TOMSK POLYTECHNIC UNIVERSITY
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

APPROVED BY

Director of Nuclear Science & Engineering School
_____________ / Oleg Yu. Dolmatov
"25" 06 _______ 2020

Course Name: Thermodynamics

Field of Study: Nuclear Physics and Technologies

Programme name: Nuclear Science and Technology

Programme name: Nuclear Power Engineering

Level of Study: Master Degree Programme

Year of admission: 2020

Semester, year: semester 1, year 1

ECTS: 4

Total Hours: 144

Contact Hours: 48

- **Lectures:** 32
- **Practical experience:** 16

Assessment: exam

Division: Nuclear-Fuel Cycle

Director of Programme _____________ / Vera V. Verkhoturova

Instructor _____________ / Konstantin V. Slyusarskiy

TOMSK POLYTECHNIC UNIVERSITY ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

Course name: Thermodynamics

Course Overview

Course Objectives	The objective of mastering the discipline is the formation of certain set of student's competence to prepare them for professional activities. Current course is aimed to form a following competences: 1. Able to apply modern communication technology for academic and professional interactions including those on foreign language. 2. Able to formulate goal and objectives of research, chose evaluation criteria, prioritize solution of tasks. 3. Able to apply modern research methods, evaluate and present the results of work performed. 4. Able to format the results of research activities in the form of articles, proceedings, scientific reports and presentations using computer typesetting systems and office software packages. 5. Able to apply the basic ways, methods and means of obtaining, storing, processing information for planning and managing the life cycle of products and their quality. 6. Able to create theoretical and mathematical models to describe the condensed state of matter, the propagation and interaction of radiation with matter, the physics of kinetic phenomena, processes in reactors, accelerators, the effect of ionizing radiation on materials, humans and environmental objects. 7. Able to independently carry out experimental or theoretical research to solve scientific and industrial problems using modern technology, methods of calculation and research.
Learning Outcomes	Upon completion of the course, a graduate is expected to acquire the **knowledge of**: – the features of professional etiquette of Western and domestic culturesж – the basics of structuring a report and preparing presentations in a foreign language, accepted in the international environment; – the goals and objectives of scientific research in the field of professional activity, basic principles and methods of their organization; – the main sources of scientific information and the requirements for the presentation of information materials; – modern methods of research, evaluation and presentation of the results of work performed; – the basics of formatting research results in the form of articles, proceedings, scientific reports and presentations using computer typesetting systems and office software packages; – the technological modes of operation of the reactor installation and service systems; – the basics of physics of a nuclear reactor, heat engineering, electrical engineering, mechanics and water treatment; – the laws of thermodynamics, cycles of steam turbine and gas turbine plants, the energy balance of nuclear power plants, the efficiency;

	– the basic principles of operation of basic equipment, pipelines, technological schemes; – the purpose, structure and principle of operation of the main systems and equipment of nuclear power plants. Graduates are also expected to develop the following **skills**: – to compile and present technical and scientific information used in professional activities in the form of a presentation; – to perceive authentic audio and video materials related to training; – to draw up a general plan of work on a given topic, suggest research methods and methods of processing the results; – to conduct research according to the plan agreed with the manager, to present the results; – to format the results of research activities in the form of articles, proceedings, scientific reports and presentations using computer typesetting systems and office software packages; – to calculate the basic physical characteristics of nuclear reactors; – to apply calculation methods that accompany the process of designing nuclear reactors; – to use modern approaches and methods for calculating thermodynamic processes and systems; – to perform an approximate or evaluation engineering calculation of equipment, station indicators. Graduates should acquire **the practical experience in**: – applying skills of monologue speech in a foreign language according to the profile of specialty, reasonably expressing his position and using auxiliary means (tables, graphs, charts, etc.); – applying knowledge of a foreign language at a sufficient level in future professional activities; – applying systematic knowledge in the field of future professional activity; – applying in-depth knowledge on the chosen orientation of training, basic skills for conducting research on the proposed topic; – designing the results of research activities in the form of articles, proceedings, scientific reports and presentations using computer typesetting systems and office software packages; – identifying and calculating the parameters of thermodynamic processes and states of matter; – combining the results of thermal hydraulic calculation with physical, strength and economic calculations in order to justify the parameters of the reactor of a nuclear installation, its heat engineering reliability; – using packages of applied computer programs to determine the properties of substances and parameters of physical processes, the application of standard methods of measurement, calculation of technological processes; – using software packages for thermodynamic calculations.
Course Outline	The course includes the following parts: • 16 lectures; • 8 practical lessons; • 8 individual homework assignments with oral submitting;

