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

School of Energy and Power Engineering
Major **14.05.02 Design, Operation and Engineering of Nuclear Power Plants**
The Butakov Research Center

GRADUATION THESIS

Title
THE PROJECT UNIT NUCLEAR ELECTRIC POWER PLANT 1200 MW WITH TWO TURBINES K-600-23,5

UDC 621.438.004:621.311.2.002.5

Student

Group	Full name	Signature	Date
505И	IBRAHIM AHMED ATEF		

Thesis supervisor

Position	Full name	Degree, academic status	Signature	Date
Associate Professor of the Butakov center	D.V. Gvozdyakov	PhD		

Consultants:

On the section of Financial management, Resource Efficiency and Resource Saving

Position	Full name	Degree, academic status	Signature	Date
Associate Professor Division for Social Sciences and Humanities School of Core Engineering Education	L.Y. Spicyna	PhD		

On the section of Social Responsibility

Position	Full name	Degree, academic status	Signature	Date
Associate Professor Department of GTD school of CEE	M.V. Gorbenko	PhD		

On the Compliance with Regulatory Documents

Position	Full name	Degree, academic status	Signature	Date
Associate Professor of the Butakov center	D.V. Gvozdyakov	PhD		

ADMITTANCE FOR THE DEFENSE:

Head of the EP (Educational Program)	Full name	Degree, academic status	Signature	Date
14.05.02 Design, Operation and Engineering of Nuclear Power Plants	A.V. Vorobiev	Candidate of Technical Sciences, associate professor		

Tomsk, 2021

Results on mastering the Educational Program

14.05.02 Design, Operation and Engineering of Nuclear Power Plants

Code	The result of mastering PEP	Requirements of FCES of HE, SSES of TPU, AEER criteria, and / or stakeholders
R1	To be capable of searching, critically analyzing and synthesizing information, applying a systematic approach for solving tasks.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R2	To be capable of determining the range of tasks within the set of goals and selecting the best ways to solve them basing on current legal norms, and available resources and restrictions.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R3	To be capable of organizing and managing teamwork, developing a team strategy to achieve the goal.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R4	To be capable of carrying out business communication in oral and written forms in the state and foreign languages for academic and professional interaction.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R5	To be capable of perceiving the cross-cultural diversity of society in socio-historical, ethical and philosophical contexts.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R6	To be capable of time management, building and implementing a trajectory of self-development based on educational principles throughout life.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R7	To be capable of maintaining a proper fitness level to ensure full-fledged social and professional activities.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R8	To be capable of creating and maintaining safe living conditions, including emergencies.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R9	To be capable of solving the problems of professional activities using basic knowledge of natural scientific disciplines and information technologies, complying with the basic requirements on informational security, including protection of the state secrets.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R10	To be capable of using scientific and technical information, local and foreign experience in order to implement researches in the field of design, modernization and operation of NPPs.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R11	To be capable of carrying out mathematical simulation of physical processes and technologic equipment based on computer-aided design and research interfaces at an NPP.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R12	To be capable of formulating the goals and objectives of the research in the field of improving NPP operation	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for

Code	The result of mastering PEP	Requirements of FCES of HE, SSES of TPU, AEER criteria, and / or stakeholders
	efficiency, selecting methodology and resources of conducting a scientific research, performing and analyzing the results of R&D activities, participate in equipment testing.	the competencies of graduates.
R13	To be capable of participating in organization of safe and effective operation of a reactor power unit, equipment, and technological systems of the nuclear power unit; analyzing technological processes, mode restrictions, control algorithms for safe operation of a NPP; monitoring environmental parameters.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R14	To be capable of participating in the design of equipment and its elements, technologic systems of NPPs, taking into account the requirements of nuclear, radiation, fire, industrial and environmental safety with the support of modern information technologies.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R15	To be capable of applying and developing technical documentation according to the state requirements, industrial and departmental standards; carrying out design activities according to the terms of reference in the field of professional activity.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R16	To be capable of conducting technical and economic analysis and assessment of the competitiveness and economic efficiency of the designed systems, equipment and NPP as a whole.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R17	To be capable of analyzing and calculating nuclear-physical, neutron-physical, thermodynamic, thermohydraulic, physico-chemical, and technological processes at a nuclear power plant.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R18	To be capable of conducting assessment of nuclear and radiation safety, organizing measures to ensure nuclear, radiation, technical, and fire safety in compliance with labor protection requirements in the process of producing electric and thermal energy at nuclear power plants, including nuclear fuel handling.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R19	To be capable of organizing the work in small groups, planning the work of personnel, developing operational plans for the work of primary production units, organizing workplaces.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R20	To be capable of participating in testing the main and auxiliary equipment of nuclear power plants and nuclear	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for

Code	The result of mastering PEP	Requirements of FCES of HE, SSES of TPU, AEER criteria, and / or stakeholders
	power units, conducting physical experiments at the stages of first criticality of a power unit in order to determine the neutron-physical parameters of the reactor plant and NPP as a whole.	the competencies of graduates.
R21	To be capable of carrying out measurements of electrical and non-electrical quantities in relation to objects of professional activity, performing work on standardization and preparation for certification of technical resources.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R22	To be capable of formulating goals and objectives of a research, selecting evaluation criteria, identifying priorities for solving problems in the field of nuclear energy and technology, theoretic and experimental research in solving professional problems.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.
R23	To be capable of analyzing the technologies of installation, repair and decommissioning of NPP equipment (and nuclear power units) in relation to the conditions of construction, operation and decommissioning of NPP power units.	Competencies of FSES of HE, SSES TPU, CDIO Syllabus, AEER, consistent with the requirements of international standards EUR-ACE and FEANI, employers' requirements for the competencies of graduates.

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The Butakov Research Center

E S T A B L I S H:
Head of Educational Program
A.V.Vorobiev

____________________ _____________
(Signature) (Date)

THE ASSIGNMENT
for graduation thesis

In form of:

Graduation project

For student:

Group	Full name
505И	**IBRAHIM AHMED ATEF**

Title of the work:

ПРОЕКТ ЭНЕРГОБЛОКА АТОМНОЙ ЭЛЕКТРИЧЕСКОЙ СТАНЦИИ МОЩНОСТЬЮ 1200 МВТ С ДВУМЯ ТУРБИНАМИ ТИПА К-600-23,5 **THE PROJECT UNIT NUCLEAR ELECTRIC POWER PLANT 1200 MW WITH TWO TURBINES K-600-23,5**	
Established by the order of Director (date, number)	

Thesis's accomplishment deadline:	**15 January 2021**

TECHNICAL ASSIGNMENT:

Basis of the work (project) *(name of the object of research or design, its capacity; operatingng mode (consistent, periodic, cyclic etc.); type of raw material or product material; requirements to product or process; special requirements to peculiarities of operation of the object or process in terms of operational safety, impact on the environment, energy consumption; economic analysis, etc.)*	The design object is a nuclear power unit with a VVER-1200 reactor. The operating mode of the system is continuous. Basic installation requirement: ▪ Increased reliability and safety of the installation. ▪ High technical and economic indicators of the installation.

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.Intodocation. 2.calculation of steam generator. 3.calculation of NPP. 4.calculation of condenser. 5.Economy. 6.social responsibility.
List of drawings: *(with exact indication of the required drawings)*	1.primary circuit of VVER 2.steam generator of VVER 3. thermal diagram of NPP

Consultants on the thesis' additional sections *(with indication of the sections)*

Section	**Consultant**
Financial Management	L.Y. Spicyna, PhD
Social Responsibility	M.V. Gorbenko, PhD

Issue date of the assignment	24.06.2020

The assignment was issued by the supervisor:

Position	Full name	Degree, academic status	Signature	Date
Associate Professor of the Butakov center	D.V. Gvozdyakov	PhD		

The assignment was accepted by the student:

Group	**Full name**	**Signature**	**Date**
505И	IBRAHIM AHMED ATEF		

ASSIGNMENT FOR THR DIPLOMA PROJECT SECTION «FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING»

Student:

Group	Name
505И	IBRAHIM AHMED ATEF ELSAYED

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

Initial data for the section "Financial Management, Resource Efficiency and Resource Saving":	
1. The cost of scientific research resources: material, technical, energy, financial, informational and human	*Budget of research not higher than 270 000 rubles, salaries of executors not higher than 165 000 rubles*
2. Norms and standards for spending resources	*Supervisor' salary – 36 000 rubles per month; engineer' salary – 18 000 rubles per month*
3. The system of taxation used, tax rates, volumes of payments, discounts and loans	*Coefficient of incentive bonuses 30%, coefficient of incentives for the manager for conscientious work activity 25%; contributions for social funds are 30,2% totally*
Problems to research, calculate and describe:	
1. Assessment of the commercial potential of engineering solutions	*Comparison of the condensers' tubes thickness*
2. Planning of research and constructing process and making schedule for all periods of the project	*Calendar plan of the project*
3. Requirement for investments	*Costs calculations*
4. Budgeting an engineering project	*Creation of the project budget*
5. Calculation of resource, financial, social, budgetary efficiency of an engineering project and potential risks	*List of resource requirements*
Graphic materials	
1. Scorecard of competitive advantages *2. Competitive power of the project*	*3. Gantt diagram* *4. The budget for scientific and technical research*

Assignment date	

Consultant:

Position	Name	Academic degree	Signature	Date
Associate Professor Division for Social Sciences and Humanities School of Core Engineering Education	L.Y. Spicyna	PhD		

Student:

Group	Name	Signature	Date
505И	IBRAHIM AHMED ATEF	(signed)	

TASK FOR SECTION «SOCIAL RESPONSIBILITY»

For the student:

Group	Full name
505И	IBRAHIM AHMED ATEF

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

Topic of the work

ПРОЕКТ ЭНЕРГОБЛОКА АТОМНОЙ ЭЛЕКТРИЧЕСКОЙ СТАНЦИИ МОЩНОСТЬЮ ВВЭР-1200 МВТ С ДВУМЯ ТУРБИНАМИ ТИПА К-600-23,5 **THE PROJECT UNIT NUCLEAR ELECTRIC POWER PLANT VVER-1200 MW WITH TWO TURBINES K-600-23,5**

Initial data to the section «Social responsibility»:	
1. *Characteristics of the object of study (substance, material, device, algorithm, method, working area) and its areas of application*	*The object of study is Nuclear desalination*
The list of issues to be investigated, designed and developed:	
1. Legal and organizational safety issues: *1.1. Special legal norms of labor legislation.* *1.2. Organizational arrangements for the layout of the working area.*	*1.1 Special legal norms of labor legislation.* *1.2 Organizational arrangements for the layout of the working area. These include:* *1.2.1. microclimate of the working room;* *1.2.2. illumination of the working area;* *1.2.3. noise level at the workplace;* *1.2.4. increased level of electromagnetic radiation.* *1.2.5 Arrangements for the layout of the working area.*
2. Industrial safety: *2.1. Analysis of harmful and dangerous factors that can be created by object of study and laboratory during research.*	*2.1 Analysis of harmful and dangerous factors that can be created by object of study and laboratory during research. These include:* *2.1.1 Analysis of identified hazardous factors.* *2.1.2 Electrical safety.* *2.2 Determination of air exchange in laboratory*

3. Ecological safety:	*The facility does not affect the environment. Disposal of equipment.*
4. Safety in emergency situations: *4.1. Analysis of probable emergencies that may occur in the laboratory during research.* *4.2. Justification of measures to prevent emergencies and the development of procedures in case of an emergency.*	*Fire safety*

Date of assignment for the section on a linear schedule	3.02.2020

Assignment was issued by an advisor:

Position	Full name	Degree	Signature	Date
Associate professor	Mikhail Vladimirovich Gorbenko	Candidate of Technical Sciences		

Assignment was accepted for execution by the student:

Group	Full name	Signature	Date
505И	IBRAHIM AHMED ATEF		

ABSTRACTS

The graduation project /project consists of about 132pages, 11 figures, 44 tables, this number of references, this number of appendices

Keywords: steam generator, turbine, condenser, regenerative feedwater heater, feedwater pump, blowdown, steam nozzles, collector

Object of the project unit nuclear electric power plant VVER-1200 MW with two turbine K-600-23.5

Goal of the work are The design object is a nuclear power unit with a VVER-1200 reactor.

The operating mode of the system is continuous.

Basic installation requirement:

- Increased reliability and safety of the installation.
- High technical and economic indicators of the installation.

Objectives of the work are

1.Intodocation.

2.calculation of steam generator.

3.calculation of NPP.

4.calculation of condenser.

5.Economy.

6.social responsibility.

Contents

INTRODUCTION

In our time, the issue of the use of energy resources is acute in connection with their exhaustion and low renewability. Coal, oil and gas are the main sources of energy in our world, and only then are water resources and nuclear fuel.
Since fossil fuel is practically irreplaceable, we are increasingly thinking about using unconventional energy sources, including nuclear power.

Nuclear energy has great opportunities for development in our country. With such advantages as the high energy intensity of fuel, the possibility of its reuse, the absence of the greenhouse effect, the nuclear industry has every chance of becoming a leading energy sector.
The plant will consist of four VVER-1200 nuclear reactors, which are capable of producing 1.2GW each. The first unit is expected to begin commercial operations in 2026, while commissioning of the remaining three reactors is scheduled for 2028.

The VVER-1200 reactor is a third-generation pressurized water reactor that is fully compliant with all international safety and post-Fukushima IAEA requirements. It is designed to withstand the crash of a 400t airplane or earthquakes up to an intensity of 9 on the Richter scale.

The purpose of this project is to design a nuclear power plant with an electric power of 1200 MW. An important aspect of the project is the calculation of a nuclear reactor for 4 loops. After a feasibility study, it is necessary to draw a conclusion about the effectiveness of each case.

1. Thermal calculation of the heating surface of SG.

1.1. Initial data.

Table 1- Initial data

Parameter	Denomination, units	Value
Coolant		water
Thermal power of reactor	Q_r, MW	3840
Thermal power of SG	Q_{sg} , MW	960
Coolant pressure at the inlet to the SG	p_1 , MPa	17,64
Coolant temperature at the inlet to the SG	t_1' , °C	328,9
Coolant temperature at the outlet of the SG	t_1'' , °C	298,2
Steam pressure at the SG	p_{st} or p_2 , MPa	7,0
Steam temperature at the outlet of the SG	t_{st} or t_s , °C	$t_s = f(p_2) = 285{,}80$
Feed water temperature	t_{fw} , °C	200
Blowdown flow rate, % (as a percentage of mass flow of steam)	α_{bd} , %	0.3

Notes: -

- purpose is for the production of the saturated steam with natural circulation;
- Thermal circuit is Evaporator;
- Basic type is Steam Generator WWER, horizontal, U-shaped tubes.

1.1.1. Calculation and construction of TQ diagram

1.1.1.1. Determination of coolant flow

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

$$Q_{sg} = G_1 \cdot (h_{in} - h_{out})$$

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;

$h_{in} = f(P_1, t_1')$ is coolant enthalpy at the steam generator inlet, kJ/kg;

$h_{out} = f(P_1, t_1'')$ is coolant enthalpy at the steam generator inlet, kJ/kg;

$$h_{in} = f(P_1, t_1') = f(17{,}64\,, 328{,}9) = 1504\,\frac{kJ}{kg}$$

$$h_{out} = f(P_1, t_1'') = f(17{,}64\,, 298{,}2) = 1326\,\frac{kJ}{kg}$$

$$G_1 = \frac{Q_{sg}}{h_{in} - h_{out}} = \frac{960 \cdot 10^3}{1504 - 1326} = 5393{,}2 \text{ kg/s}$$

1.1.1.2. Determination of steam flow rate

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

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

Where: -

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

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

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

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

$h_{fw} = f(P_2\ , t_{fw}) =$ is enthalpy of feed water, kJ/kg;

$D_{bd} = (\alpha_{bd}/100) \cdot D_2 =$ is flow rate of blowdown water, kg/s.

$$k_{hl} = 1{,}02$$

$$h'' = f(P_{st}) = f(7) = 2773 \text{ kJ/kg}$$

$$h' = f(P_{st}) = f(7) = 1267 \text{ kJ/kg}$$

$$h_{fw} = f(P_2, t_{fw}) = f(7{,}200) = 855 \text{ kJ/kg}$$

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

$$960 = 1{,}02 \cdot D_2 \cdot [(1267 - 855) + (2773 - 855)] + \left(\frac{0{,}3}{100}\right) \cdot D_2 \cdot (1267 - 855)$$

$$960 = 2376{,}6 \cdot D_2 + 1{,}236 \cdot D_2$$

$$D_2 = 403{,}72 \text{ kg/s}$$

$$D_{bd} = (\alpha_{bd}/100) \cdot D_2 = \left(\frac{0{,}3}{100}\right) \cdot 403{,}72 = 1{,}211 \text{ kg/s}$$

1.1.1.3. Determination of feed water flow rate

$$D_{fw} = D_2 + D_{bd} = 403{,}72 + 1{,}211 = 404{,}93 \text{ kg/s}$$

1.1.1.4. Building a tQ diagram

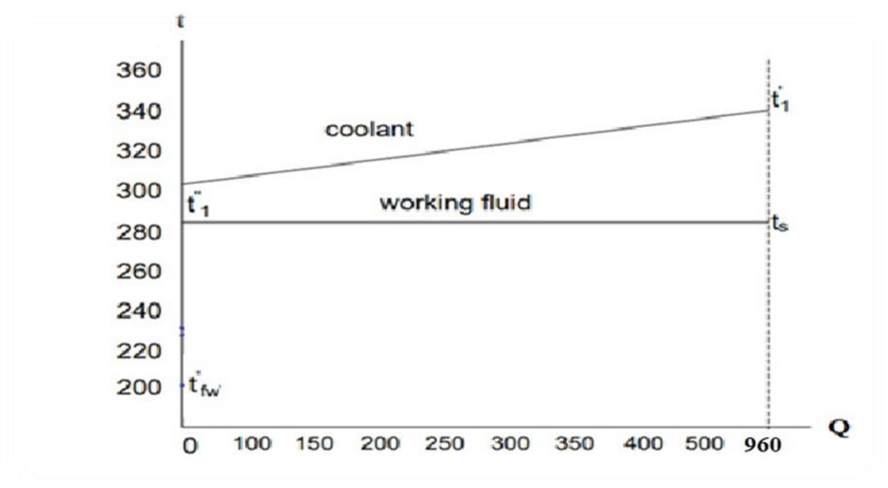


Figure 1: TQ-diagrams of the steam generator

$$\Delta t_{ev}^{min} = t' - t_{s2} = 298{,}2 - 285{,}80 = 12{,}4 \text{ °C}$$

1.1.2. 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.

1.1.3. 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. 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: -

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

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

$$P_{calc} = 0{,}9 \cdot 1{,}25 \cdot 17{,}64 = 19{,}84\ Mpa$$

$\mathrm{t_{tube.max}} = \frac{\mathrm{t}_1' + \mathrm{t_s}}{2} = \frac{328{,}9+285{,}8}{2} = 307{,}35℃$ is maximum operating temperature of the tube wall, ºC;

d_{out} is the outer diameter of the tubes, mm. The value of the diameter of the tubes is 16 mm for horizontal WWER steam generators;

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

❖ *Calculate nominal stress design*

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

Name	Sheet	№ Document	Signature	Data	ФЮРА.562527.001 ПЗ	Sheet 8

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

Where: -

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

- σ_{sl} is shakedown limit of the tube's material at the design temperature $t_{calk} = t_{tube.max} = 307{,}35°C$, MPa;
- $\sigma_{0,2}$ is yield point of the tube's material at the design temperature $t_{calk} = t_{tube.max} = 307{,}35°C$, MPa;

❖ From table 2 at a temperature of 307,35 degrees,

$$\sigma_{sl} = 363\ MPa\ , \sigma_{0,2} = 137\ MPa$$

So, we will calculate stresses taking into account safety factors

$$[\sigma] = \min\left\{\frac{\sigma_{sl}}{n_{sl}} = \frac{363}{2.6} = 140;\ \frac{137}{1.5} = 91\right\}$$

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

$$[\sigma] = 91\ \text{MPa}$$

- 08H18N10T type steel is used for manufacturing steam generator tubes in Russia (Table 2).

Table 2- Mechanical properties of steel 08X18H10T

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.

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

Where: -

- C_1 is minus technological tolerance, mm. Accepted according to the data from

Table 3 for the precision manufacturing “high accuracy".

$$\delta_{tube} - C = \frac{p_{calc} \cdot d_{out}}{2 \cdot \varphi \cdot [\sigma] + p_{calc}} = \frac{19.84 \cdot 16}{2 \cdot 1 \cdot 91 + [19.84]} = 1.57$$

Table 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 %

$$C_1 = \frac{12}{100} \cdot 1.57 = 0{,}188 \text{ mm}$$

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

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

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

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

Where: -

- R_b is the bending radius of the tube along the neutral line, mm;

$$R_b = (1{,}9\ldots3{,}5) \cdot d_{out} = 2{,}3\ d_{out} \rightarrow R_b = 2{,}3 \cdot 16 = 36{,}8\ mm$$

- a is ovality of the tube in the bent section, %; accepted $a = 5\ldots15$ %; we take it 13%
- b is relative decrease in wall thickness in the stretched part of the bent section, %. accepted

$b = 10\ldots30$ % we take it 10%

$$0.75 \cdot 10^{-2} \cdot a = (0.75 \cdot 10^{-2}) \cdot 13\% = 0.009 < [\delta_{tube} - C]$$

So, we will used second formula

$$C_4 = 1.57 \cdot \left[1 - 2 \cdot \left(1 - \frac{10}{100}\right) \cdot \frac{2 \cdot \left(\frac{36{,}8}{16}\right) + 1}{4 \cdot \left(\frac{36{,}8}{16}\right) + 1}\right] = 0{,}018mm$$

Then

$$C = 0{,}188 + 0 + 0 + 0{,}018 = 0{,}207\ mm$$

$$\delta_{tube} - C = 1{,}57 \rightarrow \delta_{tube} = 1{,}57 + 0{,}207 = 1{,}77\ mm$$

The tube wall thickness is rounded to the nearest higher value available in the tube assortment (Table 4). Rounding to the lower side by an amount of not more than 3% is allowed.

Table 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, 1.3, 1.4, 1.5, 1.8

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

$$d_{in} = d_{out} - 2 \cdot \delta_{tube}$$

$$d_{in} = 16 - 2 \cdot 1{,}8 = 12{,}4mm$$

1.1.4. **Determining the number of tubes**

$$N_{tube} = \frac{G_1}{\rho_{avr} \cdot w \cdot f_{1tube}} \text{ pc.}$$

Where: -

- G_1 is coolant flow kg/s;
- $\rho_{avr}$is the average density of the coolant;

$$\rho_{avr} = f(p_1,\ t_{1avr}) = f(17.64{,}313{,}55) = 701{,}51\ kg/m^3$$

- w is the speed of the coolant in the tubes, m/s.

