ABSTRACT

to the thesis research, submitted for the PhD degree in
specialty «6D071700 – Heat Power Engineering»

by
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A subject of this thesis paper:
«Mathematic modeling of condensing system elements for the investigating and development of improvement methods of the CHP operational efficiency»

In the dissertation work the researches were carried out on one of the priority directions of development of science of Kazakhstan "Power engineering and mechanical engineering".

According to the data of the system operator (KEGOK JSC, National Energy Report, 2021), over 82% of generation in Kazakhstan is based on thermal power plants (TPPs) operating on solid (69%) and gaseous (20%) fuels.

There are 68 TPPs in operation in Kazakhstan, of which: 41 CHPPs, with CHPPs accounting for 60% of the district heating supply.

The condensation unit is the most important technological system, largely determining the efficiency and reliability of steam turbine units (STU) of TPPs.

A 1 kPa change in steam pressure in the condenser causes a change in turbine capacity by about 1%. Disturbances in operation of the condenser unit lead to a decrease in efficiency and emergency shutdowns of the thermal power plant. This affects both plant efficiency and fuel consumption.

From the analysis of literature data it is known that the largest percentage of failures - 37% falls on the share of the turbine itself, up to 13% relate to the condensing unit and the turbine regeneration system.

Analysis of damages (failures) of condenser unit elements shows that the largest share of failures falls on condensers 46% and on ejectors - 19%.

A peculiarity of a condenser unit of a CHPP is that condensers along with the main condenser have an integrated tube bundle. Most studies have considered methods for calculating only the main bundles.

One of the important tasks at the CHPP is to carry out diagnostics and monitoring of condensing unit conditions and timely troubleshooting.

A deep understanding of the processes occurring in the elements of the condensing unit, analysis of their operating modes, design, the influence of various factors on the reliability of operation is facilitated by the creation of a mathematical model of the condensing unit and computational experiments.

The dissertation paper presents the results of mathematical modeling of condensing unit (CU) elements (condenser, ejector) in the study of CHPP efficiency improvement. Among the ways to improve the efficiency of CHPP the methods of development of new extended normative characteristics of condenser, diagnostics of

CHPP condition, transition to two-stage ejector, diagnostic model of CHPP efficiency loss risk assessment are proposed, CU-code is developed for CHPP.

Relevance of the research topic. Based on the analysis of published research results, it can be stated that little attention is paid to the condensing unit at CHPPs in Kazakhstan.

Kazakhstan stations do not actively use methods of monitoring, diagnostics and assessment of condenser unit condition, especially those based on mathematical models.

The possibility of operational management and forecasting of loss of safety, operability, serviceability and efficiency of condensing unit is not fully implemented at TPPs of Kazakhstan.

The results of mathematical modeling, diagnostics, operational management, forecasting service life and expanding the range of parameters of the condensing unit were not used.

The undoubted relevance of the development of mathematical models of condensing unit elements, diagnostics, operational control and forecasting systems is emphasized by their realization within the framework of CHPP information complexes.

The area in which the scientific problem is solved is the improvement of efficiency and reliability of CHPP operation.

The object of the study is the condensation unit of steam heating turbine T-110/120-130-5 of AlES CHPP-2. The CHP unit consists of condenser KG2-6200 with built-in and main bundles, two three-stage steam jet ejectors, four condensate pumps, two circulation pumps.

The subject of the study is the development of models for condition assessment and diagnostics of condensing unit equipment in order to predict and improve the reliability and efficiency of steam turbines of TPPs.

The aim of the research is to develop mathematical models of condensing unit elements on the basis of new methodological approaches and technical solutions and to implement the results of the dissertation work at CHPPs to ensure the improvement of the quality of prediction of reliable and efficient operation of steam turbine condensing unit.