	• 2 colloquiums (in written form); • 7 self-study topics; • 1 review and 1 presentation. Exam is set in a written form with oral comments on all questions. Main sections of the course: • Basic notions and definitions of thermodynamics. • The first and second laws of thermodynamics. • Main thermodynamic processes in gases, vapors and their mixtures. • Features of open system thermodynamics. • Cycles of thermal power plants. The course includes 8 individual homework assignments, 1 group review with presentation and 2 colloquiums.
Prerequisites (if available)	-
Course Structure	The course consists of five sections. **Section 1. Basic notions and definitions of thermodynamics.** Introduction. The subject of technical thermodynamics and its methods. Thermodynamic system. Basic parameters of state. Equilibrium and nonequilibrium state. Equations of state. Thermal and caloric equations of state. Heat and work as a form of energy transfer. Thermodynamic process. Equilibrium and non-equilibrium processes. Reversible and irreversible processes. Circular processes (cycles). Heat capacity. Mass, volume and molar heat capacity. Heat capacity at constant volume and pressure. Dependence of heat capacity on temperature and pressure. Average and true heat capacity. Equations and tables for determining the specific heat capacity. **Lecture topics:** 1. Introduction to technical thermodynamics. Concept, classification and parameters of thermodynamic systems. Unit systems. Equation of state. 2. Thermodynamic process. The concept, classification and parameters of the thermodynamic process. **Practice topics:** 1. The main parameters of the state. Unit systems and their relationship. **Section 2. The first and second laws of thermodynamics.** The first law of thermodynamics. Formulations of the first law of thermodynamics. Analytical expression of the first law of thermodynamics. Determination of work and heat using thermodynamic parameters of state. Internal energy. Enthalpy. The pv-diagram. Perfect gas. Definition and properties of perfect gas. Equation of state of perfect gas. Mixtures of working fluids. Methods for defining the composition of the mixture, the relationship between mass and volume concentrations. Calculation of the mixture parameters of state, determination of the apparent molecular mass and gas constant of the mixture, determination of the partial pressures of the components. Heat capacity of mixture of working fluids. Basic formulations of the second law of thermodynamics. Thermodynamic cycles of thermal engines. Direct and reverse cycles, their effectiveness. Carnot cycles and analysis of its properties. Analytical expression of the second law of thermodynamics. Entropy, its change in irreversible processes. The Ts-diagram. The concept of

	exergy. **Lecture topics:** 3. The first law of thermodynamics. Essence, wording and analytical expression. The concepts of internal energy and enthalpy. Pv-chart. 4. The second law of thermodynamics. Essence, wording and analytical expression. The concept of entropy. Carnot cycle. Ts-chart. **Practice topics:** 2. Parameters of the state of an ideal gas. Mixtures of ideal gases. **Section 3. Main thermodynamic processes in gases, vapors and their mixtures.** General methods for studying the processes of changing working fluid state. Polytropic process. The main characteristics of polytropic processes. Images of processes in the pv and Ts coordinates. Basic thermodynamic processes: isochoric, isobaric, isothermal, adiabatic – special cases of polytropic process. Thermodynamic processes in real gases and vapors. Properties of real gases. Vapors. Basic definitions. The processes of evaporation in pv- and Ts-diagrams. Steam. The concept of the Vukalovich-Novikov equation. Definitions of the concept of "moist air". The main values characterizing the state of moist air. Thermodynamic tables of water and steam. The pv-, Ts- and hs diagrams of steam. Calculation of the thermodynamic processes of steam using tables and hs diagram. Real thermodynamic processes of ideal gases, water and steam. **Lecture topics:** 5. The perfect gas. The equation of state of an ideal gas. Mixtures of ideal gases. 6. Isobaric, isochoric, isothermal and adiabatic processes as special cases of polytropic process 7. Real gases. The equation of van der Waals and Vukalovich-Novikov. Tables of water and water vapor. **Practice topics:** 3. Thermodynamic processes of an ideal gas. Perfect and real processes. 4. Water vapor. Ideal and real water vapor processes. **Section 4. Features of open system of thermodynamics.** Basic notions of thermodynamics of open systems. Equations of the first law of thermodynamics for a flow and its analysis. Possessed work and efflux rate. Secondary flow rate during efflux. Critical efflux rate. Critical pressure ratio. Calculation of the flow rate and the second mass flow rate for the critical regime. The conditions for obtaining speed above critical one. The Laval nozzle. Calculation of the process of steam efflux using the hs-diagram. The actual efflux process. Throttling of gases and vapors. The essence of the throttling process and its equation. Changing of parameters during throttling. The concept of the Joule-Thomson effect. Features of throttling of perfect and real gases. The concept of the inversion temperature. Applications of throttling process, its image in the hs-diagram. Isothermal, adiabatic and polytropic compression. Total work spent on the compressor drive. Multistage compression. Image in pv- and Ts-diagrams of thermodynamic compression processes. Irreversible compression. Relative internal efficiency of the compressor. Exergy of the flow of the working fluid. **Lecture topics:**