  Accept in the range from 4 to 6 m/s; So, we take it 6 m/s
- f_{1tube} is cross-section area of one tube, m².

$$f_{1tube} = \frac{\pi \cdot d_{in}^2}{4} = \pi \cdot \frac{(12{,}4 \cdot 10^{-3})^2}{4} = 1{,}27 \cdot 10^{-4}\ m^2$$

Then

$$N_{tube} = \frac{5393{,}2}{701{,}51 \cdot 6 \cdot (1{,}27 \cdot 10^{-4})} = 10529\ pc$$

1.1.5. **Calculation of heat transfer in a steam generator**

1.1.5.1. Determination of average temperature head in a steam generator

$$\Delta t_{avr} = \frac{\Delta t_{high} - \Delta t_{low}}{\ln\left(\frac{\Delta h_{high}}{\Delta t_{low}}\right)}$$

Where: -

- Δt_{high} is highest temperature head, ℃

$$\Delta t_{high} = t_1' - t_s = 328{,}9 - 285{,}80 = 43{,}10\ ℃$$

- Δt_{low} lowest temperature head, ºC

$$\Delta t_{low} = t_1'' - t_s = 298{,}2 - 285{,}80 = 12{,}40\ ℃$$

$$\Delta t_{avr} = \frac{43{,}10 - 12{,}40}{\ln\left(\frac{43{,}10}{12{,}40}\right)} = 24{,}64°C$$

1.1.5.2. 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

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

Where: -

- ν_{1avr} is average kinematic viscosity of the coolant, m²/s;
- λ_{1avr} is the average coefficient of thermal conductivity of the coolant,
- Pr is Prandtl criterion with medium coolant parameters;

From $f(p_1, t_{avg})$

Table 5–characteristics of the coolant

ν_{1avr} ,m²/s	λ_{1avr},W/(m.K)	Pr
$1{,}198 \cdot 10^{-7}$	0,5381	0,90

Re_{avg} is Reynolds criterion with medium coolant parameters.

$$\mathrm{Re}_{avr} = \frac{w \cdot d_{in}}{\nu_{1avr}} = \frac{6 \cdot 0{,}0124}{1{,}198 \cdot 10^{-7}} = 624110$$

Then

$$\alpha_{1avr} = 0.021 \cdot \left(\frac{0{,}5381}{0{,}0124}\right) \cdot (624110)^{0.8} \cdot 0{,}90^{0{,}43} = 37.53\ \mathrm{kW/m^2°C}$$

1.1.5.3. 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/m² (for the output section it is recommended to take $q_{out} = 6 \cdot 10^4$W / m²);

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

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

$$\alpha_{2in} = \frac{10,45\cdot(3\cdot10^5)^{0.7}}{3,3-0,0113\cdot(285,80-100)} = 59,4 \cdot 10^3 \text{ W/(m}^2\cdot{}^\circ\text{C)};$$

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

$$t_{tube.in} = t_s + 0.3 \cdot (t_1' - t_s), {}^\circ\text{C};$$

$$t_{tube.in} = 285,80 + 0.3 \cdot (328,9 - 285,80) = 298,73^\circ\text{C}$$

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

$$\lambda_{wal.in} = 14.48 + 0.0156 \cdot t_{tube.in}, \text{W/(m} \cdot {}^\circ\text{C)};$$

$$\lambda_{wal.in} = 14.48 + 0.0156 \cdot 298,73 = 19,14 \text{ W/(m} \cdot {}^\circ\text{C)};$$

- calculate the heat transfer coefficient

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

Where: -

- δ_{tube} is the wall thickness of the tubes, m;
- $R_{ox} = 10^{-5}$ m·ºC/W is the thermal resistance of the oxide film on stainless steel tubes;

$$k_{in} = \left[\frac{1}{37,53 \cdot 10^3} + \frac{1,8 \cdot 10^{-3}}{19,14} + 2 \cdot 10^{-5} + \frac{1}{59,4 \cdot 10^3}\right]^{-1} = 6402,4 \text{ W/(m}^2 \cdot {}^\circ\text{C)}$$

- calculate the heat flow

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

$$q'_{in} = 6402{,}4 \cdot (328{,}9 - 285{,}8) = 2{,}75 \cdot 10^5 W/m^2$$

- 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}.

$$\frac{(q'_{in})}{q_{in}} = \frac{2{,}75 \cdot 10^5}{3 \cdot 10^5} = 0{,}92$$

the condition is not right,

second try

$$q_{in} = 2{,}75 \cdot 10^5\ w/m^2$$

$$\alpha_{2in} = \frac{10{,}45 \cdot (2{,}75 \cdot 10^5)^{0.7}}{3{,}3 - 0{,}0113 \cdot (285{,}80 - 100)} = 55{,}8 \cdot 10^3\ W/(m^2 \cdot {}^oC);$$

$$k_{in} = \left[\frac{1}{37{,}53 \cdot 10^3} + \frac{1{,}8 \cdot 10^{-3}}{19{,}14} + 2 \cdot 10^{-5} + \frac{1}{55{,}8 \cdot 10^3}\right]^{-1} = 6359{,}4\ W/(m^2 \cdot {}^oC)$$

$$q'_{in} = 6359{,}4 \cdot (328{,}9 - 285{,}8) = 2{,}75 \cdot 10^5 W/m^2$$

$$\frac{(q'_{in})}{q_{in}} = \frac{2{,}75 \cdot 10^5}{2{,}75 \cdot 10^5} = 1$$

the condition is right.

- Repeat the calculation of heat transfer (α_{out} q_{out}, k_{out}) for the output section of the steam generator.

❖ We assume first value for $q_{out} = 6 \cdot 10^5 w/m^2$

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

$$\alpha_{2out} = \frac{10{,}45 \cdot (6 \cdot 10^5)^{0.7}}{3{,}3 - 0.0113 \cdot (285.8 - 100)} = 96{,}48 \cdot 10^3\ W/(m^2 \cdot {}^oC);$$

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

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

$$t_{tube.out} = 285{,}8 + 0{,}3 \cdot (298 - 285{,}8) = 289{,}52℃$$

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

$$\lambda_{wal.in} = 14{,}48 + 0{,}0156 \cdot 289{,}52 = 19 \text{ W/(m · ºC)};$$

- calculate the heat transfer coefficient

$$k_{out} = \left[\frac{1}{\alpha_{1avr}} + \frac{\delta_{tube}}{\lambda_{tube.in}} + 2 \cdot R_{ox} + \frac{1}{\alpha_{2out}}\right]^{-1}, \text{ W/(m²·ºC)};$$

$$k_{out} = \left[\frac{1}{37{,}53 \cdot 10^3} + \frac{1{,}8 \cdot 10^{-3}}{19} + 2 \cdot 10^{-5} + \frac{1}{96{,}48 \cdot 10^3}\right]^{-1} = 6648{,}1 \text{ W/(m}^2 \cdot \text{ºC}$$

- calculate the heat flow

$$q'_{out} = k_{out} \cdot (t''_1 - t_s), \text{ W/m²};$$

$$q'_{out} = 6648{,}1 \cdot (298{,}2 - 285{,}80) = 2.86 \cdot 10^5 \text{ W/m}^2$$

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

  $\frac{q'_{out}}{q_{out}} = \frac{2{,}86 \cdot 10^5}{6 \cdot 10^5} = 0{,}48$ the condition is not right

  Second try

$$q_{out} = 2{,}86 \cdot 10^5 \text{ W/m}^2$$

$$\alpha_{2out} = \frac{10{,}45 \cdot (2{,}53 \cdot 10^5)^{0.7}}{3{,}3 - 0{,}0113 \cdot (285{,}8 - 100)} = 57{,}51 \cdot 10^3 \text{ W/(m²·ºC)};$$

- calculate the heat transfer coefficient

$$k_{out} = \left[\frac{1}{37{,}53 \cdot 10^3} + \frac{1{,}8 \cdot 10^{-3}}{19} + 2 \cdot 10^{-5} + \frac{1}{57{,}51 \cdot 10^3}\right]^{-1} = 6351{,}5 \text{ W/(m}^2 \cdot \text{ºC}$$

- calculate the heat flow

$$q'_{out} = k_{out} \cdot (t''_1 - t_s), \text{ W/m²};$$

$$q'_{out} = 6351{,}5 \cdot (298{,}2 - 285{,}8) = 2{,}73 \cdot 10^5 \text{ W/m}^2$$

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

$$\frac{q'_{out}}{q_{out}} = \frac{2{,}86 \cdot 10^5}{2{,}73 \cdot 10^5} = 0{,}955 \quad \text{the condition is right}$$

1.1.6. **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.

$$\text{If } \left|\frac{k_{in} - k_{out}}{k_{out}}\right| \le 0{,}25, \rightarrow \frac{6359{,}4 - 6351{,}5}{6351{,}5} = 0{,}0012 \le 0.25$$

Then

$$k_{avr} = \frac{(k_{in} + k_{out})}{2} = \frac{6359{,}4 + 6351{,}5}{2} = 6355{,}5 \frac{\text{W}}{\text{m}^2 \cdot \text{ºC}}$$

1.1.7. **Determine the area of the heat exchange surface**

$$F = \frac{k_{sf} \cdot Q_{sg}}{k_{avr} \cdot \Delta t_{avr}}$$

Where: -

- k_{sf}= 1,05 ... 1,10 is the safety factor for taking into account deposits and plugged tubes; We will take k_{sf}=1,05.
- k_{avr} is the average heat transfer coefficient,
- Q_{sg} is thermal power of the steam generator kW;
- Δt_{avr} is average temperature head in the steam generator,

$$F = \frac{1{,}05 \cdot (960 \cdot 10^6)}{6355{,}5 \cdot 24{,}64} = 6436{,}24 \text{ m}^2$$

1.1.8. Calculate the average length of one tube of the steam generator

$$l_{avr} = \frac{k_{sf} \cdot F}{\pi \cdot d_{avr} \cdot N_{tube}}$$

Where: -

- d_{avr} is the average diameter of the heat transfer tubes, m;

$$d_{avr} = 0.5 \cdot (d_{out} + d_{in}) = d_{in} + \delta_{tube}$$

$$d_{avr} = \frac{16 + 12{,}45}{2} = 14{,}23 \text{ mm}$$

- N_{tube} is number of tubes in the steam generator.

$$l_{avr} = \frac{1{,}05 \cdot 6436{,}24}{\pi \cdot 0.0142 \cdot 10529} = 14{,}37 \text{ m}$$

1.2. Design calculation of horizontal SG of saturated vapor with U-shaped tubes

1.2.1. 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 (ºC);
- p_2 is working medium pressure, MPa;
- D_{col}^{in} is internal diameter of the collector, m;

D_{col}^{in} =0,75…0,85 m we take it =0,80 m

- S_1 is step between the holes along the height (vertical);

S_1= 0,022…0,025 m we take it 0,023m

- S_2 is step between holes along the circle (horizontal);

S_2= 0,024…0,030 m we take it 0,025m

- 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.

1.2.2. Calculation of the wall thickness of the collector, m

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

Where: -

- p_{1calk} is the rated pressure, MPa;

$$p_{1calk} = 0{,}9 \cdot 1{,}25 \cdot p_{1avr} \approx 0{,}9 \cdot 1{,}25 \cdot p_1 = 19{,}84\ MPa$$

- $[\sigma] = 215$ MPa is nominal stress design for steel 10ГН2МФА;
- φ_{min} is minimum coefficient of strength.

Let's accept the smallest value of

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

$$\varphi_1 = \frac{s_1 - d_{tube}^{out}}{s_1} = \frac{0{,}023 - 0{,}016}{0{,}023} = 0{,}30 \text{ m}$$

$$\varphi_2 = \frac{2 \cdot (s_2 - d_{tube}^{out})}{s_2} = \frac{2 \cdot (0{,}025 - 0{,}016)}{0{,}025} = 0{,}72 \text{ m}$$

So $\varphi_{min} = \varphi_1 = 0{,}30$m

Then

$$\delta_{coll} = \frac{19{,}84 \cdot 0{,}80}{2 \cdot 0{,}30 \cdot 215 - 19{,}84} = 0{,}143 \text{ m}$$

1.2.3. Outer diameter of the collector, m

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

$$D_{col}^{out} = 0{,}80 + (2 \cdot 0{,}143) = 1 \text{ m}$$

1.2.4. Recalculation of step s_2 on to the outer diameter (Fig. 2), m

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

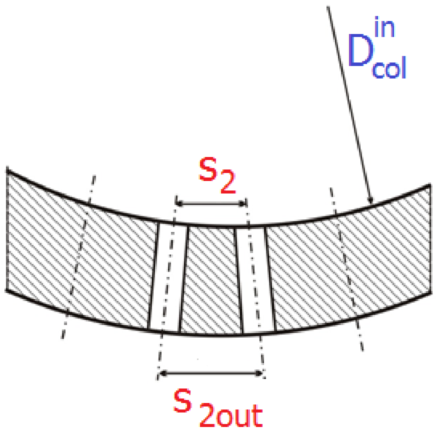


Figure 2. Fragment of the wall of the collector.

$$s_{2out} = 0{,}025 \cdot \left(\frac{1}{0{,}80}\right) = 0{,}03 \text{ m}$$

1.2.5. The length of the arc along the circumference of the collector occupied by tubes of the upper row, m

$$L_{c1} = \pi \cdot D_{col}^{out} = \pi \cdot 1 = 3{,}41 \text{ m}$$

1.2.6. Number of tubes in the upper row, pcs.

$$N_{tube1} = \frac{L_{c1}}{s_{2out}} = \frac{3{,}41}{0{,}03} \approx 100\text{m}$$

1.2.7. The maximum width of the tube bundle at the level of the upper row of tubes (taking into account 3 vertical corridors), m

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

where $B_{cor} = 0{,}15\ldots0{,}2$ m is width of vertical corridors. We take it 0,15 m

$$B_{bund}^{max} = (100 \cdot 0{,}03) + (3 \cdot 0{,}15) = 3{,}86 \text{ m}$$

1.2.8. Width of the heat exchange tube bundle package, m

$$B_{pack} = \frac{B_{bund}^{max} - 3 \cdot B_{cor}}{2}$$

$$B_{pack} = \frac{3{,}86 - (3 \cdot 0{,}15)}{2} = 1{,}71 \text{ m}$$

1.2.9. The distance between the axes of the collectors, m

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

$$B_{dac} = (2 \cdot 1{,}71) + (2 \cdot 0{,}15) = 3{,}71 \text{ m}$$

1.2.10. Width of submerged perforated plate (PP), m

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

$$B_{pp} = 1{,}1 \cdot B_{bund}^{max} = 1{,}1 \cdot 3{,}86 = 4{,}25 \text{ m}$$

1.2.11. SG vessel width at level perforated plate, m

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

where $B_{gap} = 0{,}15\ldots0{,}25$ 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. we take it =0,15 m

$$B_{ves.pp} = 4{,}25 + (2 \cdot 0.15) = 4{,}55 \text{ m}$$

1.2.12. Height of the location of the submerged perforated plate relative to the horizontal axis of the PG vessel, m

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

Where: -

- $h_0 = 0{,}2\ldots0{,}35$ m is height of the arrangement of the upper row of tubes relative to the horizontal axis of the SG; we take it 0,25m
- $h_1 = 0{,}2\ldots0{,}35$ m is the height of the location of the weight level of water above the upper row of tubes; we take it 0,25 m
- $h_{wl} = 0{,}1$ m is height of the weight level above the submerged perforated plate.

$$h_{pp} = 0{,}25 + 0{,}25 + 0{,}1 = 0{,}6 \text{ m}$$

1.2.13. The distance of the lower row of pipes of the heat exchange surface from the lower generatrix of the steam generator vessel.

Take equal $h_{dlr} = 0{,}08\ldots0{,}120$ m.

$$h_{dlr} = 0{,}10 \text{ m}$$

1.2.14. Internal diameter of the steam generator housing, m

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

$$D_{ves.in} = \sqrt{(4 \cdot 0{,}6^2) + 4{,}55^2} = 4{,}70 \text{ m}$$

1.2.15. Area of the evaporation surface, m²

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

$$F_{es} = 4{,}55 \cdot 14{,}37 = 65{,}32 \text{ m}^2$$

1.2.16. Superficial steam velocity, m/s

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

Where: -

- ρ_2'' is density of saturated vapor at the pressure p_2 of the working fluid, kg/m³.

$$\rho_2'' = f(p_2) = f(7) = 36{,}52 \text{ kg/m}^3$$

$$w_o'' = \frac{403{,}72}{65{,}32 \cdot 36{,}52} = 0{,}209 \text{ m/s}$$

1.2.17. The true volumetric vapor content in the water layer above the submerged perforated plate, m

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

$$\varphi_{bub} = \frac{0{,}209}{0{,}209 + (0{,}65 - 0{,}039 \cdot 7)} = 0{,}36 \text{ m}$$

1.2.18. Actual (real) water level above the submerged perforated plate, m

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

$$h_{real} = \frac{0{,}1}{(1 - 0{,}36)} = 0{,}16 \text{ m}$$

1.2.19. Height of steam volume, m

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

$$h_{sv} = \frac{4{,}70}{2} - (0{,}6 + 0{,}16) = 1{,}60 \text{ m}$$

1.2.20. Characteristics of steam outlet nozzles

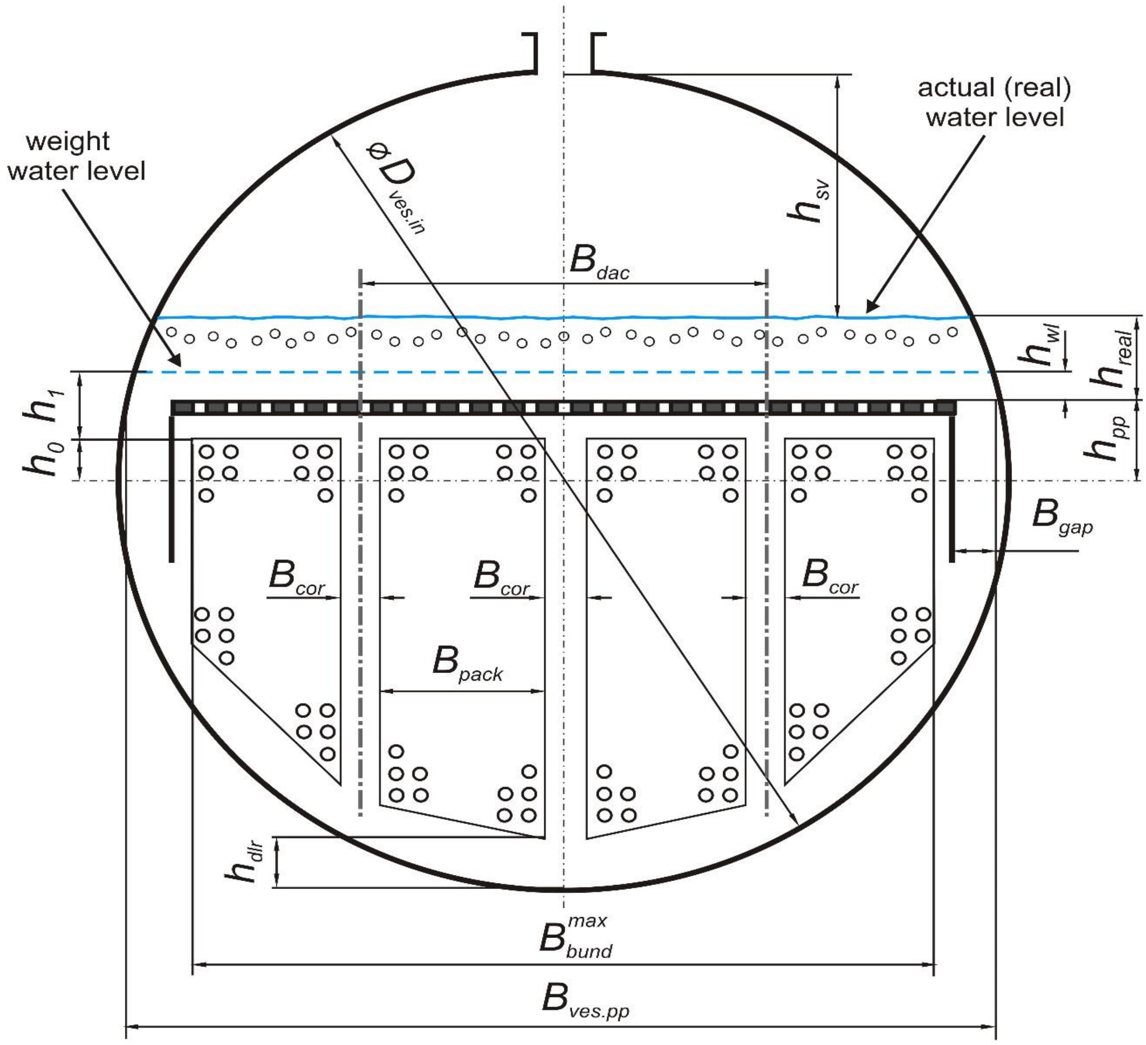
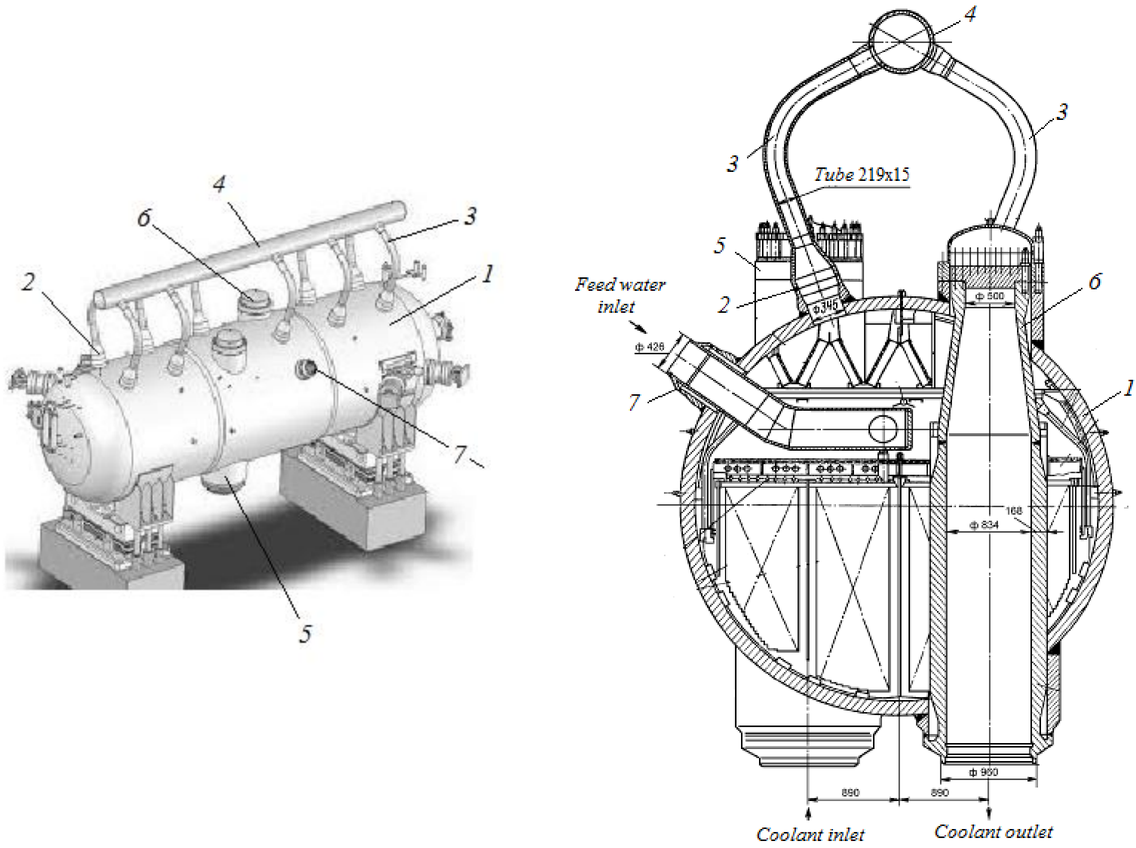


Figure 3. To determine the main layout dimensions horizontal SG



a) b)

Figure 4. 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.

1.2.20.1. The inner diameter of the steam outlet nozzles $d_{noz.in}$ can be determined from the following continuity equation

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

Where: -

- $N_{noz} = 8 \ldots 10$ pc. is number of steam outlet nozzles; take it $N_{noz} = 10$ pc
- $w_{noz} = 30 \ldots 40$ m/s is steam speed in steam outlet nozzles; take it $w_{noz} = 35\ m/s$
- D_2 is mass flow of steam, kg/s;

- ρ_2'' is density of saturated steam at the pressure p_2, kg/m³.

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

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

$$d_{noz}^{in} = \sqrt{\frac{4 \cdot 403{,}72}{10 \cdot \pi \cdot 36{,}52 \cdot 35}} = 0{,}22 \text{ m}$$

1.2.21. Characteristics of the feed pipe

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

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

Where: -

- $w_{fw} = 4\ldots5$ m/s is feed water speed in feed pipe; we take it 5 m/s
- D_{fw} is mass flow of feed water, kg/s;
- ρ_{fw} is density of feed water, kg/m³.

$$\rho_{fw} = f(p_2,\ t_{fw}) = 868{,}75 \text{ kg/m}^3$$

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

$$d_{fw}^{in} = \sqrt{\frac{4 \cdot 499{,}57}{\pi \cdot 868{,}75 \cdot 5}} = 0{,}38 \text{ m}$$

1.3. 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 "Thermohydraulic calculation". The mechanical calculation of the collectors was carried out in section 2 "Design calculation".

The mechanical calculation procedure for the steam generator housing is given below.

