_{in} + \delta_{tube}$ is the average diameter of the heat transfer tubes, m;

$$d_{avr} = 0,5 \cdot (16 + 12,56) = 14.28 \text{ mm} = 0,01428 \text{ m} ;$$

N_{tube} is number of tubes in the steam generator which is $= 11654$ 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;
  - $D_{col}^{in} = 0.75 \ldots 1 = 0.85$ m is internal diameter of the collector, m;
  - $S_1 = 0.022 \ldots 0{,}025 = 0.023$ m is step between the holes along the height (vertical);
  - $S_2 = 0.024 \ldots 0.030 = 0.028$ 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 10ГН2МФА.

2.2.1 Calculation of the Wall Thickness of the Collector, m

$$\delta_{coll} = \frac{p_{1calk} \cdot D_{col}^{in}}{2 \cdot \varphi[\sigma]_{1calk_{min}}} ;$$

$$\delta_{coll} = \frac{19.125 \cdot 0.85}{2 \cdot 0.304 \cdot (215) - 19.125} = 0.145 \text{ m};$$

where:

$p_{1calk} = 0.9 \cdot 1.25 \cdot p_{1avr} \approx 0.9 \cdot 1.25 \cdot p_1$ is the rated pressure, MPa;

$$P_{1\ calc} = 0.9 \cdot 1.25 \cdot 17 = 19.125 \text{ MPa};$$

$$D_{col}^{in} = 0{,}85 ;$$

$[\sigma] = 215$ MPa is nominal stress design for steel 10ГН2МФА;

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

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

$$\varphi_1 = \frac{s_1 - d_{tube}^{out}}{s_1} = \frac{0{,}023 - (16 \cdot 10^{-3})}{0{,}023} = 0{,}304;$$

$$\varphi_2 = \frac{2 \cdot (s_2 - d_{tube}^{out})}{s_2} = \frac{2 \cdot (0{,}028 - (16 \cdot 10^{-3}))}{0{,}028} = 0{,}857;$$

So $\varphi_1 < \varphi_2$, then $\varphi 1_{min} = 0{,}304$;

If $\varphi_1 \geq \varphi_2$, then $\varphi 2_{min}$, but if $\varphi_1 < \varphi_2$, then $\varphi_1 < \varphi_2$.

2.2.2 Outer Diameter of the Collector, m.

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

$$D_{col}^{out} = 0.85 + 2 \cdot 0.145 = 1{,}141 \text{ m.}$$

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

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

$$s_{2out} = 0.028 \cdot \left(\frac{1.141}{0.85}\right) = 0.038 \text{ m.}$$

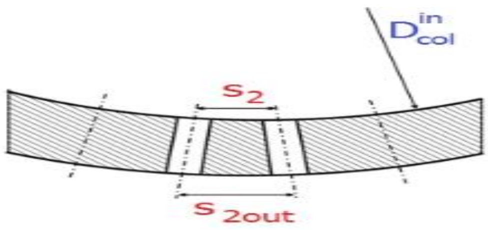


Figure 2.4- Fragment of the wall of the collector.

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

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

$$L_{c1} = \pi \cdot 1.141 = 3.586 \text{ m.}$$

2.2.5 Number of Tubes in the Upper Row, pcs

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

$$N_{tube1} = \frac{3.586}{0.038} = 95{,}4 = 95 \text{ pcs} .$$

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

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

$$B_{bund}^{max} = 95 \cdot 0.038 + 3 \cdot 0.2 = 4.19 \text{ m} ;$$

where $B_{cor} = (0{,}15\ldots0{,}2)$ assume it as 0.2 m which is width of vertical corridors.

2.2.7 Width of the Heat Exchange Tube Bundle Package, m

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

$$B_{pack} = \frac{4.19 - (3 \cdot 0.2)}{2} = 1.79 \text{ m} .$$

2.2.8 The distance between the axis of the collectors, m

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

$$B_{dac} = (2 \cdot 1.79) + (2 \cdot 0{,}2) = 3.99 \text{ m}$$

2.2.9 Width of Submerged Perforated Plate (PP), m

$$B_{pp} = (1{,}05\ldots1{,}1) \cdot B_{bund}^{max};$$

$$B_{pp} = 1.05 \cdot (4.19) = 4{,}39 \text{ m} .$$

2.2.10 SG Vessel Width at Level Perforated Plate, m

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

$$B_{ves.pp} = 4.39 + (2 \cdot 0.15) = 4.69 \text{ m} ;$$

where:

$B_{gap} = (0{,}15\ldots0{,}025\,)$ Assume 0.15 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

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

$$h_{pp} = 0.25 + 0.25 - 0.1 = 0.4 \text{ m};$$

where:

$h_0 = (0,2\ldots0,35)$ assume 0.25 is height of the arrangement of the upper row of tubes relative to the horizontal axis of the SG;

$h_1 = (0,2\ldots0,35)$ assume $= 0.25$ m is the height of the location of the weight level of water above the upper row of tubes;

$h_{wl} = 0.1$ 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

$h_{dlr} = 0{,}08\ldots0{,}120$ m and we assumed it equal to 0,1 m.

2.2.13 Internal Diameter of the Steam Generator Vessel, m

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

$$D_{ves.in} = \sqrt{4 \cdot 0{,}4^2 + 4{,}69^2} = 4.76 \text{ m}.$$

2.2.14 Area of the Evaporation Surface, m²

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

$$F_{es} = 4.69 \cdot 13.43 = 63.08 \text{ m}^2.$$

2.2.15 Superficial Steam Velocity, m/s

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

$$w_o'' = \frac{D_2}{F_{es} \cdot \rho_2''} = \frac{506.61}{63.08 \cdot 36{,}52} = 0.22 \ \text{m}/\text{s};$$

where:

ρ''_2 is density of saturated vapor at the pressure p_2 of the working fluid, $^{kg}/_{m^3}$;

$$\rho''_2 = f(p_2) = f(7) = 36.52\ ^{kg}/_{m^3}.$$

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

$$\varphi_{bub} = \frac{w''_0}{w''_0 + (0.65 - 0.039 \cdot p_2)};$$

$$\varphi_{bub} = \frac{0.22}{0.22 + (0.65 - 0.039 \cdot 7)} = 0,37 \text{ m}.$$

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

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

$$h_{real} = \frac{0.1}{(1 - 0,37)} = 0.158 \text{ m}.$$

2.2.18 Height of Steam Volume, m

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

$$h_{sv} = \frac{4.76}{2} - (0.4 + 0.158) = 1.82 \text{ m}.$$

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

$$h_{sv} = 1.82 \gg 0.4 \text{ m} \qquad \text{so} \qquad h_{sv} \gg 0.4 \text{ m}.$$

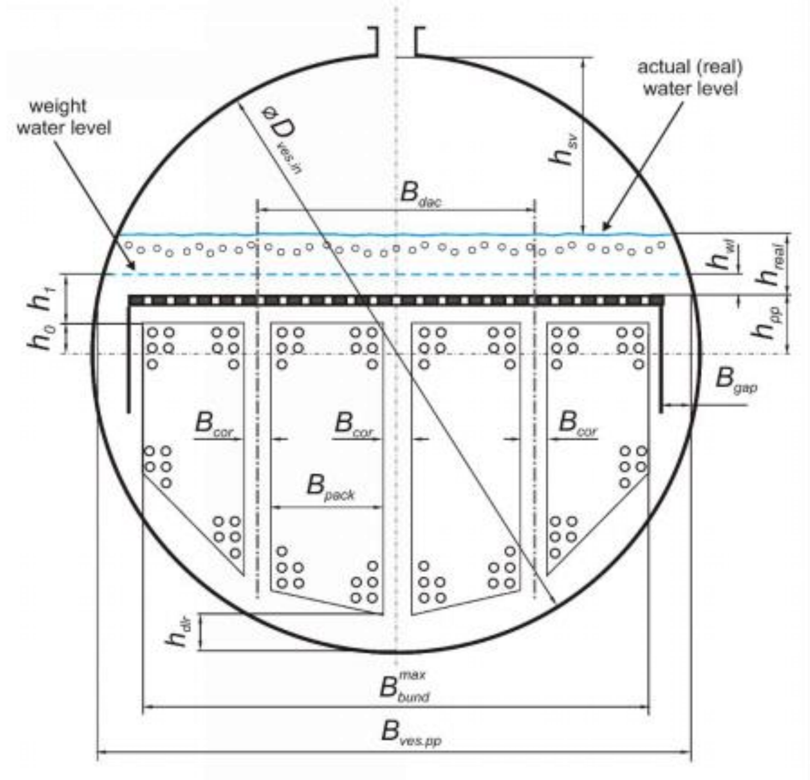


Figure 2.5- To determine the main layout dimensions horizontal SG.

2.2.19 Characteristics of steam outlet nozzles

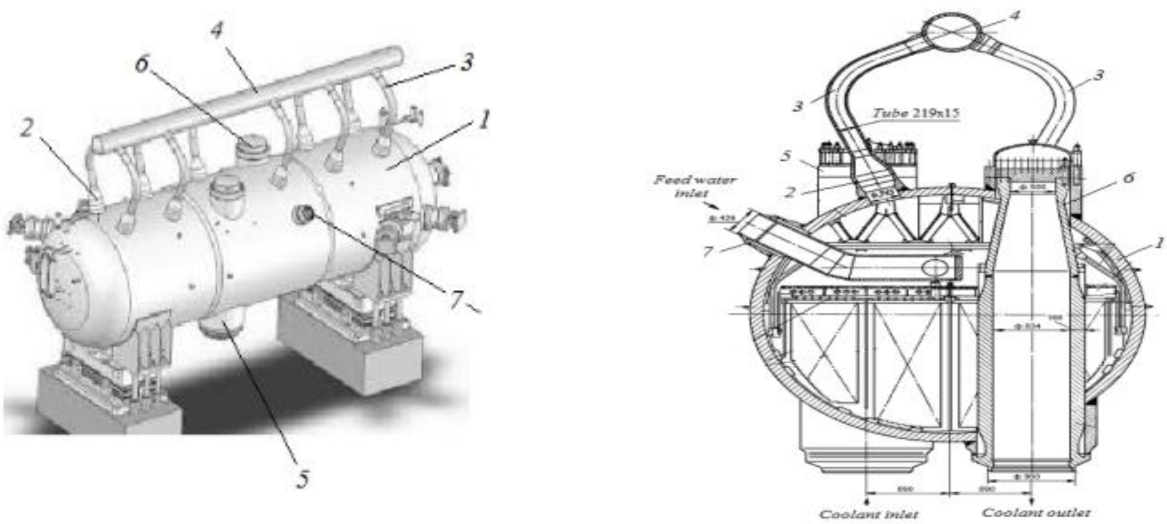


Figure 2.6- Exterior (a) and Cross section (b) of a horizontal steam generator:
1 - vessel; 2 - steam outlet nozzles; 3 - steam pipes; 4 - steam collector; 5 - input collector of the coolant; 6 - output collector of the coolant; 7 - pipe feed water

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

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

$$N_{noz} = 10 \cdot \frac{\pi \cdot d_{noz.in}^2}{4} \cdot 30 = \frac{506.61}{36.52}.$$

$$d_{noz.in} = 0{,}243 \text{ m};$$

where:

$N_{noz} = (8\ldots10)$ assume: 10 pc. is number of steam outlet nozzles;

$w_{noz} = 30\ldots40$ = 30 $^{m}/_{s}$. 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, $^{kg}/_{m^3}$;

$$\rho_2'' = f\,(7) = 36.52\ ^{kg}/_{m^3}.$$

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.

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

$$\frac{\pi \cdot d_{fw.in}^2}{4} \cdot 5 = \frac{509.14}{837.81};$$

$$d_{fw.in} = 0{,}39 \text{ m};$$

where:

$w_{fw} = (4\ldots5)$ Assume:5 m/s is feed water speed in feed pipe;

$D_{fw} = D_2 + D_{bd}$ is mass flow of feed water, $^{kg}/_{s}$;

$$D_{fw} = 506.61 + 2.53 = 509.14 \ {}^{kg}/_{s};$$

$\rho_{fw} = f(p_2,\ t_{fw}) = f\,(7, 225) = \ 837.81 \ {}^{kg}/_{m^3}$ is density of feed water, ${}^{kg}/_{m^3}$.

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. 2.7) 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.

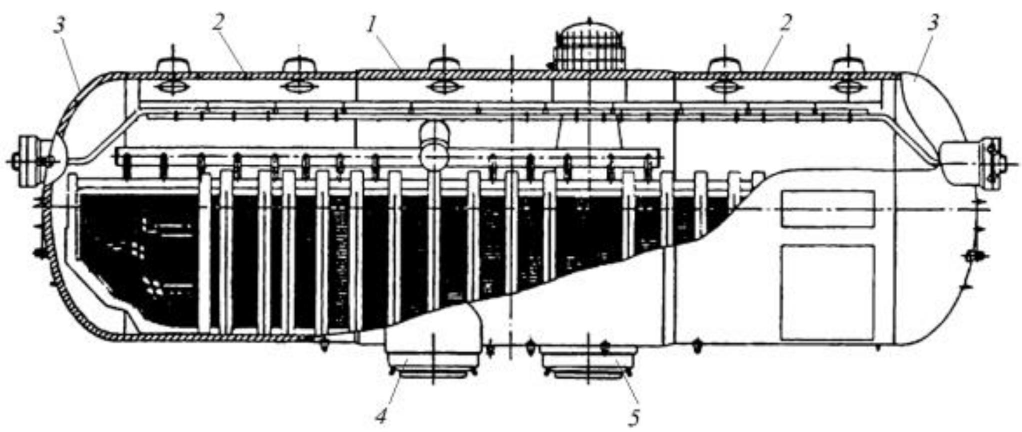


Figure 2.7- Longitudinal section of a horizontal steam generator:

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 (vss).

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

$$\delta_{vss} - c = \frac{7.875 \cdot 4.76}{2 \cdot 1 \cdot (181.15) - 7{,}875} = 0{,}106 \text{ m} = 106 \text{ mm}.$$

$$\delta_{vss} = 106\text{mm} \gg 20 \text{ mm}\,;$$

So, $C = 0$;

where:

δ_{vss} is in m;

$D_{ves.in}$ = 4.76m. 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 $\varphi = 1$;

$p_{calc} = 0.9 \cdot 1.25 \cdot p_2$ is the rated (design) pressure;

$$p_{calc} = 0.9 \cdot 1.25 \cdot 7 = 7.875 \text{ MPa};$$

$ts_{vss.max} = 286.8°C$ 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 $t_{calk} = t_s$, MPa;

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

From initial data

$t_{calk} = t_s$= 285.8 ºC;

From table 2.6 at a temperature of 307,45 ℃, select

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

We calculate stresses taking into account safety factors

$$\frac{\sigma_{sl}}{n_{sl}} = \frac{471}{2{,}6} = 181.15 \text{ MPa} \qquad \frac{\sigma_{0,2}}{n_{0,2}} = \frac{304}{1{,}5} = 202{,}67 \text{ MPa};$$

Compare the obtained values. Nominal voltage tolerance is equal to a lower value $[\sigma] = 181.15$.

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

Table 2.6- Mechanical properties of steel 10ГН2МФА

t_{calc}, °C	100	150	200	250	300	350
σ_{sl}, MPa	510	510	510	491	471	491
$\sigma_{0,2}$, 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).

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

$$\delta_{vcs} = \frac{7.875 \cdot 4.76}{2 \cdot 0.75 \cdot [181.15] - 7.875} + 0 = 0.142 \text{ m}.$$

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.

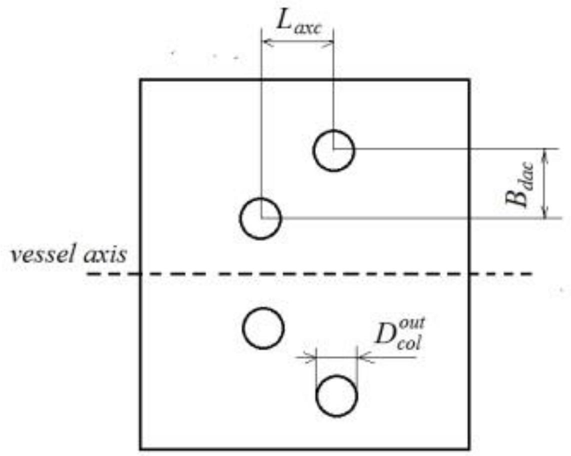


Fig. 2.8- To the calculation of the strength coefficient

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.

$$\varphi_1 = \frac{2 \cdot L_{axc} - D_{col}^{out}}{2 \cdot L_{axc}} = \frac{2 \cdot 2.282 - 1.141}{2 \cdot 2.282} = 0.75\ ;$$

$$\varphi_2 = \frac{2 \cdot (2 \cdot B_{dac} - D_{col}^{out})}{2 \cdot B_{dac}} = \frac{2 \cdot (2 \cdot 3.99 - 1.141)}{2 \cdot 3.99} = 1.71\ ;$$

$$\varphi_3 = \frac{1 - \frac{D_{col}^{out}}{L_{axc}} \cdot \frac{1}{\sqrt{1 + m^2}}}{\sqrt{1 - 0{,}75 \cdot \left(\frac{m^2}{1 + m^2}\right)^2}} = \frac{1 - \frac{1.141}{2.282} \cdot \frac{1}{\sqrt{1 + 1.747^2}}}{\sqrt{1 - 0.75 \cdot \left(\frac{1.747^2}{1 + 1.747^2}\right)^2}} = 0{,}991\ ;$$

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

because of φ_1 is minimum so we used it.

where:

δ_{vcs} is in m;

$$m = \frac{B_{dac}}{L_{axc}} = \frac{3.99}{2.282} = 1.747m\ ;$$

$B_{dac} = 3.99$ m. is the radial distance between the axis of the collectors, m. It is calculated in the section "Design calculation of the steam generator".

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

$$L_{axc} = 2 \cdot 1.141 = 2.282 \text{ m};$$

$D_{col}^{out} = 1{,}141$ 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

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

$$\delta_{bot} = \frac{7.875 \cdot 4.76}{4 \cdot 1 \cdot [181.15]} \cdot \frac{4.76}{2 \cdot 0.953} = 0.129 \text{ m}.$$

where:

δ_{bot}, is in m;

h is height of the bottom, m. It can be calculated from relation $\frac{h}{D_{ves.in}} \geq 0.2$

$$\frac{h}{4.76} \geq 0.2;$$

$$h = 0.2 \cdot 4.76 = 0.953 \text{ m};$$

$\varphi = 1$ 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).