The goal is accomplished by accomplishing the following **objectives**:

– bibliographic review on the topic of the thesis;

– collection of information on condensing unit of AlES TPP-2;

– processing of the results of the industrial experiment at the condenser unit of AlES TPP-2;

– analyzing the steam turbine condenser calculation methodology to determine the appropriate methodology to use;

– development of a mathematical model of the condenser taking into account the operation of the main and built-in tube bundles;

– software implementation and verification in a series of computational experiments of the developed capacitor model;

– mathematical modeling of vapor jet ejector;

– software implementation and approbation in a series of computational experiments of the developed ejector model;

– model diagnostics of the condenser, including analysis of the influence of air suction and contaminants on steam pressure inside the condenser;

– risk analysis regarding possible loss of efficiency, reliability, functionality and safety of condensing equipment;

– creation of the "Condensing Unit" (CU-code) software system for CHPPs.

The scientific novelty of the work consists in the following:

1. Mathematical models of the condenser and ejector used in heat generating plants with T-type turbines have been developed. The models were verified and tested for compliance with the operating conditions of AlES TPP-2. The software product implemented in Microsoft Excel tabular editor includes mathematical models of condenser and ejector. The method proposed in the model takes into account the peculiarities of determining the steam pressure in different zones of the condenser when supplying cooling water to the main bundles and raw water to the built-in bundles. The dependence for calculation of steam parameters in the condenser with main and built-in tube bundles is obtained. The developed methodology can be used for extrapolation of standard condenser characteristics in the area of steam flow rates higher than Dk > 78 kg/s (280 t/h).

2. It was obtained that at barometric pressure in the turbine condenser below 100 kPa it is reasonable to install a new main two-stage steam jet ejector instead of the existing one (a patent for the utility model of the two-stage ejector was obtained). It has been established that the working steam consumption of the two-stage ejector is significantly (by 30%) lower than that of the three-stage ejector, which leads to saving of steam and, ultimately, fuel for auxiliary needs of the CHPP.

3. On the basis of the developed model of accounting for separate air suction and contaminated surface of the condenser of the steam turbine of AlES CHPP-2 it was established that the deviation of the actual condenser performance from the normative (calculated) indicators is determined mainly by contamination of the condenser tubes. Air suction in most modes has no influence.

4. On the basis of the full multilevel analysis of operational risks of the condensing unit equipment, the probabilities of different types of condenser malfunctions were determined: loss of safety is 29%, loss of operability is 55%, loss of serviceability is 50%, and loss of efficiency is 17%.

5. For the first time the author obtained a software complex "Condensing Unit" (CU-code), including the following modules: mathematical models of condenser and steam jet ejector, diagnostic model of condenser, event tree, two-stage ejector. The developed modules are interconnected with each other but can be used separately. The CU-code is transferred to the CHPP for further use together with recommendations to the CHPP working personnel on improving the efficiency of the CHPP condensing unit.

The obtained results of the dissertation work have **scientific and practical value**:

– Mathematical models and calculation programs for condenser and steam jet ejector are presented, which are recommended for use in diagnostics and monitoring of equipment condition, as well as for energy audit of the plant.

– Mathematical models of a condenser and a steam jet ejector are presented, which can be used in the process of training of thermal power engineers when conducting virtual laboratory works.

– According to the results of processing of the industrial experiment the dependence for determination of steam pressure in the condenser having main and built-in tube bundles is obtained, which allows to obtain normative characteristics of the condenser for the whole range of steam flow rate variation.

– The methodology of experimental data processing for evaluating technical and economic indicators of CHPPs is presented.

– The CU-code program complex solves practical tasks aimed at improving the reliability and efficiency of the condensing unit of AlES TPP-2 and TPPs of RK.

The validity of the obtained results is confirmed by the following:

1. The studies were carried out on operating equipment using actual data obtained at AlES TPP-2.
2. The developed mathematical models of the condenser and ejector were tested at AlES TPP-2 with high accuracy of results.
3. Acts of introduction on the results of the dissertation work were received from AlES TPP-2 named after A. Zhakutov and JSC "Institute KazNIPIEnergoprom".