- Calculation of the SG vessel

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

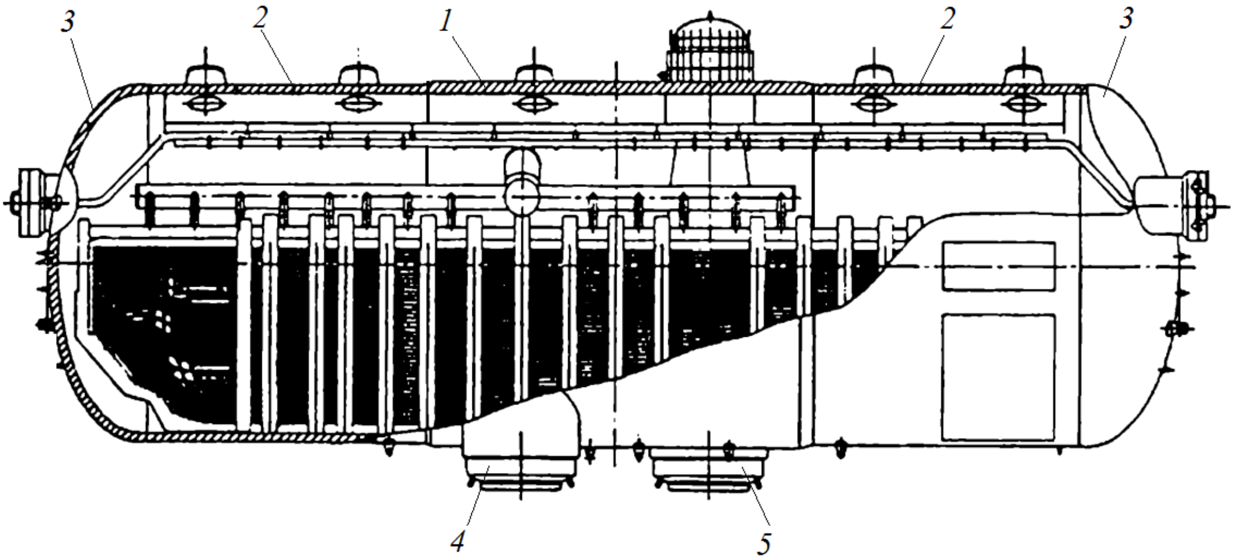


Figure 5. Longitudinal section of a horizontal steam generator:
1 is central shell; 2 are side shells; 3 are bottoms; 4 - input collector of the coolant; 5 - output collector of the coolant

1.4. Calculation of the wall thickness of the shell

1.4.1. Calculation of the wall thickness of the side shell

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

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

where: -

- δ_{vss} is in m;
- $D_{ves.in}$ 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} is the rated (design) pressure, MPa;

$$p_{calc} = 0{,}9 \cdot 1{,}25 \cdot p_2 = 0{,}9 \cdot 1{,}25 \cdot 7 = 7{,}87 \text{ Mpa}$$

- $ts_{vss.max}$ is maximum operating temperature of the side shell, ºC;
- 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.

- [σ]is nominal stress design, MPa**;**

Calculate nominal stress design

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

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

Here n_{sl}=2,6 and $n_{0,2}$=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;

- 10ГН2МФА type steel is used for manufacturing steam generator vessels in Russia (Table 6).

Table 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

$$[\sigma] = \min\left\{\frac{481}{2.6} = 185;\ \frac{304}{1.5} = 202.67\right\} = 185 \text{ MPa}$$

$$\delta_{vss} = \frac{7{,}87 \cdot 4{,}70}{2 \cdot 1 \cdot 185 - 7{,}87} + 0 = 0{,}102 \text{ m} \approx 105\text{mm}$$

1.4.2. 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)

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

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.

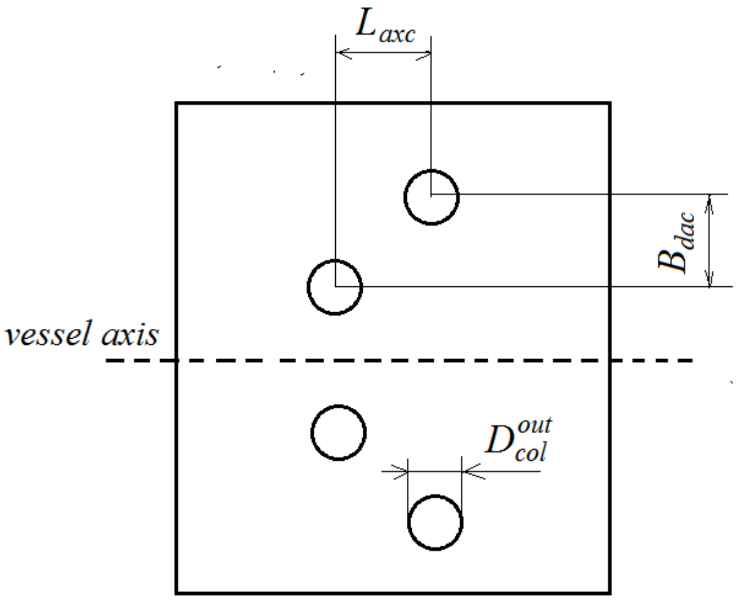


Fig. 6. To the calculation of the strength coefficient

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.

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

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

$$\varphi_3 = \frac{1 - \frac{D_{col}^{out}}{L_{axc}} \cdot \frac{1}{\sqrt{1 + m^2}}}{\sqrt{1 - 0.75 \cdot \left(\frac{m^2}{1 + m^2}\right)^2}}$$

Where: -

- δ_{vcs} is in m;
- B_{dac} is the radial distance between the axes of the collectors, m.
- L_{axc} is axial distance between collector axes, m;

$$L_{axc} \approx 2 \cdot D_{col}^{out} = 2 \cdot 1{,}086 = 2{,}17 \text{ m}$$

$$\text{m} = \frac{\text{B}_{\text{dac}}}{\text{L}_{\text{axc}}} = \frac{3{,}71}{2{,}17} = 1{,}71 \text{ m}$$

so $\varphi_1 = 0{,}75$, $\varphi_2 = 0{,}71$, $\varphi_3 = 0{,}98$

$$\varphi = min\{\varphi_1,\ \varphi_2,\ \varphi_3\} = \varphi_2 = 0{,}71$$

$$\delta_{\text{vcs}} = \frac{7{,}87 \cdot 4{,}70}{2 \cdot 0{,}71 \cdot 185 - 7{,}87} = 0.146 \text{ m } \approx 145 \text{ mm}$$

1.5. Calculation of the thickness of bottom

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

where: -

- δ_{bot} is in m;
- h is height of the bottom, m.

  It can be calculated from relation $\frac{h}{D_{ves.in}} \geq 0{,}2$. Then we take $h = 0{,}94\ m$
- $\varphi = 1$ is coefficient of strength.

$$\delta_{bot} = \frac{7{,}87 \cdot 4{,}70}{4 \cdot 1 \cdot 185} \cdot \frac{4{,}70}{2 \cdot 0{,}94} = 0{,}125 \text{ m}$$

1.6. Hydraulic calculation of the steam generator

The purpose of hydraulic calculation of the steam generator is to determine the pressure loss 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

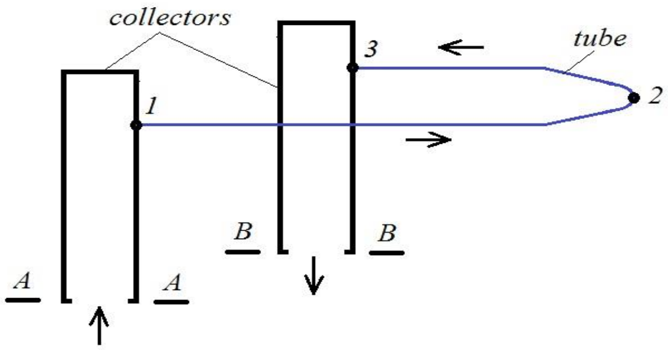


Figure 7. Flow diagram of the coolant circulation in a horizontal steam generator

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

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

Where: -

- $\Delta p_{col.in}$ and $\Delta p_{col.out}$ are hydraulic resistances of the input and output collectors;
- friction pressure losses Δp_{fr}
- local pressure losses Δp_{loc}
- static pressure differences Δp_{cpd} and pressure losses due to flow acceleration Δp_{acc}

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

- 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.

- Then formula will be

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

1.6.1. calculate the friction pressure losses

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

Where: -

- L is plot length, m;
- d_h is characteristic size (hydraulic diameter), m;
- ρ_{avr} is the average density of the coolant in the SG, kg/m³;
- *w* is the characteristic velocity of the coolant, m/s;
- ξ_{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 $\Delta_{col} \le 0.1 \cdot 10^{-3}$ m;

  For tubes made of austenitic steel $\Delta_{tube} \le 0.05 \cdot 10^{-3}$ m;

- Re is Reynolds number;

$$Re = \frac{w \cdot d_h}{\nu_{avr}}$$

- ν_{avr} is the average kinematic viscosity of the coolant in the SG;

- Lifting movement of the coolant in the inlet collector (from section A-A to point 1)

$$d_h = D_{col}^{in} = 0{,}80 \text{ m}$$

$$L \approx \frac{D_{ves.in}}{2} = \frac{4.91}{2} = 2{,}35 \text{ m}$$

$$w_{c_{in}} = \frac{4 \cdot G_1}{\pi \cdot \rho_{in} \cdot d_c^2} = \frac{4 \cdot 5393{,}2}{\pi \cdot 662{,}34 \cdot 0{,}80^2} = 16{,}21 \text{ m/s}$$

$$Re = \frac{w_{c_{in}} \cdot d_h}{\nu_{avr}} = \frac{16{,}21 \cdot 0{,}80}{1.2 \cdot 10^{-7}} = 10{,}83 \cdot 10^7$$

$$\xi_{fr} = 0.11 \cdot \left[\left(\frac{0.1 \cdot 10^{-3}}{0{,}80}\right) + \left(\frac{68}{10{,}83 \cdot 10^7}\right)\right]^{0.25} = 0{,}0116$$

$$\Delta p_{fr} = 0{,}0116 \cdot \frac{2{,}35}{0{,}80} \cdot \frac{701{,}51 \cdot 16{,}21^2}{2} = 3{,}15 \text{ kPa}$$

- Movement of the coolant in heat exchange tubes (from point 1 to point 3)

$$d_h = d_{in} = 12{,}45 \cdot 10^{-3} \text{m}$$

$$L = l_{avg} = 14{,}37 \text{ m}$$

$$Re = \frac{w_{tube} \cdot d_h}{\nu_{avr}} = \frac{6 \cdot (12{,}45 \cdot 10^{-3})}{1{,}2 \cdot 10^{-7}} = 6{,}24 \cdot 10^5$$

$$\xi_{fr} = 0.11 \cdot \left[\left(\frac{0.05 \cdot 10^{-3}}{12{,}45 \cdot 10^{-3}}\right) + \left(\frac{68}{6{,}24 \cdot 10^5}\right)\right]^{0.25} = 0{,}0279$$

$$\Delta p_{fr} = 0{,}0279 \cdot \frac{14{,}37}{12{,}45 \cdot 10^{-3}} \cdot \frac{701{,}51 \cdot 6^2}{2} = 406{,}25\ \text{kPa}$$

- Downward movement of the coolant in the output collector (from point 3 to section B-B)

$$d_h = D_{col}^{in} = 1{,}08\ \text{m}$$

$$L \approx \frac{D_{ves.in}}{2} = \frac{4{,}70}{2} = 2{,}35\ \text{m}$$

$$w_{c_{out}} = \frac{4 \cdot G_1}{\pi \cdot \rho_{out} \cdot d_c^2} = \frac{4 \cdot 5393{,}2}{\pi \cdot 734{,}07 \cdot 1{,}08^2} = 14{,}62\ \text{m/s}$$

$$Re = \frac{w_{c_{out}} \cdot d_h}{\nu_{avr}} = \frac{14{,}62 \cdot 1{,}08}{1.2 \cdot 10^{-7}} = 13{,}26 \cdot 10^7$$

$$\xi_{fr} = 0.11 \cdot \left[\left(\frac{0{,}1 \cdot 10^{-3}}{1{,}08}\right) + \left(\frac{68}{13{,}26 \cdot 10^7}\right)\right]^{0.25} = 0.0108$$

$$\Delta p_{fr} = 0{,}0108 \cdot \frac{2{,}35}{1{,}08} \cdot \frac{701{,}51 \cdot 14{,}62^2}{2} = 1{,}75\ \text{kPa}$$

1.6.2. calculate of local pressure losses

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

Where: -

- ξ_{loc} is local resistance coefficient.

- Inlet of the coolant to the tubes from the collector (point 1)

$$\xi_{loc} = 0{,}5$$

$$\Delta p_{loc} = 0.5 \cdot \frac{701{,}51 \cdot 6^2}{2} = 6{,}3\ \text{kPa}$$

- Output of the coolant from the tubes to the collector (point 3)

$$\xi_{loc} = 1$$

$$\Delta p_{loc} = 1 \cdot \frac{701{,}51 \cdot 6^2}{2} = 12{,}62\ \text{kPa}$$

Then

$$\Delta p_{tot} = 3{,}15 + 406{,}25 + 1{,}75 + 6{,}31 + 12{,}62 = 430\ \text{kPa} = 0{,}430\ \text{MPa}$$

1.7. 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

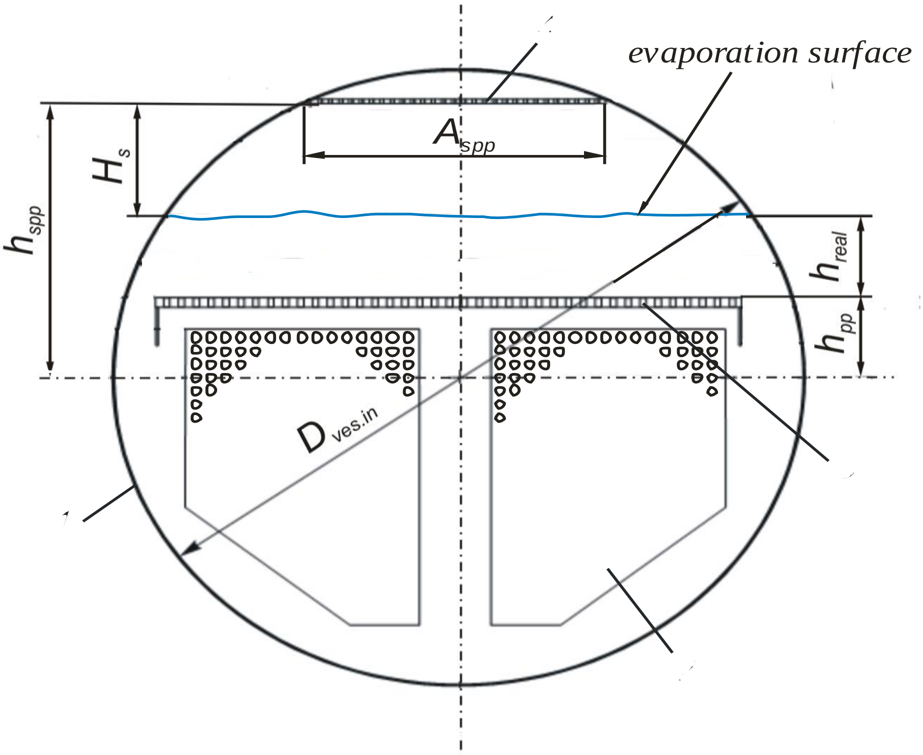


Figure 8. To the calculation of separation
1 is vessel; 2 are tubes; 3 is submerged perforated plate; 4 is steam-receiving perforated plate

1.7.1. Determination of the area steam-receiving perforated plate

$$F_{spp} = A_{spp} \cdot l_{avr} \;\; m^2$$

Where: -

- A_{spp} is width of the steam-receiving perforated plate m²

$$A_{spp} = 2 \cdot \sqrt{\left(\frac{D_{ves.in}}{2}\right)^2 - \left(h_{spp}\right)^2}$$

- h_{spp} is height of the steam-receiving perforated plate relative to the axis of the SG vessel, m.

$$h_{spp} = (0{,}8 \ldots 0{,}85) \cdot \frac{D_{ves.in}}{2} \rightarrow h_{spp} = \frac{0{,}80 D_{ves.in}}{2} = 1{,}88 \text{ m}$$

$$A_{spp} = 2 \cdot \sqrt{\left(\frac{4,70}{2}\right)^2 - (1,88)^2} = 2,82 \text{ m}$$

$$F_{spp} = 2,82 \cdot 14,37 = 41 \text{ m}^2$$

1.7.2. Distance (height) from the evaporation surface to steam-receiving perforated plate

$$H_s = h_{spp} - h_{pp} - h_{real}, \text{ m}$$

Where: -

- h_{pp} is height of the location of the submerged perforated plate relative to the horizontal axis of the PG vessel.
- h_{real} is actual (real) water level above the submerged perforated plate.

$$H_s = 1,88 - 0,6 - 0,16 = 1,13 \text{ m}$$

1.7.3. Steam velocity before steam-receiving perforated plate

$$w''_{spp} = \frac{D_2}{\rho'' \cdot F_{spp}} = \frac{403,72}{36,52 \cdot 41} = 0,34\ m/s$$

1.7.4. Determining the critical height of the steam volume

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

Where: -

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

Where: -

ρ''= 36,52 kg/m³ is vapor density at saturation at pressure;
ρ'= 739,72 kg/m³ is water density at saturation at pressure.

$$F(p) = 3,45 \cdot 10^3 \cdot \left[\frac{36,52 \cdot (739,72)^2}{(739,72 - 36,52)^6}\right]^{0,25} = 12,37$$

$$H_{sv}^{cr} = 0.087 \cdot [0,209 \cdot 12,37]^{1,3} = 0,30 \text{ m}$$

1.7.5. Steam moisture at the top of the steam volume

- $H_s > H_{sv}^{cr}$,

Then

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

Where: -

- M is a pressure dependent coefficient.

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

p_2 in MPa.

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

$$Y = (27,82 \cdot 10^{-4}) \cdot \frac{(0.209)^{2,76}}{1,13^{2.3}} = 2,81 \cdot 10^{-5} = 0.00281\%$$

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 $Y \leq Y_{cr}$.

1.8. 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.

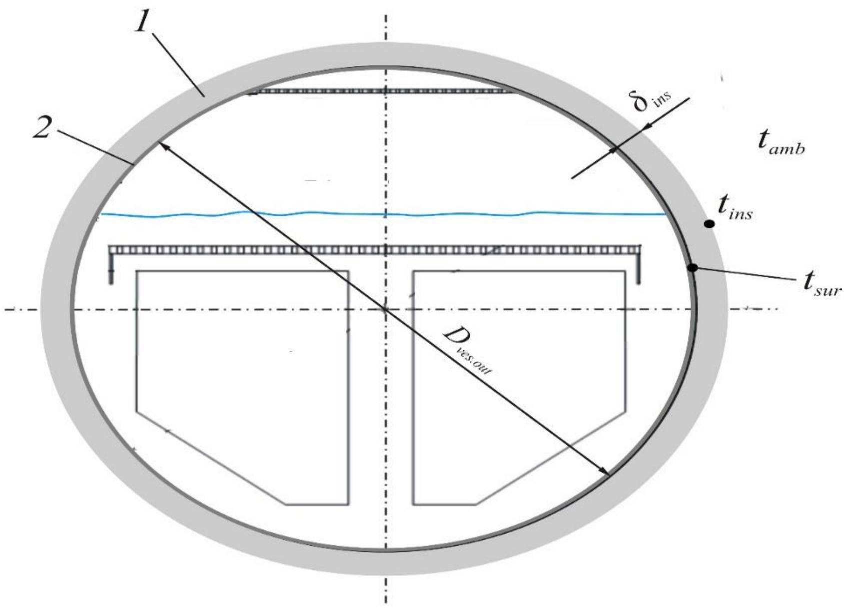


Fig. 9. Design scheme of single-layer thermal insulation with a coating layer: 1 is thermal insulation; 2 is vessel of SG

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

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

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

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

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

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

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

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

Where: -

- δ_{ins} is the thickness of the insulation layer, m
- d_{ins} is outer diameter of insulation, m
- d_{out} is diameter of the external insulated object, m

$$d_{out} = D_{ves.out} = D_{ves.in} + 2 \cdot \delta_{vss} \ ;$$

$$d_{out} = 4{,}70 + (2 \cdot 0{,}102) = 4{,}91 \text{ m}$$

- t_{sur} is surface temperature of the insulated object

$$t_{sur} = t_s = 313{,}55 \text{ ℃}$$

- $t_{amb} = 20 \ldots 25$ °C is the temperature of the ambient air (environment); take 23℃.
- $\alpha_{out} = 6 \ldots 10$ W/(m²·K) - coefficient of heat transfer from the insulation surface to the surrounding air; take it 8 $w/(m^2 \cdot K)$.
- λ_{ins} is coefficient of thermal conductivity of the insulation layer, $W/(m \cdot K)$. It determined by the formula

$\lambda_{ins} = 0.0002 \cdot t_{ins}^{avr} + 0.036$ for super-thin fiberglass mats;

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

$$t_{ins}^{avr} = 0.5 \cdot (t_{sur} + t_{ins}) = 0.5 \cdot (313{,}55 + 45) = 168{,}2\text{°C}$$

$$\lambda_{ins} = (0.0002 \cdot 168{,}2) + 0.036 = 0{,}070 \text{ W/(m} \cdot \text{K)}.$$

$$\delta_{ins} = \frac{0.070 \cdot (313{,}55 - 45)}{8 \cdot (45 - 23)} = 0{,}106\, m \approx 106\, mm$$

2. NPP CALCULATIONS

2.1. Initial data of term project on “Nuclear power plants” for thermal calculation.

Table 7– Initial Data

N_e , MW	1200
P_0 , MPa	7
t_0 , ℃	285,80
P_c , kPa	4
Superheater	double-stage
t_{fw} , ℃	200
P_d , MPa	0,7
n HPH	-
n MLPH	-

2.2. Calculation part of the work

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

Feedwater regenerative heater

Low pressure regenerative heater

2.2.1 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 $\Delta t_d = 12 \div 15$ ℃
  assume $\Delta t_d = 12$ ℃

$$t_d = f(p_d) = f(0{,}7) = 165 \text{ ℃}$$

$$t_{mc} = t_d - \Delta t_d = 165 - 12 = 153 \text{ ℃}$$

2.2.2. Main condensate temperature after seal coolers and ejector temperature $\mathbf{t_{cse}}$

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

Where: -

- t_c is final temperature
- Δt_{cse} is and it between $\Delta t_{cse} = 3 \div 5$℃
  assume $\Delta t_{cse} = 3{,}5$ ℃

$$t_c = f(p_c) = f(0{,}004) = 29\ ℃$$

$$t_{cse} = t_c + \Delta t_{cse} = 29 + 3{,}5 = 32{,}5\ ℃$$

2.2.3. Temperature rise after each low-pressure heater $\mathbf{\Delta t_{LPH} = 25 \div 35}$ assume $\mathbf{\Delta t_{LPH} = 31}$℃

$$\Delta t_{LPH} = \frac{t_{mc} - t_{cse}}{n_{LPH}}$$

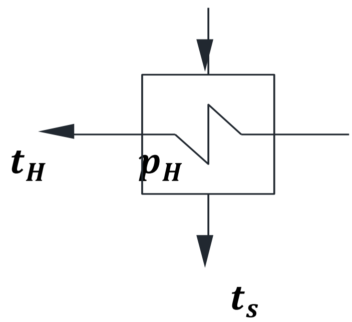
- where n_{LPH} number of low-pressure reheaters,

$$n_{LPH} = \frac{t_{mc} - t_{cse}}{\Delta t_{LPH}} = \frac{153 - 32{,}5}{31} = 3{,}88 \approx 4$$

Real temperature rises after each heater

$$\Delta t_{LPH} = \frac{t_{mc} - t_{cse}}{n_{LPH}} = \frac{153 - 32{,}5}{4} = 30{,}1℃$$

- **Closed type**



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

where $\theta = (1 \div 2)$ is subcooled temperature in reheater, assume 1,5℃

$$\boldsymbol{t_{Hj} = t_{Hj+1} + \Delta t_{LPH}; p_{exj} = (1,02 \div 1,05) p_{Hj}; assume = (1,04)}$$

closed

$$t_{H5} = t_{Hcse} + \Delta t_{LPH} = 32{,}5 + 30{,}1 = 62{,}6\ ℃$$

$$t_{s5} = t_{H5} + \theta_{LPH} = 62{,}6 + 1{,}5 = 64{,}1\ ℃ \rightarrow p_{H5} = f(t_{s5}) = f(64{,}1) = 0{,}024\ MPa$$

$$p_{ex5} = (1{,}04)p_{H5} = 1{,}04 \cdot 0{,}024 = 0{,}025\ MPa$$

closed

$$t_{H4} = t_{H5} + \Delta t_{LPH} = 64{,}1 + 30{,}1 = 92{,}7\ ℃$$

$$t_{s4} = t_{H4} + \theta_{LPH} = 92{,}7 + 1{,}5 = 94{,}2\ ℃ \rightarrow p_{H4} = f(t_{s4}) = f(94{,}2) = 0{,}082\ MPa$$

$$p_{ex4} = (1{,}04)p_{H4} = 1{,}04 \cdot 0{,}082 = 0{,}085\ MPa$$

closed

$$t_{H3} = t_{H4} + \Delta t_{LPH} = 92{,}7 + 30{,}1 = 122{,}83\ ℃$$

$$t_{s3} = t_{H3} + \theta_{LPH} = 122{,}83 + 1{,}5 = 124{,}3\ ℃ \rightarrow p_{H3} = f(t_{s3}) = f(124{,}3) = 0{,}227\ MPa$$

$$p_{ex3} = (1{,}04)p_{H3} = 1{,}04 \cdot 0{,}227 = 0{,}237\ MPa$$

closed

$$t_{H2=mc} = t_{H3} + \Delta t_{LPH} = 122{,}83 + 30{,}1 = 153\ ℃$$

$$t_{s2} = t_{H2} + \theta_{LPH} = 153 + 1{,}5 = 154{,}5\ ℃ \rightarrow p_{H2} = f(t_{s2}) = f(154{,}5) = 0{,}536\ MPa$$

$$p_{ex2} = (1{,}04)p_{H2} = 1{,}04 \cdot 0{,}536 = 0{,}557\ MPa$$

Table 8– Low pressure heater parameters

Type	NO	t_{Hj}, ℃	t_{sj}, ℃	p_{Hj}, MPa	p_{exj}, MPa
CL	2~mc	153	154,5	0,536	0,557
CL	3	122,83	124,3	0,227	0,237
CL	4	92,7	94,2	0,082	0,085
CL	5	62,6	64,1	0,024	0,025
-	cse	32,5	-	-	-