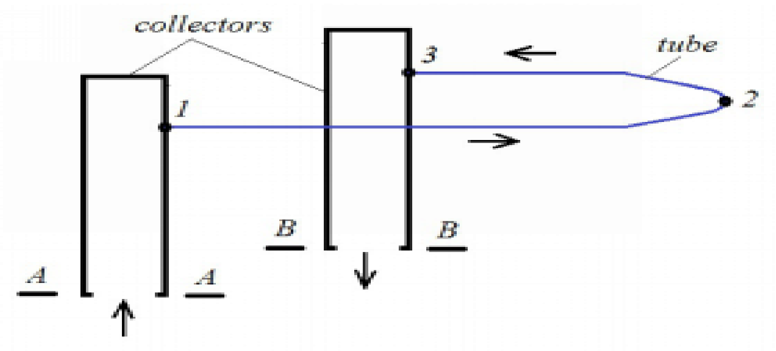


Figure 2.9- Flow diagram of the coolant circulation in a horizontal steam generator

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

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

$$\Delta p_{\Sigma} = 1936 + 1740 + 258702 = 262378 \text{ Pa.}$$

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}.

$$\Delta p_{i} = \Delta p_{fr.i} + \Delta p_{loc.i} + \Delta p_{cpd.i} + \Delta p_{acc.i};$$

Where:

i is plot number

$$\Delta p_{total} = 275512 \text{ Pa}.$$

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, $^{kg}/_{m^3}$.

W is the characteristic velocity of the coolant, $^{m}/_{s}$;

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

$\xi_{fr}$is coefficient of friction;

$$\xi_{fr} = 0.11 \cdot \left[\left(\frac{\Delta}{d_h}\right) + \left(\frac{68}{Re}\right)\right]^{0.25} \ ;$$

*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):

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

$$D_{col}^{in} = 0{,}85m \ ;$$

$$\rho_{in} = f(p_1,\ t'_1)\ ,{}^{kg}/_{m^3}\ ;$$

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

$$d_h = D_{col}^{in} = 0.85\ m\ \ ;$$

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

$$\nu_{in} = f(p_1,\ t'_1)\ ,{}^{m^2}/_{s}\ ;$$

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

$$\xi_{fr.col} = 0.11\left[\left({}^{\Delta}/_{d_h}\right) + \left({}^{68}/_{Re}\right)\right]^{0,25}\ \ ;$$

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

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

(From point 1 to point 3)

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

$$D_{col}^{in} = 0.85\ m\ ;$$

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

$$w_{tube} = 5\ \ {}^{m}/_{s}\ ;$$

$$d_h = d_{in} = 12.56\ mm\ ;$$

$$L = l_{avr} = 13.43\ m\ ;$$

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

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

$$\xi_{fr.col} = 0.11\left[\left({}^{\Delta}/_{d_h}\right) + \left({}^{68}/_{Re}\right)\right]^{0,25}\ \ ;$$

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

2.4.3 Downward movement of the coolant in the output collector

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

$$D_{col}^{in} = 0.85m\,;$$

$$\rho_{out} = f(p_1, t''_1)\,, {}^{kg}/_{m^3}\;;$$

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

$$d_h = D_{col}^{in} = 0.85\ m\;;$$

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

$$\nu_{out} = f(p_1,\ t''_1), {}^{m^2}/_{s}\,;$$

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

$$\xi_{fr.col} = 0.11\left[\left({}^{\Delta}/_{d_h}\right) + \left({}^{68}/_{Re}\right)\right]^{0,25}\;;$$

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

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 ξloc
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

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

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

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

Table.2.8- Summarize of the results

	ρ	w	d_h	v	Re	ξ_{fr}	L	Δp_{fr}
fr inlet collector	659.6	13.52	0.85	$1.17 \cdot 10^{-7}$	135482563	0,01147	2,39	1936
fr in H.ET	700.4	5	0.0126	$1,2 \cdot 10^{-7}$	3321941035	0,0277	13.43	258702
fr outlet collector	734.1	12.14	0.85	$1,22 \cdot 10^{-7}$	116666439	0,01147	2,39	1740
	loc	Δp_{loc}					SUM	262378
ξ_{tube}^{in}	0,5	4378						
ξ_{tube}^{out}	1	8756						
SUM	-	13134						

Then:

$$\Delta p_{total} = 262378 + 13134 = 262378 \text{ Pa.}$$

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} =13.52 m/s (The continuity equation for the collector)	$d_h = D_{col}^{in}$ =0.85 m $L \approx \frac{D_{ves.in}}{2}$ =4.76 / 2 =2.38m (Section 2 "Design calculation")	1936
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»)	$d_h = d_{in}$ =0.0126m (Section 1.3. «Thermal calculation»)	4378
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»)	$d_h = d_{in}$ =12.6 mm $L = l_{avr}$ = 13.43 m (Section 1.3. «Thermal calculation»)	258702
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»)	$d_h = d_{in}$ =0.0126m (From section 1.3. «Thermal calculation»)	8756
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} =12.14 m/s (From the continuity equation for the collector)	$d_h = D_{col}^{in}$ = 0.85 m $L \approx \frac{D_{ves.in}}{2}$ = 4.76 / 2 =2.38 m (Section 2 " Design calculation")	1740

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.

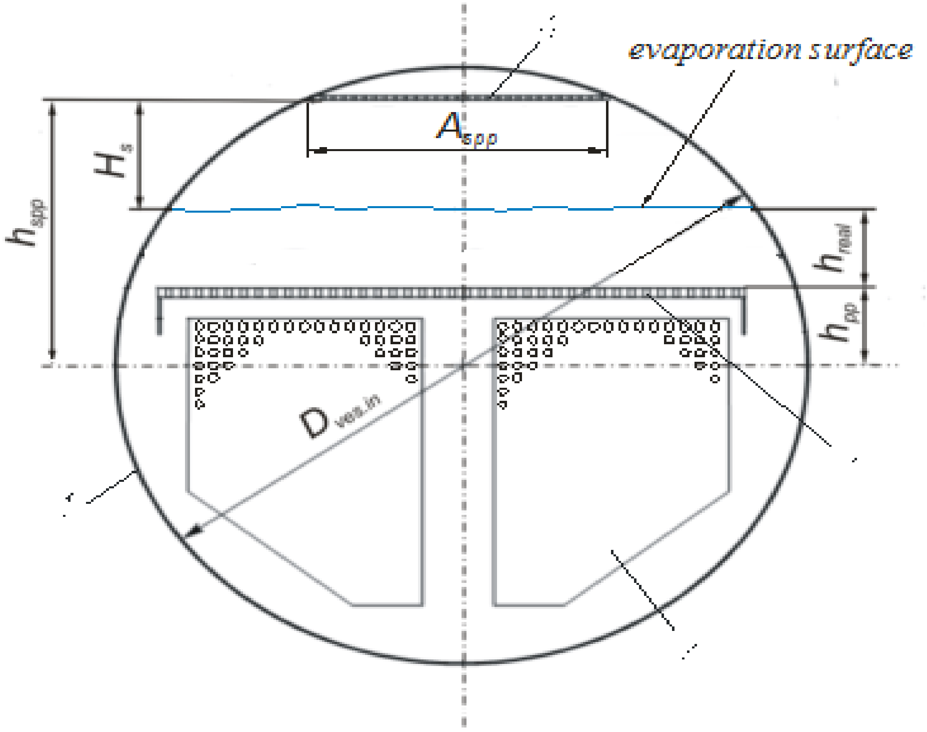


Figure 2.10- To the calculation of separation

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 = 506.61 $^{kg}/_{s}$ is mass flow of working fluid (steam);
- p_2= 7 MPa is working medium pressure;
- $D_{ves.in}$= 4.76 m, is internal diameter of the steam generator vessel, m. It is calculated in the section "Design calculation of the steam generator";

- $F_{es} = 63.08\ m^2$ is area of the evaporation surface, m². It is calculated in the section "Design calculation of the steam generator";
- l_{avr}= 13.43 m is average length of tubes. It is calculated in the section “Thermal calculation of the SG of saturated vapor”;
- w_0'' = 0.22 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

$$F_{spp} = A_{spp} \cdot l_{avr} = 2{,}509 \cdot 13.43 = 33.71\ m^2\ ;$$

where:

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

$$A_{spp} = 2 \cdot \sqrt{\left(\frac{4{,}76}{2}\right)^2 - (2{,}024)^2} = 2{,}509\ m^2;$$

$$h_{spp} = (0{,}8\ldots0{,}85) \cdot \frac{D_{ves.in}}{2};$$

$h_{spp} = (0{,}85) \cdot \frac{4{,}76}{2} = 2{,}024$ m. (h_{spp} 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

$$H_s = h_{spp} - h_{pp} - h_{real} = 2.024 - 0.4 - 0.158 = 1.466 \text{ m};$$

where:

$h_{pp} = 0.4$ 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";

$h_{real} = 0,158$ 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

$$w''_{spp} = \frac{D_2}{\rho'' \cdot F_{spp}} = \frac{506.61}{36.52 \cdot 33.71} = 0.41 \text{ m/s};$$

where:

$\rho'' = f(p_2) = 36.52 \ {}^{kg}/_{m^3}$, is vapor density at saturation at pressure.

2.5.4 Determining the Critical Height of the Steam Volume

$$H_{sv}^{cr} = 0.087 \cdot [w''_0 \cdot F(p)]^{1,3};$$

$$H_{sv}^{cr} = 0.087 \cdot [0.22 \cdot 12.37]^{1,3} = 0,319\text{m};$$

where:

$$F(p) = 3.45 \cdot 10^3 \cdot \left[\frac{\rho'' \cdot (\rho')^2}{(\rho' - \rho'')^6}\right]^{0,25};$$

$$F(p) = 3.45 \cdot 10^3 \cdot \left[\frac{36.52 \cdot (739.72)^2}{(739.72 - 36.52)^6}\right]^{0,25} = 12,37;$$

where:

$\rho'' = f(p_2) = 36.52 \ {}^{kg}/_{m^3}$ is vapor density at saturation at pressure;

$\rho' = f(p_2) = 739.72 \ {}^{kg}/_{m^3}$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

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

$$Y = 27.82 \cdot 10^{-4} \cdot \left(\frac{(0.22)^{2,76}}{1.466^{2,3}}\right) = 1.76 \cdot 10^{-4}\ \%\ ;$$

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.

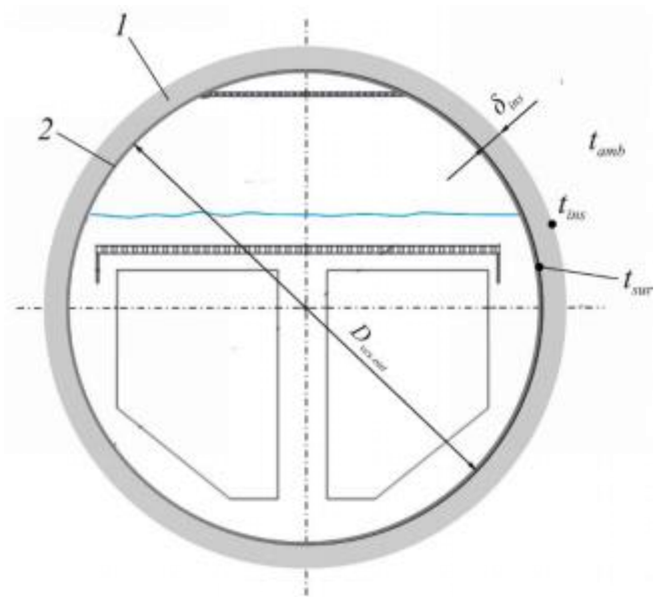


Fig. 2.11- Design scheme of single-layer thermal insulation with a coating layer: (1- is thermal insulation; 2- is vessel of SG)

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 $50 \ldots 55\ °C$ 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.

$$\delta_{ins} = \frac{\lambda_{ins} \cdot (t_{sur} - t_{ins})}{\alpha_{out} \cdot (t_{ins} - t_{amb})};$$

$$\delta_{ins} = \frac{0.069 \cdot (285.8 - 45)}{6 \cdot (45 - 25)} = 0.1039 \text{ m}.$$

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

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

Where:

$\delta_{ins}$is the thickness of the insulation layer, m;

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

$$d_{out} = D_{ves.out} = D_{ves.in} + (2 \cdot \delta_{vss}) = 4.76 + (2 \cdot 0{,}106) = 4.974\text{m};$$

is diameter of the external insulated object, m;

$D_{ves.in} = 4.76$ m is internal diameter of the steam generator vessel, m. It is calculated in the section "Design calculation of the steam generator";

$\delta_{vss} = 0.106$ 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);

$t_{amb} = 20\ldots25$ °C, assume 25 °C is the temperature of the ambient air(environment);

$\alpha_{out} = 6\ldots10\ ^{W}/_{(m^2 \cdot k)}$ and we assumed it as 8 $^{W}/_{(m^2 \cdot k)}$;

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, $^{W}/_{(m \cdot K)}$. It determined by the formula:

$$\lambda_{ins} = 0.0002 \cdot t_{ins}^{avr} + 0.036\,;$$

$$\lambda_{ins} = 0{,}0002 \cdot (165.41 + 0.036) = 0.069;$$

For super-thin fiberglass mats;

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

$$t_{ins}^{avr} = 0{,}5 \cdot (285.8 + 45) = 165.41\ ℃\,.$$

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	1300	electrical power
p_2, MPa	7	Steam pressure at the SG
p_0, MPa	6.65	Initial pressure
t_0, °C	282.4	Initial temperature
p_c, kPa	4.5	Pressure of condenser
superheater	2	Number of stages of superheater
t_{fw}, °C	225	Temperature of feedwater
p_d , MPa	0.6	Pressure of deaerator

Notes:

$$p_0 = (0.94 \ldots 0.95)\, p_2 = 0.95 \cdot 7 = 6.65 \text{ Mpa};$$

$$t_0 = f(p_0) = 282.4 °C;$$

3.1 Determination of the composition and parameters of the designed turbine installation of the power unit

3.1.1Feedwater 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 deference temperature and it between $\Delta t_d = 12 \div 15$ °C ;assume $\Delta t_d = 12$ °C;

$$t_d = f(p_d) = f(0.6) = 158.8 °C;$$

$$t_{mc} = t_d - \Delta t_d = 158.8 - 12 = 146.8 °C.$$

- **Main condensate temperature after seal coolers and ejector temperature t_{cse}.**

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

where:

t_c is final temperature;

$\Delta t_{cse}$is and it between $\Delta t_{cse} = 3 \div 5$℃ , assume $\Delta t_{cse} = 4$ ℃;

$$t_c = f(p_c) = f(0.0045) = 31 \text{ ℃};$$

$$t_{cse} = t_c + \Delta t_{cse} = 31 + 4 = 35 \text{ ℃};$$

$$h_{cse} = f(t_{cse}) = f(35) = 147 \ {}^{kJ}/_{kg}.$$

- **Temperature rises after each low-pressure heater $\Delta t_{LPH} = 25 \div 35$ assume $\Delta t_{LPH} = 30$℃.**

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

where:

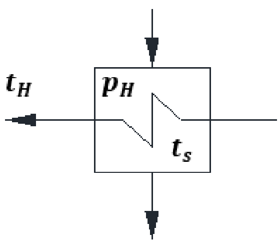
z_{LPH} number of low-pressure reheaters;

$$z_{lpH} = \frac{t_{mc} - t_{cse}}{\Delta t_{lpH}} = \frac{146.8 - 35}{30} = 3.73 \approx 4 \ ;$$

Real temperature rises after each heater;

$$\Delta t_{mcs} = \frac{t_{mc} - t_{cse}}{z_{LPH}} = \frac{146.8 - 35}{4} = 28 \text{ ℃}.$$

- **Closed type**



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

Where:

$\theta = (1 \div 2)$ is subcooled temperature in reheater, assume 1.59 ℃

$t_{Hj} = t_{Hj+1} + \Delta t_{LPH}$, $p_{exj} = (1.02 \div 1.05) p_{Hj}$, assume (1.03).