	8. The processes of gas outflow. Critical expiration mode. Laval nozzle. The expiration of water vapor. 9. The process of throttling the ideal gas and water vapor. Throttling in pv and Ts diagrams. 10. The process of adiabatic, isothermal and polytropic compression of an ideal gas. Irreversible compression. The relative internal efficiency of the compressor. Colloquium. **Practice topics:** 5. The processes of the outflow of ideal gas and water vapor. Throttling. **Section 5. Cycles of thermal power plants.** Schemes and images of cycles in pv- and Ts-diagrams, thermal and exergic efficiency of cycles: Carnot cycle. Carnot cycle on steam. The Rankine cycle and its analysis. Influence of the initial and final parameters on the thermal efficiency of the Rankine cycle. The concept of nuclear power plant cycles. Cycles with turbines on saturated and superheated steam with intermediate steam separation and superheating. Methods for increasing thermal efficiency of steam turbine units (STU). Regeneration of heat in the cycles of gas-turbine unit. Heating cycle. Principle of operation of GTU. GTU cycle with isobaric heat supply. Methods to increase the thermal efficiency of GTU. Regenerative cycle of GTU. Steam and gas cycles. NPP with gas turbine. Cycles of gas turbine units. Efficiency of the helium cycle for nuclear power plants with HTGR. Perspective thermodynamic cycles of nuclear power plants. Nuclear power plants with reactors for supercritical parameters. Nuclear power plant cycles with heat supply. Cycles of nuclear power plants on dissociating gases. The reverse Carnot cycle. Cycle of gas refrigerating machine. A cycle of vapor compression refrigeration machine with an expander and a throttle. Heat pump. Efficiency of the reverse cycle. **Lecture topics:** 11. The Rankine cycle. Rankine cycle on saturated and superheated steam. 12. The Rankine cycle with separation, intermediate fire and steam overheating. Ways to increase the dryness of steam at the outlet of the turbine. 13. Ideal gas cycles. Brighton and Otto cycles. Cycles of nuclear power plants with gas turbine plants. 14. Ways to increase the efficiency of heat power plant cycles: changing the initial parameters, regeneration, heating, turbo drive. NPP cycles for supercritical parameters. 15. Cycles of nuclear power plants with helium coolant. Dissociating gas NPP cycles. Combined cycle gas power plants. 16. Reverse cycles of heat engines. Cycles of gas and vapor compression refrigerators. Heat pump cycles. Colloquium. **Practice topics:** 6. The Rankine cycle on saturated and superheated steam. Start and end parameters. 7. The Rankine cycle with separation and intermediate overheating. Fire and steam overheating. 8. Regeneration. Renkin and Brighton cycles with regeneration.
Facilities and Equipment	Lecture hall with the multimedia equipment: Lenina ave., 30a, building 4, room 31.

Grading Policy	In accordance with TPU assessment system we use: - Current assessment which is performed on a regular basis during the semester by scoring the quality of mastering of theoretical material and the results of practical activities (individual homework assignments and group review). Max score for current assessment is 80 scores, min – 44 scores. - Course final assessment (exam/ credit test) is performed at the end of the semester. Max score for course final assessment is 20 scores, min – 11 scores. The final score is determined by summing the scores of the current assessment during the semester and exam (credit test) scores at the end of the semester. Maximum overall rating corresponds to 100 scores, min pass score is 55.
Course Policy	Attendance is strictly controlled. All classes are obligatory to attend.
Teaching Aids and Resources	**Compulsory reading**: 1. Hołyst, R., Poniewierski, A. Thermodynamics for Chemists, Physicists and Engineers / R. Hołyst, A. Poniewierski. — Dordrecht: Springer, 2012. — 343 p. — Текст: электронный // SpringerLink.– URL: https://link.springer.com/book/10.1007/978-94-007-2999-5 (дата обращения: 20.09.2020). – Режим доступа: из корпоративной сети ТПУ. 2. Henning Struchtrup. Thermodynmmics and Energy Conversion / Henning Struchtrup. – Springer, 2014. - 597 p. — Текст: электронный // SpringerLink.– URL: https://link.springer.com/book/10.1007/978-3-662-43715-5 (дата обращения: 20.02.2021). – Режим доступа: из корпоративной сети ТПУ. **Additional reading:** 1. Hoffelner W. Materials for Nuclear Plants. From Safe Design to Residual Life Assessments / W. Hoffelner. – New York : Springer, 2013. – 477 p. — Текст: электронный // SpringerLink. – URL: https://link.springer.com/book/10.1007/978-1-4471-2915-8 (дата обращения: 20.09.2020). – Режим доступа: из корпоративной сети ТПУ
Instructor	Dr. Konstantin V. Slyusarskiy, Associate professor, The Butakov Research Center, School of Energy and Power Engineering, TPU, e-mail: konstantinsv@tpu.ru, phone: +7 (3822) 701-777 (ext. 1697) Personal site: https://portal.tpu.ru/SHARED/k/KONSTANTINSV/eng