2.2.4. Condensate pumps pressure p_{cp}

- $p_{cp1} = 4 \div 5\ bar$, assume 4,5 bar (0,45 MPa)
- $p_{cp2} = (1{,}1 \div 1{,}4)p_d$, assume 1,35 p_d

$$p_{cp2} = 1{,}35(p_d) = 1{,}35(0{,}7) = 0{,}945\ MPa$$

High pressure feedwater regenerative heater

2.2.5. Temperature of feed water pump t_{fwp}

$$t_{fwp} = f\left(p_{fwp}\,, h_{fwp}\right);$$

Where: -

- p_{fwp} is pressure of feed water pump
- h_{fwp} is enthalpy of feed water pump

$$p_{fwp} = 1{,}25\ \ ; 1{,}3\ p_0 = 1{,}25 p_0$$

$$p_{fwp} = 1{,}25 \cdot 7 = 8{,}750\ MPa$$

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

- h'_d is enthalpy of water in deaerator

$$h'_d = f(p_d) = 697{,}1\ kJ/kg$$

- Δh_{fwp}

$$\Delta h_{fwp} = v \cdot \left(p_{fwp} - p_d\right);$$

- v is specific volume

$$v = f(p_d) = 0{,}001108\ m^3/kg$$

$$\Delta h_{fwp} = 0{,}001108 \cdot (8750 - 700) = 8{,}9\ kJ/kg$$

$$h_{fwp} = 697{,}1 + 8{,}9 = 706{,}1\ kJ/kg$$

So,

$$t_{fwp} = f\left(p_{fwp}, h_{fwp}\right) = 166\ ℃$$

2.2.6. Temperature rise after each high-pressure heater $\Delta t_{HPH} = 25 \div 35$ assume $\Delta t_{HPH} = 34$℃

$$\Delta t_{HPH} = \frac{t_{fw} - t_{fwp}}{z_{HPH}}$$

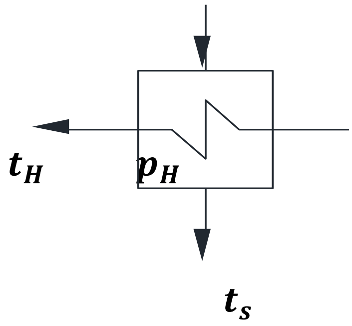
- Where $z_{HPH}\ number\ of\ high - pressure\ reheater$

$$z = \frac{t_{fw} - t_{fwp}}{\Delta t_{HPH}} = \frac{200 - 166}{34} = 1$$

- *Real temperature rises after each heater*

$$\Delta t_{HPH} = \frac{t_{fw} - t_{fwp}}{z_{HPH}} = \frac{200 - 166}{1} = 34℃$$

- **Closed type**



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

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

$$\boldsymbol{t_{Hj} = t_{Hj+1} + \Delta t_{HPH}; p_{exj} = (1.02 \div 1.05)p_{Hj}; \text{assume } (1,04)}$$

closed

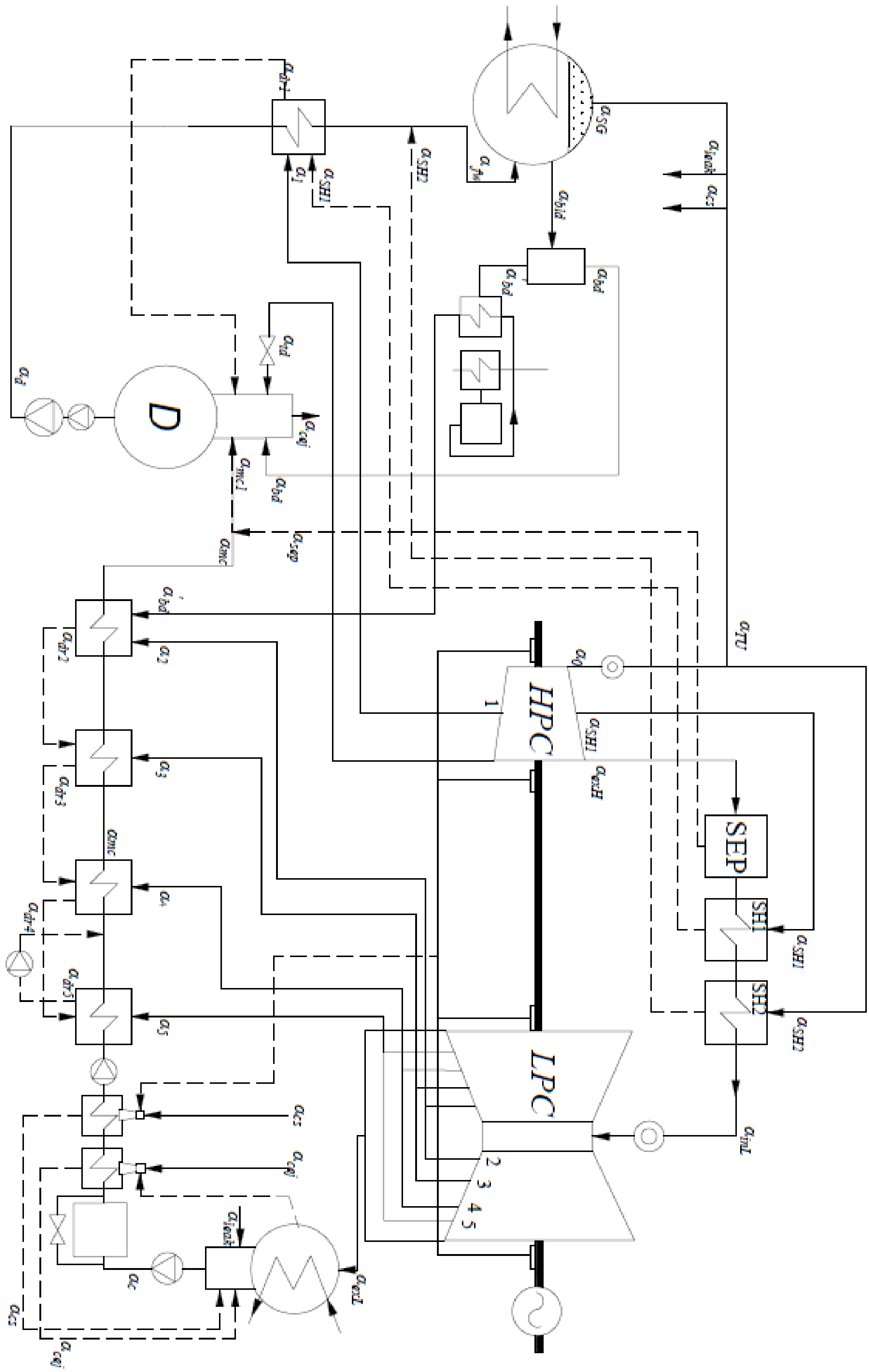
$$t_{H1} = t_{fwp} + \Delta t_{HPH} = 166 + 34 = 200 \text{ ℃}$$

$$t_{s1} = t_{H1} + \theta_{HPH} = 200 + 4 = 204℃ \rightarrow p_{H1} = f(t_{s1}) = f(204) = 1{,}689\ MPa$$

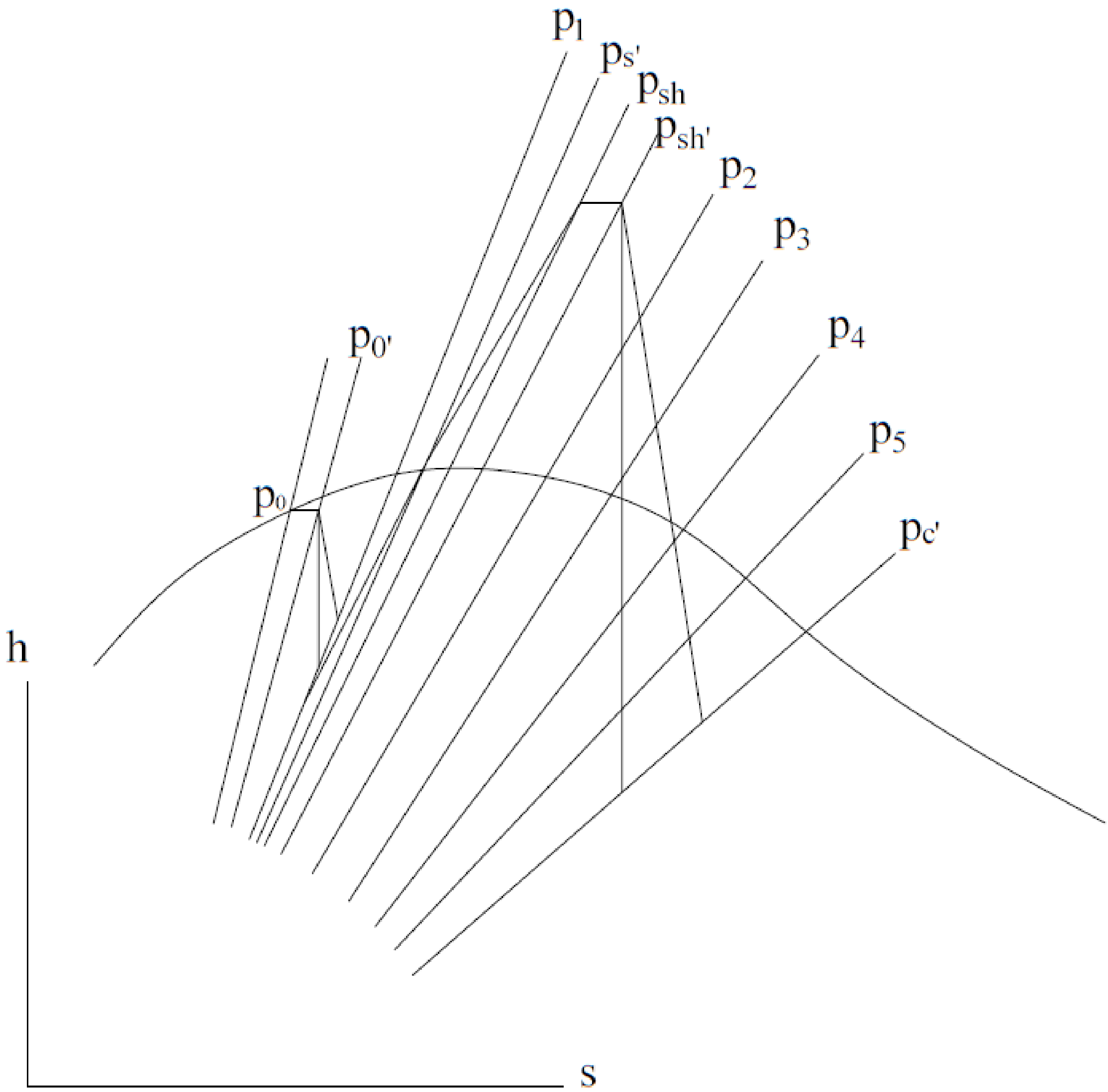
$$p_{ex1} = (1{,}04)p_{H1} = 1{,}04 \cdot 1{,}689 = 1{,}757 MPa$$

Table 9– High pressure heater parameters

Type	NO	t_{Hj} ,℃	t_{sj} ,℃	p_{Hj} , MPa	p$_{exj}$, MPa
CL	1~fw	200	204	1,689	1,757
fwp	fwp	166	-	-	-



D
HPC
LPC
SEP
SH1
SH2



2.3. 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÷5% of p_0

$$p_{0'} = p_0(0{,}95 \div 0{,}97) = p_0\,(0{,}95) = 7(0{,}95) = 6{,}650\ \text{MPa}$$

Steam parameters at 0′

Table 10– Steam parameters (0’)

$p_{0'}$, MPa	6,650
$h_{0'} = h_0$, kJ/kg	2773
$t_{0'} = f(p_{0'}, h_{0'})$, ℃	282,4

$s_{0'} f(p_{0'}, h_{0'})$, kJ/(kg°C)	5,83230

Calculation of processes

I will use two turbines of type k-600-23,5

2.3.2. **For HPC** (High Pressure Cylinder)
with absolute internal efficiency $\eta_{0i}^{HPC} = 0,77$

Isentropic process 1st extraction where $p_1 = p_{ex1} = 1{,}756$ MPa, from *Table 9*

$$s_{0'} = s_{1t} = 5{,}83230\ kJ/(kg°C)$$

$$h_{1t} = f(p_1.s_{0'}) = f(1{,}7566{,}6{,}5{,}83230) = 2585\ kJ/kg$$

$$H_0^{HPC} = h_0 - h_{1t} = 2773 - 2585 = 243\ kJ/kg$$

$$H_i^{HPC} = H_0^{HPC} \cdot \eta_{0i}^{HPC} = 243 \cdot 0{,}77 = 188\ kJ/kg$$

$$h_1 = h_0 - H_i^{HPC} = 2773 - 188 = 2585\ kJ/kg$$

$$s_1 = f(p_1.h_1) = f(1{,}756{,}6\ {,}2585) = 5{,}94627\ kJ/(kg°C)$$

$$t_1 = f(p_1.s_1) = f(1{,}756{,}6\ {,}94627) = 206\ °C$$

Exhaust steam quality from HPC,$x^{HPC} = f(t_2.h_2) = f(165\ {,}2468) = 0{,}85730$ which is allowable

2.3.3. Properties of superheating system

2.3.3.1. Separation

$$p_s = 0{,}7 \text{ MPa}$$

Pressure losses in separator is about 5 %

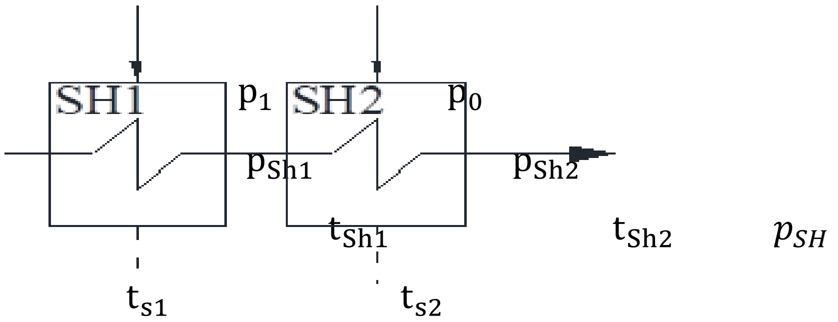
$$p_{s'} = (1 - 0{,}05)p_s = (1 - 0{,}05) \cdot 0{,}7 = 0{,}665 \text{ MPa}$$

Enthalpy after separation $h_{s'}$

$$h_{s'} = f(p_{s'}.x = 1) = f(0{,}665.x = 1) = 2761\ kJ/kg$$

2.3.3.2. Superheating parameters

double-stage reheater



Pressure losses in superheater p_{SH} is about 95% of $p_{s'}$

$$p_{SH} = (0,95)p_{s'} = (0,95) \cdot 0,665 = 0,632 \text{ MPa}$$

- $\Delta t_R = 15 \div 20°C$ for the first stage, assume 15 °C
- $\Delta t_R = 10 \div 15°C$ for the second stage, assume 15 °C

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

Sh2

$$t_{Sh2} = t_o - \Delta t_R = 285,8 - 15 = 271℃ \ ;$$

$$p_{Sh2} = f(t_{Sh2}) = f(271) = 0,632 \ MPa$$

Enthalpy of steam after second superheater h_{sh2}

$$h_{Sh2} = f(p_{SH}.t_{sh2}) = f(0,632\ ,271) = 3000\ kJ/kg$$

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

$$\Delta h_R = \frac{h_{Sh2} - h'_s}{2} = \frac{3000 - 2761}{2} = 120\ kJ/kg$$

2.3.4. **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

$$p_{SH'} = p_{SH}(0,95 \div 0,97) = \ p_{SH} \ \cdot (0,95) = \ 0,632 \cdot (0,95) = 0,60 \text{ MPa}$$

At LPC Exhaust $p_{c'} = (1,03 \div 1,05)p_c = 1,03 \cdot p_c = 1,03 \cdot 0.004 = 0,0041\ MPa$

Steam parameters at 0′

Table 11- Steam parameters (0’)

$p_{SH'}$, MPa	0,60
$h_{SH'} = \mathrm{h_{Sh2}}$, kJ/kg	3000
$t_{SH'} = f(p_{SH'}, h_{SH'})$, °C	270,8
$s_{SH'}\mathrm{f}(p_{SH'}, h_{SH'})$, kJ/(kg°C)	7,26327

with absolute internal efficiency $\eta_{0i}^{LPC} = 0{,}77$

Isentropic process 2nd extraction where $p_2 = p_{ex2} = 0{,}557\ MPa$, from *Table 8*

$$s_{SH'} = \mathrm{s_{2t}} = 7{,}26327\ \mathrm{kJ/(kg°C)}$$

$$h_{2t} = f(p_2.s_{SH'}) = f(0{,}557\ , 7{,}26327) = 2982\ kJ/kg$$

$$H_0^{LPC} = h_{SH'} - h_{2t} = 3000 - 2982 = 18\ kJ/kg$$

$$H_i^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 18 \cdot 0{,}77 = 14\ kJ/kg$$

$$h_2 = h_{SH'} - H_i^{LPC} = 3000 - 14 = 2986\ kJ/kg$$

$$\mathrm{s_2} = f(\mathrm{p_2}.h_2) = f(0{,}55\ , 2986) = 7{,}27084\ \mathrm{kJ/(kg°C)}$$

$$t_2 = f(p_2.s_2) = f(0{,}557\ , 7{,}27084) = 263\ \mathrm{°C}$$

Isentropic process 3rd extraction where $\mathrm{p_3} = \mathrm{p_{ex3}} = 0{,}237\ \mathrm{MPa}$, from *Table 8*

$$s_{SH'} = s_{3t} = 7{,}26327\ kJ/(kg\mathrm{°C})$$

$$h_{3t} = f(p_3.s_{SH'}) = f(0{,}23\ , 7{,}36593) = 2794\ kJ/kg$$

$$H_0^{LPC} = h_{SH'} - h_{3t} = 3000 - 2794 = 206\ kJ/kg$$

$$H_i^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 206 \cdot 0{,}77 = 160\ kJ/kg$$

$$h_3 = h_{SH'} - H_i^{LPC} = 3000 - 160 = 2840\ kJ/kg$$

$$s_3 = f(p_3.h_3) = f(0{,}23\ , 2840) = 7{,}36593\ kJ/(kg\mathrm{°C})$$

$$t_3 = f(p_3.s_3) = f(0{,}23\ , 7{,}36593) = 186\mathrm{°C}$$

Isentropic process 4th extraction where $\mathrm{p_4 = p_{ex4}} = 0{,}085$ MPa, from *Table 8*

$$s_{SH'} = s_{4t} = 7{,}26327\ kJ/(kg°C)$$

$$h_{4t} = f(p_4 . s_{SH'}) = f(0{,}085\ , 7{,}26327) = 2613\ kJ/kg$$

$$H_0^{LPC} = h_{SH'} - h_{4t} = 3000 - 2613 = 387\ kJ/kg$$

$$H_i^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 387 \cdot 0{,}77 = 301\ kJ/kg$$

$$h_4 = h_{SH'} - H_i^{LPC} = 3000 - 301 = 2700\ kJ/kg$$

$$s_4 = f(p_4 . h_4) = f(0{,}085\ , 2700) = 7{,}49569\ kJ/(kg°C)$$

$$t_4 = f(p_4 . s_4) = f(0{,}085\ , 7{,}49569) = 111\ ℃$$

Isentropic process 5th extraction where $p_5 = p_{ex5} = 0{,}025\ MPa$, from *Table 8*

$$s_{SH'} = s_{5t} = 7{,}26327\ kJ/(kg°C)$$

$$h_{5t} = f(p_5 . s_{SH'}) = f(0{,}025\ , 7{,}26327) = 2426\ kJ/kg$$

$$H_0^{LPC} = h_{SH'} - h_{5t} = 3000 - 2426 = 575\ kJ/kg$$

$$H_i^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 575 \cdot 0{,}77 = 446\ kJ/kg$$

$$h_5 = h_{SH'} - H_i^{LPC} = 3000 - 446 = 2554\ kJ/kg$$

$$s_5 = f(p_5 . h_5) = f(0{,}025\ , 2512) = 7{,}64224\ kJ/(kg°C)$$

$$t_5 = f(p_5 , s_5) = f(0{,}025\ , 7{,}64224) = 65\ ℃$$

Isentropic process C' point

$$s_{SH'} = s_{c't} = 7{,}26327\ kJ/(kg°C)$$

$$h_{c't} = f(p_{c'} . s_{SH'}) = f(0{,}0041\ , 7{,}26327) = 2192\ kJ/kg$$

$$H_0^{LPC} = h_{SH'} - h_{c't} = 3000 - 2192 = 809\ kJ/kg$$

$$H_i^{LPC} = H_0^{LPC} \cdot \eta_{0i}^{LPC} = 809 \cdot 0{,}77 = 628\ kJ/kg$$

$$h_{c'} = h_{SH'} - H_i^{LPC} = 3000 - 628 = 2372\ kJ/kg$$

$$s_{c'} = f(p_{c'} . h_{c'}) = f(0{,}0041\ , 2372) = 7{,}85922\ kJ/(kg°C)$$

$$t_{c'} = f(p_{c'}.s_{c'}) = f(0{,}0041\ , 7{,}859222) = 29{,}5\ ℃$$

Exhaust steam quality from LPC, $x^{LPC} = f(t_{c'}.h_{c'}) = f(29{,}5\ , 2372) = 0{,}92485$ which is allowable for low-speed turbine (25Hz)

2.4. Underproduction factor

$$y_i = \frac{H_i - H_j}{H_i}$$

For turbine with steam separating and superheating system

$$H_i = (h_0 - h_{c'}) + (h_{SH2} - h_s) = (2773 - 2372) + (3000 - 2468) = 933\ kJ/kg$$

where h_s, Enthalpy before separation. $\Delta h_{SSH} = \mathrm{h_{SH2}} - h_s = 3000 - 2468 = 532\ kj/kg$

For extraction before separating and superheating $H_j = h_0 - h_j$

$$H_0 = h_{0'} - h_{0'} = 2773 - 2773 = 0\ kJ/kg$$

$$H_1 = h_0 - h_1 = 2773 - 2585 = 188\ kJ/kg$$

$$H_{td} = h_0 - h_{end} = 2773 - 2468 = 305\ kJ/kg$$

For extraction after separating and superheating $H_j = \left(h_0 - h_j\right) + \Delta h_{SSH}$

$$H_2 = (h_0 - h_2) + \Delta h_{SSH} = (2773 - 2986) + 532 = 319\ kJ/kg$$

$$H_3 = (h_0 - h_3) + \Delta h_{SSH} = (2773 - 2840) + 532 = 465\ kJ/kg$$

$$H_4 = (h_0 - h_4) + \Delta h_{SSH} = (2773 - 2700) + 532 = 605\ kJ/kg$$

$$H_5 = (h_0 - h_5) + \Delta h_{SSH} = (2773 - 2554) + 532 = 751\ kJ/kg$$

$$H_{c'} = (h_0 - h_{c'}) + \Delta h_{SSH} = (2773 - 2372) + 532 = 933\ kJ/kg$$

$$y_0 = \frac{H_i - H_0}{H_i} = \frac{933 - 0}{933} = 1$$

$$y_1 = \frac{H_i - H_1}{H_i} = \frac{933 - 188}{933} = 0{,}7984$$

$$y_{td} = \frac{H_i - H_{td}}{H_i} = \frac{933 - 305}{933} = 0{,}6735$$

$$y_2 = \frac{H_i - H_2}{H_i} = \frac{933 - 319}{933} = 0{,}6584$$

$$y_3 = \frac{H_i - H_3}{H_i} = \frac{933 - 465}{933} = 0{,}5019$$

$$y_4 = \frac{H_i - H_4}{H_i} = \frac{933 - 605}{933} = 0{,}3513$$

$$y_5 = \frac{H_i - H_5}{H_i} = \frac{933 - 751}{933} = 0{,}1950$$

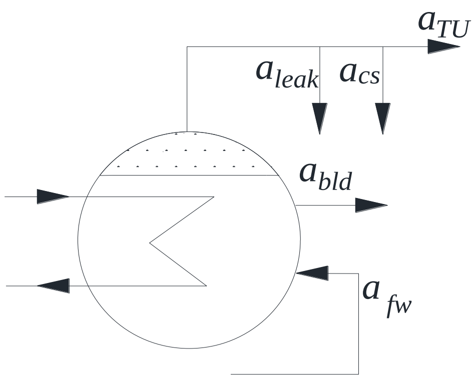
$$y_{c\prime} = \frac{H_i - H_6}{H_i} = \frac{933 - 933}{933} = 0$$

Table 12–Steam and water parameter

No.	Extracted steam			Steam in heaters (drain)			Heater's outlet water			Extracted steam work in cylinder	Under production factor
	P_j	t_j	h_j	P_{Hj}	t_{sj}	h'_j	P_{wj}	t_{wj}	h_{wj}	H_j	Y_j
	MPa	°C	kJ/kg	MPa	°C	kJ/kg	MPa	°C	kJ/kg	kJ/kg	
0	7,00	285,8	2773	–	–	–	–	–	–	0	1
1	1,76	205,9	2585	1,7	204	870	8,75	200	852	188	0,7984
D	0,70	165	2468	0	0	879	8,75	166	702	305	0,6735
Sh1	0,70	165	2468	0,70	165	697	0,70	165	697	–	–
Sh2	0,67	162,9	2761	0,67	162,9	688	–	–	–	–	–
2	0,63	190,9	2829	1,28	205,9	879	–	–	–	–	–
3	0,63	270,8	3000	5,575	285,8	1267	–	–	–	–	–
4	0,56	263	2986	0,495	154,5	652	0,9450	153	645	319	0,6584
5	0,24	185,8	2840	0,225	124,3	522	0,9450	122,8	516	465	0,5019
C'	0,0855	110,8	2700	0,082	94,2	395	0,082	92,7	388	605	0,3513
C	0,025	65	2554	0,024	64,1	268	0,024	62,6	262	751	0,1950

Material and thermal balance equations calculation

2.4.2. Feedwater



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

$$\alpha_{TU} = \alpha_0 + \alpha_{SH2}$$

Where, α_{cs}, is a relative steam flowrate out of the turbine seals

$\alpha_{cs} = 0.005 \div 0.012$; assume 0,005

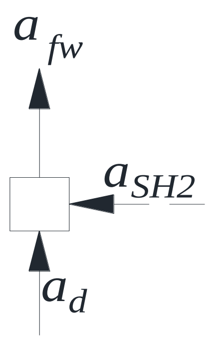
α_{leak}, is a relative leakage flowrate, $\alpha_{leak} \leq 0{,}01$.