- **Closed**

$$t_{H6} = t_{cse} + \Delta t_{LPH} = 35 + 28 = 63 \ {}^{\circ}\text{C} \ ;$$

$$t_{s6} = t_{H5} + \theta_{LPH} = 63 + 1 = 64\ °C;$$

$$p_{H6} = f(t_{s6}) = f(64) = 0.024\ MPa\ ;$$

$$p_{ex6} = (1.03)p_{H6} = 1.03 \cdot 0.024 = 0.025\ MPa\ .$$

- **closed**

$$t_{H5} = t_{H6} + \Delta t_{LPH} = 63 + 28 = 90.6\ °C\ ;$$

$$t_{s5} = t_{H4} + \theta_{LPH} = 90.9 + 1 = 91.9\ °C;$$

$$p_{H5} = f(t_{s5}) = f(91.9) = 0.075\ MPa\ ;$$

$$p_{ex5} = (1.03)p_{H5} = 1.03 \cdot 0.075 = 0.0.78\ MPa\ .$$

- **closed**

$$t_{H4} = t_{H5} + \Delta t_{LPH} = 90.9 + 28 = 118.9°C\ ;$$

$$t_{s4} = t_{H4} + \theta_{LPH} = 118.9 + 1 = 119.9\ °C;$$

$$p_{H4} = f(t_{s4}) = f(119.9) = 0.198\ MPa\ ;$$

$$p_{ex4} = (1.03)p_{H4} = 1.03 \cdot 0.198 = 0.204\ MPa\ .$$

- **closed**

$$t_{H3} = t_{H4} + \Delta t_{LPH} = 118.9 + 28 = 146.8\ °C\ ;$$

$$t_{s3} = t_{H3} + \theta_{LPH} = 146.8 + 11 = 147.8\ °C;$$

$$p_{H3} = f(t_{s3}) = f(147.8) = 0.449\ MPa\ ;$$

$$p_{ex3} = (1.03)p_{H3} = 1.03 \cdot 0.449 = 0.463\ MPa\ .$$

Table 3.2- Low pressure heater parameters

Type	NO	t_{Hj}, °C	t_{sj}, °C	p_{Hj}, MPa	p_{exj}, MPa
CL	3~mc	146.8	147.8	0.449	0.463
CL	4	118.9	119.9	0.198	0.204
CL	5	90.9	91.9	0.075	0.078
CL	6	63	64	0.024	0.025
–	cse	35	–	–	–

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

$$p_{cp} = (1.1 \div 1.4)p_d\text{ , assume } 1.35\ p_d;$$

$$p_{cp} = 1.35(p_d) = 1.35(0.6) = 810\ MPa\ .$$

3.1.1.2 High pressure feedwater regenerative heater.

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

$$t_{fwp} = \ 159.8\ °C;$$

where:

p_{fwp} is pressure of feed water, $p_{fwp} = (1.2 \div 1.3)\ p_0$, assume 1.3;

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

- **Pressure of feed water pump.**

$$p_{fwp} = 1.3p_0 = 1.3 \cdot 6.65 = 8.645\ \text{MPa}\,.$$

- **Enthalpy of feed water pump.**

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

Where:

- $h'_d$is enthalpy of water in deaerator;

$$h'_d = f(p_d) = f(0.60) = 671\ {}^{kJ}/_{kg};$$

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

$$v = f(p_d) = f(0.60) = 0.001101\,{}^{m^3}/_{kg};$$

$$\Delta h_{fwp} = v\left(p_{fwp} - p_d\right) = 0.0011(8.645 - 0.60) \cdot 10^3 = 8.85\ {}^{kJ}/_{kg};$$

$$h_{fwp} = h'_d + \Delta h_{fwp} = 671 + 8.85 = 679\ {}^{kJ}/_{kg};$$

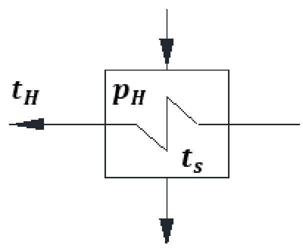
$$t_{fwp} = f(p_{fw}\,, h_{fw}) = 159.8\ °C.$$

- **Temperature rises after each high-pressure heater $\boldsymbol{\Delta t_{HPH} = 25 \div 35}$.**

  Real temperature rises after each heater

$$\Delta t_{HPH} = \frac{t_{fw} - t_{fwp}}{z_{HPH}} = \frac{225 - 159.8}{2} = 32.6\ °C.$$

- **Closed type**



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

where:

$\theta_{HPH} = (3 \div 5)$ is subcooled temperature in reheater, assume 4℃;

$t_{Hj} = t_{Hj+1} + \Delta t_{HPH}$; $p_{exj} = (1.02 \div 1.05)p_{Hj}$; assume (1.03);

- **closed**

$$t_{H2} = t_{fwp} + \Delta t_{HPH} = 159.8 + 32.6 = 195.4℃;$$

$$t_{s2} = t_{H2} + \theta_{HPH} = 192.4 + 3 = 195.4\ ℃;$$

$$p_{H2} = f(t_{s2}) = f(195.4) = 1.411\ \text{MPa};$$

$$p_{ex2} = (1.03)p_{H2} = 1.03 \cdot 1.411 = 1.453\ \text{MPa}.$$

Table 3.3- High pressure heater parameters

Type	NO	t_{Hj}, ℃	t_{sj}, ℃	p_{Hj}, MPa	p_{exj}, MPa
CL	1~fw	225	228	2.696	2.777
CL	2	192.4	195.4	1.411	1.453
–	fwp	159.8	–	–	–

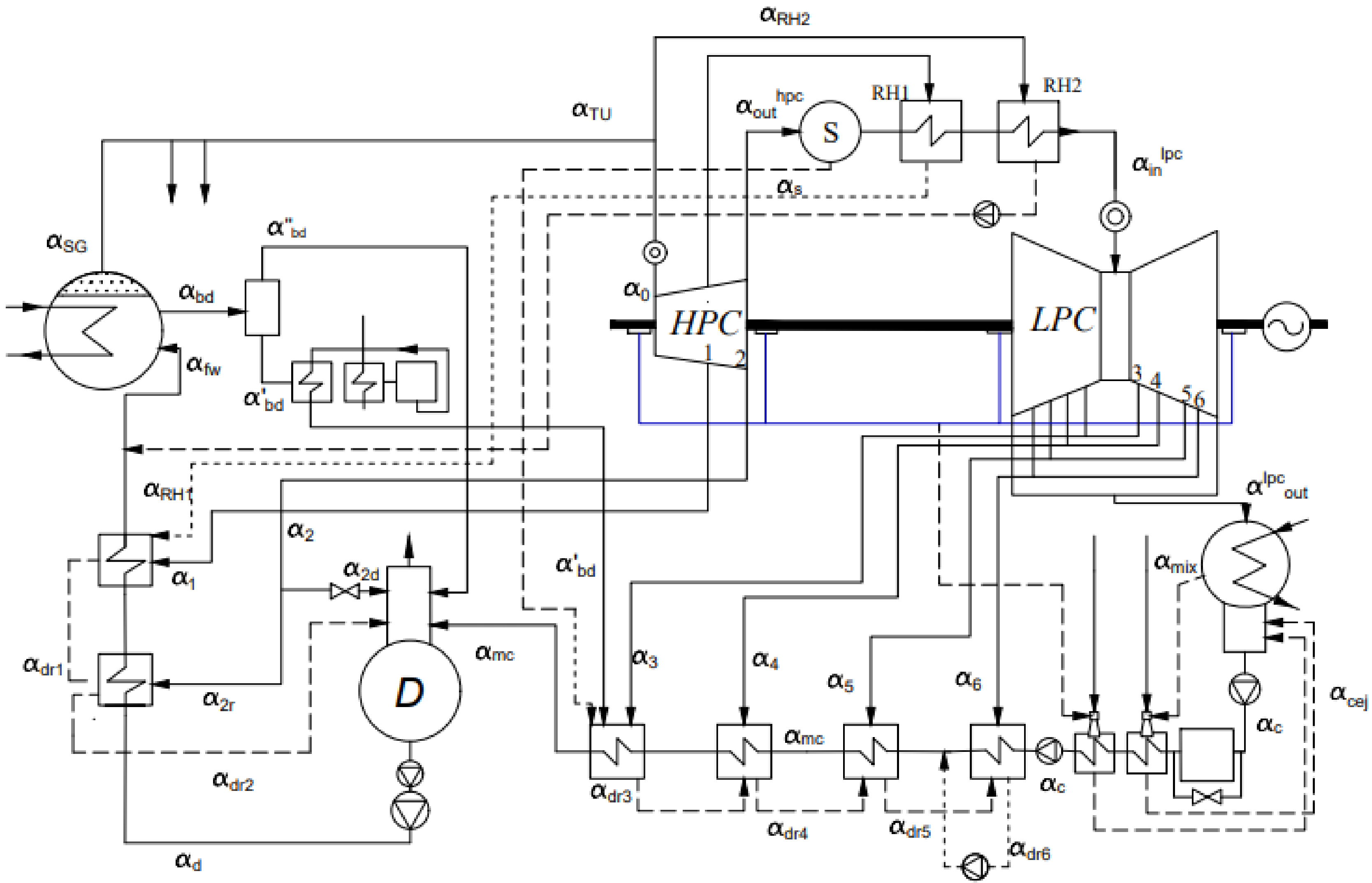


Figure 3.1- Designed Scheme

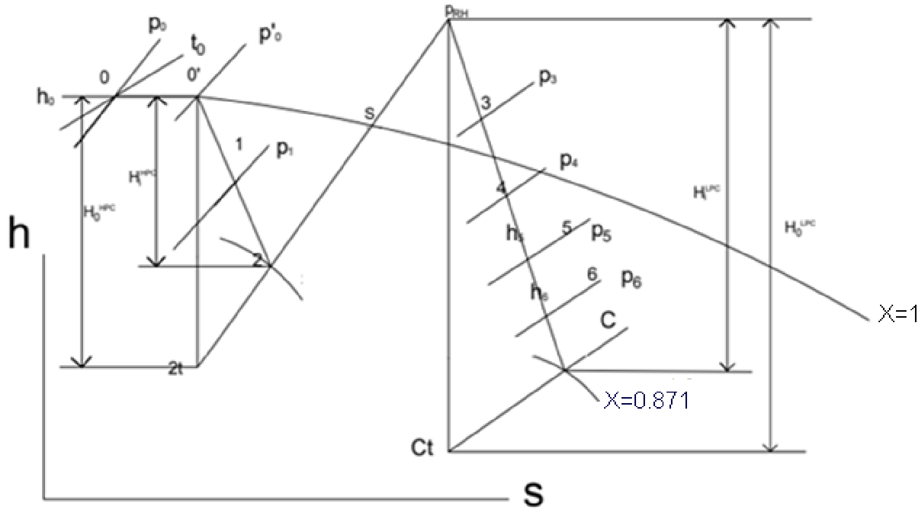


Figure 3.2- h-s diagram

3.2 Parameters at the Turbine Entry.

The steam pressure before the nozzles of the HPC is less than before the turbine: Throttle valve which keeps enthalpy constant but make some pressure losses $3 \div 5\%$ of p_0.

$$P_0' = 0.98 \cdot P_0 = 0.98 \cdot 6.65 = 6.517 \text{ MPa};$$

$$S_0' = f(p_0', h_0') = 5.8473 \ {}^{kJ}/_{(kg\,.\,°C)};$$

$$h_0' = 2777 \, {}^{kJ}/_{kg}.$$

Table 3.4- Steam parameters (0')

$p_{0'}$, MPa	6.517
$h_0 = h_{0'}$, ${}^{kJ}/_{kg}$	2777
$t_{0'} = f(p_{0'}, h_{0'})$, °C	281
$s_{0'} = f(p_{0'}, h_{0'})$, ${}^{kJ}/_{(kg\,.\,°C)}$	5.8473

3.3 Calculation of Processes

3.3.1 For HPC (High Pressure Cylinder)

- with absolute internal efficiency $\eta_{0i}^{HPC} = 0.862$.
- Isentropic process 1st extraction where $p_1 = p_{ex1} = 2.77$ MPa.

$$h_0 = h_{0'} = 2777 \ {}^{kJ}/_{kg};$$

$$s_{0'} = s_{1t} = f(p_{0'}, h_0) = 5.8473\ ^{kJ}/_{(kg\,.\,°C)}\ ;$$

$$h_{1t} = f(p_1, s_{0'}) = f(2.777\ , 5.8473) = 2618\ ^{kJ}/_{kg};$$

$$h_1 = h_0 - 0.862 \cdot (h_0 - h_{1t}) = 2777 - 0.862 \cdot (2777 - 2618) = 2640\ ^{kJ}/_{kg}$$

$$t_1 = f(p_1, h_1) = f(2.77\ , 2640) = 229.6\ °C.$$

- Isentropic process 2nd extraction where $p_2 = p_{ex2} = 1.453$ MPa.

$$s_{0'} = s_{2t} = 5.8473\ ^{kJ}/_{(kg\,.\,°C)}\ ;$$

$$h_{2t} = f(p_2, s_{0'}) = f(1.453\ , 5.8473) = 2505\ ^{kJ}/_{kg};$$

$$h_2 = h_0 - 0.862 \cdot (h_0 - h_{2t}) = 2777 - 0.862 \cdot (2777 - 2505) = 2542\ ^{kJ}/_{kg};$$

$$t_2 = f(p_2, h_2) = f(1.453, 2542) = 196.8°C.$$

Exhaust steam quality from HPC,$x^{HPC} = f(p_2, h_2) = f(1.453{,}2542) = 0.873$ which is allowable

- **Properties of superheating system**

➢ For Separator.

p_s = constant line;

$$p_s = p_2 = 1.453 \text{ MPa};$$

So, the loses of pressure after separator is

$$p'_s = (0.95 \div 0.94)p_s = 0.95 \cdot p_s;$$

$$p'_s = 1.380 \text{ MPa};$$

- So, the enthalpy of separator h_S;

$$h_s = f(p'_s) = 2788 \ {}^{kJ}/_{kg}.$$

➢ For Double superheater.

$$p_{SH} = (0.95)p_{s'} = (0.95)1.380 \ = 1.311 \text{ MPa};$$

$\Delta t_R = \ 15 \div 20°C$ for the first stage, assume 15 °C;

$\Delta t_R = \ 10 \div 15°C$ for the second stage, assume 10 °C;

Where 1^{st} stage is heated from extraction from HPC and 2^{nd} stage is heated from fresh steam

Sh2

$$t_{Sh2} = t_o - \Delta t_R = 282.4 - 10 = 272.4°C;$$

$$p_{Sh2} = p_0 = 6.65 \text{ MPa};$$

Enthalpy of steam after second superheater h_{sh2}

$$h_{Sh2} = f(p_{SH}, t_{sh2}) = f(1.311, 272.4) = 2982 \ {}^{kJ}/_{kg};$$

From enthalpy equality the enthalpy rise is equal in each heater Δh_R

$$\Delta h_R = \frac{h_{Sh2} \ - h'_s}{2} = \frac{2982 - 2788}{2} = 97 \ \ {}^{kJ}/_{kg};$$

Sh1

$$t_{Sh1} = t_1 - \Delta t_R = 229.6 - 15 = 214.6 \,°C;$$

$$h_{Sh1} = f(p_{SH}, t_{Sh1}) = f(1.311, 214.6) = 2847 \ {}^{kJ}/_{kg};$$

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.

$$P'_{sh} = 0.95 \cdot P_{sh} = 0.95 \cdot 1.311 = 1.246 \text{ MPa.}$$

Table 3.5- Steam parameters (SH)

p'_{Sh}, MPa	1.246
$h'_{Sh} = f(P_{sh}, t_{sh})$, ${}^{kJ}/_{kg}$	2982
t'_{Sh}; °C	271
$s'_{Sh} = f(p_{Sh}, h_{Sh})$, ${}^{kJ}/_{(kg\,.\,°C)}$	6.9020

- with absolute internal efficiency $\eta_{0i}^{LPC} = 0.831$.

Isentropic process 3rd extraction where $p_3 = p_{ex3} = 0.282$ MPa.

$$s_{SH'} = s_{3t} = 6.9020\ {}^{kJ}/_{(kg\,.\,°C)};$$

$$h_{3t} = f(p_3, s_{SH'}) = f(0.463\ ,6.9020) = 2768\ {}^{kJ}/_{kg};$$

$$h_3 = h_{sh} - 0.831 \cdot (h_{sh} - h_{3t}) = 2982 - 0.831 \cdot (2982 - 2768) = 2804\,{}^{kJ}/_{kg};$$

$$t_3 = f(p_3, h_3) = f(0.463\ , 2804) = 175.3\ °C.$$

- Isentropic process 4th extraction where $p_4 = p_{ex4} = 0.204$ MPa.

$$s_{SH'} = s_{4t} = 6.9020\ {}^{kJ}/_{(kg\,.\,°C)};$$

$$h_{4t} = f(p_4, s_{SH'}) = f(0.204\ , 6.9020) = 2621\ {}^{kJ}/_{kg};$$

$$h_4 = h_{sh} - 0.831 \cdot (h_{sh} - h_{4t}) = 2982 - 0.831 \cdot (2982 - 2621)$$
$$= 2682\ {}^{kJ}/_{kg};$$

$$t_4 = f(p_4, h_4) = f(0.204\ , 2682) = 120.8\ °C.$$

- Isentropic process 5th extraction where $p_5 = p_{ex5} = 0.078$ MPa.

$$s_{SH'} = s_{5t} = 6.9020\ {}^{kJ}/_{(kg\,.\,°C)};$$

$$h_{5t} = f(p_5, s_{SH'}) = f(0.078\,, 6.9020) = 2466\ {}^{kJ}/_{kg};$$

$$h_5 = h_{sh} - 0.831 \cdot (h_{sh} - h_{5t}) = 2982 - 0.831 \cdot (2982 - 2466)$$

$$= 2553\ {}^{kJ}/_{kg};$$

$$t_5 = f(p_5, h_5) = f(0.078\,, 2553) = 92.7\ ℃.$$

- Isentropic process 5th extraction where $p_6 = p_{ex6} = 0.025$ MPa.

$$s_{SH'} = s_{6t} = 6.9020\ kJ/(kg℃);$$

$$h_{6t} = f(p_6, s_{SH'}) = f(0.025\,, 6.9020) = 2302\ {}^{kJ}/_{kg};$$

$$h_6 = h_{sh} - 0.831 \cdot (h_{sh} - h_{6t}) = 2982 - 0.831 \cdot (2982 - 2302)$$

$$= 2417\ {}^{kJ}/_{kg};$$

$$t_6 = f(p_6, h_6) = f(0.025\,, 2417) = 65\ ℃.$$

- Isentropic process C' point

$$p_{c'} = 1.03 \cdot p_c = 1.03 \cdot 0.0045 = 0.00463\ MPa;$$

$$s_{SH'} = s_{c't} = 6.9020\ {}^{kJ}/_{(kg\,.\,℃)};$$

$$h'_{ct} = f(p_c\,, s_{sh}) = f(0.00463\,, 6.9020) = 2096\,{}^{kJ}/_{kg};$$

$$H_0^{LPc} = h_{sh} - h_{ct} = 2982 - 2096 = 887\,{}^{kJ}/_{kg};$$

$$H_i^{LPc} = H_0^{LPc} - \eta_{LPC} = 887 \cdot 0.831 = 737\,{}^{kJ}/_{kg};$$

$$h'_c = h_{sh} - \left(H_i^{LPc}\right) = 2982 - 737 = 2245\,{}^{kJ}/_{kg};$$

$$t_c' = f(p_c', h_c') = f(0.00463\,, 2245) = 31.5\ ℃.$$

Exhaust steam quality from LPC,$x^{LPC} = f(p_c', h_c') = f(0.0046\,, 2245) = 0.871$; it is allowable dryness factor for low-speed turbine (25Hz).