Positions and results of the study put forward for defense:

1. Mathematical model of the capacitor, its software implementation and results of approbation.
2. Condenser calculation methodology, taking into account peculiarities of determining steam pressure in different condenser zones when supplying cooling water to main bundles and raw water to built-in bundles.
3. Mathematical model of vapor jet ejector, its software implementation and results of approbation.
4. Useful model of two-stage vapor jet ejector.
5. Methodology that takes into account the separate effect of air suction and contaminants on the vapor pressure in the condenser.
6. Risk analysis of efficiency loss by condensing plant with development of an event tree.
7. CU-code program complex.

The main provisions are reflected in **scientific publications**: 15 scientific articles and ISTC reports, including: 5 scientific articles in domestic editions from the list of recommended by the ISTC; 8 scientific reports in collections in international scientific and technical conferences; 2 scientific articles indexed in Scopus database: one article in Journal of Applied Engineering Science (JAES) with a percentile at the time of publication of 52% in the section "General Engineering", one article in Thermal Engineering (English translation of Teploenergetika) with a percentile at the time of publication of 42% in the section "Energy and Energy Technologies". There is a patent for a utility model and methodological instructions for virtual laboratory works have been developed.

The author's personal contribution is determined by the aim and objectives of the research and consists in analytical review of literature data, calculation studies, development of mathematical models of condenser and ejector, creation of programs of calculations on models in MS Excel tabular editor, development of questionnaires for collecting information from CHPP, development of risk analysis of efficiency loss of condensing unit, preparation of main publications on the work performed.

The dissertation work was carried out by the author in accordance with the current requirements of design, structure and content. The work consists of 6 sections, list of symbols and abbreviations, introduction, conclusion, list of used literature and appendices. The work includes 15 tables, 40 figures, 88 sources used.

The first section contains a review of analytical studies devoted to improving the efficiency of condensing unit elements. Faults in condensing unit operation; existing methods of diagnostics and monitoring of equipment condition; existing methods of condenser and ejector calculation; expert systems used in practice are analyzed.

The second section is devoted to the development of a mathematical model of a condenser having main and embedded tube bundles. The calculation algorithm, the system of equations allowing to determine the values of vapor pressure in the main and built-in bundles and software implementation are presented.

The results of data processing of the industrial experiment are presented. Verification of the results of the computational experiment is carried out.

The third section reflects the process of development of the mathematical model of the vapor jet ejector. Software implementation and verification of the results of computational experiment are given.

Justification of the replacement of the main ejector is given. A new two-stage steam jet ejector is presented.

The fourth section describes a methodology that allows the separate effects of suction and fouling to be considered. It is important to note that fouling of the heat exchange surface has the greatest impact on the vapor pressure. Therefore, it is necessary to regularly clean the fouling of the condenser surface to prevent the condenser efficiency from decreasing and to improve the energy efficiency of the whole system.

In the computational experiment, it was found that the cleanliness of the heat transfer surface has a significant effect on the vapor pressure in the condenser.

Calculation of the optimal term of condenser cleaning is performed. Methods of condenser tube bundle cleaning are considered. Recommendations on cleaning of tube bundles are given to the operating personnel. Various ways of checking the tightness of the turbine unit vacuum system to prevent air and other non-condensable gases from entering the condenser are considered.

The fifth section analyzes the risks of loss of efficiency of a condensing unit of a CHPP with the development of a failure tree. The values of probability events leading to loss of safety, serviceability, operability and efficiency are calculated.

The sixth section includes a description of the CU-code software structure and provides recommendations to the operating personnel.

The conclusion summarizes the obtained research results and the main conclusions of the dissertation work.

The appendices contain the results of data processing of the industrial experiment, the following are presented: energy characteristics of the turbine T-110/120-130-5, patent for utility model, acts of implementation of the developed models and programs in the educational process, calculations of the event tree.