α_{bld}, is a relative blowdown flowrate, $\alpha_{bld} = 0{,}005$

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

$$\alpha_{fw} = 1 + 0{,}01 + 0{,}005 + 0{,}005 + \alpha_{SH2} \quad (1)$$

2.4.3. Mixing point before steam generator (FW)

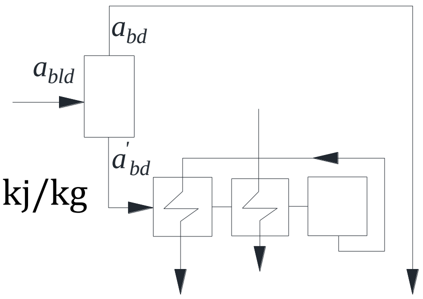


$$\frac{\alpha_{fw} \cdot h_{fw}}{\eta_{oph}} = \alpha_{SH2} \cdot h_0' + \alpha_d \cdot h_{w1}$$

$$\frac{\alpha_{fw} \cdot h_{fw}}{0{,}99} = \alpha_{SH2} \cdot 1267{,}4 + \alpha_d \cdot 852 \quad (2)$$

$$\alpha_{fw} = \alpha_{SH2} + \alpha_d \quad (3)$$

2.4.4. Blowdown system



$h'_{bd} = f(p_{tank}) = f(714) = 592$ kj/kg

$h_{bd} = f(p_{tank}) = f(714) = 2764$ kj/kg

$h'_{bd} = f(p_{tank}, t_{tank} - 25) = f(714\,,140{,}8) = 592$ kj/kg

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

$0{,}005 = \alpha'_{bd} + \alpha_{bd};$

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

$0{,}005 \cdot (1267{,}4) = \alpha'_{bd} \cdot (592) + \alpha_{bd} \cdot (2764),$ by solving both equations

$\alpha_{bd} = 0{,}00155$

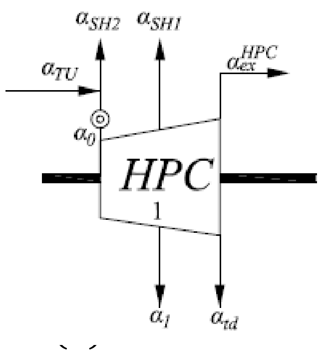
$\alpha'_{bd} = 0{,}00344$

2.4.5. Separator

$$\alpha_{ex}^{HPC} = \alpha_s + \alpha_{in}^{LPC} \quad (4)$$

$$\alpha_s = \frac{x_{out} - x_{in}}{x_{out}} \cdot \alpha_{ex}^{HPC} \to \alpha_{ex}^{HPC} = \frac{\alpha_s}{\frac{x_{out} - x_{in}}{x_{out}}} = \frac{\alpha_s}{\frac{1-0{,}85730}{1}} = \frac{\alpha_s}{0{,}14270} \quad (5)$$

2.4.6. High pressure cylinder extraction outlet

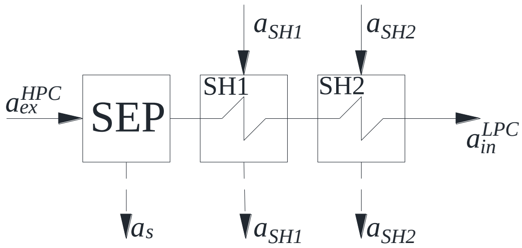


$$\alpha_{ex}^{HPC} = \alpha_0 - \alpha_1 - \alpha_{td} - \alpha_{SH1}$$

$$\alpha_{ex}^{HPC} = 1 - \alpha_1 - \alpha_{td} - \alpha_{SH1} \quad (6)$$

$$\frac{\alpha_s}{0{,}14270} = 1 - \alpha_1 - \alpha_{td} - \alpha_{SH1}$$

2.4.7. First Superheater



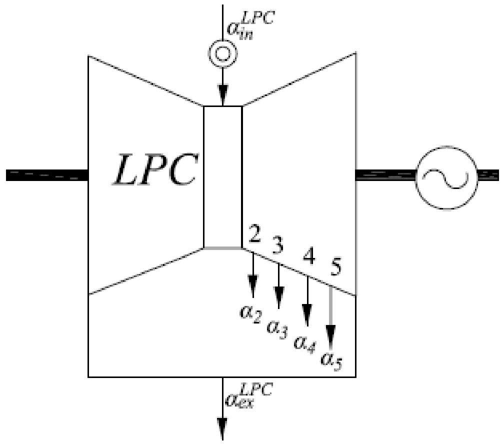
$$\alpha_{in}^{LPC} \cdot \left(h_{R1} - h_{asp} \right) = \frac{\left(\alpha_{SH1} \cdot (h_1 - h_1')\right)}{\eta_{sh}}$$

$$\alpha_{in}^{LPC} \cdot (2880 - 2761) = \frac{\left(\alpha_{SH1} \cdot (2585 - 870)\right)}{0{,}98} \qquad (8)$$

2.4.8. Second Superheater

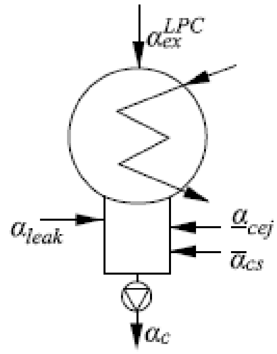
$$\alpha_{inL} \cdot (h_{R2} - h_{R1}) = \frac{\left(\alpha_{SH2} \cdot (h_0 - h_0')\right)}{\eta_{sh}} \rightarrow \alpha_{inL} \cdot (3000 - 2880) = \frac{\left(\alpha_{SH2} \cdot (2773 - 1267{,}4)\right)}{0{,}98} \qquad (9)$$

2.4.9. Low pressure cylinder extraction



$$\alpha_{ex}^{LPC} = \alpha_{in}^{LPC} - \alpha_2 - \alpha_3 - \alpha_4 - \alpha_5 \qquad (10)$$

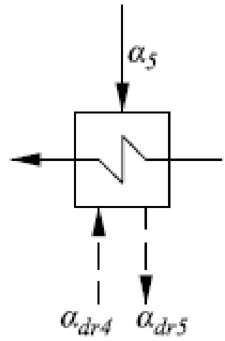
2.4.10. Condenser



$$\alpha_c = \alpha_{ex}^{LPC} + \alpha_{cej} + \alpha_{leak} + \alpha_{cs} \qquad (11)$$

2.4.11. RFWH 5 ‘Closed’

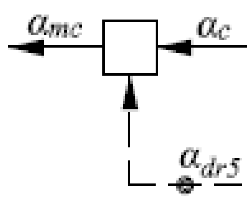
$$\frac{\alpha_c \cdot (h_{w5} - h_{cse})}{\eta_h} = \alpha_5 \cdot (h_5 - h_{dr5}) + \ \alpha_{dr4} \cdot (h_{dr4} - h_{dr5})$$



$$\frac{\alpha_c \cdot (262 - 136)}{0{,}98} = \alpha_5 \cdot (2554 - 268) + \alpha_{dr4} \cdot (395 - 268) \qquad (12)$$

$$\alpha_{dr5} = \alpha_5 + \alpha_{dr4} \qquad (13)$$

2.4.12. Mixing point between RFWH 4 and 5



$$\frac{\alpha_{mc} \cdot h_{mc}}{\eta_{oph}} = (\alpha_c \cdot h_{w5}) + (\alpha_{dr5} \cdot h_{dr5})$$

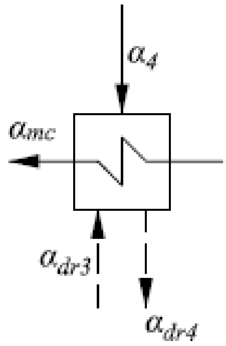
$$\alpha_{mc} = \alpha_c + \alpha_{dr5}$$

$$\frac{\alpha_{mc} \cdot h_{mc}}{0{,}99} = (\alpha_c \cdot 262) + (\alpha_{dr5} \cdot 268) \qquad (14)$$

$$\alpha_{mc} = \alpha_c + \alpha_{dr5} \qquad (15)$$

2.4.13. RFWH 4 ‘Closed’

$$\frac{\alpha_{mc} \cdot (h_{w4} - h_{mc})}{\eta_h} = \alpha_4 \cdot (h_4 - h_{dr4}) + \alpha_{dr3} \cdot (h_{dr3} - h_{dr4})$$

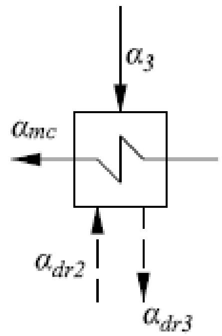


$$\frac{\alpha_{mc} \cdot (388 - h_{mc})}{0{,}98} = \alpha_4 \cdot (2700 - 395) + \alpha_{dr3} \cdot (522 - 395) \qquad (16)$$

$$\alpha_{dr4} = \alpha_4 + \alpha_{dr3} \qquad (17)$$

2.4.14. RFWH 3 ‘Closed’

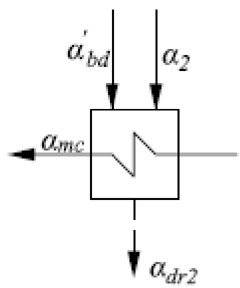
$$\frac{\alpha_{mc} \cdot (h_{w3} - h_{w4})}{\eta_h} = \alpha_3 \cdot (h_3 - h_{dr3}) + \alpha_{dr2} \cdot (h_{dr2} - h_{dr3})$$



$$\frac{\alpha_{mc} \cdot (516 - 395)}{0{,}98} = \alpha_3 \cdot (2840 - 522) + \alpha_{dr2} \cdot (652 - 522) \qquad (18)$$

$$\alpha_{dr3} = \alpha_3 + \alpha_{dr2} \qquad (19)$$

2.4.15. RFWH 2 ‘Closed’

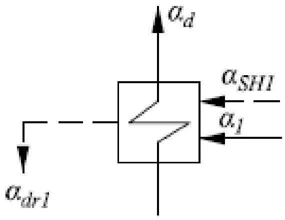


$$\frac{\alpha_{mc} \cdot (h_{w2} - h_{w3})}{\eta_h} = \alpha_2 \cdot (h_2 - h_{dr2}) + \alpha'_{bd} \cdot (h'_{bd} - h_{dr2})$$

$$\frac{\alpha_{mc} \cdot (645 - 516)}{0{,}98} = \alpha_2 \cdot (2986 - 652) + 0{,}00367 \cdot (592 - 652) \qquad (20)$$

$$\alpha_{dr2} = \alpha'_{bd} + \alpha_2 \qquad (21)$$

2.4.16. RGFW 1 ‘HPH’

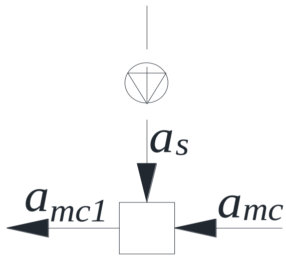


$$\frac{\alpha_d \cdot (h_{w1} - h_{fwp})}{\eta_h} = \alpha_1 \cdot (h_1 - h_{dr1}) + \alpha_{SH1} \cdot (h'_1 - h_{dr1})$$

$$\frac{\alpha_d \cdot (852 - 706)}{0,98} = \alpha_1 \cdot (2585 - 870) + \alpha_{SH1} \cdot (870 - 870) \qquad (22)$$

$$\alpha_{dr1} = \alpha_1 + \alpha_{SH1} \qquad (23)$$

2.4.17. Main condensate before deaerator

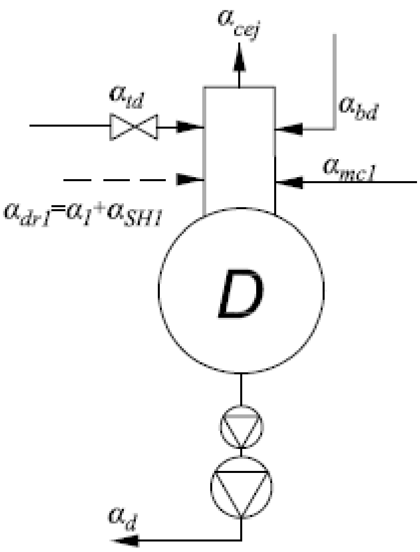


$$\frac{\alpha_{mc1} \cdot h_{mc1}}{\eta_{oph}} = \alpha_s \cdot h'_s + \alpha_{mc} \cdot h_{w2}$$

$$\frac{\alpha_{mc1} \cdot h_{mc1}}{0,99} = (\alpha_s \cdot 688) + (\alpha_{mc} \cdot 645) \qquad (24)$$

$$\alpha_{mc1} = \alpha_s + \alpha_{mc} \qquad (25)$$

2.4.18. Deaerator



$$\frac{\alpha_d \cdot h'_d + \alpha_{cej} \cdot h''_d}{\eta_{oph}} = \alpha_{td} \cdot h_{end} + \alpha_{bd} \cdot h_{bd} + \alpha_{mc1} \cdot h_{mc1} + (\alpha_{dr1} \cdot h_{dr1})$$

$$\alpha_{td} + \alpha_{mc1} + \alpha_{bd} + \alpha_{dr1} = \alpha_d + \alpha_{cej}$$

$$\frac{\alpha_d \cdot 697 + 0{,}003 \cdot 2762}{0{,}99} = \alpha_{td} \cdot 2468 + 0{,}00133 \cdot 2764 + \alpha_{mc1} \cdot h_{mc1} + (\alpha_{dr1} \cdot 870) \quad (26)$$

$$\alpha_{td} + \alpha_{mc1} + 0{,}00133 + \alpha_{dr1} = \alpha_d + 0{,}003 \quad (27)$$

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By solving equations (1) – (27) using MATHCAD software we obtain values of relative flow rate and unknown enthalpies

Table.13- Relative flowrate

α_1	0,0886
α_2	0,0422
α_3	0,0395
α_4	0,0374
α_5	0,0267
α_s	0,1193
α_c	0,5968
α_d	1,02
α_{dr1}	0,1379
α_{dr2}	0,0459
α_{dr3}	0,0853
α_{dr4}	0,1227
α_{dr5}	0,1495
α_{mc}	0,7462
α_{mc1}	0,8655
α_{ex}^{HPC}	0,8438
α_{in}^{LPC}	0,7246
α_{ex}^{LPC}	0,5788
α_{TU}	1,0566
α_{SH1}	0,0493
α_{SH2}	0,0566
α_{fw}	1,0766
h_{mc}	260,5 kj/kg
h_{fw}	865 kj/kg
h_{mc1}	644 kj/kg
α_{td}	0,0183

2.5. Efficiencies

2.5.1. Determining steam flow to a turbine

Steam flow rate for a turbine is determined by the formula

$$D_0 = 2 \cdot D_2$$

Where: -

- $D_2\ is\ steam\ flow\ rate\ from\ the\ steam\ generator\ , kg/s$

$$D_0 = 2 \cdot 403{,}72 = 807{,}4\ kg/s$$

2.5.2. Determining Electrical power from turbine

$$D_0 = \frac{N_e \cdot 10^3}{H_i \cdot \eta_M \cdot \eta_g \cdot (1 - \sum(\alpha_j \cdot y_j) - \alpha_s \cdot y_s)}$$

So: -

$$Ne = D_0 \cdot H_i \cdot \eta_M \cdot \eta_g \cdot (1 - \sum(\alpha_j \cdot y_j) - \alpha_s \cdot y_s)$$

Where: -

η_M is mechanical efficiency of a steam turbine installation; $= 0{,}98$
η_g is efficiency of the generator $= 0{,}985 \div 0.99$ assume it 0.99
α_j is relative steam consumption in the j^{th} 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

$$H_i = (h_0 - h_c) + (h_{SH2} - h_s) = (2773 - 2372) + (3000 - 2468) = 933\ kJ/kg$$

Table.14- Flowrate and y factor

NO j	α_j	y_j	$(\alpha_j \cdot y_j)$
1	0,0886	0,7984	0,07074
td	0,0183	0,6735	0,01233
2	0,0422	0,6584	0,02778
3	0,0395	0,5019	0,01957
4	0,0374	0,3513	0,01314

5	0,0267	0,1950	0,00521
$\sum(\alpha_j \cdot y_j)$	-	-	0,14877
Separator (s)	0,1193	0,6735	0,08035

$$Ne = 807{,}4 \cdot 933 \cdot 0{,}98 \cdot 0{,}99 \cdot (1 - 0{,}14877 - 0{,}08035) = 563{,}4\ MW$$

2.5.3. Thermal loading of turbine Q_{ts} , kW

$$\eta_{pipeII} = \frac{Q_{ts}}{Q_{sg}}$$

Where: -

η_{pipeII} is Efficiency of heat transport of the 1st circuit (0,97÷0,98) assume it=0,98

So: -

$$Q_{ts} = \eta_{pipeII} \cdot Q_{sg} = 0{,}98 \cdot 960 = 941\ MW$$

2.5.5. **NPP Efficiency Electrical**

$$\eta_{NPP} = \frac{N_e}{Q_{Total}} = \frac{Q_{ts}}{Q_{ts}} = \frac{Q_{rs}}{Q_{rs}} \to \eta_{pipe} = \frac{Q_{ts}}{Q_{rs}}, \eta_{rs} = \frac{Q_{rs}}{Q_{Total}}, \eta_e = \frac{N_e}{Q_{ts}}$$

$$\eta_e = \frac{N_e}{Q_{ts}} = \frac{563{,}4}{941} = 0{,}345 = 34{,}5\ \%$$

2.5.6. **Turbine system efficiency**

$$\eta_{ts} = \frac{\eta_e}{\eta_{eg}} = \frac{0{,}345}{0{,}99} = 0{,}348 = 34{,}8\ \%$$

2.5.7. Steam turbine plant (STP) heat rate, for generating electricity, $kJ/(kW \cdot h)$

$$q_{ts} = \frac{3600}{\eta_{ts}} = \frac{3600}{0{,}348} = 10332\ \frac{kJ}{kW\ h}$$

2.5.8. NPP Efficiency

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

$$\eta_{npp} = 0{,}99 \cdot 0{,}99 \cdot 0{,}98 \cdot 0{,}985 \cdot 0{,}348 = 0{,}330 = 33\ \%$$

2.5.9. Overall reactor heat flow, MW

$$Q'_{rs} = \frac{Q_{sg}}{\eta_{sg}} = \frac{960}{0,985} = 974,6\ MW$$

$$Q_{rs} = \frac{Q'_{rs}}{\eta_{pipesII}} = \frac{974,6}{0,98} = 994,5$$

2.5.10. Total power, MW

$$Q_{total} = \frac{Q_{rs}}{\eta_{rs}} = \frac{994,5}{0,99} = 1004,5\ MW$$

2.5.11. Burnup fuel rate

$$T_{eff} = 6000 \frac{hr}{year}\ ,\ \bar{B} = 35 \cdot 10^3\ \frac{MW\ day}{ton}$$

$$b_{nf} = \frac{Q_{total} \cdot T_{eff}}{24 \cdot \bar{B} \cdot 10^3} = \frac{1004,5 \cdot 6000}{24 \cdot (35 \cdot 10^3)} = 7,18\ \frac{ton}{year}$$

2.6. Steam and water consumption at characteristic points

$D_j = \alpha_j \cdot D_0\ \ kg/s$ for steam

$G_j = \alpha_j \cdot G_0\ \ kg/s$ for water

Table15–steam and water consumption

D_1 kg/s	71,5
D_2 kg/s	34,1
D_3 kg/s	31,5
D_4 kg/s	30,2
D_5 kg/s	21,6
G_{dr1} kg/s	111,3
G_{dr2} kg/s	37,1
G_{dr3} kg/s	68,9
G_{dr4} kg/s	99,1
G_{dr5} kg/s	120,7
D_s kg/s	96,3
D_c kg/s	481,9
G_d kg/s	823,6
D_{SH_1} kg/s	39,8
D_{SH_2} kg/s	45,7
G_{fw} kg/s	869,3

2.7. CHOICE OF EQUIPMENT FOR THE WATER-STEAM CIRCUIT

2.7.1. **Feed water pump**

A volumetric flow rate $V, m^3/h$

$$V_{FWP} = 1{,}05 \cdot \frac{3600 G_d}{\rho} = 1{,}05 \cdot \frac{3600 \cdot (823{,}6)}{904{,}5} = 3442\ m^3/h$$

Where: -

- G is mass flow rate kg/s
- ρ is density $\frac{\text{kg}}{\text{m}^3}$

A head H

$$H = \frac{\Delta p}{\rho g} = \frac{7837{,}3 \cdot 10^3}{904{,}5 \cdot 9{,}8} = 884{,}2\ m$$

- Δp is a difference pressure in Pa

$$\Delta p = p_{fwp} - (p_d + \rho g \Delta h)$$

Δh = the height of deaerator ≈ 14÷24 m, assume 24 m

$$\Delta p = 8750 - [(700) + (904{,}5 \cdot 9{,}8 \cdot 24 \cdot 10^{-3})] = 7837{,}3\ kPa$$

- The choice of this pump is quite special because it has a high volumetric flow rate

There will be 4 pumps each one works at 33.33 % of flow, 3 is in operation and the 4^{th} is reserving pump in care of outrunning, the following is the description of the pump

2.7.2. Condensate pumps

A volumetric flow rate $V, m^3/h$

$$V_{CPi} = \frac{3600 \cdot D}{\rho}$$

Where: -

- D_c is mass flow rate condenser kg/s

A head H

$$H = \frac{\Delta p}{\rho g}$$

- Δp is a difference pressure in Pa

$$\Delta p = p_{cp1} - p_c$$

- **First condensate pump CP1**

$$\Delta p = p_{cp1} - p_c = 450 - 4 = 446\ kPa$$

$$H = \frac{\Delta p}{\rho g} = \frac{446 \cdot 10^3}{996 \cdot 9{,}8} = 45{,}7\ m$$

$$V_{CP1} = \frac{3600 \cdot D_c}{\rho} = \frac{3600 \cdot (481{,}9)}{996} = 1742\ m^3/h$$