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

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

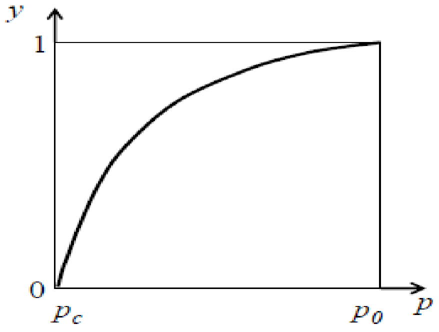


Fig 3.3- Show relation between y and p

$$0 \le y_j \le 1\,;$$

Where:

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

➢ First for HPC:

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

$$H_1 = (h_o - h_1) = (2777 - 2640) = 137\ {}^{kJ}/_{kg};$$

$$H_2 = (h_o - h_2) = (2777 - 2542) = 235\ {}^{kJ}/_{kg};$$

$$H_i^{HPC} = H_2 = 235\ {}^{kJ}/_{kg}.$$

➢ For LPC:

$$H_3 = (h_{sh} - h_3) + H_i^{HPC} = (2982 - 2804) + 235 = 412\ {}^{kJ}/_{kg};$$

$$H_4 = (h_{sh} - h_4) + H_i^{HPC} = (2982 - 2682) + 235 = 535\ {}^{kJ}/_{kg};$$

$$H_5 = (h_{sh} - h_5) + H_i^{HPC} = (2982 - 2553) + 235 = 664\ {}^{kJ}/_{kg};$$

$$H_6 = (h_{sh} - h_6) + H_i^{HPC} = (2982 - 2417) + 235 = 800\ {}^{kJ}/_{kg};$$

$$H_c' = (h_{sh} - h_c') + H_i^{HPC} = (2982 - 2245) + 235 = 971\ {}^{kJ}/_{kg}.$$

➢ Total heat drops:

$$H_i^{total} = 971\ {}^{kJ}/_{kg}.$$

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

$$y_1 = \frac{H_i - H_1}{H_i} = \frac{971 - 137}{971} = 0.8586;$$

$$y_2 = \frac{H_i - H_2}{H_i} = \frac{971 - 235}{971} = 0.7584;$$

$$y_3 = \frac{H_i - H_3}{H_i} = \frac{971 - 412}{971} = 0.5784;$$

$$y_4 = \frac{H_i - H_4}{H_i} = \frac{971 - 535}{971} = 0.4495;$$

$$y_5 = \frac{H_i - H_5}{H_i} = \frac{971 - 664}{971} = 0.3167;$$

$$y_6 = \frac{H_i - H_6}{H_i} = \frac{971 - 800}{971} = 0.1762;$$

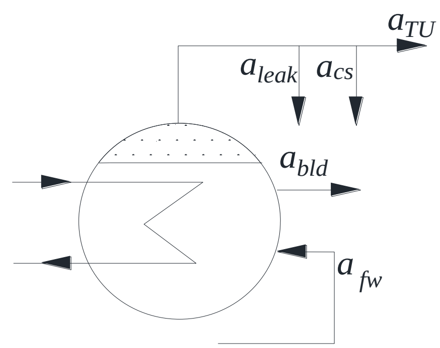
$$y_{c'} = \frac{H_i - H_6}{H_i} = \frac{971 - 971}{971} = 0.$$

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	6.65	282.4	2777	–	–	1249	–	–	–	–	–
0’	6.52	281	2777	–	–	–	–	–	–	0	1
1	2.78	229.6	2640	2.70	228.0	981	8.65	225.0	968	137	0.8586
2	1.45	196.8	2542	1.41	195.4	832	8.65	192.4	822	235	0.7584
D	1.45	196.8	2542	0.6	158.8	671	0.6	158.8	671	–	–
Sep	1.453	2788	2788	1.453	196.8	838	–	–	–	–	–
SH1	1.311	214.6	2847	2.78	229.6	988	–	–	–	–	–
SH2	1.311	272.4	2982	6.65	282.4	1249	–	–	–	–	–
3	0.463	175.3	2804	0.449	148	623	0.81	146.8	619	412	0.5754
4	0.204	120.8	2682	0.198	119.9	503	0.81	118.9	499	535	0.4495
5	0.078	92.7	2553	0.075	91.9	385	0.81	90.9	381	664	0.3167
6	0.025	65	2417	0.024	64.0	268	0.81	63.0	264	800	0.1762
C’	0.00464	31.5	2245	–	–	–	–	–	–	971	0
C	0.0045	31.0	2092	0.0045	31.0	130	–	–	–	–	–

3.6 Material and thermal balance equations calculation

- **Feedwater**



$\alpha_{fw} = \alpha_{TU} + \alpha_{leak} + \alpha_{cs} + \alpha_{bld}$;

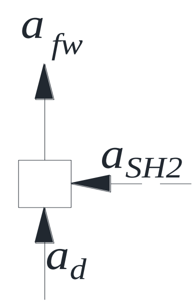
$\alpha_{TU} = \alpha_0 + \alpha_{SH}$;

$\alpha_{cs} = 0.005 \div 0.012$; assume 0.005 ;
$\alpha_{leak} \leq 0.01$;
$\alpha_{bld} = 0.005$;

$\alpha_{fw} = \alpha_0 + \alpha_{leak} + \alpha_{cs} + \alpha_{bld} + \alpha_{SH}$;

$\alpha_{fw} = 1 + 0.002 + 0.005 + 0.005 + \alpha_{SH}$.

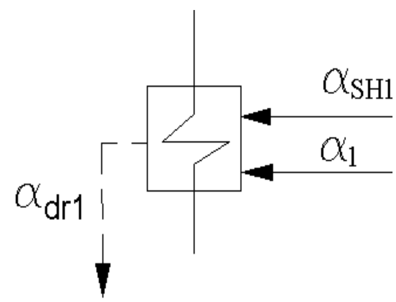
- **For Mixing point before SG**



$\alpha_{fw} = \alpha_{SH2} + \alpha_d$;

$$\frac{\alpha_{fw} \cdot h_{fw}}{\eta_{oph}} = \alpha_{SH2} \cdot h'_0 + \alpha_d \cdot h_{w1};$$

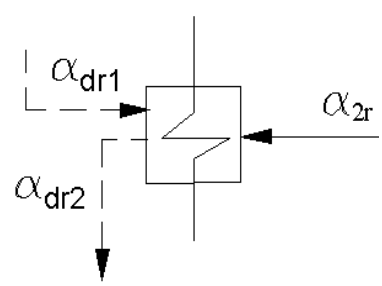
- **For Heater (1)**



$\alpha_{dr1} = \alpha_{sH1} + \alpha_1$;

$$\frac{\alpha_d \cdot (h_{w1} - h_{w2})}{\eta_H} = \alpha_1 \cdot (h_1 - h_{dr1}) + \alpha_{SH1} \cdot (h'_1 - h_{dr1});$$

- **For Heater (2)**

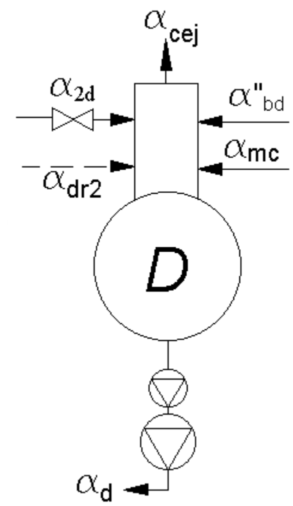


$\alpha_2 = \alpha_{2r} + \alpha_{2d}$;

$\alpha_{dr2} = \alpha_{2r} + \alpha_{dr1}$;

$$\frac{\alpha_d \cdot \left(h_{w2} - h_{fwp}\right)}{\eta_h} = \alpha_{2R}(h_2 - h_{dr2}) + \alpha_{dr1} \cdot (h_{dr1} - h_{dr2});$$

- **For Deaerator**



$$\alpha_{ej} = 0.003;$$

$$\alpha_{mc} + \alpha_{dr2} + \alpha_{2d} + \alpha''_{bd} = \alpha_d + \alpha_{ej};$$

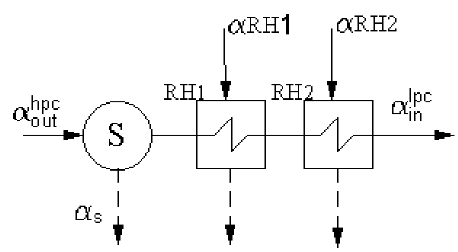
$$\alpha_{mc} \cdot h_{w3} + \alpha_{dr2} \cdot h_{dr2} + \alpha_{2d} \cdot h_2 + \alpha''_{bd} \cdot h''_{bd} = \frac{\alpha_d \cdot h'_d + \alpha_{cej} \cdot h''_d}{\eta_{oph}};$$

$$h'_d = f(p_d) = 674\ {kJ}/{kg};$$

$$h''_d = f(p_d) = 2757\ {kJ}/{kg};$$

$$h_{mc} = h_{w3} = 619\ {kJ}/{kg};$$

- **For separator**



$$\alpha_{ex}^{HPC} = \alpha_s + \alpha_{in}^{LPC};$$

- **For First Super heater**

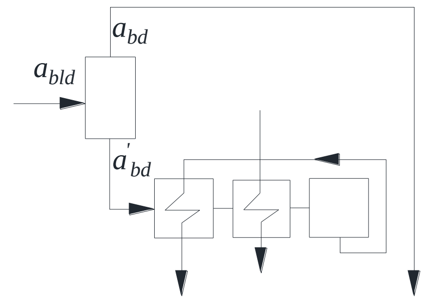
$$\alpha_{in}^{LPC} \cdot (h_{SH1} - h_s) = \frac{\left(\alpha_{SH1} \cdot (h_1 - h_{dr1})\right)}{\eta_{sh}};$$

$$\alpha_{in}^{LPC} = 1 - \alpha_1 - \alpha_2 - \alpha_{SH1} - \alpha_s;$$

- **For Second Super heater**

$$\alpha_{in}^{LPC} \cdot (h_{SH2} - h_{SH1}) = \frac{\left(\alpha_{SH2} \cdot (h_0 - h'_0)\right)}{\eta_{sh}};$$

- **For Blowdown system**



$p_{tank} = p_d \cdot 1.02 = 612 \text{ kPa}$;

$h'_{bd} = f(p_{tank}) = f(612) = 674 \, ^{kJ}/_{kg}$;

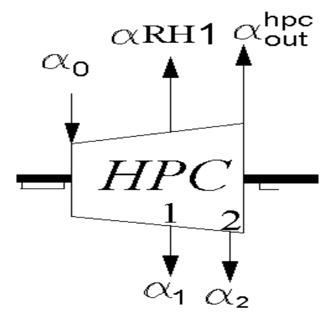
$h''_{bd} = f(p_{tank}) = f(612) = 2757 \, ^{kJ}/_{kg}$;

$\alpha_{bld} = \alpha'_{bd} + \alpha''_{bd}$;

$0.005 = \alpha'_{bd} + \alpha''_{bd}$;

$\alpha_{bld} \cdot h'_0 = \alpha'_{bd} \cdot h'_{bd} + \alpha''_{bd} \cdot h''_{bd}$;

- **For High pressure cylinder extraction outlet**

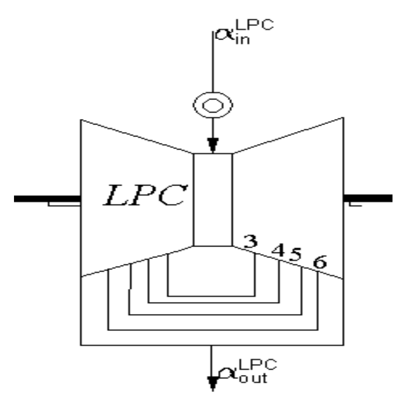


$\alpha_{ex}^{HPC} = \alpha_0 - \alpha_1 - \alpha_2 - \alpha_{SH1}$;

$\alpha_2 = \alpha_{2R} + \alpha_{2D}$;

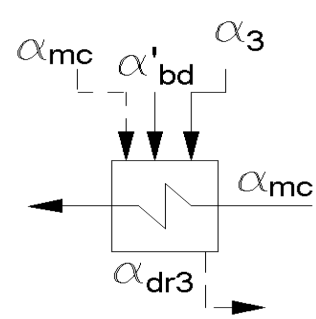
$\alpha_{ex}^{HPC} = 1 - \alpha_1 - \alpha_2 - \alpha_{SH1}$;

- **For Low pressure cylinder extraction outlet**



$\alpha_{ex}^{LPC} = \alpha_{in}^{LPC} - \alpha_3 - \alpha_4 - \alpha_5 - \alpha_6$;

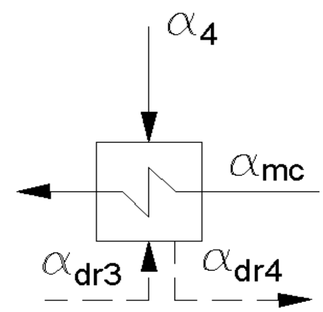
- **For Heater (3)**



$\alpha_{dr3} = \alpha_3 + \alpha_s + \alpha'_{bd}$;

$\alpha_3(h_3 - h_{dr3}) + \alpha_s(h'_s - h_{dr3}) = \alpha_{mc}(h_{w3} - h_{w4}) \cdot \frac{1}{\eta_H}$;

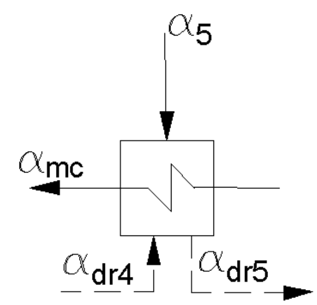
- **For Heater (4)**



$$\alpha_{dr4} = \alpha_4 + \alpha_{dr3};$$

$$\alpha_4(h_4 - h_{dr4}) + \alpha_{dr3}(h_{dr3} - h_{dr4}) = \alpha_{mc}(h_{w4} - h_{w5}) \cdot \frac{1}{\eta_H}\ ;$$

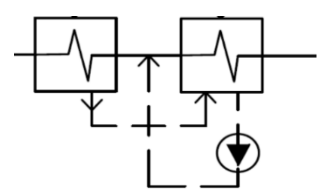
- **For Heater (5)**



$$\alpha_{dr5} = \alpha_{dr4} + \alpha_5;$$

$$\alpha_5(h_5 - h_{dr5}) + \alpha_{dr4}(h_{dr4} - h_{dr5}) = \alpha_{mc}(h_{w5} - h_{mc}) \cdot \frac{1}{\eta_H}$$

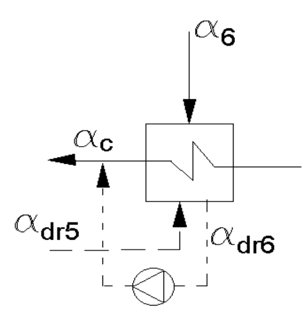
- **Mixing Point between Heater 5 and 6**



$$\alpha_{mc} = \alpha_{dr6} + \alpha_c;$$

$$\alpha_c \cdot h_{w6} + \alpha_{dr6} \cdot h_{dr6} = \alpha_{mc} \cdot h_{mc} \cdot \frac{1}{\eta_H}\ ;$$

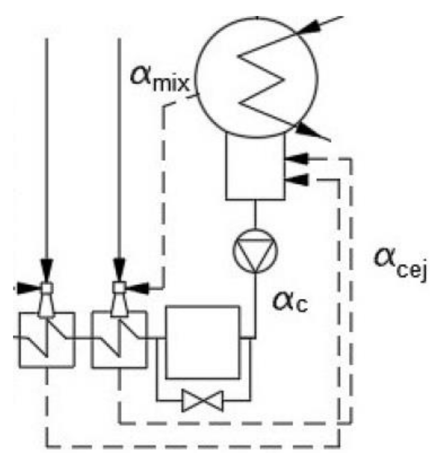
- **For Heater (6)**



$$\alpha_{dr6} = \alpha_6 + \alpha_{dr5};$$

$$\alpha_6(h_6 - h_{dr6}) + \alpha_{dr5}(h_{dr5} - h_{dr6}) = \alpha_c(h_{w6} - h_{cse}) \cdot \frac{1}{\eta_H}\ ;$$

- **For Condenser**



$$\alpha_c = \alpha_{ex}^{LPC} + \alpha_{cej} + \alpha_{leak} + \alpha_{cs}\ ;$$

$$\alpha_{in}^{LPC} = \alpha_{ex}^{LPC} + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 = 0.5669 + 0.0355 + 0.037 + 0.0355 + 0.0205 = 0.6954\ ;$$

$$\alpha_c = \alpha_{ex}^{LPC} + \alpha_{cej} + \alpha_{leak} + \alpha_{cs} = 0.5669 + 0.0030 + 0.0050 + 0.002 = 0.5769.$$

Table 3.7- Relative flowrate

α_1	0.0909	α_{SH2}	0.0602
α_2	0.0891	α_{fw}	1.0722
α_3	0.0355	h_{mc}, $^{kJ}/_{kg}$	263
α_4	0.037	h_{fw}, $^{kJ}/_{kg}$	975
α_5	0.0355	α_{dr1}	0.1151
α_6	0.0205	α_{dr2}	0.1927
α_s	0.1004	α_{dr3}	0.1395
α_c	0.5769	α_{dr4}	0.1766
α_d	1.012	α_{dr5}	0.2121
α_{2D}	0.0115	α_{dr6}	0.2326
α_{2R}	0.0775	α_{leak}	0.002
α_{mc}	0.9193	α_{cs}	0.005
α_{ex}^{HPC}	0.7958	α_{csj}	0.003
α_{in}^{LPC}	0.6954	α'_{bd}	0.00385
α_{ex}^{LPC}	0.5669	α''_{bd}	0.00127
α_{TU}	1.0602	α_{bld}	0.005
α_{SH1}	0.0242	–	–

3.7 Determining steam flow to a turbine

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

$$G_0 = \frac{1300 \cdot 10^3}{971 \cdot 0.98 \cdot 0.99 \cdot (1 - 0.1975 - 0.0761)} = 1898.9\ ^{kg}/_{s}.$$

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, ${}^{kJ}/_{kg}$;

$$H_i = (h_{sh2} - h_{c'}) + H_i^{HPC} = (2982 - 2245) + 235 = 971\ {}^{kJ}/_{kg}.$$

- Total heat drops:

$$H_i^{total} = 971\,{}^{kJ}/_{kg}.$$

3.8 Power for a turbine is determined by the formula

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

$$N_e = \frac{1898.9 \cdot 971 \cdot 0.98 \cdot 0.99 \cdot (1 - 0.1975 - 0.0761)}{10^3} = 1299.994\ \text{MW}.$$

Table 3.8- Relative flow rate and under production factor

NO j	α_j	y_j	$(\alpha_j \cdot y_j)$
1	0.0909	0.8586	0.07805
2	0.0891	0.7584	0.06758
3	0.0355	0.5754	0.02043
4	0.037	0.4495	0.01663
5	0.0355	0.3167	0.01124
6	0.0205	0.1762	0.00361
$\sum(\alpha_j \cdot y_j)$	–	–	0.1975
Separator (s)	0.1004	0.7584	0.0761

- **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_1	172.618	G_{SH1}	45.955
G_2	169.200	G_{SH2}	114.319
G_3	67.414	G_{fw}	2036.093
G_4	70.262	G_{dr1}	218.573
G_5	67.414	G_{dr2}	365.935
G_6	38.929	G_{dr3}	264.909
G_s	190.658	G_{dr4}	335.361
G_c	1095.525	G_{dr5}	402.775
G_d	1921.774	G_{dr6}	441.704
G_{1D}	21.838	G_{leak}	3.798
G_{1R}	147.171	G_{cs}	9.495
G_{mc}	1537.229	G_{cej}	5.697
G_{ex}^{HPC}	1511.213	G'_{bd}	7.311
G_{in}^{LPC}	1320.555	G''_{bd}	2.412
G_{ex}^{LPC}	1076.535	G_{bld}	9.495
G_{TU}	2013.305	–	–

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)

$$Q_{SG} = G_0\left[\left(\alpha_{TU} + \alpha_{leak} + \alpha_{sg}\right)(h_0 - h_{fw}) + \alpha_{bd}(h_{bd} - h_{fw})\right];$$

$$Q_{SG} = 1898.9 \cdot \left((1.0602 + 0.002 + 0.005) \cdot (2777 - 975) + 0.005(1249 - 975)\right)$$

$$= 3655 \text{ MW};$$

where:

$G_0 = 1898.9$ kg/s is steam flow to a turbine, $^{kg}/_{s}$;

$\alpha_{TU} = 1.0602$ is the relative flow rate for turbine installation;

$\alpha_{bd} = 0.005$ is the relative flow rate of blowdown water;

$\alpha_{leak} = 0.002$ is a relative leakage flow rate;

$\alpha_{cs} = 0.005$ is a relative steam flow rate out of the turbine seals;

$h_0 = 2777\ {}^{kJ}/_{kg}$ is enthalpy of steam at the turbine inlet;

$h_{fw} = 975\ {}^{kJ}/_{kg}$ is enthalpy of feed water at the steam generator inlet.