- **Second condensate pump CP2**

$$\Delta p = p_{cp2} - p_{w4} = 945 - 82{,}2 = 862{,}8 kPa$$

$$H = \frac{\Delta p}{\rho g} = \frac{862{,}8 \cdot 10^3}{963{,}7 \cdot 9{,}8} = 91{,}4\ m$$

$$V_{CP2} = \frac{3600 \cdot D_c}{\rho} = \frac{3600 \cdot 481{,}9}{963{,}7} = 1800\ m^3/h$$

Table.16- Characteristic of pumps in NPP and chooses

PUMPS	Head H , m	Volumetric flow rate V , m^3/h	Chaise pump	Type	V , m^3/h	no.	Operating	Reserve
Feed water	884,2	3442		ПЭА 1650-75	1840	3	2	1
First main condensate	45,7	1742		ПЭА 1300-185	1300	3	2	
Second main condensate	91,4	1800		ПЭА 1300-185	300	3	2	
Drain	78,2	462		ПЭА 270-160	90	3	2	

2.7.3. The regenerative heaters

Evaluate heat transfer Area F m^2

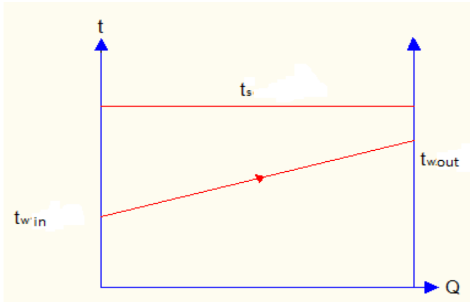
$$F = \frac{Q}{k\overline{\Delta t}}$$

Where: -

- Q is heat load of the heater
- K is heat transfer coffinite $3500 \div 4000 \frac{\mathrm{W}}{\mathrm{m^2K}}$, assume $4000 \frac{\mathrm{W}}{\mathrm{m^2K}}$

$$Q = G \cdot \Delta h$$

- Δh is deference enthalpy between outlet and inlet kg/kJ
- G mass flow rate of water



Logarithmic temperature difference $\overline{\Delta t}$°C

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

Where: -

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

RFWH 5 ‘Closed’

$$\Delta h = h_{w5} - h_{cse} = 262 - 136 = 126\ kJ/kg$$

$$Q = G_c \cdot \Delta h = 481{,}9 \cdot 126 = 60685\ kW$$

$$\Delta t_{big} = t_{s5} - t_{cse} = 64{,}1 - 32{,}5 = 31{,}6\ ℃$$

$$\Delta t_{small} = t_{s5} - t_{w5} = 64{,}1 - 62{,}6 = 1{,}5\ ℃$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{31{,}6 - 1{,}5}{ln\left(\frac{31{,}6}{1{,}5}\right)} = 9{,}9\ ℃$$

$$F = \frac{Q}{k\overline{\Delta t}} = \frac{60685 \cdot 10^3}{4000 \cdot 9{,}6} = 1535{,}3\ m^2$$

RFWH 4 ‘Closed’

$$\Delta h = h_{w4} - h_{mix} = 388 - 260 = 128\ kJ/kg$$

$$Q = G_{mc} \cdot \Delta h = 602{,}5 \cdot 128 = 76996\ kW$$

$$\Delta t_{big} = t_{s4} - t_{w5} = 94{,}2 - 62{,}2 = 31{,}6\ ℃$$

$$\Delta t_{small} = t_{s4} - t_{w4} = 94{,}2 - 92{,}7 = 1{,}5\ ℃$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{31,6 - 1,5}{ln\left(\frac{31,6}{1,5}\right)} = 9,6\ ℃$$

$$F = \frac{Q}{k\overline{\Delta t}} = \frac{76996 \cdot 10^3}{4000 \cdot 9,6} = 1948\ m^2$$

RFWH 3 ‘Closed’

$$\Delta h = h_{w3} - h_{w4} = 516 - 388 = 127\ kJ/kg$$

$$Q = G_{mc} \cdot \Delta h = 602,5 \cdot 127 = 76796\ kW$$

$$\Delta t_{big} = t_{s3} - t_{w4} = 124,3 - 92,7 = 31,6\ ℃$$

$$\Delta t_{small} = t_{s3} - t_{w3} = 124,3 - 122,8 = 1,5\ ℃$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{31,6 - 1,5}{ln\left(\frac{31,6}{1,5}\right)} = 9,9\ ℃$$

$$F = \frac{Q}{k\overline{\Delta t}} = \frac{76796 \cdot 10^3}{4000 \cdot 9,9} = 1943\ m^2$$

RFWH 2 ‘Closed’

$$\Delta h = h_{w2} - h_{w3} = 645 - 500 = 129\ kJ/kg$$

$$Q = G_{mc} \cdot \Delta h = 602,5 \cdot 129 = 77840\ kW$$

$$\Delta t_{big} = t_{s2} - t_{w3} = 154,5 - 122,8 = 31,6\ ℃$$

$$\Delta t_{small} = t_{s2} - t_{w2} = 154,5 - 153 = 1,5\ ℃$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{31,6 - 1,5}{ln\left(\frac{31,6}{1,5}\right)} = 9,9\ ℃$$

$$F = \frac{Q}{k\overline{\Delta t}} = \frac{77840 \cdot 10^3}{4000 \cdot 9,9} = 1969,3\ m^2$$

For RGFW 1 ‘HPH’

$$\Delta h = h_{w1} - h_{fwp} = 852 - 706 = 146\ kJ/kg$$

$$Q = G_d \cdot \Delta h = 823,6 \cdot 146 = 120516\ kW$$

$$\Delta t_{big} = t_{s1} - t_{fwp} = 204 - 153 = 38\ ℃$$

$$\Delta t_{small} = t_{s1} - t_{w1} = 204 - 200 = 4\ ℃$$

$$\overline{\Delta t} = \frac{\Delta t_{big} - \Delta t_{small}}{ln\left(\frac{\Delta t_{big}}{\Delta t_{small}}\right)} = \frac{38 - 4}{ln\left(\frac{38}{4}\right)} = 15{,}1\ ℃$$

$$F = \frac{Q}{k\overline{\Delta t}} = \frac{120516 \cdot 10^3}{4000 \cdot 15{,}1} = 1994\ m^2$$

Table.17- Summary of results

NO	$\Delta h\ , kJ/kg$	$G\ , kg/s$	$Q\ , kW$	$\overline{\Delta t}$, ℃	F, m^2		Type	$G\ ,\ kg/s$	no.
5	126	482	60685	9.9	1535,3	Choose reheater	ПНСВ-2000-2	1500	1
4	128	602,5	76996	9.9	1948		ПНСВ-2000-2	1500	1
3	127	602,5	76796	9.9	1943		ПН-1900-32-6-II	1500	1
2	129	602,5	77840	9.9	1969		ПН-1900-32-6-II	1500	1
1	146	823,6	120516	15,1	1994		ПВ-1600-92-20	1000	2

3. 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 (Fig. 10). 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.

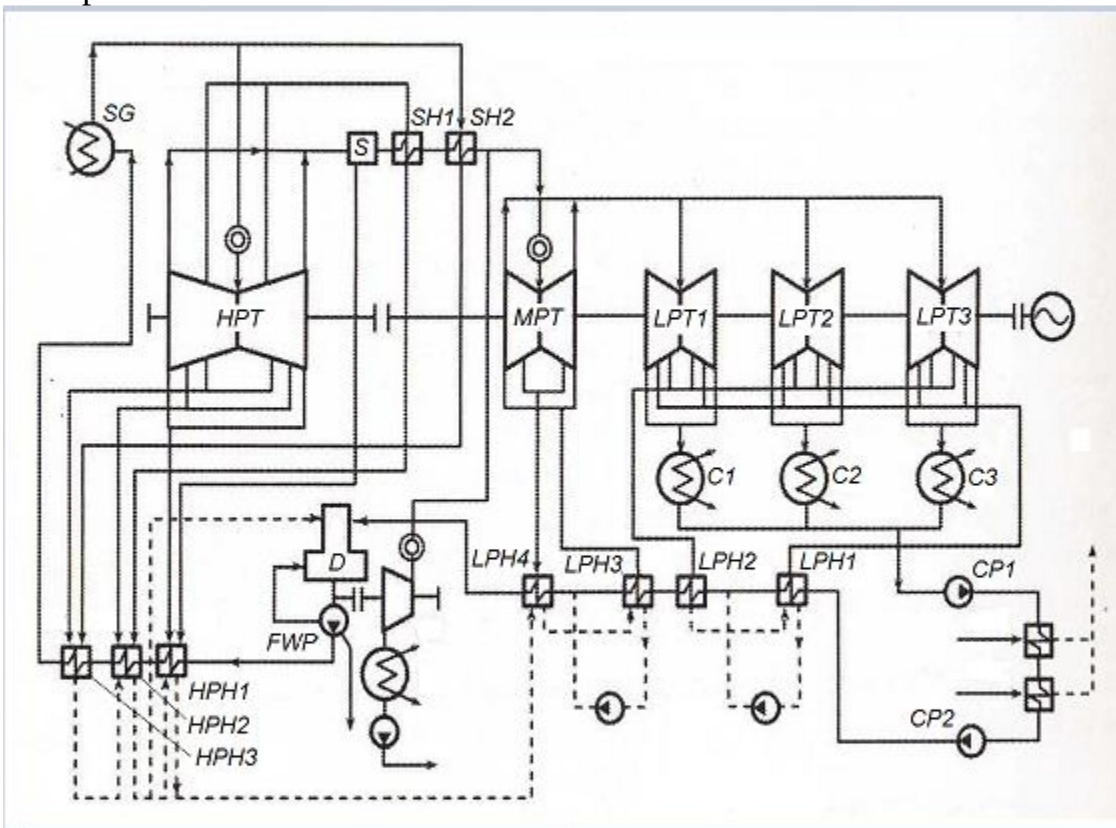


Figure 10. Schematic diagram of the VVER power unit

3.1. Calculation of the number of flows in low-pressure cylinder of turbine

3.1.1. Number of flows of spent steam going to the condenser

$$i = \frac{N_e}{\eta_\mathrm{m} \cdot \eta_\mathrm{g} \cdot N_i^{\max}}$$

Where: -

- $N_i^{\max}$ maximum power of a single-flow turbine, MW
- N_e is total electric power of the turbine unit, MW
- η_m is mechanical efficiency of the turbine unit
- η_g efficiency of the generator.

3.1.2. Maximum power of a single-flow turbine, MW

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

Where: -

- $m1 = 1{,}1 \div 1{,}3$ coefficient that takes into account power generation by steam streams of regenerative bleed-offs;(assume it 1,1).
- $k_{\text{unl}} = 2{,}3 \div 2{,}4$ 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 extracted steam work in turbine, kJ/kg;
- $[\sigma]$ is allowable tensile stress for the material of the blades.
  - For stainless steel $[\sigma] = 450$ MPa;
  - For titanium alloy BT6 $[\sigma] = 950 \div 1000$ MPa;
- $\rho_{mat} = 7800$ kg/m³ is density of the blade material (stainless steel);
  - for titanium alloy BT6 $\rho_{mat} = 4300$ kg/m³;
- n is rotor's rotation frequency, rev/s;
- v_2 is specific volume of steam at the outlet of the last stage of the turbine, m³/kg.

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

- c_2 output steam speed, m/s. Depends on the allowable power loss at the output speed $\Delta h_{\text{os}} = 20 \div 35$ kJ/kg (assume it 32 kJ/kg).

The output speed of steam is determined from the following equation

$$\Delta h_{\text{os}} = \frac{c_2^2}{2000} \rightarrow c_2 = \sqrt{\Delta h_{\text{os}} \cdot 2000} = \sqrt{32 \cdot 2000} = 253 m/s.$$

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

$$= \frac{1{,}1}{2 \cdot 10^{-3} \cdot \pi} \cdot 2{,}3 \cdot 933 \cdot \frac{450 \cdot 253}{7800 \cdot 25^2 \cdot 31{,}3} = 280{,}5 \text{ MW}$$

$$i = \frac{N_e}{\eta_{\text{m}} \cdot \eta_{\text{g}} \cdot N_i^{\max}} = \frac{600}{0.99 \cdot 0.98 \cdot 280{,}5} = 2{,}204 = 4$$

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

$$n_{cond} = \frac{i}{2} = \frac{4}{2} = 2$$

3.1.3. Exhaust steam flow per condenser

$$G_{c1} = \frac{2 \cdot G_c}{i} = \frac{2 \cdot 481{,}9}{4} = 241 \text{ kg/s}$$

Where: $G_c = \alpha_c \cdot G_0$ is total exhaust steam flow, kg/s;

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

3.2. Initial data for the calculation of the condenser

Table 18- Initial data

Parameter	Denomination, units	Value
Exhaust steam flow per condenser	G_{c1}, kg/s	241
Condenser pressure	p_c, MPa	0,004
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	28×0,7
Tube material		stainless steel

Notes: -

- take the cooling water density equal to ρ_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...0,85. (assume it 0,75)

3.3. Determining the characteristics of a condenser

3.3.1. Flow rate of cooling water per condenser

$$W_1 = m \cdot G_{c1} = 50 \cdot 241 = 12047{,}5 \text{ kg/s}$$

where $m = 40\ldots50$ is the cooling ratio for two-way condensers ($z = 2$), (assume it 50 kg/kg)

3.3.2. The number of heat transfer tubes, pieces

$$n_{tube} = \frac{4 \cdot W_1 \cdot z}{\pi \cdot d_{inn}^2 \cdot \rho_w \cdot w_w} = \frac{4 \cdot 12047{,}5 \cdot 2}{\pi \cdot 0{,}0266^2 \cdot 1000 \cdot 2} = 21690 \text{ tubes}$$

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

d_{inn} is inner diameter of the tubes, m;

$$d_{inn} = d_{out} - 2 \cdot \delta_{wall} = 28 \cdot 0{,}7 = 26{,}6 \text{ mm} = 0{,}0266 \text{ m}$$

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

3.3.3. Cooling water heating in the condenser, ºC

$$\Delta t_w = \frac{r}{c_w \cdot m} = \frac{2432{,}30}{4{,}19 \cdot 50} = 11{,}61 \text{ ºC}$$

where $r = h'' - h'$ is latent heat of vaporization under pressure p_c, kJ/kg;

$$h'' = f_{sv}(p_c) = f_{sv}(0.004) = 2554 \text{ kJ/kg}$$

$$h' = f_{sl}(p_c) = f_{sl}(0.004) = 121 \text{ kJ/kg}$$

$$r = h'' - h' = 2554 - 121 = 2432{,}3 \text{ kJ/kg}$$

c_w is heat capacity of cooling water, kJ/(kg °C).

3.3.4. Temperature of the cooling water at the condenser outlet, ºC

$$t_{w2} = t_{w1} + \Delta t_w = 15 + 11{,}61 = 26{,}61 \text{ º}C$$

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

$$Q_{w1} = W_1 \cdot c_w \cdot \Delta t_w = 12047{,}5 \cdot 4{,}19 \cdot 11{,}61 = 586064{,}05 \text{ kW}$$

3.3.6. The average temperature difference, ºC

$$\Delta t_{avr} = \frac{\Delta t_w}{ln\left(\frac{t_s - t_{w1}}{t_s - t_{w2}}\right)} = \frac{11{,}61}{ln\left(\frac{29 - 15}{29 - 26{,}61}\right)} = 6{,}51 \text{ ºC}$$

Where t_s is saturation temperature at condenser pressure p_c.

$$t_s = f(p_c) = f(0.0040) = 29 \text{ ºC}$$

3.3.7. Specific vapor load of the condenser d_c. Initially set in the range of 40 ... 60 kg / (m² · h), and then must be checked. (Assume it 55 kg / (m²· h))

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

If $t_{w1} \leq 35$ °C

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

where k - in W/(m²·°C);

$$x = 0{,}12 \cdot a \cdot (1 + 0{,}15 \cdot t_{w1}) = 0{,}12 \cdot 0{,}6375 \cdot (1 + 0{,}15 \cdot 15) = 0{,}24862$$

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

$$a = 0{,}75 \cdot 0{,}85 = 0{,}6375$$

- a_0 coefficient that takes into account tube contamination;
- a_m correction factor that takes into account tube material:
  - 1 – for brass;
  - 0,92 – for cupronickel;
  - 0,85 – for stainless steel;
  - 0,9 – for titanium.
- d_{inn} inner diameter of tubes, m;
- w_w speed of water in tubes, m / s.
- t_{w1} is the temperature of the cooling water at inlet to condenser; °C;
- z number of tube-side passes for cooling water;
- Φ_d - coefficient taking into account the effect of the vapor load of the condenser. Under load from d_c^{nom} to $d_c^{bn} = (0{,}9 - 0{,}012 \cdot t_{w1}) \cdot d_c^{nom}$ value Φ_d=1, under load $d_c < d_c^{bn}$ value $\Phi_d = \delta \cdot (2 - \delta)$, here $\delta = \frac{d_c}{d_c^{bn}}$.

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

$$k = 4070 \cdot 0{,}6375 \cdot \left(\frac{1{,}1 \cdot 2}{0{,}0266^{0{,}25}}\right)^{0{,}24862} \cdot \left[1 - \frac{0{,}52 - 0{,}002 \cdot 40 \cdot \sqrt{0{,}6375}}{1000} \cdot (35 - 15)^2\right],$$

$$= 3233{,}2 \text{ W/(m}^2 \cdot \text{°C)}$$

3.3.9. Heat transfer surface area, m²

$$F = \frac{Q_w}{k \cdot \Delta t_{avr}} = \frac{586064{,}05 \cdot 10^3}{3233{,}2 \cdot 6{,}51} = 27811 \text{ m}^2$$

3.3.10. The length of the heat transfer tubes, m

$$L = \frac{F}{n \cdot \pi \cdot d_{out}} = \frac{27811}{21690 \cdot \pi \cdot 28 \cdot 10^{-3}} = 14{,}58\ m$$

Where: -

- d_{out} outer diameter of tubes, m.
- length of tubes must be less than 16 m.

3.3.11. The calculated value of the specific steam load of the condenser, kg / (m²·h)

$$d_c^{calk} = \frac{3600 \cdot D_2}{F} = \frac{3600 \cdot 241}{27811} = 31{,}19\ \frac{kg}{m^2 \cdot\ h}$$

3.3.12. The obtained value d_c^{calk} must be compared with the specified in paragraph (5.3.7). 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 5.3.7.

By repeating the calculation, in (5.3.7) with new $d_c = d_c^{calk}$, we obtain

Table 19

$dc, kg/(m2 \cdot\ h)$	40	31,19
$k, W/(m^2 \cdot ºC)$	3233,2	3210,9
F, m²	27811	28004
L, m	14,58	14,68
ERROR %	28,25	0,69

3.3.13. Mass of condenser tubes, kg.

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

$$= 21690 \cdot 14{,}58 \cdot \frac{\pi \cdot (0{,}028^2 - 0{,}0266^2)}{4} \cdot 7800 = 149102 \text{ kg}$$

Where: -

- L, d_{out} and d_{inn} are in m;
- ρ_{mat} density of the pipe material, kg/m³.

3.3.14. Cost of condenser tubes, million rubles.

$$C_{tube} = \frac{M_{tube} \cdot c_{mat}}{10^6} = \frac{149102 \cdot 350}{10^6} = 52 \text{ million rubles}$$

Where: -

- c_{mat} is price 1 kg of tubes, rub/kg.

- For stainless steel tubes c_{mat}= 350…400 rub/kg; take 350 rub/kg
- For titanium tubes c_{mat}= 1900…2100 rub/kg.

3.3.15. Cost of the condenser, million rubles.

$$C_{cond} = K_c \cdot C_{tube} = 1{,}75 \cdot 52 = 91 \text{ million rubles}$$

Where: -

K_c=1.75…2 is empirical coefficient. (Assume it 1.75)

3.4. Hydraulic calculation of the condenser

3.4.1. 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.

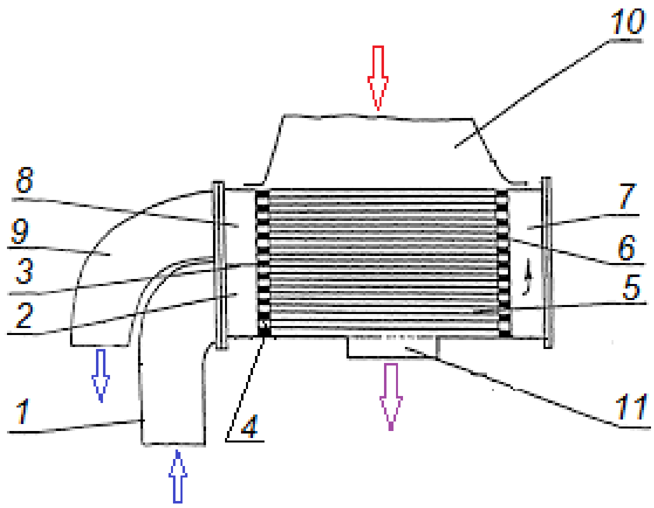


Figure 11. To the hydraulic calculation of condenser

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

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

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

Where: -

- Δp_{loc} local pressure losses;
- Δp_{fr} friction losses in condenser tubes;
- $\Delta p_{wch.in}$ local hydraulic resistance at the water inlet to the tubes from the water chamber;
- $\Delta p_{wch.out}$ local hydraulic resistance at the water outlet from the pipes to the water chamber;

- Δp_{turn} 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 20.

Table20-The values of the coefficient of local resistance

Type of local resistance	Coefficient value ξ_{loc}
Inlet to the tubes from the water chamber	0,5
Outlet from the pipes to the water chamber	1,0
Turning the water in the water chamber	0,5

$$\Delta p_{wch.in} = \xi_{loc} \cdot \frac{\rho_w \cdot w_w^2}{2} = 0{,}5 \cdot \frac{1000 \cdot 2^2}{2} = 1000 \text{ Pa}$$

$$\Delta p_{wch.out} = \xi_{loc} \cdot \frac{\rho_w \cdot w_w^2}{2} = 1 \cdot \frac{1000 \cdot 2^2}{2} = 2000 \text{ Pa}$$

$$\Delta p_{turn} = \xi_{loc} \cdot \frac{\rho_w \cdot w_w^2}{2} = 0{,}5 \cdot \frac{1000 \cdot 2^2}{2} = 1000 \text{ Pa}$$

$$\Delta p_{loc} = 2 \cdot \Delta p_{wch.in} + 2 \cdot \Delta p_{wch.out} + \Delta p_{turn} = 2 \cdot 1000 + 2 \cdot 2000 + 1000 = 7000 \text{ Pa}$$

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

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

Where: -

L is length of heat transfer tubes, m;

$d_h = d_{inn}$ is characteristic size (hydraulic diameter), m;

ξ_{fr}=0,035…0,037 is coefficient of friction. Assume 0.036

$$\Delta p_{fr} = \xi_{fr} \cdot \frac{2 \cdot L}{d_h} \cdot \frac{\rho_w \cdot w_w^2}{2} = 0.036 \cdot \frac{2 \cdot 14{,}6}{0{,}0266} \cdot \frac{1000 \cdot 2^2}{2} = 39754 \text{ Pa}$$

$$\Delta p_\Sigma = \Delta p_{loc} + \Delta p_{fr} = 7000 + 39754 = 46754 \text{ Pa} = 0{,}046754 \text{ Mpa}$$

3.4.2. Power of the pump for pumping water through the condenser

$$N_p = \Delta p_\Sigma \cdot \frac{W}{\rho_w \cdot \eta_p \cdot 1000} = 46754 \cdot \frac{12047{,}5}{1000 \cdot 0.87 \cdot 1000} = 647 \text{ kW}$$

Where: -

- Δp_Σ is total hydraulic resistance of a two-way condenser, Pa;
- η_p= 0,86…0,88 is the efficiency of the pump.

3.4.3. Electric power consumption for the circulation pump drive

$$E_p = N_p \cdot \tau_{rp} = 647 \cdot 6600 = 4273116 \text{ kWh}$$

Where: -

- τ_{rp}= 6500…7000 h is number of hours of use of rated power.

3.4.4. The cost of electricity for pumping water through the condenser

$$C_{el} = \frac{E_p \cdot T_{el}}{10^6} = \frac{4273116 \cdot 15}{10^6} = 64 \text{ million rubles.}$$

Where: -

- T_{el}=14…16 $rub/kW \cdot h$ is electricity tariff for nuclear power plants.

Table 21

	Options			
	$d_{out} = 28$ mm δ_{wall}=0,7 mm	$d_{out} = 28$ mm δ_{wall}=1 mm	$d_{out} = 28$ mm δ_{wall}=1,5 mm	$d_{out} = 28$ mm δ_{wall}=2 mm
C_{cond}, million rubles	91	129	189	247
C_{el}, million rubles	64	63	61	58

4. Financial management, resource efficiency and resource conservation

4.1. Analysis of competitive technical solutions

The condenser is designed for circulating water supply systems for steam turbines. 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 condenser with a cooling medium with minimal energy and labor costs. Adecrease 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 22).