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

$$Q_{ts} = G_0\big((\alpha_{TU} + \alpha_{cs})(h_0 - h_{fw}) + \alpha_{leak}(h_c - h_{fw}) + \alpha_{bd}(h_{bd} - h_{fw})\big);$$

$$Q_{ts} = 1898.9 \cdot \big((1.0602 + 0.005) \cdot (2777 - 975) + 0.002 \cdot (147 - 975) + 0.005(1249 - 975)\big) = 3644 \text{ MW}.$$

3.9.3 Electrical efficiency of turbo-generator

$$\eta_e = \eta_{ts} = \frac{N_e}{Q_{ts}} = \frac{1300}{3644} = 0.357.$$

3.9.4 Efficiency of heat transport of the 2nd circuit

$$\eta_{pipeII} = \frac{Q_{ts}}{Q_{SG}} = \frac{3644}{3655} = 0.996\,.$$

3.9.5 Steam turbine plant (STP) heat rate, for generating electricity, ${}^{kJ}/_{(kW \cdot h)}$

$$q_{ts} = \frac{3600}{\eta_{ts}} = \frac{3600}{0.357} = 10.092 \cdot 10^3\ {}^{kJ}/_{(kW \cdot h)}.$$

3.9.6 NPP efficiency

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

$$\eta_{npp} = 0.99 \cdot 0.995 \cdot 0.996 \cdot 0.99 \cdot 0.357 = 0.347 = 34.7\%\,;$$

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;

$\eta_{pip}^{II} = 0.996$ is the efficiency of heat transport of the 2nd circuit;

$\eta_{sg} = 0.99$ is the efficiency of the steam generator.

3.9.7 Burnup fuel rate, ton/year

$$b_{nf} = \frac{Q_r \cdot T_{eff}}{24 \cdot \overline{B} \cdot 10^3} = \frac{3655 \cdot 6000}{24 * 35 * 10^3} = 26.107\ {}^{ton}/_{year}\ ;$$

where:

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

$\overline{B} = 35 \cdot 10^3\ {}^{MW \cdot day}/_{ton}$ 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 m^2;

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

where:

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

Δh is deference enthalpy between outlet and inlet, ${}^{kJ}/_{kg}$;

G mass flow rate of water, ${}^{kg}/_{s}$;

$k = 3500 \div 4000\ {}^{W}/_{(m^2 \cdot K)}$ is heat transfer coefficient;

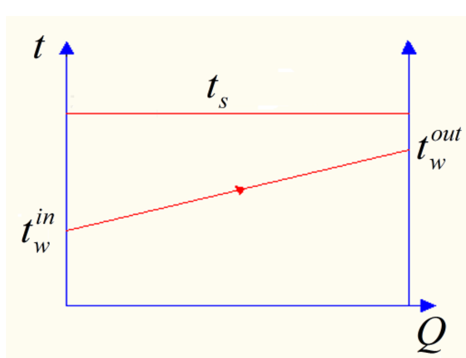


Figure 3.4- To the calculation of the logarithmic temperature difference

$\bar{\Delta t}$ is logarithmic temperature difference, ℃ ;

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

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.

RFWH 6 ''closed''

$$\Delta h = h_{w6} - h_{cse} = 264 - 147 = 117 \ {}^{kJ}/_{kg} \ ;$$

$$Q = G_c \cdot \Delta h = 1095.52 \cdot 117 = 127964.8 \text{ kW};$$

$$\Delta t_{big} = t_{s6} - t_{cse} = 64 - 35 = 29 \text{ ℃} \ ;$$

$$\Delta t_{small} = t_{s6} - t_{w6} = 64 - 63 = 1\text{℃} \ ;$$

$$\bar{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{29 - 1}{\ln\left(\frac{29}{1}\right)} = 8.3 \text{ ℃} \ ;$$

$$F = \frac{Q}{k\bar{\Delta t}} = \frac{127964.8 \cdot 10^3}{4000 \cdot 8.3} = 3851.7 \text{ m}^2.$$

RFWH 5 ''closed ''

$$\Delta h = h_{w5} - h_{mc} = 381 - 263 = 118 \ {}^{kJ}/_{kg} \ ;$$

$$Q = G_{mc} \cdot \Delta h = 1537.229 \cdot 118 = 182039.1 \text{ kW};$$

$$\Delta t_{big} = t_{s5} - t_{w6} = 91.9 - 63 = 29 \text{ ℃};$$

$$\Delta t_{small} = t_{s5} - t_{w5} = 91.9 - 90.9 = 1\text{℃};$$

$$\bar{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{29 - 1}{\ln\left(\frac{29}{1}\right)} = 8.3 \text{ ℃};$$

$$F = \frac{Q}{k\bar{\Delta t}} = \frac{182039.1}{4000 \cdot 8.3} = 5479 \text{ m}^2.$$

RFWH 4 ''closed''

$$\Delta h = h_{w4} - h_{w5} = 499 - 381 = 118\ {}^{kJ}/_{kg}\ ;$$

$$Q = G_{mc} \cdot \Delta h = 1537.229 \cdot 118 = 181440.3\ Kw\ ;$$

$$\Delta t_{big} = t_{s4} - t_{w5} = 119.9 - 90.9 = 29\ ℃\ ;$$

$$\Delta t_{small} = t_{s4} - t_{w4} = 119.9 - 118.9 = 1℃;$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{29 - 1}{\ln\left(\frac{29}{1}\right)} = 8.3\ ℃\ ;$$

$$F = \frac{Q}{k\overline{\Delta t}} = \frac{181440.3}{4000 \cdot 8.3} = 5461\ m^2.$$

RGFW 3 ''closed ''

$$\Delta h = h_{w3} - h_{w4} = 619 - 499 = 120\ {}^{kJ}/_{kg}\ ;$$

$$Q = G_{mc} \cdot \Delta h = 1537.229 \cdot 120 = 183498.9\ kW\ ;$$

$$\Delta t_{big} = t_{s3} - t_{w4} = 147.8 - 118.9 = 29\ ℃\ ;$$

$$\Delta t_{small} = t_{s3} - t_{w3} = 147.8 - 146.8 = 1℃\ ;$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{29 - 1}{\ln\left(\frac{29}{1}\right)} = 8.3\ ℃\ ;$$

$$F = \frac{Q}{k\overline{\Delta t}} = \frac{83498.9}{4000 \cdot 8.3} = 5526\ m^2.$$

For RGFW 2 ''HPH''

$$\Delta h = h_{w2} - h_{fwp} = 822 - 679 = 142\ {}^{kJ}/_{kg}\ ;$$

$$Q = G_d \cdot \Delta h = 1921.774 \cdot 142 = 273378.8\ kW\ ;$$

$$\Delta t_{big} = t_{s2} - t_{fwp} = 195.4 - 159.8 = 35.6\ ℃\ ;$$

$$\Delta t_{small} = t_{s2} - t_{w2} = 195.4 - 192.4 = 3℃\ ;$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{35.6 - 3}{\ln\left(\frac{35.6}{3}\right)} = 13.2\ ℃\ ;$$

$$F = \frac{Q}{k\bar{\Delta t}} = \frac{273378.8}{4000 \cdot 13.2} = 5186\ m^2\ ;$$

<u>For RGFW 1 ‘’HPH’’</u>

$$\Delta h = h_{w1} - h_{w2} = 968 - 822 = 147\ {}^{kJ}/_{kg}\ ;$$

$$Q = G_d \cdot \Delta h = 1921.774 \cdot 147 = 282008\ kW\ ;$$

$$\Delta t_{big} = t_{s1} - t_{w2} = 228 - 192.4 = 35.6\ ℃\ ;$$

$$\Delta t_{small} = t_{s1} - t_{w1} = 2281 - 225 = 3℃\ ;$$

$$\bar{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{\ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{35.6 - 3}{\ln\left(\frac{35.6}{3}\right)} = 13.2\ ℃\ ;$$

$$F = \frac{Q}{k\bar{\Delta t}} = \frac{282008}{4000 \cdot 13.2} = 5350\ m^2.$$

Table 3.10- Characteristic of closed RFWH in NPP

RFWH No	G, ${}^{kg}/_{s}$	Δh, ${}^{kJ}/_{kg}$	Q, MW	$\bar{\Delta t}$, ℃	F, m2		Type	G kg/s	F, m^2	n
HPH (1)	1921.774	147	282.008	13.2	5350	Selected heaters	ПВ-2500-97-28А	908	2500	3
HPH (2)	1921.774	142	273.378	13.2	5186		ПВ-2500-97-28А	908	2500	3
LPH (3)	1537.229	119	183.498	8.3	5523		ПН-3000-25-16-IIIA	1112.5	3000	2
LPH (4)	1537.229	118	181.440	8.3	5461		ПН-3000-25-16-IIIA	1112.5	3000	2
LPH (5)	1537.229	118	182.039	8.3	5479		ПН-3000-25-16-IIIA	1112.5	3000	2
LPH (6)	1095.525	117	127.964	8.3	3852		ПН-1900-42-4-IA	733	1900	2

- **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.

A volumetric flow rate $V, {}^{m^3}/_{h}$.

$$V_D = \frac{3600(G_d)}{\rho};$$

$$G_d = 1921.774\ {}^{kg}/_{s};$$

$$V_D = \frac{3600 \cdot 1921.774}{908.58} = 7614.43\ {}^{m^3}/_{h};$$

The volume of deaerator v.

$$v = \frac{G_d \tau k}{\rho};$$

where:

τ is time need to full deaerator with water ≈ 3 mins;

k is deaerator coefficient storage = 1.15;

$$v = \frac{1921.774 \cdot (3 \cdot 60) \cdot 1.15}{908.58} = 437.8\ m^3;$$

Deaerator is selected: Four columns of the ДП-2800 type (feed water flow rate 2×777.7 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

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

$$N_i^{max} = \frac{1{,}2}{2 \cdot 10^{-3} \cdot \pi} \cdot 2.3 \cdot 971 \cdot \frac{[450] \cdot 223.607}{7800 \cdot 25^2 \cdot 25.163} = 350.04\ \text{MW}\;;$$

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, 971 $^{kJ}/_{kg}$;

$[\sigma]$ 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;

$\rho_{mat} = 7800$ $^{kg}/_{m^3}$ is density of the blade material (stainless steel); for titanium alloy BT6 $\rho_{mat} = 4300$ $^{kg}/_{m^3}$;

n is rotor's rotation frequency, 25 $^{rev}/_{s}$;

$v_2 = f(p_c, h_c)$ is specific volume of steam at the outlet of the last stage of the turbine, $^{m^3}/_{kg}$;

$$v_2 = f(0.005\,, 2092) = 25.163 \ \ {}^{m^3}/_{kg};$$

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 $25 \ {}^{kJ}/_{kg}$.

4.1.2 Number of Flows of Spent Steam going to the Condenser

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

$$i = \frac{1300}{0.98 \ \cdot \ 0.99 \ \cdot \ 350.04} = 3.827 = 4\,;$$

So, we’ll have two condensers;

where:

N_i^{max} is the maximum power of a single-flow turbine, 350.04 MW;

N_e is total electric power of the turbine unit, 1300 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

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

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

$$c_2 = 223.607 \ \ {}^{m}/_{s} \ ;$$

4.1.4 Exhaust steam flow per condenser

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

$$G_{c1} = \frac{2 \cdot 1095.525}{4} = 574.763 \ {}^{kg}/_{s} \ ;$$

where:

$G_c = 1095.525\ {}^{kg}/_{s}$,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	$G_{c1},\ {}^{kg}/_{s}$	574.763
Condenser pressure	p_c, MPa	0.0045
Number of tube-side passes for cooling water	z	2
Coolant temperature at the inlet to the condenser	t_{w1}, °C	15
Speed of the cooling water in the tubes of the condenser	$w_w,\ {}^{m}/_{s}$	2
Condenser tube sizes	$d_{out} \times \delta_{wall}$, mm	28×1
Tube material		stainless steel

Notes:

- take the cooling water density equal to $\rho_w = 1000\ {}^{kg}/_{m3}$;

- take the average heat capacity of cooling water equal to $c_w = 4.19\ {}^{kJ}/_{kg}$;

- the coefficient that takes into account the contamination of pipes is equal to $a_0 = 0.65\ldots0.85$, assume it 0.75.

4.2 Determining the characteristics of a condenser.

4.2.1 Flow rate of cooling water per condenser.

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

$$W_1 = 50 \cdot 574.763 = 27388.13\ {}^{kg}/_{s} ;$$

where:

$m = 50$ is the cooling ratio for two-way condensers ($z = 2$), ${}^{kg}/_{s}$.

4.2.2 The number of heat transfer tubes, pieces

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

$$n_{tube} = \frac{4 \cdot 27388.13 \cdot 2}{\pi \cdot (0.026)^2 \cdot 1000 \cdot 2} = 51611 \text{ pcs} \ ;$$

where:

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

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

$$d_{inn} = 28 - (2 \cdot 1) = 26 \text{ mm};$$

d_{inn} 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, ºC

$$\Delta t_w = \frac{r}{c_w \cdot m} \ ;$$

$$\Delta t_w = \frac{2427}{4.19 \cdot 50} = 11.6 \text{ °C} \ ;$$

where:

$$r = h'' - h' = 2557 - 130 = 2427 \ ^{kJ}/_{kg} \ ;$$

$$h'' = f(p_c) = 2557 \ ^{kJ}/_{kg} \ ;$$

$h' = f(p_c) = 130 \ ^{kJ}/_{kg}$, is latent heat of vaporization under pressure p_c, kJ/kg;

$c_w = 4.19$ is heat capacity of cooling water, $^{kJ}/_{(kg \ °C)}$.

4.2.4 Temperature of the cooling water at the condenser outlet, ºC

$$t_{w2} = t_{w1} + \Delta t_w \ ;$$

$$t_{w2} = 15 + 11.6 = 26.6 \text{ °C} \ .$$

4.2.5 The Heat power that is transferred to the cooling water in the condenser, kW

$$Q_{w1} = W_1 \cdot c_w \cdot \Delta t_w \ ;$$

$$Q_{w1} = 27388.13 \cdot 4.19 \cdot 11.6 = 1329655 \text{ kW}.$$

4.2.6 The average temperature difference, ºC

$$\Delta t_{avr} = \frac{\Delta t_w}{\ln\left(\frac{t_s - t_{w1}}{t_s - t_{w2}}\right)};$$

$$\Delta t_{avr} = \frac{11.6}{\ln\left(\frac{31 - 15}{31 - 26.6}\right)} = 9.01\ ℃;$$

where:

$t_s = f(p_C) = 31℃$, 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 $kg/(m^2 \cdot h)$,and then must be checked

$$d_c = 50\ \text{kg}/(\text{m}^2 \cdot \text{h});$$

The overall heat transfer coefficient (BTИ formula) is calculated using one of two expressions. $t_{w1} = 15$ ℃. So, we will use the following expression:

If $t_{w1} \le 35$ ℃

$$k = 4070 \cdot a \cdot \left(\frac{1,1 \cdot w_w}{d_{inn}^{0,25}}\right)^x \cdot \left[1 - \frac{0,52 - 0,002 \cdot d_c \cdot \sqrt{a}}{1000} \cdot (35 - t_{w1})^2\right] \cdot \left[1 - \frac{z-2}{10} \cdot \left(1 - \frac{t_{w1}}{35}\right)\right] \cdot \Phi_d;$$

$$k = 4070 \cdot 0.6375 \cdot \left(\frac{1.1 \cdot 2}{0.026^{0,25}}\right)^{0.248} \cdot \left[1 - \frac{0.52 - 0.002 \cdot 50 \cdot \sqrt{0.6375}}{1000} \cdot (20)^2\right] \cdot \left[1 - \frac{2-2}{10} \cdot \left(1 - \frac{15}{35}\right)\right] \cdot 1 = 3263.04\ \text{W}/(\text{m}^2 \cdot ℃);$$

where:

k - in $\text{W}/(\text{m}^2 \cdot ℃)$;

$$x = 0.12 \cdot a \cdot (1 + 0.15 \cdot t_{w1}) = 0.12 \cdot 0.6375 \cdot (1 + 0.15 \cdot 15) = 0.248;$$

$$a = a_0 \cdot a_m = 0.75 \cdot 0.85 = 0.6375\ ;$$

x is coefficient taking into account pollution of tubes and tube material;

$a_0 = 0.65 \ldots 0.85$ is coefficient that takes into account tube contamination;

Assume it 0.75;

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 $2\ ^m/_s$;

t_{w1} is the temperature of the cooling water at the inlet to the condenser, 15 °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**

$$F = \frac{Q_w}{k \cdot \Delta t_{avr}}\ ;$$

$$F = \frac{1329655 \cdot 10^3}{3263.04 \cdot 9.01} = 45220.59\ m^2.$$

- **The length of the heat transfer tubes, m**

$$L = \frac{F}{n_{tube} \cdot \pi \cdot d_{out}}\ ;$$

$$L = \frac{45220.59}{51611 \cdot \pi \cdot 0.028} = 9.97\ m < 16\ m;$$

Where:

$d_{out} = 0.028$ m, is outer diameter of the tubes;

L is the length of the tubes must be less than 16 m.