Table 22 – The results of calculations of the competitive structures of the condenser

Type of Cost		Design options	
		1000-КЦС -1 with d_{out} = 28 mm; δ_{wall}=0.7 mm	1000-КЦС -1 with d_{out} = 28 mm; δ_{wall} =2 mm
C_{cond} ,	million rubles	91	247
C_{el} ,	million rubles	64	58

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

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 thickness. Condensers for NPP turbines are manufactured at Leningrad Metal Plant (Power Machines).

Table 23 - Scorecard for comparing competitive technical solutions

Items to assess	Value of criteria C	Points		Competitiveness	
		B_1	B_2	$К_1$	$К_2$
Technical criteria for evaluating resource efficiency					
1. Energy efficiency	0,2	3	4	0,6	0,8
2. Dimensions and weight	0,15	4	2	0,6	0,3
3. Environmental safety	0,05	4	3	0,2	0,15
4. Lifetime	0,2	3	4	0,6	0,8
5. Reliability	0,2	2	4	0,4	0,8
Economic performance indicators					
1. Price	0,15	4	2	0,6	0,3
2. Maintenance	0,02	3	3	0,06	0,06
3. The competitiveness of the product	0,03	3	3	0,09	0,09
Total	1			3,15	3,3

The analysis of competitive technical solutions is defined as follows:

$$К_i = \sum_{i=1}^{2} C \cdot B_i$$

Where: -

- $К_i$ - competitiveness of scientific research;
- C - indicator weight (in unit fractions);
- B_i - score of the i^{th} indicator.

Indices for indicators "1" - first type 1000-КЦС -1 with d_{out} = 28 mm; δ_{wall}=0.7 mm; "2" - second type1000-КЦС -1 with d_{out} = 28 mm; δ_{wall}=2mm.

Calculation example:

$$К_1 = \sum С \cdot В_1 = 0{,}2 \cdot 3 + 0{,}15 \cdot 4 + \ldots + 0{,}03 \cdot 3 = 3{,}15.$$

The results show that the competitiveness of option 1 was 3.15, while that of option 2 was 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.

4.2.Project initiation

Initiation processes define initial goals and content and fix initial financial resources. The internal and external stakeholders of the project are determined, which will interact and influence the overall result of the scientific project.

4.2.1. Project goals and results

Information about the stakeholders of the project, the hierarchy of project goals and criteria for achieving goals is presented in table below.

Table 24 – Stakeholders of the project

Stakeholders of the project	**Stakeholders of the project expectations**
TPU, NPP operation, design and engineering, project executor	High efficiency equipment (condenser)

Information about the hierarchy of project goals and criteria for achieving goals is given in the table below.

Table 25 – Project goals and results

Project goals	Provide reliable condensers for the turbine installation of a nuclear power plant, reduce energy costs for driving circulation pumps, and increase the efficiency of using the condenser
Expected results of the project	Based on the conducted research, analyze the sensitivity, find shortcomings, suggest the necessary measures to improve these indicators.
Acceptance criteria of the project result	Improving efficiency in relation to the proposed measures to improve the reliability of the equipment.
Requirements to the project results	Project completion on time
	Stability of technological equipment
	The efficiency of the equipment used
	Convenience in usage

4.2.2. Organizational structure of the project

The organizational structure of the project is presented in the table 26.

According to calculations the amount of work time for Engineer and Supervisor we found the number of hours like it mentioned in table 26

Table 26 – Project Working Group

№	**Name**	**Position**	**Functions**	**Working days spent**
1	Ahmed Ibrahim	Project Executor	Work on project implementation	56
2	Gvozdyakov D.V.	Project Manager	Coordination of work activities and assistance in project implementation	10
Total:				66

So, the time spent for my research is equal:

for your Supervisor (Project Manager) → $10 \cdot 4 = 40$ hours;

for me as an Engineer (Project Executor) → $56 \cdot 10 = 560$ hours.

4.2.3. Assumptions and constraints

Limitations and assumptions are summarized in table 24.

Table 27 – Limitations and assumptions

Factor	Limitations/assumptions
1. Project budget for design	270 000 RUB
1.1 Source of budgeting	Own funds / Rosatom scholarship
2. Project timeline:	1 October 2020 – 15 January 2021
2.1 Date of approval of the project management plan	1 October 2020
2.2 Project completion date	31 December 2020
3. Other	-

As a result of the initialization of the project, the goals and expected results were formulated, the stakeholders of the project and the financial framework were identified, which is very important for the successful completion of the project and its implementation.

4.2.4. Project planning

The main way to develop a design implementation schedule is called a Gantt chart. A Gantt chart is a horizontal graph that depicts work on a topic in long time periods, described by completion dates and start dates for the assigned work (tables 28 and 29)

Note: -

- $t_{ож} = (3 \cdot t_{\min} + 2 \cdot t_{\max}) \cdot 0.2$ is expected labor intensity of performing one job, person-days;
- $T_p = t_{ож} / Ч$ 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, where k_k =1.65 is calendar factor.

Table 28 – Design and research timing

№	Task	The laboriousness of the task						Duration of the task in working daysT_{pi}		Duration of the task in calendar days$T_{кi}$	
		t_{min}, person-days		t_{max}, person-days		$t_{ожi}$, person-days					
		SV	Eng	SV	Eng	SV	Eng	SV	Eng	SV	Eng
1	Drawing up the technical assignment	2,8		3,3		3		3		5.0	
2	Literature review		4,3		6,8		5,3		5,3		8.7
3	Selection of the research field		4,1		6,6		5,1		5,1		8.4
4	Calendar planning	2,8		3,3		3		3		5.0	
5	Description of the design object		4,5		7		5,5		5,5		9.1
6	Statement of the design problem		4,1		6,1		4,9		4,9		8.1
7	Development of the calculation model		6,5		7		6,7		6,7		11.1
8	Variational calculations of the object		5,7		7,7		6,5		6,5		10.7
9	Evaluation of calculation results	3,2		5,2		4		4		6.6	
10	Comparative calculations of economic efficiency object		6		8,5		7		7		11.6
11	Choosing the optimal design		6,3		8,8		7,3		7,3		12.0
12	Drawing up a final report		6,5		9		7,5		7,5		12.4

№	Task	Executors	$T_{кі}$ days	Duration of the task											
				OCT				NOV				DEC			
				1	2	3	4	1	2	3	30	1	2	4	30
1	Drawing up the technical assignment	SV	5												
2	Literature review	Eng	8,7												
3	Selection of the research field	Eng	8,4												
4	Calendar planning	SV	5												
5	Description of the design object	Eng	9,1												
6	Statement of the design problem	Eng	8,1												
7	Development of the calculation model	Eng	11,1												
8	Variational calculations of the object	Eng	10,7												
9	Evaluation of calculation results	SV	6,6												
10	Comparative calculations of economic	Eng	11,6												
11	Choosing the optimal design	Eng	12												
12	Drawing up a final report	Eng	12,4												

	– Eng		– SV

Thus, the duration of the task performed by the engineer and the supervisor. In general, the duration of work in calendar days for an engineer is 56 days, and for a supervisor is 10 days.

4.2.5. Project budgeting

The project budget must display reliable values for all types of costs associated with its implementation. The costs of this project include:

- costs of purchasing equipment;
- costs for materials and other products;
- expenses for the main and additional salaries of the theme performers;
- costs for special equipment;
- costs of social security contributions;
- overhead costs.

4.2.5.1. Costs for materials and other products

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

Table 30 – Costs for materials for the project

Name	Unit of measurement	Number	Price per unit, RUB	Expenses (E_M), RUB
Paper	Pack	1	250	250
Pens	Unit	2	50	100
Pencils	Unit	1	50	50
Ruler	Unit	1	40	40
Printing	Page	200	2	400
Folder	Unit	2	5	10
Stapler	Unit	1	150	150
Staples	Pack	1	40	40
Hole puncher	Unit	1	250	250
Total				**1 290**

4.2.5.2. Costs for specialized equipment

This item includes all costs that are associated with the purchase of special equipment (for example, instruments, instrumentation, stands, devices and mechanisms) necessary for the project.

Table 31 – Costs for specialized equipment

№	Name	Number	Price per unit, RUB	Total price of equipment, RUB
1	Laptop	1	55 000	55 000
2	Microsoft Windows 10 Professional x64	1	4 500	4 500
3	MacAfee Anti-Virus	1	1 690	1 690
4	Microsoft Office 2019 Pro Plus	1	3 500	3 500
Total, RUB				**64690**

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 64690 RUB. The operating life of the computer is 7 years, the Microsoft Windows 10 license is 4 years, the rest of the software is a year. Then the annual depreciation rate for them, respectively:

$$N_{DL} = \frac{1}{7} \cdot 100\% = 14{,}29\%;$$

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

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

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

$$D_L = 55000 \cdot \frac{N_{DL}}{100\%} \cdot \frac{T}{365} = 30000 \cdot \frac{14{,}29\%}{100\%} \cdot \frac{90}{365} = 1938 \text{ RUB},$$

$$D_{Win10} = 4500 \cdot \frac{N_{DWin}}{100\%} \cdot \frac{T}{365} = 4500 \cdot \frac{25\%}{100\%} \cdot \frac{90}{365} = 277.4 \text{ RUB},$$

$$D_{SS} = 5190 \cdot \frac{N_{DSS}}{100\%} \cdot \frac{T}{365} = 5190 \cdot \frac{100\%}{100\%} \cdot \frac{90}{365} = 1279.7 \text{ RUB},$$

where T – number of working days

Total depreciation for a year:

$$D = D_L + D_{Win10} + D_{SS} = 3495.1 \text{ RUB}$$

4.2.5.3. Basic salary

The amount of expenses for wages of employees is determined based on the labor intensity of the work performed and the current system of salaries and tariff rates.

The calculation of the basic salary of the head of a scientific project is based on the sectoral wage system. The branch system of remuneration at TPU assumes the following composition of wages:

1) Salary - determined by the enterprise. In TPU, salaries are distributed in accordance with the positions held, for example, assistant, art. lecturer, associate professor, professor (see "Regulations on remuneration" given on the website of the Planning and Finance Department of TPU).
2) Incentive payments - set by the head of departments for effective work, performance of additional duties, etc.
3) Other payments; district coefficient.

Since incentive bonuses, other payments and incentives depend on the activities of the manager in particular, we will take the coefficient of incentive bonuses equal to 30%, and the coefficient of incentives for the manager for conscientious work activity is 25%.

The basic salary of a manager is determined by the formula:

$$S_b = S_r \cdot T_w, \quad (11)$$

where S_r is worker's regular salary;

T_p is duration of work, work days.

Additional salary:

$$S_{add} = 0{,}15 \cdot S_b \quad (12)$$

Average daily salary for a 5-day working week:

$$S_d = \frac{S_m \cdot M}{F_d}, \quad (13)$$

where S_m is worker's monthly salary, RUB;

F_d is number of working days in a month, days,

M =11.2 is number of months of work without vacation during the year

Full salary can be defined as:

$$S_F = S_b + S_{add}, \quad (14)$$

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 A design engineer with no experience in Tomsk has an average salary of 18,000 rubles. With this in mind, we calculate the size of the total salary of the project manager and design engineer during the study.

Monthly salaries:

- For project supervisor:

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

$$S_{F.sup} = S_{b.sup} + S_{add} = 72\,540 + 0{,}15 \cdot 72\,540 = 83420 \text{ RUB}.$$

- For engineer developer:

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

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

Average daily salary:

$$S_{D.sup.} = \frac{S_{b.sup.}}{F_d} = \frac{72540}{20,58} = 3524,1 \text{ RUB};$$

$$S_{D.eng.} = \frac{S_{b.eng.}}{F_d} = \frac{36270}{20,58} = 1762,4 \text{ RUB},$$

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

$$F_d = \frac{T_w}{12} = \frac{247}{12} = 20,58.$$

Let's assume that the project manager spent 25 working days on it, then the design engineer was engaged in the rest of the time (80 days). Salaries of project participants for the period of work:

$$S_{sup} = S_{D.sup.} \cdot t_{sup} = 3524.2 \cdot 10 = 35242 \text{ RUB};$$

$$S_{eng} = S_{D.eng.} \cdot t_{eng} = 1762.1 \cdot 56 = 986678 \text{ RUB}.$$

Additional salaries of project participants:

$$S_{add.sup.} = 0,15 \cdot 35242 = 10881 \text{ RUB};$$

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

Daily additional salaries:

$$S_{D.add.sup.} = \frac{10880,3}{20,58} = 528,63 \text{ RUB};$$

$$S_{D.add.eng.} = \frac{5440,5}{20,58} = 264,4 \text{ RUB}.$$

Additional salary for the entire project period:

$$S_{Padd.sup} = S_{D.add.sup} \cdot t_{sup} = 528,63 \cdot 10 = 5286,3 \text{ RUB};$$

$$S_{Padd.eng} = S_{D.add.eng.} \cdot t_{eng} = 264,4 \cdot 56 = 14801,7 \text{ RUB}.$$

Full salary for the period of the project:

$$S_{F.sup} = S_{b.sup} + S_{Padd.sup} = 72540 + 5286,3 = 77826,3 \text{ RUB};$$

$$S_{F.eng} = S_{b.eng} + S_{Padd.eng} = 36270 + 14801,7 = 51071,7 \text{ RUB}.$$

4.2.5.4. Contributions to social funds

Here I will consider the obligatory contributions according to the norms established by the legislation of the Russian Federation to the state social insurance bodies (FSS), the pension fund (PF) and medical insurance (FFOMS) from the costs of wages of employees. The amount of contributions to extra-budgetary funds is determined by the formula:

$$S_{exb} = k_{exb}(S_{F.sup} + S_{F.eng}), \quad (15)$$

where k_{exb}– contribution rate to extrabudgetary funds.

To date, the following contributions must be made from the amount provided as payment for labor:

- 22% towards the accrual of future pension;
- 5,1% to the Mandatory Health Insurance Fund;
- 2,9% to the Social Insurance Fund;
- from 0,2 to 8,5% for insurance against accidents that may occur at work (the exact amount depends on the risk class, which includes the profession and position of the employee).

The work of a manager and a design engineer belongs to the 1 risk class. Thus, the total deductions amount to 30,2%.

$$S_{exb} = 0{,}302 \cdot (77826{,}3 + 51071{,}7) = 38927{,}2 \text{ RUB}$$

4.2.5.5. Organization of research costs budget

In the previous subchapters, the values of the main costs of the research were calculated. Let us take them all in one table 29.

Table 32 – Research cost budgeting

Name	Cost, RUB.	Cost, %
Costs for materials and other products	1290.0	0.62
Costs for specialized equipment	3494.5	1.69
Supervisor salary costs	77826.3	37.66
Design engineer salary costs	51071.7	24.71
Contributions to social funds	38927.2	18.83

Overheads	34065.7	16.48
Research budget	206675.4	100.0

In the course of the completed project, a condenser-refrigerator was calculated for the implementation of the condenser types depending on the sickness that is 0.7 and 1.5 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 this variant 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 0.7 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 1000-КЦС -1 d_{out} = 28 mm; δ_{wall} = 2 mm.

5. Social responsibility

Introduction

In modern conditions, one of the main directions of radical improvement of all preventive work to reduce occupational injuries and occupational morbidity is the widespread introduction of a comprehensive occupational health and safety management system, that is, by combining disparate measures into a single system of targeted actions at all levels and stages of the production process.

Labor security could be a framework of authoritative, social and financial, organizational, mechanical, sterile and restorative and preventive measures and implies that guarantee the safety, preservation of human wellbeing and proficiency within the prepare of work.

Rules on labor security and security are presented in arrange to anticipate mishaps, guarantee secure working conditions for representatives and are required for laborers, directors, building and specialized laborers.

A dangerous generation figure may be a generation figure whose introduction beneath certain conditions leads to harm or other sudden, sharp deterioration of health.

A destructive generation calculate may be a generation figure whose affect on an representative in certain conditions leads to sickness or a diminish in working capacity.

6. Safe working conditions

6.1. Special legal norms of labor legislation

Most of the work that is carried out in production is directly related to the presence of dangerous and harmful production factors.

When hiring, the applicant is informed about this, and also indicated in the employment contract. And, accordingly, the employer is also obliged to familiarize not only with such working conditions, but also to teach safety measures, safe work practices, conduct internships at the workplace, provide training on labor protection, and periodically check the employee's knowledge of labor protection requirements.

In accordance with Art. 221 - 225 of the Labor Code of the Russian Federation in the conditions of dangerous and (or) harmful production factors, it should be provided by the employer of workers with personal protective equipment, special clothing, disinfecting or rinsing agents, all necessary share of first aid, etc. Also, at his own expense, the employer must ensure the issuance of special shoes and clothes, as well as other personal protective equipment. In addition, according to part 3 of article 221 of the Labor Code of the Russian Federation, the employer must provide care for special clothing (I.E. storage, repair, replacement, washing, drying).

It is also envisaged to undergo a medical examination for workers who perform work in conditions with dangerous and (or) harmful production factors, which is indicated in Article 213 of the Labor Code of the Russian Federation. Moreover, both during employment and in the process of work. In the order of the Ministry of Health and Social Development of the Russian Federation dated 12.04.2011 № 302n. The procedure for conducting a medical examination is indicated. The requirements of this document stipulate that a medical examination should be carried out once a year, or twice a year. It depends on the type of activity of the employee in the workplace, as well as on the presence of specific harmful factors. According to part 6 of article 213 of the Labor Code of the Russian Federation, for workers whose work is associated with sources of increased danger (for example, the influence of adverse production factors and harmful substances), as well as for those working under conditions of increased danger, a mandatory psychiatric examination should be performed at least once every 5 years. According to the Decree of the Ministry of Labor of the Russian Federation and the Ministry of Education of the Russian Federation of 13.01.2003 No. 1/29 “On approving the procedure for training on labor protection and testing knowledge of labor protection requirements for employees of organizations”, a production worker must, in addition to a medical examination at least once every 3 years, pass his knowledge test occupational safety, as well as first aid training for injured people.

6.2. Organizational arrangements for the layout of the working area

6.2.1. Microclimate of the working room

During work in the laboratory, it is necessary to create favorable conditions for the microclimate of the workplace. Prolonged exposure of a person to adverse weather conditions can dramatically worsen his well-being, reduce labor productivity and lead to diseases. The microclimate is determined by combinations of temperature, humidity, air velocity and thermal radiation acting on the human body.

High air temperature contributes to rapid fatigue of the worker, and can lead to overheating of the body, cause a violation of thermoregulation, poor health, decreased attention, heat stroke, increased stress on the heart. Low air temperature can cause local or general hypothermia, cause colds, and lead to diseases of the peripheral nervous system (radiculitis, bronchitis, rheumatism). Low humidity can cause the mucous membranes of the respiratory tract to dry out. Air mobility effectively contributes to the heat transfer of the human body and is positively manifested at high temperatures and negatively at low.

According to SanPin 2.2.4.548–96, work in the laboratory belongs to category 1b in terms of energy consumption - this is light physical work, which does not require lifting and carrying heavy loads, is performed while sitting or is connected with walking.

We give the optimal and permissible microclimate indicators of industrial premises in accordance with SanPin 2.2.4.548–96

Table 33 - Optimum microclimate indicators

Period of the year	Temperature, degrees, °C	Relative humidity, %	Air flowrate, m / s
Cold	21–23	40–60	0.1
Warm	22–24	40–60	0.1

Table 34 - Permissible indicators microclimate

Period of the year	Temperature, degrees, C		Surface temperature, C	Relative humidity, %	Air flowrate, m / s	
	Range below r.h.	Range above r.h.			for air temperature range below (relative humidity), no more	for air temperature range above (relative humidity), no more
Cold	19.0 – 20.9	23.1 – 24.0	18.0 – 25.0	15-75	0.1	0.2
Warm	20.0 – 21.9	24.1 – 28.0	19.0 – 29.0	15-75	0.1	0.3

6.2.2. Work area illumination

Not only eye health and human performance, but also his physical and psych emotional state directly depends on the degree of illumination. Moreover, in premises for various purposes, the lighting requirements should vary. Also, when calculating the illumination, it is reasonable to take into account the characteristics of the working process carried out by a person in such a room, its frequency and duration

In practice, two types of lighting are used: natural and artificial. Natural lateral and artificial working, as well as combined, which consists of local lighting of workplaces and general lighting of the room. These types of lighting are standardized by Set of rules 52.13330.2011.

In this laboratory, work is carried out on personal computers. According to SanPin 2.2.2 / 2.4.1340–03[1] “Hygienic requirements for personal electronic computers and organization of work”, artificial lighting in premises for the operation of a personal computer should be carried out by a general uniform lighting system. Illumination on the table surface in the area of the working document should be 300-500 lux. Lighting should not create glare on the surface of the screen. Illumination of the screen surface should not be more than 300 lux.

In the laboratory, medium-precision work is carried out with the smallest size of the object of discrimination 0.5 - 1.0 mm, the contrast of the object of discrimination with the background is medium. The category of visual work is IV, sub discharge b, thus the illumination of the working surface from general lighting systems is 200 lux (Set of rules 52.13330.2011 “Natural and artificial lighting”).

Table 35 - Lighting requirements for residential and public buildings.

Artificial lighting		Natural lighting, DLR, %, at	
Illumination on the working surface from the general lighting system, lux	Coefficient of pulsation of illumination CP, %, no more	Top lighting or combined	Side
300	20	2.5	0.7

Thus, there are no violations of the lighting standards in the laboratory.

6.2.3. Noise level at the workplace

Noise pollution of the environment at the workplace adversely affects workers: attention is reduced, energy consumption increases with the same physical

activity, the speed of mental reactions slows down, etc. As a result, labor productivity and the quality of the work performed are reduced.

The main sources of noise in rooms equipped with computer technology are printers, plotters, copying equipment and equipment for air conditioning, fans of cooling systems.

accordance with SanPin 2.2.2 / 2.4.1340–03[1] "Hygienic requirements for personal electronic computers and organization of work", the noise level at workplaces should not exceed 50 dB

6.2.4. Elevated electromagnetic radiation

PCs are sources of broadband electromagnetic radiation:

• soft x-ray;

• ultraviolet 200-400 nm;

• visible 400–750 nm;

• near infrared 750–2000 nm;

• 3 kHz radio frequency range;

• electrostatic fields;

Table 36 - Temporary permissible levels of EMF created by PC in the workplace.

Name of parameters	Temporary Permissible Levels	
Electric field strength	In the frequency range 5 Hz - 2 kHz	25 V/m
	In the frequency range 2 kHz - 400 kHz	2.5 V/m
Magnetic flux density	In the frequency range 5 Hz - 2 kHz	250 nT
	In the frequency range 2 kHz - 400 kHz	25 nT

Electrostatic field strength		15 kV/m

If at the surveyed workplace equipped with a PC, the intensity of the electric and / or magnetic field in the range of 5 - 2000 Hz exceeds the values given above, it is necessary to measure the background EMF levels of industrial frequency (with the equipment turned off). The background level of the electric field with a frequency of 50 Hz should not exceed 500 V / m.

The background levels of the magnetic field induction should not exceed the values causing violations of the requirements for the visual parameters of the VDT. As a precaution, you should limit the duration of work with the PC, do not place them concentrated in the work area and turn them off if they are not working. Along with this, it is necessary to install air ionizers in the room, ventilate the room more often and, at least once during the work shift, clean the screen of dust (SanPin 2.2.2 / 2.4.1340–03)[1].

6.2.5. Arrangements for the layout of the working area

Of great importance in the work is the organization of jobs for employees and the creation of favorable working conditions. Work in the laboratory is usually characterized by low motor activity, monotony, prolonged stay indoors. All this causes fatigue and naturally affects the results of labor.

In a laboratory with an area of 30 m2, no more than 5 people can work simultaneously, therefore, the norms of the office space are taken into account. To ensure favorable microclimate conditions, the room is equipped with a hood. The depth of the table is 800mm, width 1.5m. The distance between workers is at least 1.5 m. The width of the passage is about 2m. The planes of computer screens are perpendicular to the windows, the dimensions of the furniture correspond to the size of the room, there is no clutter.

The mode of work and rest provides for compliance with a certain duration of continuous work on the PC and breaks, regulated taking into account the duration of the shift, types and categories of work.