- **The calculated value of the specific steam load of the condenser, $\mathbf{kg/(m^2 \cdot h)}$**

$$d_c^{calk} = \frac{3600 \cdot G_{c1}}{F}\ ;$$

$$d_c^{calk} = \frac{3600 \cdot 574.763}{45220.59} = 43.61 \ {}^{kg}\!/_{(m^2 \cdot h)}.$$

- **The obtained value d_c^{calk} must be compared with the specified in paragraph**

$$\frac{d_c^{calk}}{d_c} = \frac{43.61}{50} = 0.87 \,;$$

$$\left|\frac{d_c^{calk} - d_c}{d_c^{calk}}\right| \cdot 100 = \left|\frac{43.61 - 50}{43.61}\right| \cdot 100 = 14.66 \,\% \,.$$

The obtained value d_c^{calk} 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 $d_c = d_c^{calk}$ and repeat the calculation, starting with paragraph (4.2.7).

By repeating the calculation, in (4.2.7) with new $d_c = d_c^{calk}$, we obtain

dc, ${}^{kg}\!/_{(m^2 \cdot h)}$	50	43.61	43.39
k, ${}^{W}\!/_{(m^2 \cdot ℃)}$	3263.04	3246.87	3246.33
F, m^2	45220.59	45445.82	45453.47
L, m	9.97	10.015	10.017
ERROR %	14.66	0.50	−

The condition is met, so the calculation ended.

4.2.8 Mass of condenser tubes

$$M_{tube} = n_{tube} \cdot L \cdot \frac{\pi \cdot \left(d_{out}^2 - d_{inn}^2\right)}{4} \cdot \rho_{mat} \,, kg \,;$$

where:

L, d_{out} and d_{inn} are in m;

$$M_{tube} = 51611 \cdot 10.015 \cdot \frac{\pi \cdot (0{,}028^2 - 0{,}026^2)}{4} \cdot 7800 = 341817.5 \text{ kg} \,;$$

ρ_{mat} is density of the pipe material, kg/m³. For brass tubes $\rho_{mat} = 8750 \,{}^{kg}/_{m^3}$; for cupronickel tubes $\rho_{mat} = 8900 \,{}^{kg}/_{m^3}$; for stainless steel tubes $\rho_{mat} = 7800 \,{}^{kg}/_{m^3}$; for titanium tubes $\rho_{mat} = 4500 \,{}^{kg}/_{m^3}$.

4.2.9 Cost of condenser tubes

$$C_{tube} = \frac{M_{tube} \cdot c_{mat}}{10^6}, \text{million rubles};$$

$$C_{tube} = \frac{341817.5 \cdot 350}{10^6} = 119.64 \text{ million rubles};$$

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

$$C_{cond} = K_c \cdot C_{tube}, \text{million rubles};$$

$$C_{cond} = K_c \cdot C_{tube} = 1.75 \cdot 119.64 = 209.36 \text{ million rubles}.$$

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.

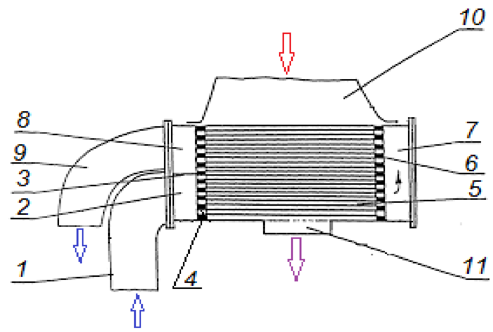


Figure 4.1- To the hydraulic calculation of the condenser

The hydraulic resistance of a two-way condenser with straight tubes can be represented as follows

$$\Delta p_{\Sigma} = \Delta p_{loc} + \Delta p_{fr} = 7000 + 53928 = 60928 \text{ Pa} ;$$

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:

$\rho_w \approx 1000$ kg/m³ 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.

$$\Delta p_{loc} = 2 \cdot \Delta p_{wch.in} + 2 \cdot \Delta p_{wch.out} + \Delta p_{turn} ;$$

$$\Delta p_{loc} = (2 \cdot \xi_{in} + 2 \cdot \xi_{out} + \xi_{turn}) \cdot \frac{\rho_w \cdot w_w^2}{2} ;$$

$$\Delta p_{loc} = \left((2 \cdot 0.5) + (2 \cdot 1) + 0.5\right) \cdot \left(\frac{1000 \cdot 2^2}{2}\right) = 7000 \text{ Pa} .$$

Table 4.2- The values of the coefficient of local resistance

Type of local resistance	Coefficient value ξloc
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

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{2 \cdot L}{d_h} \cdot \frac{\rho_w \cdot w_w^2}{2} \text{ , pa;}$$

$$\Delta p_{fr} = 0.035 \cdot \frac{2 \cdot 14.813}{0{,}026} \cdot \frac{1000 \cdot 2^2}{2} = 79761.64 \text{ Pa ;}$$

where:

L is length of the heat transfer tubes, 14.813 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

$$N_p = \Delta p_\Sigma \cdot \frac{W}{\rho_w \cdot \eta_p \cdot 1000} \text{ , kW ;}$$

$$N_p = 60928 \cdot \frac{27388.13}{1000 \cdot 0{,}87 \cdot 1000} = 1918.053 \text{ kW.}$$

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 $0{,}87$.

4.3.3 Electric power consumption for the circulation pump drive

$$E_p = N_p \cdot \tau_{rp} \text{ , (kW · h) ;}$$

$$E_p = 1918.053 \cdot 6500 = 12467343 \text{ (kW · h) ;}$$

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

$$C_{el} = \frac{E_p \cdot T_{el}}{10^6}, \text{million rubles} ;$$

$$C_{el} = \frac{12467343 \cdot 14}{10^6} = 174.5428 \text{ million rubles} ;$$

where:

$T_{el} = 14 \dots 16 \ {}^{rub}/_{(kW \cdot h)}$, 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}, ${}^{kg}/_{s}$	574.763
Condenser pressure	p_c, MPa	0.0045
Number of tube-side passes for cooling water	z	2
Coolant temperature at the inlet to the condenser	t_{w1}, °C	15
Speed of the cooling water in the tubes of the condenser	w_w, ${}^{m}/_{s}$	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

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

$$W_1 = 50 \cdot 574.763 = 27388.125 \ {}^{kg}/_{s} .$$

4.4.2 The number of heat transfer tubes, pieces

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

$$n_{tube} = \frac{4 \cdot 27388.125}{\pi \cdot (24 \cdot 10^{-3})^2 \cdot 1000 \cdot 2} = 56878 \text{ pcs} ;$$

where:

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

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

$d_{inn} = 28 - (2 \cdot 1) = 24$mm, is the inner diameter of the tubes;

4.4.3 Cooling water heating in the condenser, ºC

$$\Delta t_w = \frac{r}{c_w \cdot m} ;$$

$$\Delta t_w = \frac{2427}{4.19 \cdot 50} = 11.6 \text{ °C} ;$$

where:

$$r = h'' - h' = 2557 - 130 = 2427 \ ^{kJ}/_{kg} ;$$

$$h'' = f(p_c) = 2557 \ ^{kJ}/_{kg};$$

$h' = f(p_c) = 130 \ ^{kJ}/_{kg}$ 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, ºC

$$t_{w2} = t_{w1} + \Delta t_w ;$$

$$t_{w2} = 15 + 11.6 = 26.6 \text{ °C} .$$

4.4.5 The Heat power that is transferred to the cooling water in the condenser, kW

$$Q_{w2} = W_1 \cdot c_w \cdot \Delta t_w ;$$

$$Q_{w2} = 27388.125 \cdot 4.19 \cdot 11.6 = 1329655.2 \text{ kW} .$$

4.4.6 The average temperature difference, ºC

$$\Delta t_{avr} = \frac{\Delta t_w}{\ln\left(\frac{t_s - t_{w1}}{t_s - t_{w2}}\right)} ;$$

$$\Delta t_{avr} = \frac{11.6}{\ln\left(\frac{31 - 15}{31 - 26.6}\right)} = 9.01 \,℃ ;$$

where:

$t_s = f(p_c) = 31$ ℃, 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

$$d_c = 55 \; {}^{kg}/_{(m^2 \cdot h)} ;$$

- **The overall heat transfer coefficient (ВТИ formula) is calculated using one of two expressions**

$t_{w1} = 20$ °C. So, I will use the following expression:

If $t_{w1} \le 35$ ℃

$$k = 4070 \cdot a \cdot \left(\frac{1{,}1 \cdot w_w}{d_{inn}^{0{,}25}}\right)^x \cdot \left[1 - \frac{0{,}52 - 0{,}002 \cdot d_c \cdot \sqrt{a}}{1000} \cdot (35 - t_{w1})^2\right] \cdot$$
$$\cdot \left[1 - \frac{z - 2}{10} \cdot \left(1 - \frac{t_{w1}}{35}\right)\right] \cdot \Phi_d ;$$

$$k = 4070 \cdot 0.6375 \cdot \left(\frac{1{,}1 \cdot 2}{24^{0{,}25}}\right)^{0.248}$$
$$\cdot \left[1 - \frac{0{,}52 - 0{,}002 \cdot 55 \cdot \sqrt{0{,}6375}}{1000} \cdot (20)^2\right]\left[1 - \frac{2 - 2}{10} \cdot \left(1 - \frac{15}{35}\right)\right] \cdot 1$$
$$= 3292.03 \; {}^{W}/_{(m^2 \cdot °C)} ;$$

where:

k - in ${}^{W}/_{(m^2 \cdot °C)}$;

$$x = 0.12 \cdot a \cdot (1 + 0.15 \cdot t_{w1}) = 0.248;$$

$a = a_0 \cdot a_m$ is coefficient taking into account pollution of tubes and tube material;

$$a = 0.75 \cdot 0.85 = 0.6375;$$

$a_0 = 0.65 \dots 0.85$ is coefficient that takes into account tube contamination, Assume it 0,75;
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 $2\ {}^{m}/_{s}$;
t_{w1} is the temperature of the cooling water at the inlet to the condenser; 15 °C;
z = 2 is number of tube-side passes for cooling water;

Φ_d= 1 When designing condensers, this coefficient is taken equal to 1.

- **Heat transfer surface area, m²**

$$F = \frac{Q_{w2}}{k \cdot \Delta t_{avr}} \ ;$$

$$F = \frac{1329655.3 \cdot 10^3}{3292.03 \cdot 5.06} = 44822.429\ m^2.$$

- **The length of the heat transfer tubes, m**

$$L = \frac{F}{n_{tube} \cdot \pi \cdot d_{out}} \ ;$$

$$L = \frac{44822.429}{60572 \cdot \pi \cdot 0{,}028} = 8.42\ m < 16\ m\ .$$

- **The calculated value of the specific steam load of the condenser,** ${}^{\boldsymbol{kg}}/_{(\boldsymbol{m}^2 \cdot \boldsymbol{h})}$

$$d_c^{calk} = \frac{3600 \cdot G_{c1}}{F} \ ;$$

$$d_c^{calk} = \frac{3600 \cdot 574.763}{44822.429} = 43.99\ {}^{kg}/_{(m^2 \cdot h)}.$$

- **The obtained value $\boldsymbol{d_c^{calk}}$ must be compared with the specified in paragrap**

$$\frac{d_c^{calk}}{d_c} = \frac{43.99}{55} = 0.80\ ;$$

$$\left|\frac{d_c^{calk} - d_c}{d_c^{calk}}\right| .100 = \left|\frac{43.99 - 55}{43.99}\right| .100 = 25.02\ \%\ .$$

The obtained value d_c^{calk} 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 $d_c = d_c^{calk}$ and repeat the calculation, starting with paragraph (4.4.7).

By repeating the calculation, in (4.4.7) with new $d_c = d_c^{calk}$, we obtain

dc, $^{kg}/_{(m^2 \cdot h)}$	55	43.99	43.62
k, $^{W}/_{(m^2 \cdot °C)}$	3292.03	3264.05	3263.10
F, m^2	44822.429	45206.63	45219.8
L, m	8.42	8.49	8.49
ERROR %	25.02	0.86	−

The condition is met, So the calculation ended.

4.4.7 Mass of condenser tubes

$$M_{tube} = n_{tube} \cdot L \cdot \frac{\pi \cdot \left(d_{out}^2 - d_{inn}^2\right)}{4} \cdot \rho_{mat}\text{ , kg;}$$

$$M_{tube} = 60572 \cdot 12.54 \cdot \frac{\pi \cdot (0{,}028^2 - 0{,}024^2)}{4} \cdot 7800 = 654850.38 \text{ kg}.$$

4.4.8 Cost of condenser tubes

$$C_{tube} = \frac{M_{tube} \cdot c_{mat}}{10^6}\text{, million rubles ;}$$

$$C_{tube} = \frac{654850.38 \cdot 350}{10^6} = 229.20 \text{ million rubles}.$$

4.4.9 Cost of the condenser

$$C_{cond} = K_c \cdot C_{tube}\text{, million rubles ;}$$

$$C_{cond} = K_c \cdot C_{tube} = 1.75 \cdot 229.20 = 401.10 \text{ million rubles}.$$

4.4.10 Hydraulic calculation of the condenser

The hydraulic resistance of a two-way condenser with straight tubes can be represented

$$\Delta p_{\Sigma} = \Delta p_{loc} + \Delta p_{fr}\text{ ;}$$

$$\Delta p_{\Sigma} = 7000 + 49532 = 56532 \text{ Pa;}$$

For the calculate of local pressure losses it is necessary to use the following formula

$$\Delta p_{loc} = \xi_{loc} \cdot \frac{\rho_w \cdot w_w^2}{2}\text{ , pa ;}$$

$$\Delta p_{loc} = 2 \cdot \Delta p_{wch.in} + 2 \cdot \Delta p_{wch.out} + \Delta p_{turn}$$

$$\Delta p_{loc} = (2 \cdot \xi_{in} + 2 \cdot \xi_{out} + \xi_{turn}) \cdot \frac{\rho_w \cdot w_w^2}{2}$$

$$\Delta p_{loc} = \left((2 \cdot 0{,}5) + (2 \cdot 1) + 0{,}5\right) \cdot \frac{1000 \cdot 2^2}{2} = 7000 \text{ Pa};$$

For the calculate the friction pressure losses it is necessary to use the Altshul's formula

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{2 \cdot L}{d_h} \cdot \frac{\rho_w \cdot w_w^2}{2}, \text{pa};$$

$$\Delta p_{fr} = 0{,}035 \cdot \left(\frac{2 \cdot 12.54}{0{,}024}\right) \cdot \left(\frac{1000 \cdot 2^2}{2}\right) = 73178 \text{ Pa}.$$

4.4.11 Power of the pump for pumping water through the condenser

$$N_p = \Delta p_\Sigma \cdot \frac{W}{\rho_w \cdot \eta_p \cdot 1000}, \text{kW};$$

$$N_p = 56532 \cdot \left(\frac{27388.125}{1000 \cdot 0{,}87 \cdot 1000}\right) = 1779.667 \text{ kW}.$$

4.4.12 Electric power consumption for the circulation pump drive

$$E_p = N_p \cdot \tau_{rp}, (\text{kW} \cdot \text{h});$$

$$E_p = 1779.667 \cdot 6500 = 11567841 \ (\text{kW} \cdot \text{h}).$$

4.4.13 The cost of electricity for pumping water through the condenser

$$C_{el} = \frac{E_p \cdot T_{el}}{10^6}, \text{million rubles};$$

$$C_{el} = \frac{11567841 \cdot 14}{10^6} = 174.54 \text{ million rubles};$$

where:

$T_{el} = 14 \ldots 16 \ {}^{\text{rub}}/_{\text{kW} \cdot \text{h}}$, is electricity tariff for nuclear power plants.

Table 4.4- Results of variant calculations of the condenser

	Option 1	Option 2
	$d_{out} = 28$ mm $\delta_{wall} = 1$ mm	$d_{out} = 28$ mm $\delta_{wall} = 2$ mm
G_{c1}, kg/s	574.763	574.763
W_1, kg/s	27388.125	27388.125
M_{tube}, kg	341817.5	654850.38
C_{tube}, million rubles	119.64	229.20
C_{cond}, million rubles	209.36	401.10
N_p, kW	1918	1779.667
E_p, kW·h	12467343	1156841
C_{el}, million rubles	174.54	161.94

Chapter 5 – financial management, resource efficiency and resource saving

To the student:

Group	Full name
506И	Shahin Ahmed Elsayed Abdelsatar Elsayed

School	**ИШЭ**	**Division**	**The Butakov Research Center**
Degree	**Specialist**	**Educational Program**	**14.05.02 Design, Operation and Engineering of Nuclear Power Plants.**

Input data to the section «Financial management, resource efficiency and resource saving»:	
Resource cost of scientific and technical research (STR): material and technical, energetic, financial and human	Budget of research not higher than 270 000 rubles. salaries of executors not higher than 165 000 rubles,
Expenditure rates and expenditure standards for resources	Supervisor' salary – 36 000 rubles per month; engineer' salary – 18 000 rubles per month.
Current tax system, tax rates, charges rates, discounting rates and interest rates	Coefficient of incentive bonuses 30%, coefficient of incentives for the manager for conscientious work activity 25%; contributions for social funds are 30,2% totally.
The list of subjects to study, design and develop:	
Assessment of commercial and innovative potential of STR	Comparison of the condensers' types
Development of charter for scientific-research project	SWOT-analysis
Scheduling of STR management process: structure and timeline, budget, risk management	Calendar plan of the project
Resource efficiency	List of resource requirements
A list of graphic material (with list of mandatory blueprints):	
Competitiveness analysis SWOT- analysis Gantt chart and budget of scientific research Assessment of resource, financial and economic efficiency of STR Potential risks	

Date of issue of the task for the section according to the schedule	

Task issued by adviser:

Position	Full name	Scientific degree, rank	Signature	Date
Associate professor	N.A. Goncharova	PhD		

The task was accepted by the student:

Group	Full name	Signature	Date
506И	Shahin Ahmed Elsayed Abdelsatar Elsayed		

2022

5.1. Competitiveness analysis of 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 1000-КЦС -1	Condenser -2 1000-КЦС -1
	$\mathrm{dout} = 28\ \mathrm{mm}$; $\delta\mathrm{wall} = 1\ \mathrm{mm}$	$\mathrm{dout} = 28\ \mathrm{mm}$; $\delta\mathrm{wall} = 2\ \mathrm{mm}$
C_{cond} , million RUB	209.36	401.10
C_{el} , million RUB	174.54	161.94

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 - Evaluation card for comparison of competitive technical solutions

Items to assess	Value of criteria	Points		Competitiveness	
		P_1	P_2	C_1	C_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. 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:

$$C_i = \sum W_i \cdot P_i \;;$$

where:

C - competitiveness of scientific research;

Wi - indicator weight (in unit fractions);

Pi - point of the i^{th} indicator.

Indices for indicators "1" - first type 1000-КЦС -1 with d_{out} = 28 mm; δ_{wall}=1 mm; "2" - second type1000-КЦС -1 with d_{out} = 28 mm; $\delta_{wall} = 2$ mm.

Calculation example:

$$C_1 = \sum W_i \cdot P_{1i} = (0{,}2 \cdot 3) + (0{,}15 \cdot 4) + \ldots + (0{,}03 \cdot 3) = 3{,}15 .$$

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. SWOT analysis

The goal of SWOT analysis is to learn how to develop strengths, eliminate weaknesses, exploit opportunities, and avoid risks and threats.

Table 5.3-Matrix of SWOT-analysis

Strengths: – It is a major contributor to reduction of GHG emissions and the resulting global warming. – NPP provide reliable base-load electricity. – Cost of nuclear fuel is lower than cost of coal. – Cost of nuclear electricity generation is lower than coal-based electricity generation	Weaknesses: – High-level nuclear waste disposal. – Suppliers' risk. – Safety and public concern. – Cost competitiveness of nuclear electricity
Opportunities: – To mitigate risk of investing in new NPPs, governments should provide loan guarantees to finance investors interesting in building commercial NPPs. – Nuclear-electricity needs government subsidies just like renewable energy sources and energy conservation initiatives.	Threats: – The high price and the price of electricity – Global nuclear energy policy changes.

5.3. 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.

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 5.4– Stakeholders of the project

Project stakeholders	**Stakeholder 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 5.5 – Project goals and results

Purpose of project	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

The organizational structure of the project

The organizational structure of the project is presented in the table 5.6.

Table 5.6 – Participant of the project

№	Name	Position	Functions	Labor time, hours.
1	Shahin. A.E	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.

Project limitations

Limitations and assumptions are summarized in table 5.7.

Table 5.7– Project limitations

Factor	Limitations/assumptions
1. Project’s budget	270 000 RUB
1.1 Source of financing	Own funds / Rosatom scholarship
2. Project timeline:	10 July 2021 – 15 January 2022
2.1 Date of approval of plan of project	10 July 2021
2.2 Completion date	25December 2021

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.

Project Schedule

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:

$t_{ож} = (3 \cdot tmax_{min} \cdot 0{,}2)$, is expected labor intensity of performing one job, person-days;

$T_p = \frac{t_{ож}}{Ч}$, is the duration of the execution of one job, working days;

Where:

$Ч = 1$, is number of performers performing the same job, person.

$T_k = T_p \cdot k_k$ - duration of one job, calendar days,

$k_k = 1{,}65$, is calendar factor.

Table 5.8 – 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, $T_{кi}$	
		t_{min}, person-days		t_{max}, person-days		$t_{ожi}$, 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 5.9 – Schedule of the project design

№	Task	Executors	$T_{кi}$ 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																				

5.4. Scientific and technical research budget

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.

Calculation of material costs

These costs include office supplies, printing costs, and various equipment required for paperwork.

Table 5.10 – Costs for materials for the project

Name	Unit of measurement	Number	Price per unit, RUB	Material costs, 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**

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 5.11 – 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:

$$\mathrm{N_{DL}} = \frac{1}{7} \cdot 100\% = 14.29\ \%\ ;$$

$$\mathrm{N_{DWin}} = \frac{1}{4} \cdot 100\% = 25\ \%\ ;$$

$$\mathrm{N_{DSS}} = \frac{1}{1} \cdot 100\% = 100\ \%\ .$$

Academic year depreciation (9 months) for Laptop, Microsoft Windows 10 License, and Supporting Software:

$$\mathrm{D_L} = 30000 \cdot \frac{\mathrm{N_{DL}}}{100\%} \cdot \frac{\mathrm{T}}{365} = 30000 \cdot \frac{14.29\%}{100\%} \cdot \frac{90}{365} = 1057\ \text{RUB};$$

$$\mathrm{D_{Win10}} = 4000 \cdot \frac{\mathrm{N_{DWin}}}{100\%} \cdot \frac{\mathrm{T}}{365} = 4000 \cdot \frac{25\%}{100\%} \cdot \frac{90}{365} = 246{,}6\ \text{RUB};$$

$$D_{SS} = 3820 \cdot \frac{N_{DSS}}{100\%} \cdot \frac{T}{365} = 3820 \cdot \frac{100\%}{100\%} \cdot \frac{90}{365} = 941{,}9 \text{ RUB};$$

Where:

T – number of working days

Total depreciation for a year:

$$D = D_L + D_{Win10} + D_{SS} = 2245{,}2 \text{ RUB}.$$

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:

$$S_b = S_a \cdot T_w ;$$

where:

S_a is basic salary per participant;

T_p is the duration of the work performed by the scientific and technical worker, working days;

Average daily salary for a 5-day working week:

$$S_d = \frac{S_m \cdot M}{F_v} \;;$$

where:

S_m is monthly salary of a participant, RUB;

F_v 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:

$$S_{month} = S_{base} \cdot \left(1 + k_{premium} + k_{bouns}\right) \cdot k_{reg};$$

Additional salary:

$$w_{add} = k_{extra} \cdot\; w_b \;;$$

k_{extra} is additional salary coefficient=0.15;

- For project supervisor:

$$S_{m.sup} = S_b \cdot \left(1 + k_{pr} + k_d\right) \cdot k_r = 36000 \cdot (1 + 0{,}3 + 0{,}25) \cdot 1{,}3 = 72540\ \text{RUB}\;;$$

$$S_{F.sup} = S_{b.sup} + w_{add} = 72540\;\; + (0{,}15 \cdot 72540) = 83421\ \text{RUB}\,.$$

- For engineer developer:

$$S_{m.eng} = S_b \cdot \left(1 + k_{pr} + k_d\right) \cdot k_r = 18000 \cdot (1 + 0{,}3 + 0{,}25) \cdot 1{,}3 = 36\,270\ \text{RUB}\;;$$

$$S_{F.eng} = S_{b.eng} + w_{add} = 36270 + 0{,}15 \cdot 36270 = 41711\ \text{RUB}.$$

Average daily salary:

$$S_{D.sup.} = \frac{S_{b.sup.}}{F_v} = \frac{72540}{20.58} = 3524{,}1 \text{ RUB};$$

$$S_{D.eng.} = \frac{S_{b.eng.}}{F_v} = \frac{36270}{20.58} = 1762.4 \text{ RUB};$$

where the average number of working days in a month was determined as:

$$F_v = \frac{T_w}{12} = \frac{247}{12} = 20{,}58;$$

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:

$$w_{add.sup.} = 0{,}15 \cdot 72540 = 10881 \text{ RUB};$$

$$w_{add.eng.} = 0{,}15 \cdot 36270 = 5440{,}5 \text{ RUB}.$$

Full salary for the period of the project:

$$S_{F.sup} = S_{b.sup} + S_{Padd.sup} = 72540 + 18502 = 91042 \text{ RUB};$$

$$S_{F.eng} = S_{b.eng} + S_{Padd.eng} = 36270 + 39648 = 75918 \text{ RUB}.$$

Table 5.12–Calculation of the base salaries

Performers	S_b, RUB	k_{pr}	k_d	k_{reg}	S_{month}, RUB	w_{add}, RUB	T_P, days
supervisor	36000	0,3	0,25	1,3	72540	10881	20.58
engineer	18000				36 270	5440,5	20.58

Labor tax

Labor tax Tax to extra-budgetary funds is compulsory according to the norms established by the legislation of the Russian Federation to the state social insurance (SIF), pension fund (PF) and medical insurance (FCMIF) from the costs of workers. Payment to extra-budgetary funds is determined of the formula:

$$P_{social} = k_b(w_{base} + w_{add});$$

In accordance with the Federal law of July 24, 2009 No. 212-FL, the amount of insurance contributions is set at 30%. Institutions conducting educational and scientific activities have rate - 27.1%.

$$P_{social} = 0{,}271 \cdot (91042 + 75918) = 45246 \text{ RUB}.$$

Formation of budget costs

In the previous subchapters, the values of the main costs of the research were calculated. Let us take them all in one table 5.13.

Table 5.13–Formation of budget costs

Name	Cost, RUB.	Cost, %
Costs for materials and other products	1290	0,51
Costs for specialized equipment	2245,2	0,89
Supervisor salary costs	91042,1	36,47
Design engineer salary costs	75917,4	30,3
Labor tax	45246	18,19
Overheads	34065,7	13,64
Research budget	249806.4	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; δ_{wall} = 2 mm.

Chapter 6 – Social responsibility

Student:

<table>
<tr><th colspan="2">Group</th><th colspan="2">Name</th></tr>
<tr><td colspan="2">506И</td><td colspan="2">Shahin Ahmed Elsayed Abdelsatar Elsayed</td></tr>
<tr><td>School</td><td>ИШЭ</td><td>Division</td><td>The Butakov Research Center</td></tr>
<tr><td>Educational level</td><td>Specialist</td><td>Course/Specialty</td><td>14.05.02 Design, Operation and Engineering of Nuclear Power Plants</td></tr>
</table>

Topic of FQW:

<table>
<tr><td colspan="2">Design of a power unit of a nuclear power plant with a VVER reactor with an electrical capacity of 1300 MW.</td></tr>
<tr><td colspan="2">Initial data for the chapter «social responsibility»:</td></tr>
<tr><td>1. Characteristics of the researched object (substance, material, device, algorithm, technique, working area)</td><td>The object a power unit of a nuclear power plant with a VVER reactor with an electrical capacity of 1300 MW, it includes:
– The design of the steam generator;
– Determined the main feature of turbine instillation;
– Design of a condenser.</td></tr>
<tr><td colspan="2">List of questions to be researched, designed and developed:</td></tr>
<tr><td>1. Legal and organizational issues of occupational safety
– consider special (specific to the projected work area) law norms of labor legislation.
– indicate the features of the labor legislation in relation to the specific conditions of the project.</td><td>– GOST 12.2.003-91 Occupational safety standards system. Industrial equipment. General safety requirements;
– Labor Code of the Russian Federation Article 351.6. "Peculiarities of labor regulation of workers in the electric power industry, heat supply, in the field of industrial safety, the field of safety of hydraulic structures";
– Federal Law of November 21, 1995 N 170-FZ "On the Use of Atomic Energy"
– Standard Content of Action Plans for Personnel Protection in the Event of Accident at a Nuclear Power Plant. NP-015-12
Approved by Order of the Federal Environmental, Industrial and Nuclear Supervision Service No. 518, dated of September 18, 2012. Registered in the Ministry of Justice of the Russian Federation, No. 27011, dated of February 12, 2013. Entered into force on May 03, 2013.</td></tr>
<tr><td>2. Occupational safety:
2.1. Analysis of the identified harmful and dangerous factors: the sourse of factor, the impact on human's body</td><td>Harmful factors include:
– ionizing radiation;
– Electromagnetic fields
– Toxic, affecting oppressing, in general, the entire human body.</td></tr>
</table>

2.2 Suggest measures to reduce the impact of identified harmful and dangerous factors	– Moving parts of trade and technological equipment, moving goods, containers; – emotional overload. **Dangerous factors include:** – increased pressure of vapors or gases in vessels; – Increased voltage in an electrical circuit, the closure of which can pass through the human body;
3. Environmental Safety: Influence on the atmosphere, hydrosphere, lithosphere	**Atmosphere:** gaseous radioactive emissions into the atmosphere, release of large amounts of heat. **Hydrosphere:** discharge of liquid radioactive waste into the opening of water bodies. **Lithosphere:** disposal of spent fuel.
4. Emergency Safety: describe the most likely emergency situation	Possible emergencies: – Most typical emergency- fire breakout; – Failure of power unit safety systems.
Date issue of the task for the chapter	

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2022

6.1 Legal and organizational safety issues

6.1.1 The projected work area, law norms of labor legislation.

Nuclear power plant safety is a complex field related to the safety, health and well-being of people at work. It tells the strategy and methods in place to ensure the health and safety of employees within the workplace. Nuclear power plant safety includes the awareness of employees regarding basic safety knowledge, workplace hazards, hazard related hazards, implementation of hazard prevention, implementation of practice of necessary safer methods, techniques, processes and safety culture in the workplace. It also includes safety rules and regulations mostly designed on the basis of current government policies. Every organization establishes a number of safety rules and regulations for its employees. Safety training and education are provided to employees on a regular basis with the aim of educating them and updating them with the latest safety measures.

NPP safety is about putting an end to employee injuries and illnesses in the workplace. Therefore, it is about protecting the assets and the health and life of the employees. It also has the advantage of lowering the cost of lost man-hours, time spent on short-term assistance and schedule services that may fall back due to lack of service providers, or pressure on providers choosing to part with absent or poor staff, having to close or stop the program due to lack of service providers. [12]

Basic Objectives of NPP Safety

The basic objectives of NPP safety are as follows:

- Preservation of and assistance for employees' or workers' health and well-being
- Enhancing workability of employees by ensuring a safe and congenial work environment
- Growth of the organization that remains free from prospective hazards and mishaps
- Encouraging a favorable social climate in the organization that motivates the employees to work efficiently towards organizational progress and prosperity

- Secure the health and safety of workers and workplace by eliminating or minimizing risks
- Achieve higher productivity among the employees by providing a safe and secure environment
- Focus on employees' safety and health arising from chemicals and hazardous elements.

6.1.2 Features of the labor legislation in relation to the specific conditions of the project.

Employment at nuclear plants may include obligations and benefits related to issues by the following state or company: forms, regulations, and rates of wages for workers, engineers, and managers; disbursement of interest and compensation working and leisure hours, including matters relating to the granting and duration of leave; ; environmental safety and health protection of workers at work; guarantees and privileges for employees who combine their work and studies; health rehabilitation and free time for employees and members of their families; partial or full reimbursement of employee meals; Monitoring the implementation of the collective agreement, the procedure for its amendment, the responsibilities of the parties, ensuring normal conditions for the activities of employee representatives, the procedure for informing employees of the implementation of the collective agreement; The obligation to refrain from a strike if the relevant terms and conditions of the agreement are observed. [13]

Hour working

- Clarification of Nuclear Power Plant Staff Working Hours:

Clarification of the technical specifications (TS) related to the working hours of employees of nuclear power plants: Individual staff members should not work more than 16 straight hours, more than 16 hours in a 24-hour period, more than 24 hours in a 48-hour period, or more than 72 hours in a 7-day period. The 7-day period specified in TS's should be treated as any rolling 7-day period.

Standard TS's state that for personnel performing safety related functions "... in the event overtime is to be used, on a temporary basis, the following guidelines shall be followed:

1. An individual should not be permitted to work more than 16 hours straight, excluding shift turnover time.
2. An individual should not be permitted to work more than 16 hours in any 24-hour period, nor more than 24 hours in any 48-hour period, nor more than 72 hours in any 7-day period, all excluding shift turnover time.
3. A break of at least 8 hours should be allowed between work periods, including shift turnover time.

Any deviation from the above guidelines shall be authorized in advance by the Plant Superintendent or his deputy or higher levels of management." [14]

A review of a regional inspection report and resulting Notice of Violation has suggested that clarification is needed concerning TS's on working hours for nuclear power plant staffs, including HP's. In the reported violation, the 7-day week period was treated by the licensee as a fixed, one-week period, Sunday through Saturday. This allowed the 7-day window to be reset at the end of the week. The 7-day week period specified in TS's should be treated as any rolling 7-day period.

Another concern in the inspection report was what the licensee interpreted as "shift turnover." Shift turnover consists of non-working activities such as casual conversation with fellow employees concerning watch relief, review of shift logs and the changing of clothing (modesty garments into street clothes and vice versa). The Radiation Protection and Operations supervisors misinterpreted this TS and permitted off-going technicians to complete radiological survey maps after shift relief. This time was incorrectly left off the time applied toward the 72-hour TS requirement, which added to the violation. [15]

In addition, other activities, such as individual decontamination, whole-body counting, and decay (e.g., to permit the decay of gaseous radon daughter products), should not normally be considered part of shift turnover time. The time associated with these activities (as well as other related activities to be considered on a case-by-case basis) should be considered working time towards TS limits. This added time should not cause the individual to have less than 8 hours off between shifts. However, the licensee should not be cited for a violation of the TS limits for permitting the individual to work more than 16 hours straight (as this in not safety related work) as long as a break of at least 8 hours is allowed between work periods.

A technician worked a double shift of 16 hours and, after being relieved of his duties, was found to be contaminated. After an initial survey, decontamination, re-survey and whole-body count, two hours of additional time elapsed which are not part of normal shift turnover. The technician was not performing technical specification (TS) work during this 2-hour period so the TS that restricts work to 16 hours straight was not violated; however, if the technician reported for his next regular shift, he would have been in violation for not having an 8 hour break between work periods. The technicians next shift would have to be modified (pushed back at least two hours). This health physics position was reviewed by the TS Branch for generic applicability and it agrees with the position.

Health protection and medical examinations.

Prevention of occupational diseases shall be practiced in accordance with provisions made in this Act and the Health Care Act in cooperation with the health authorities.

The government or company is responsible for developing a written safety and health program at NPP. The program should include a risk assessment,

The Occupational Safety and Health Administration should monitor to ensure that written

To put in place safety and health programs in the workplace. The government or the company must make

The program is available to its managers, employees and occupational safety management and health. [15]

6.2 Occupational safety.

Occupational safety is understood as a system of organizational measures and technical means that prevent or reduce the possibility of exposure of workers to dangerous harmful production factors arising at nuclear power plants during work activity. In our work, it is necessary to detect dangerous and harmful factors that may arise when working with an information system. Subsequent selection is carried out using GOST 12.0.003–2015 "Hazardous and harmful production factors. Classification". The results of the selection are shown in the table below. [16]

6.2.1Analysis of harmful and dangerous factors that can be created.