Labor in the laboratory belongs to category B - creative work in dialogue with a PC, the third category of severity. The mode of work and rest of operators working with computers should be as follows: after every hour of intensive work, a 15-minute break should be arranged, with a less intensive break every 2 - hours. The effectiveness of regulated breaks increases when combined with workout gymnastics. Gymnastics should include a set of exercises aimed at filling the deficit of motor activity, relieving tension in the muscles of the neck, back, and reducing vision fatigue. It is carried out for 5 to 7 minutes. 1-2 times per shift (SanPin 2.2.2 /2.4.1340–03[1]) Since the work was carried out mainly on a PC, according to (SanPin 2.2.2 /2.4.1340–03[1]) the following requirements are imposed on the layout of the workplace of a computer operator:

The desktop should be adjustable in height within 680-800 mm; in the absence of such a possibility, its height shall be 725 mm. The optimal dimensions of the worktop are 1400x1000 mm. Under the tabletop, there should be free legroom with a height of at least 600 mm, a width of 500 mm, and a depth of 650 mm. On the surface of the desktop for documents, it is necessary to provide for the placement of a special stand, the distance from which should be the same as the distance from the eyes to the keyboard, which reduces visual fatigue.

The working chair (chair) must be equipped with a lifting and swiveling device that provides seat and backrest height adjustment; its design should also include a change in the angle of inclination of the back. The working chair must have armrests. The adjustment of each parameter should be easy to carry out, be independent and have a secure fit. The height of the seat surface must be adjustable between 400–500 mm. The width and depth of the seat must be at least 400 mm. The height of the back surface should be at least 300 mm, width at least

380 mm. The radius of its curvature in the horizontal plane is 400 mm. The angle of the backrest should vary between 90-110º to the plane of the seat. The coating material of the working chair should allow easy cleaning from contamination. The surface of the seat and back should be semi-soft, with a non-slip, non-electrifying and breathable coating.

7. Industrial safety

Industrial safety is understood as a system of organizational measures and technical means that prevent or reduce the likelihood of exposure to working personnel of dangerous traumatic production factors that arise in the work area during the course of labor activity. In our work, it is necessary to find out dangerous and harmful factors that may arise when working with an information system. Subsequent selection is made using GOST 12.0.003–2015 "Dangerous and harmful production factors. Classification". The selection results are shown in the table below.

Table 37 - Harmful and dangerous factors when working with a computer.

Source of factor, name of the type of work	List of factors (according to GOST12.0.003–2015)		Relevant regulatory documents
	Harmful	Dangerous	
1) Computer work	1) The microclimate of the working room; 2) increased or decreased humidity of the air of the working area 3)Illumination of the working area; 4)Increased noise in the workplace; 5) Increased level of electromagnetic radiation	1) Exposure to electrical current	1) SanPin 2.2.4.548–96; 2)GOST R 12.1.019–2009; 3)GOST 12.1.030–81; 4)SP 52.13330.2011; 5)SanPin 2.2.2/2.4.1340–03; 6) GOST 12.1.003–83; 7) SanPin 2.2.2/2.4.1340–03

7.1. Analysis of harmful and dangerous factors that can be created by object of study and laboratory during research

7.1.1. Analysis of identified hazardous factors

The laboratory room where the work was carried out belongs to category B The causes of the fire may be:

1. Short circuit currents.
2. Malfunction of electric networks.
3. Ignorance of fire safety rules or negligence of staff.
4. Smoking in the wrong places.

In this regard, the following fire safety standards must be observed in the laboratory:

1. To protect the network from overloads, it is forbidden to include additional non- intended consumers.
2. Carry out work in the laboratory only when the equipment and electrical wiring are in good condition.
3. For extinguish a fire (fire extinguisher).
4. Have a plan of evacuation of people, which should hang in a conspicuous place.
5. Place the equipment so that there is sufficient passageway to the exit.

The building of the Tomsk polytechnical University, in which the laboratory is located, meets the fire safety requirements.

7.1.2. Electrical safety

Electrical safety is a system of organizational and technical measures aimed at protecting people from the harmful and dangerous effects of electric current. There is a danger of electric shock in all cases where electrical installations and equipment are used. Electrical installations are classified by voltage - with a rated voltage of up to 1000 V (rooms without increased danger), up to 1000 V with the presence of an aggressive environment (rooms with increased danger) and over 1000 V (rooms especially dangerous) (according to the Rules for the Installation of Electrical Installations). To ensure safe operation, it is necessary to exclude possible sources of electric shock:

1. Accidental contact with live parts under voltage.
2. The appearance of voltage on the mechanical parts of electrical equipment (cases, covers, etc.) due to insulation damage or other reasons.
3. The occurrence of stress on the ground or supporting surface.

According to the degree of danger of electric shock, this laboratory belongs to rooms without increased danger, it is a dry room without increased dusting, the air temperature is normal, the floor is covered with insulating material. All electrical equipment and devices are in place and have protective grounding with a resistance of not more than 4 ohms (GOST 12.1.030-81.) All employees undergo initial electrical safety training. Before starting work, it is necessary to check the serviceability of conductive wires. It is forbidden to use wires with damaged insulation or without insulation, as well as wires that are not equipped with plugs or soldered terminals, to connect electrical appliances. Instruments must be kept clean. At the end of the work, disconnect the equipment from the network.

Electric shock during GQW can occur during careless handling of the connecting wires or in the event of an emergency - shorting of live parts to the equipment case in the absence of grounding and grounding. This can happen when working with electrical laboratory equipment.

Table 38 - Permissible levels of touch voltages and currents.

Mode	Type of Current					
	Variable, 50 Hz			Constant		
	U, B	I, мA	Duration, min	U, B	I, мA	Duration, min
Normal	2	0.3	<10	8	1	<10

First aid to the victim should consist in immediately disconnecting the current that caused the injury, disconnecting (in rubber gloves) the victim from the leads and calling the doctor. If the victim is conscious, but before that he was swooning or has been under current for a long time, he needs to ensure peace before the doctor arrives. If the victim lost consciousness, but breathing persists, it is necessary to put him in comfortably, evenly, unfasten his tight clothes, create an influx of fresh air, remove unnecessary people from the room, breathe ammonia, spray with water, rub and warm the body. With convulsive and rare breathing, artificial respiration is necessary. In the absence of signs of life (lack of pulse and breathing), the victim cannot be considered.

It is necessary immediately, without wasting time, before the arrival of the doctor to do artificial respiration.

7.2.Air exchange in laboratory

Air exchange in public buildings is necessary to clean the air of harmful substances: to remove harmful substances (emitted harmful gases, vapors and dust), to remove water vapor and excess heat.

In residential and public buildings, carbon dioxide (CO2) exhaled by people is a constant harmful emission. The required air exchange is determined by the amount of carbon dioxide exhaled by a person and by its permissible concentration. The amount of carbon dioxide, depending on the age of the person and the work performed, as well as the permissible concentration of carbon dioxide for different rooms. The carbon dioxide content in the air can be determined by the chemical composition of the air[4]. However, given the increased carbon dioxide content in the atmosphere of settlements, the CO2 content should be taken into account when calculating:

- for large cities (over 300 thousand inhabitants)– 0.5 l/m^3.

Determine the required rate of air exchange in a laboratory for two people, if the volume of the room is V=32 m^3. The laboratory is located in 442б office of the hostel building Vershinina of Tomsk university. The amount of carbon dioxide exhaled by an adult with light work in an institution is 18 l/h[4]. The maximum permissible concentration of carbon dioxide for institutions is 1.25 l/m3. The required air exchange in the laboratory is determined by the formula 1:

$$L = \frac{G \cdot P}{x_v - x_n}$$

where L – air exchange required, m^3/h;

G –is the amount of harmful substances released into the room air, g/h;

P – number of people working in the laboratory;

x_v – maximum permissible concentration of harmfulness in the air of the working area of the room [3], mg/m^3;

x_n – the maximum possible concentration of the same harmfulness in the air of populated areas [3], mg/m^3.

The rate of air exchange (n), which shows how many times in one hour the air is completely replaced in the room, which is determined by the formula 2.

$$n = \frac{L}{V_n}\ , h^{-1}$$

where -V_n is the internal volume of the room, m^3

- According to [3], the permissible air exchange rate should be in the range from 3 to 10 h^{-1}.

Required air exchange in the laboratory, according to 1:

$$\mathrm{L} = \frac{18 \cdot 1}{1.25 - 0.5} = 24\ m^3/h$$

The required air exchange rate is:

$$n = \frac{24}{32}\ , = 0.75\ h^{-1}$$

Thus, the calculated consumed air exchange in the laboratory should be 48 m^3/h.

Safety in emergency situations

In case of emergency, you must immediately call the fire department at number “01” from your business phone or “101” from your mobile phone.

The notification of civil defense alerts in the event of an emergency to the personnel of the objects is carried out using voice information through broadcasting channels, radio broadcast networks and communication networks. On the territory of the Tomsk university hostel they do not use, do not produce, do not process, do not store radioactive, fire hazardous, and also explosive substances that create a real threat of an emergency source. As the most probable technological emergencies, the project considers

Fire at the territory object.

Fire hazards for humans include toxic combustion products, low oxygen concentration, open flames, smoke, and high air temperatures.

The following measures must be observed to prevent fire:

- Reducing the determining size of the combustible medium.
- Prevention of the formation of a combustible medium.

In case of overheating, short circuits, etc. possible ignition of electrical installations, wiring. To extinguish the fire, it is necessary to use special means, it is impossible to use water and other conductive substances. Therefore, the premises should be equipped with means for extinguishing electrical installations and electrical wiring under voltage.

In case of overheating, short circuits, etc. possible ignition of electrical installations, wiring. To extinguish the fire, it is necessary to use special means, it is impossible to use water and other conductive substances. Therefore, the premises should be equipped with means for extinguishing electrical installations and electrical wiring under voltage.

8. Ecological safety

8.1. Environmental impact of nuclear power

The environmental impact of nuclear power results from the nuclear fuel cycle, operation, and the effects of nuclear accidents.

The greenhouse gas emissions from nuclear fission power are much smaller than those associated with coal, oil and gas, and the routine health risks are much smaller than those associated with coal. However, there is a "catastrophic risk" potential if containment fails, which in nuclear reactors can be brought about by overheated fuels melting and releasing large quantities of fission products into the environment.

The most long-lived radioactive wastes, including spent nuclear fuel, must be contained and isolated from the environment for a long period of time. On the other side, spent nuclear fuel could be reused, yielding even more energy, and reducing the amount of waste to be contained.

- Other waste

Moderate amounts of low-level waste are through chemical and volume control system (CVCS). This includes gas, liquid, and solid waste produced through the process of purifying the water through evaporation. Liquid waste is reprocessed continuously, and gas waste is filtered, compressed, stored to allow decay,[3] diluted, and then discharged. The rate at which this is allowed is regulated and studies must prove that such discharge does not violate dose limits to a member of the public (see radioactive effluent emissions).

Solid waste can be disposed of simply by placing it where it will not be disturbed for a few years.

Power plant emission

- Radioactive gases and effluents

Most commercial nuclear power plants release gaseous and liquid radiological effluents into the environment as a byproduct of the Chemical Volume Control System.

Civilians living within 50 miles (80 km) of a nuclear power plant typically receive about 0.1 μSv per year. For comparison, the average person living at or above sea level receives at least 260 μSv from cosmic radiation.

All reactors are to have a containment building. The walls of containment buildings are several feet thick and made of concrete and therefore can stop the release of any radiation emitted by the reactor into the environment. If a person is to worry about an energy source that releases large amounts of radiation into the environment, they should worry about coal- fired plants. "The waste produced by coal plants is actually more radioactive than that generated by their nuclear counterparts. In fact, the fly ash emitted by a [coal] power plant— a by-product from burning coal for electricity—carries into the surrounding environment 100 times more radiation than a nuclear power plant producing the same amount of energy." Coal-fired plants are much more hazardous to people's health than nuclear power plants as they release much more radioactive elements into the environment and subsequently expose people to greater levels of radiation than nuclear plants do. "Estimated radiation doses ingested by people living near the coal plants were equal to or higher than doses for people living around the nuclear facilities. At one extreme, the scientists estimated fly ash radiation in individuals' bones at around 18 millirems (thousandths of a rem, a unit for measuring doses of ionizing radiation) a year. Doses for the two nuclear plants, by contrast, ranged from between three and six millirems for the same period. And when all food was grown in the area, radiation doses were 50 to 200 percent higher around the coal plants."

The total amount of radioactivity released through this method depends on the power plant, the regulatory requirements, and the plant's performance. Atmospheric dispersion models combined with pathway models are employed to accurately approximate the dose to a member of the public from the effluents emitted. Effluent monitoring is conducted continuously at the plant.

9. Comparison to coal-fired generation

In terms of net radioactive release, the National Council on Radiation Protection and Measurements (NCRP) estimated the average radioactivity per short ton of coal is 17,100 millicuries/4,000,000 tons.

In terms of dose to a human living nearby, it is sometimes cited that coal plants release 100 times the radioactivity of nuclear plants[3]. This comes from NCRP Reports No. 92 and No. 95 which estimated the dose to the population from 1000 MWe coal and nuclear plants at 4.9 man-Sv/year and 0.048 man-Sv/year respectively (a typical Chest x-ray gives a dose of about 0.06 mSv for comparison). The Environmental Protection Agency estimates an added dose of 0.3 µSv per year for living within 50 miles (80 km) of a coal plant and 0.009 milli-rem for a nuclear plant for yearly radiation dose estimation. Nuclear power plants in normal operation emit less radioactivity than coal power plants.

Unlike coal-fired or oil-fired generation, nuclear power generation does not directly produce any sulfur dioxide, nitrogen oxides, or mercury (pollution from fossil fuels is blamed for 24,000 early deaths each year in the U.S. alone). However, as with all energy sources, there is some pollution associated with support activities such as mining, manufacturing and transportation.

A major European Union-funded research study known as Extern, or Externalities of Energy, undertaken over the period of 1995 to 2005 found that the environmental and health costs of nuclear power, per unit of energy delivered, was €0.0019/kWh. This is lower than that of many renewable sources including the environmental impact caused by biomass use and the manufacture of photovoltaic solar panels, and was over thirty times lower than coals impact of €0.06/kWh, or 6 cents/kWh. However, the energy source of the lowest external costs associated with it was found to be wind power at €0.0009/kWh, which is an environmental and health impact just under half the price of Nuclear power.

- Waste heat

As with all thermoelectric plants, nuclear power plants need cooling systems. The most common systems for thermal power plants, including nuclear, are:

- Once-through cooling, in which water is drawn from a large body, passes through the cooling system, and then flows back into the water body.
- Cooling pond, in which water is drawn from a pond dedicated to the purpose, passes through the cooling system, then returns to the pond.
- Cooling towers, in which water recirculates through the cooling system until it evaporates from the tower.

Nuclear plants exchange 60 to 70% of their thermal energy by cycling with a body of water or by evaporating water through a cooling tower. This thermal efficiency is somewhat lower than that of coal-fired power plants, thus creating more waste heat.

It is possible to use waste heat in cogeneration applications such as district heating. The principles of cogeneration and district heating with nuclear power are the same as any other form of thermal power production. One use of nuclear heat generation was with the Ågesta Nuclear Power Plant in Sweden. In Switzerland, the Beznau Nuclear Power Plant provides heat to about 20,000 people. However, district heating with nuclear power plants is less common than with other modes of waste heat generation.

A number of thermal stations use indirect seawater cooling or cooling towers that in comparison use little to no freshwater.

9.1. 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[2].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.

9.2. Greenhouse gas emissions

Many stages of the nuclear fuel chain — mining, milling, transport, fuel fabrication, enrichment, reactor construction, decommissioning and waste management — use fossil fuels, or involve changes to land use, and hence emit carbon dioxide and conventional pollutants.

Nuclear energy contributes a very small amount of emissions into the atmosphere which can cause many environmental problems such as global warming. Uranium is not burned in a nuclear power plant as coal is so there are no emissions from it. All of the waste that comes from the fission of uranium stays in the plant and is therefore able to be disposed of in a safe way in which the uranium is kept out of the environment. “

Nuclear energy produces far less carbon dioxide than coal, 9 grams per kilowatt hour compared with 790–1017 grams per kilowatt hour for coal[5]. Also, nuclear energy produces the same amount if not less greenhouse gasses than renewable resources. Like all energy sources, various life cycle analysis (LCA) studies have led to a range of estimates on the median value for nuclear power, with most comparisons of carbon dioxide emissions show nuclear power as comparable to renewable energy sources.

Nuclear power, primarily from ~1970 to 2013, is estimated to have prevented the atmospheric emission of 64 gigatons of CO_2-equivalent.

10. 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, Ne, of the NPP is known.

Emission goes through the chimney consisting of the main chimney and internal one.

The internal one has diameter d, and it is used during normal operation mode, when the gas mixture is being vented with the volumetric flow rate $V1$.[2] The main chimney is needed to emit the gas mixture during repair period, when the volumetric flow rate is $V2$. The diameter of the main tube is D.

NPP's normal operation mode time assumed equal to tno. 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.

Notes: -

Critical groups of population are exposed to external and internal irradiations; internal one includes irradiation due to breathing and with dietary intake (all of the possible ways).

11.Maximum permissible discharge

Table39-. Initial Data

Region, city	Russian Far East
N_e, MW	1200
H, m	160
d, m	1.3
D, m	3.5
$V_1, \frac{м^3}{с}$	55
$V_2, \frac{м^3}{с}$	120
$\Delta T, ℃$	18
$t_{ot}, \frac{days}{year}$	320
Reactor type	WWER

$$MPD_i = K_d(TC_i - C_{ni}) \quad \frac{Bq}{s}$$

Where: -

K_d is coefficient of meteorological dilution of component in the atmosphere, $\frac{m^3}{s}$;

TC_i is tolerable concentration of the component, $\frac{Ci}{m^3}$;

C_{ci} is background concentration of the component, $\frac{Ci}{m^3}$.

If the value of C_{ni} is unknown, the evaluation of MPD_i can be done via the formula below: -

$$MPD_i = \frac{1}{\gamma} K_d TC_i, \qquad \frac{Bq}{s},$$

$$TC_i = 2346367 \frac{Ci}{m^3},\ K_d = 559558115.6 \frac{m^3}{s},\ \gamma = 30,$$

$$MPD_i = \frac{1}{30} \cdot 559558115.6 \cdot 2346367 = 1.12 \cdot 10^{13} \quad Bq/s.$$

Where: -

is γ is a factor; $\gamma = 30$ for operating NPP and, if the following capacity expansion is planned; $\gamma = 10$ at the stage of NPP design.

Coefficient of meteorological dilution of component in the atmosphere is calculated with the formula

$$K_d = \frac{H^2\sqrt{V\Delta T}}{A \cdot F \cdot m \cdot n \cdot \alpha \cdot c \cdot \left(\frac{v}{v_0}\right)}, \frac{m^3}{s}$$

$$K_d = \frac{160^2\sqrt{120 \cdot 18}}{0.2 \cdot 1 \cdot 0{,}35 \cdot 1.58 \cdot 0.07 \cdot 3 \cdot \left(\frac{3}{1}\right)}, \frac{m^3}{s} = 559558115.6 \ \frac{m^3}{s}.$$

Where: -

H is height of the tube, m;

V_2 is volumetric flow rate of the gas mixture, $\frac{m^3}{s}$;

A is a factor depending on temperature stratification of the atmosphere and defining the conditions of vertical or horizontal dissipation at an intensive turbulent exchange in the atmosphere , $s^{\frac{2}{3}} \cdot °C^{\frac{1}{3}}$;

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 40- A factor values

Russian Far East	0.2

Table *41*- F factor values

$F = 1$	Gases and aerosol

$$m = \frac{1}{0.67 + 0.1\sqrt{f} + 0.34\sqrt[3]{f}};$$

$$m = \frac{1}{0.67 + 0.1\sqrt{13.05} + 0.34\sqrt[3]{13.05}} = 0.35.$$

$$f = \frac{10^3 w_0^2 D}{H^2 \Delta T},$$

$$f = \frac{10^3 \cdot 41.45^2 \cdot 3.5}{160^2 \cdot 18} = 13.05.$$

$$w_0 = \frac{v_1}{A},$$

$$w_0 = \frac{55}{1.32} = 41.45\,\frac{m}{s}.$$

$$A = \frac{\pi}{4} \cdot d_0^2,$$

$$A = \frac{\pi}{4} \cdot 1.3^2 = 1.32\,m^2.$$

where w_0 is outlet velocity of gases, $\frac{m}{s}$;

D is chimney diameter ($D \equiv d$ in case repair period).

The factor n depends on parameter V_m:

$$V_m = 0.65\sqrt[3]{\frac{V \Delta T}{H}},$$

$$V_m = 0.65\sqrt[3]{\frac{55 \cdot 18}{160}} = 1.19.$$

Table 42- n factor values

$$n = 3 - \sqrt{(1.19 - 0.3)(4.36 - 1.19)} = 1.85.$$

$n = 3 - \sqrt{(V_m - 0.3)(4.36 - V_m)}$	$V_m \in (0.3; 2]$

Table 43- Wind predominant directions for different regions of Russia

Region	Wind predominant direction	$\left(\frac{v}{v_0}\right)$
Russian Far East	North – North - West	$3:1$

$c = 1.3 - 1.5$ if hill country, slope is 0.1-0.15; difference of elevation less than 100m

Firstly, annual discharge of radioactive noble gases of a NPP is calculated with the following formula:

$$B_{an} = B_n N_e, \qquad \frac{Ci}{year},$$

$$B_{an} = 20 \cdot 800 = 16000 \frac{Ci}{year}.$$

Where: -

B_n is normalized discharge of radioactive noble gases, B_n is assumed equal to $20 \frac{Ci}{MW \cdot year}$;

Capacity expansion limit is calculated with the formula

$$N_e^{lim} = N_e \frac{\sum_i MPD_i^{RNG} \cdot t_{no}}{B_{an}},$$

$$t_{no} = 320 \cdot 24 \cdot 60 \cdot 60 = 27648000$$

$$B_{an} = 16000 \cdot 3.7 \cdot 10^{10} = 5.9 \cdot 10^{14}$$

where $\sum_i MPD_i^{RNG}$ is maximum permissible discharge of radioactive noble gases only.

$$MPD_{RNG} = \frac{1}{\gamma} K_d T C_{RNG}, \qquad \frac{Bq}{s},$$

$$MPD_{RNG} = \frac{1}{30} \cdot 559558115.6 \cdot 80000000 = 1.49 \cdot 10^{15} \frac{Bq}{s}.$$

$$N_e^{lim} = 1200 \cdot \frac{1.49 \cdot 10^{15} \cdot 27648000}{5.9 \cdot 10^{14}} = 5.57 \cdot 10^{10}$$

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:

$$\beta = 4.95 V_m \left(1 + 0.28 f^{\frac{1}{3}}\right), \text{ if } V_m \le 2;$$

$$\beta = 4.95 \cdot 0{,}93 \left(1 + 0.28 \cdot 13.05^{\frac{1}{3}}\right) = 6.55,$$

$$X = 2 \cdot 6.55 \cdot 160 = 2099.08.$$

Table 44- All results

Element	η	TC , Bq/m^3	η /TC	MPD_i Bq/s	MPD_i Bq/day
^{41}Ar	74000000	77700	952.38	1.22E+12	1.05E+17
^{85}kr	1200000	4070000	0.29	6.36E+13	5.50E+18
^{85m}Kr	12000000	629000	19.08	9.84E+12	8.50E+17
^{87}Kr	25000000	129500	193.05	2.03E+12	1.75E+17
^{88}Kr	34000000	48100	706.86	7.52E+11	6.50E+16
^{133}Xe	67000000	2257000	29.69	3.53E+13	3.05E+18
^{135}Xe	48000000	407000	117.94	6.36E+12	5.50E+17
^{89}Sr	0.4	35	0.01	5.47E+08	4.73E+13
^{90}Sr	1	1.5	0.67	2.35E+07	2.03E+12
^{131}I	1200	5	240.00	7.82E+07	6.76E+12
^{134}Cs	0.1	0.42	0.24	6.57E+06	5.67E+11
^{137}Cs	0.3	0.31	0.97	4.85E+06	4.19E+11
$^{140}Ba + ^{140}La$	0.4	22	0.02	3.44E+08	2.97E+13

- **Conclusion:**

The project was to design nuclear power plant with electric power 1200 MW with Four loops horizontal steam generator, in the thermal calculation part calculation of thermal the heating surfaces of steam generator, in the design calculation of SG to determine the main dimension to design horizontal steam generator, in the mechanical calculation part determined the static strength of the main elements of the steam generator and determine the wall thickness of these elements, in the hydraulic calculation of steam generator determined the pressure losses when the coolant moves in it, in the calculation of separation part is to estimate the humidity of steam in front of the steam receiving ceiling, which is located at the top of the steam volume, in thermal insulation part calculated the parameters of thermal insulation layer .

In the part of NNP thermal calculation the application of knowledge, skills, tools, and techniques to project activities to meet project requirements. Project management is accomplished through the use of processes such as: initiating, designing, calculating, choosing equipment, and representing.

As in the previous project stages, all activities are accomplished fulfilling the established management system that ensures the achievement of all the NPP project goals.

As a result of the calculations, of NPP with a VVER-300 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.

In this work, 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.

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