All dangers in nuclear plants are divided into several categories, the basis of their classification lies in determining their effect on certain organs of the human body, as well as the method of affecting them.

Table 6.1 - Potential hazardous and harmful production factors

Factors (GOST 12.0.003-2015)	**The Type**	**The source of the factor**	**Impact on the human body**	**Legislation documents**
Ionizing radiation	Physical	radioactive materials and radiation-generating machines.	Harmful	GOST 12.2.003-91 Occupational safety standards system.
Moving parts of trade and technological equipment, moving goods, containers.	Physical	loaded and unloaded, stacked, transported efficiently	Harmful	GOST 12.4.011-89 Means of protection. General requirements and classification.
Toxic, affecting oppressing, in general, the entire human body	Chemical	Highly radioactive fission products and transuranic elements	Dangerous	GOST 12.1.007-76 Occupational safety standards system. Noxious substances. Classification and general safety requirements.
Electromagnetic fields	Physical	nuclear radiation exists within a reactor: alpha, beta, gamma, and neutron.	Harmful	SanPiN2.2.4.1329-03
Emotional overload	Psychophysiological	depression, anxiety	Harmful	GOST 9241-4-2009 terminals (VDT). Part 4. Keyboard requirements.
Increased voltage in an electrical circuit	Physical	amounts of power shorter distances from the high voltage	Dangerous	GOST 12.1.019-2017 Electrical safety. General requirements and nomenclature of types of protection.
Increased pressure of vapors or gases in vessels	Physical	Leakage from conductive pipes	Dangerous	GOST 12.4.011-89 Means of protection. General requirements and classification.

- **Ionizing radiation:** A type of high-energy radiation that has enough energy to remove an electron (negative particle) from an atom or molecule. **causing** it to become ionized. Ionizing radiation can cause chemical changes in cells and damage DNA.

  To minimize the impact:
  - Education and training
  - Reducing exposure time
  - Increasing the distance from the radiation source
  - Using a physical barrier that modifies the pathway between worker and source of radiation e.g., concrete or lead
  - Monitoring of exposures (individual and collective monitoring)
    - Recording exposures
    - Providing health surveillance
    - Promoting a health and safety culture
    - Complying with established radiation exposure (dose) limits
- **Moving parts of trade and technological equipment, moving goods, containers:** means of protection against the effects of mechanical factors (moving machines and mechanisms; moving parts of production equipment and tools; moving products, workpieces, materials; violation of the integrity of structures; collapsing rocks; bulk materials; objects falling from a height; sharp edges and surface roughness of workpieces, tools and equipment; sharp corners).

  To minimize the impact:

  increasing the services component, fostering trade in certain goods such as time-sensitive products, changing patterns of comparative advantage and affecting the complexity and length of global value chains.
- **Toxic, affecting oppressing, in general, the entire human body:** A toxin is a harmful substance produced inside cells or living organisms; Thus, synthetic toxicants resulting from artificial processes are excluded. When toxins damage your

enzymes, they prevent the production of hemoglobin in your blood, which can accelerate aging. It also can lead to the failure of energy production and lower your protection against oxidated stress. Failure of these normal body functions increases your risk of diseases like: Cancer.

To minimize the impact:

Putting distance and shielding between you and a radiation source is an immediately effective way of reducing your exposure.

- **Electromagnetic fields:** electromagnetic field, a property of space caused by the motion of an electric charge. A stationary charge will produce only an electric field in the surrounding space. If the charge is moving, a magnetic field is also produced. An electric field can be produced also by a changing magnetic field.

  To minimize the impact:

  - Disable Wireless Functions. Wireless devices — including routers, printers, tablets, and laptops — all emit a Wi-Fi signal.
  - Replace Wireless with Wired Devices.
  - Keep EMF Sources at a Distance.
  - Use Your Smartphone Safely.
  - Prioritize Sleeping Areas.

- **Emotional overload :**The emotional consequences of nuclear power plant disasters include depression, anxiety, post-traumatic stress disorder, and medically unexplained physical symptoms. These effects are often long-term and linked to concerns about developing cancer. Research on disasters involving radiation, particularly evidence from Chernobyl, indicates that mothers of young children and clean-up workers are the most at-risk groups. Emotional consequences occur independently of the actual exposure received. On the other hand.

  To minimize the impact:

  Providing psychiatrists

- **Increased voltage in an electrical circuit:** Electric current is able to create severe burns in the body. The reason is hidden in the power dissipation across the body´s electrical resistance. Shock can cause: cardiac arrest, burns to tissues and organs, muscle spasms, serious effects to the nervous system and other unexpected consequences.

  To minimize the impact:

  Providing insulating materials and providing insulating clothing.

- **Increased pressure of vapors or gases in vessels:** Dangerous gases and confined spaces are a dangerous mix. It can take only a few seconds for workers to succumb to a hazardous atmosphere

  To minimize the impact:

  - Ventilation needed
  - Use of mechanical devices that withstand pressure.

6.3 Environmental safety.

6.3.1 Environmental impact of nuclear power

The environmental impact of nuclear energy results from the nuclear fuel cycle, operation, and the effects of nuclear accidents.

However, there is the potential for a "catastrophic hazard" in the event of a containment failure, which can occur in nuclear reactors by heating smelting fuels and releasing large amounts of fission products into the environment. It is of three types, including atmosphere, hydrosphere, and lithosphere. [17]

- **Atmosphere:** radioactive gaseous emissions into the atmosphere, releasing large amounts of heat;
- **water ocean:** discharge of liquid radioactive waste into open water bodies;
- **Lithosphere:** disposal of spent fuel.

Radioactive waste is not unique to the nuclear fuel cycle. Radioactive materials are used extensively in medicine, agriculture, research, manufacturing, non-destructive testing, and minerals exploration. Unlike other hazardous industrial materials, the level of hazard of all radioactive waste – its radioactivity – diminishes with time.

Types of radioactive waste

Radioactive waste includes any material that is either intrinsically radioactive, or has been contaminated by radioactivity, and that is deemed to have no further use. Government policy dictates whether certain materials – such as used nuclear fuel and plutonium – are categorized as waste.

Every radionuclide has a half-life – the time taken for half of its atoms to decay, and thus for it to lose half of its radioactivity. Radionuclides with long half-lives tend to be alpha and beta emitters – making their handling easier – while those with short half-lives tend to emit the more penetrating gamma rays. Eventually all radioactive waste decays into non-radioactive elements. The more radioactive an isotope is, the faster it decays. Radioactive waste is typically classified as either low-level (LLW), intermediate-level (ILW), or high-level (HLW), dependent, primarily, on its level of radioactivity. [7]

Funding waste management

- **Treatment** involves operations intended to change waste streams' characteristics to improve safety or economy. Treatment techniques may involve compaction to reduce volume, filtration or ion exchange to remove radionuclide content, or precipitation to induce changes in composition.
- **Conditioning** is undertaken to change waste into a form that is suitable for safe handling, transportation, storage, and disposal. This step typically involves the immobilization of waste in containers. Liquid LLW and ILW are typically solidified in cement, whilst HLW is calcined/dried then vitrified in a glass matrix. Immobilized waste will be placed in a container suitable for its characteristics.

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 .

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. [18]

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.

6.3.2 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. [22]

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 6.2- Initial Data

H, m	110
d, m	1,3
D, m	3,4
$V_1, \frac{м^3}{с}$	53
$V_2, \frac{м^3}{с}$	100
ΔT, °C	16
$t_{ot}, \frac{days}{year}$	320

- **Maximum Permissible Discharge**

$$MPD_i = \frac{1}{\gamma} K_d TC_I, \frac{Bq}{s};$$

Where:

γ is a factor; $\gamma = 30$ for operating NPP

$$K_d = \frac{H^2\sqrt{V\Delta T}}{A \cdot F \cdot m \cdot n \cdot \alpha \cdot c \cdot \left(\frac{V}{V_0}\right)}, \frac{m^3}{s};$$

$$K_d = 11269149.17\ \frac{m^3}{s}\ \text{for Opration mode;}$$

$$K_d = 25532056.02\ \frac{m^3}{s}\ \text{for Opration mode;}$$

Where: H is height of the tube, m;

V is volumetric flow rate of the gas mixture, $\frac{m^3}{s}$; 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, $s^{\frac{2}{3}} \cdot °C^{\frac{1}{3}}$;

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 6.3- F factor values

F = 1	Gases and aerosol

$$m = \frac{1}{0,67 + 0,1\sqrt{f} + 0,34\sqrt[3]{f}};$$

$$f = \frac{10^3 w_0^2 D}{H^2 \Delta T} = \frac{10^3 \cdot 39.95^2 \cdot 3.4}{110^2 \cdot 16} = 28.02932121 \text{ for Opration mode };$$

$$f = \frac{10^3 w_0^2 D}{H^2 \Delta T} = \frac{10^3 \cdot 75.3778^2 \cdot 3.4}{110^2 \cdot 16} = 99.784 \text{ for Repair mode };$$

$$m = 0.447 \text{ for Opration mode };$$

$$m = 0.308 \text{ for Repair mode };$$

where:

w_0 is outlet velocity of gases, $\frac{m}{s}$;

$$w_0 = \frac{V}{area} = \frac{53}{\left(\frac{3.14}{4}\right) \cdot 1.3^2} = 39.95 \text{ for Opration mode };$$

$$w_0 = \frac{V}{area} = \frac{100}{\left(\frac{3.14}{4}\right) \cdot 1.3^2} = 75.3778 \text{ for Repair mode };$$

The factor n depends on parameter V_m:

$$V_m = 0,65\sqrt[3]{\frac{V\Delta T}{H}} = 0,65\sqrt[3]{\frac{53 \cdot 16}{110}} = 1.284 \text{ for Opration mode };$$

$$V_m = 0,65\sqrt[3]{\frac{V\Delta T}{H}} = 0,65\sqrt[3]{\frac{100 \cdot 16}{110}} = 1.5867 \text{ for Repair mode };$$

Table 6.4- n factor values

$n = 3 - \sqrt{(V_m - 0{,}3)(4{,}36 - V_m)}$	$V_m \in (0{,}3; 2]$

$$n = 1.26 \quad \text{for Opration mode} \;;$$

$$n = 1.11 \;\; \text{for Repair mode} \;;$$

Correction factor c depends on relied features:

$c = 3$ if difference of elevation is greater than $200\text{m} - 300\text{m}$.

- **Capacity expansion limit**

Firstly, annual discharge of radioactive noble gases of a NPP is calculated with the following formula:

$$B_{an} = B_n N_e, \qquad \frac{\text{Ci}}{\text{year}};$$

$$B_{an} = 1000 \cdot 20 = 20000 \quad \frac{\text{Ci}}{\text{year}};$$

Where:

B_n is normalized discharge of radioactive noble gases, B_n is assumed equal to $20 \frac{\text{Ci}}{\text{MW}\cdot\text{year}}$;

Capacity expansion limit is calculated with the formula

$$N_e^{lim} = N_e \frac{\sum_i {MPD_i}^{RNG} \cdot t_{no}}{B_{an}};$$

$$t_{no} = 320 \cdot 24 \cdot 60 \cdot 60 = 27648000 \;\frac{\text{s}}{\text{years}} \;;$$

$$\sum_i {MPD_i}^{RNG} = 4.772 \cdot 10^{10} \;\frac{\text{Bq}}{\text{s}} \;\text{for Opration mode} \;;$$

$$\sum_i {MPD_i}^{RNG} = 1.081 \cdot 10^{11} \;\frac{\text{Bq}}{\text{s}} \;\text{for Repair mode} \;;$$

$$N_e^{lim} = 1783005.727 \;\;\text{MW} \;\;\text{for Opration mode} \;;$$

$$N_e^{lim} = 4039684.045 \;\;\text{MW} \;\;\text{for Repair mode} \;;$$

Where:

$\sum_i MPD_i^{RNG}$ is maximum permissible discharge of radioactive noble gases only.

- **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;

$$\beta = 4{,}95V_m\left(1 + 0{,}28f^{\frac{1}{3}}\right), \text{ if } V_m \leq 2;$$

$$\beta = 11.76 \quad \text{for Opration mode};$$

$$\beta = 18.054 \quad \text{for Repair mode};$$

$$\text{so } X = 2 \cdot 110 \cdot 11.76 = 2587.66 \quad \text{for Opration mode};$$

$$\text{so } X = 2 \cdot 110 \cdot 18.054 = 3971.9 \quad \text{for Repair mode}.$$

Table 6.5- According to the Excel, Result of MPD with influence TC_i .

Element	TC_i	MPD for Opration mode	MPD for Repair mode
^{41}Ar	56626.9597	21271255216	48193423614
^{85m}Kr	535.210533	201045577.9	455500843.8
^{85}Kr	5312.35967	1995525784	4521182153
^{87}Kr	12099.9277	4545196358	10297867770
^{88}Kr	0.00219027	822.7503685	1864.072272
^{133}Xe	30051.6803	11288562264	25576039480
^{135}Xe	22416.8959	8420644812	19078314768
^{89}Sr	0.00018148	68.17191927	154.4543634
^{90}Sr	0.00044277	166.321188	376.8271964
^{131}I	0.59430123	223242.3085	505791.0796
^{134}Cs	7.6537E − 05	28.75017559	65.13811138
^{137}Cs	0.00013285	49.90300935	113.0632323
$^{140}Ba + ^{140}La$	0.00017706	66.50937795	150.6876107

Conclusion:

In this Calculation, it was 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.

MPD_i values obtained in the normal operation mode and repair mode can be concluded that in the repair mode emission limit values higher than during normal operation of the planned power plant.

This is 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.

6.4 Emergency safety.

The NPP emergency planning procedures on protection of personnel and population in the event of an accident at the NPP considering radiological consequences of accidents shall be developed and made available. Plans shall be elaborated on the basis of NPP design characteristics and parameters, criteria for decision making relating to arrangements on protection of population in case of an accident at the NPP taking into account economic, natural and other site-specific features and extent of actual hazard of occurrence of the emergency situation.

The emergency plan on protection of population to be elaborated in the established order by competent bodies in case of an accident shall suggests co-ordination of actions to be undertaken within the site and in the whole territory by civil defence and emergency control bodies, local self-control bodies as well as ministries and departments involved in implementation of measures on protection of population and mitigation of accident consequences. [23]

Fire safety assessments and operational experience gained from events in nuclear energy Factories have shown that fires and explosions have a high potential to severely affect safety from NPP. Since a fire can occur at any time in the plant, the fire protection of the nuclear power plant is important Throughout its life, that is, from the design stage to operation and even decommissioning.

Fire safety in national nuclear plants is addressed in IAEA safety standards publications covering design and safe operation of nuclear power plants. [11] Other IAEA public publications provide more details guidelines for fire safety assessment and for fire safety reviews. In this it documents the analysis of the aforementioned fire experience as an essential tool to meet the following objectives:

- To conduct a safety review of the procedures in place at the operating stations (operational safety objective).
- To conduct a periodic safety review of fire safety issues in design and operation.
- To support probabilistic fire risk analysis of new and existing plants targeting

Better identify aspects of fire safety and prioritize safety improvement tasks.

To achieve these goals, a broad track record of experience derives from fire events in surrounding plants the world is strongly encouraged to create a reliable database that will enable fire safety experts to make recommendations for current and future factories and can be used for statistics purposes. Events must be collected and analyzed by fire safety experts to derive them recommendations for current and future plants. [24]

In this regard, the international atomic energy agency has begun a systematic process of collecting data on events in this framework the objectives of this task are: to collect and evaluate. Operational experience on fires and explosions in factories in a systematic way to obtain information necessary for a comprehensive safety analysis; to use lessons learned from past events. For operational feedback; and successfully applied in plants to avoid, or at least, reduce the frequency of events. [25]

Conclusion

According to the calculations is a design of a nuclear power plant with an electric power of 1300 MW with 4 loops of a horizontal steam generator, in the thermal calculation part of the thermal calculation of the heating surfaces of the steam generator, in the calculation of the SG design to determine the main dimension of the horizontal steam design determines the generator, in the mechanical calculation part, the static power for the main elements of the steam generator and determines the wall thickness of these elements, in the hydraulic calculation of the steam generator determines the pressure losses when the refrigerant moves in it, in the calculation of the separation part is the estimation of the steam moisture in front of the steam receiving roof, which is located in the upper part of the steam volume, in the calculated thermal insulation part Parameters of the thermal insulation layer. The main result iswe obtained the following results:

- Coolant flow rate = 5062.54 kg/s;
- Steam flow rate = 506.61 kg/s;
- Wall thickness of tube = 1.718 mm;
- Number of tubes = 11654 pcs;
- Average temperature head in SG = 24.2 ℃;
- Area of heat exchange surface = 7028.4 m^2;
- Average length of one tube of SG = 13.43 m;
- Wall thickness of the collector = 0.145 m;
- Internal diameter of SG vessel = 4.76 m;
- Height of steam volume = 1.82m
- Wall thickness of the side shell = 0.106 m;
- Wall thickness of the central shell = 0.142 m;
- Thickness of the bottom = 0.129 m;
- Thickness of the heat insulating layer = 0.103 m.

For calculations of NPP with a VVER-1300 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 $Q_{SG} = 3655$ MW;
- Thermal power of Turbine unit is $Q_{Ts} = 3644$ MW;
- Overall NPP efficiency is $\eta_{npp} = 34.7\ \%$;
- Number of High-Pressure Heater $n_{HPH} = 2$;
- Steam flow rate from steam generator to the turbine unit is $G_{SG} = 2026.5\ kg/s$;
- Feedwater flow rate $G_{fw} = 2036.5\ kg/s$;
- Burn up fuel rate $b_{nf} = 26.107\ {}^{ton}/_{year}$.

About condenser determined two options of condenser to compare and select the pest one of them with efficiency and costs. So, select the condenser with option 2 wall thickness 2.

- $C_{cond} = 401.1$ million rubles;
- $C_{el} = 161.9$ million rubles.

According to the part of financial management calculations the economics results show that the competitiveness of option 1 was 3.15, while that of option 2 was 3.3.

Thus, the investigated scientific development (condenser design), which uses tubes with d_{out} = 28 mm; δ_{wall} = 2 mm, is competitive 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 $\sum_i \mathrm{MPD}_i^{\mathrm{RNG}}$ 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 Р1 Reactor installation. Structural energy diagram.

ФЮРА.31 1115.004 Р3 Turbine installation. Energy schematic diagram.

assembly drawings:

ФЮРА.693100.002 СБ Nuclear reactor. Assembly drawing.

ФЮРА.693410.003 СБ Steam generator. Assembly drawing.