DOI: https://doi.org/10.15407/pmach2024.01.035

UDC 621.165

RATIONAL MODE PARAMETERS OF POWER UNITS OPERATING IN MODERN ENERGY MARKET CONDITIONS

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The paper analyzes the operation of condensing and heating turbines in modern energy market conditions with an assessment of the impact of operating parameters of live and secondary steam on economic indicators. It has been shown that when operating at variable loads, the most effective in terms of high-pressure turbines is a rational reduction in the initial pressure p_s (sliding pressure), which leads to an increase in thermal efficiency by 1–1.5%. The experimental results of a study of the vacuum effect in the condenser on fuel consumption are presented in the paper as well. Using a specific example of the K-320-26.5 turbine unit, the need for a rational choice of cooling water flow in winter season to ensure optimal vacuum is shown. The issue of choosing a rational steam reheat temperature t_r is examined in more detail. It has been established that one of the main reasons for the decrease in the efficiency of turbine units when operating in variable modes is the irrational use of the reheat temperature and the heat of phase transition in the flow part of the low pressure cylinder. The physical explanation of these processes in the turbine as t_r decreases is given in detail. It has been shown that, as a result of analyzing the operation of turbine units of various capacities, a rational choice of reheat temperature (reducing t_r by 10–20 °C) increases thermal efficiency by 1–2 %, and turbine efficiency – by 0.4–1.0 %. It is recommended to consider the pressure of the hot steam of the high pressure cylinder (p_s), the pressure in the condenser ($p_c=f(t_{circ.water})$), as well as the reheating temperature t_r, which altogether leads to a reduction in heat consumption by 2.5–3.5 % as rational parameters of steam when operating in variable modes. In order to increase the economic efficiency of the operation of turbine units of TPPs and CPPs at reduced loads, it is recommended to revise the regulatory documentation on the current amendments for changes in the reheat temperature. It is stated that with strict adherence to the recommendations discussed above, fuel savings at TTPs and CHPs in Ukraine can amount to 250–300 thousand tons of coal per year.

Keywords*: steam turbine, variable loads, mode parameters, fuel consumption, efficiency.*

Introduction

The requirements for the efficiency of power equipment because of continuously rising energy prices and increasing energy consumption are becoming stricter. At the same time, due to the physical deterioration of the equipment and non-optimal operating conditions, the specific fuel consumption at Ukrainian TPPs is constantly growing and has already reached ~390 g.e.f./(kW·h) compared to 300 g.e.f./(kW·h) worldwide in average. Physical deterioration of equipment is only one of, but not always the main reason for this situation. The most significant influence on the efficiency of a turbine unit is its operating modes.

In accordance with the dispatch schedule of energy market, the electrical load of powerful turbine plants of TPPs changes during the day from the maximum value to 50–60 % of the rated power. Such a fluctuation of the electrical load and a change in the pressure in the condenser, caused by seasonal changes in the temperature of the cooling water during the year from 1 to 30 °C, lead to a decrease in the efficiency of the turbine unit.

In the conditions prevailing in the domestic energy sector, powerful TPPs and CPPs will operate in variable modes in the foreseeable future. Choosing the rational operating parameters that allow saving fuel in such off-design operating modes of the turbine plant is a very important factor under these conditions.

The studies carried out by the researchers of IPMach NAS of Ukraine at various power units [1–4] showed that when turbine plants operate at partial loads, the correct choice of regime parameters can significantly increase their efficiency. At the same time, rational operating parameters in such cases may differ tangibly from the traditionally used operating parameters in the rated mode.

It is preferable to use statistical information about the operation of turbines during the period of several months when conducting research in this field. It is much easier to obtain such information if turbine units are equipped with modern operational control systems allowing synchronous measurement of parameters at any given time interval. Moreover, using an array of data over a long period of time makes it possible

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to carry out the necessary sampling (on the basis of factor analysis) of, for example, regime parameters, including rational ones. In fact, it's very important because the researchers get the opportunity to obtain the information from the data array on the influence of regime parameters on efficiency, fuel consumption, output, etc. when the turbine is operating at variable loads without conducting expensive full-scale experiments. In this paper, unit No. 8 of the turbine plant K-325-23.5 of Zmiivska TPP, which is known as the thriftiest in Ukraine and was manufactured by Turboatom OJSC and Siemens, was taken as the base for research. This unit operates in accordance with the dispatch schedule (at maximum loads of 320–300 MW during the day, with a load of 200–280 MW at night) (Fig. 1).

To give an example, Fig. 2 indicates the change in heat consumption depending on the load of turbines with a capacity of 325 MW, equipped with the OM650L "Teleperm Me" operational control system. The figure shows that different amounts of heat can be spent to generate the same output under real operating conditions. For example, to obtain the same 300 MW output it is possible to spend from 610 to 670 MJ/s, depending on the combination of regime parameters and actual operating conditions. This means that each turbine plant, including those named above, depending on their technical condition, has maximum efficiency only under quite certain optimal operating parameters, which primarily include the parameters of fresh and secondary steam, as well as the temperature of the cooling water and flow rate in the condenser.

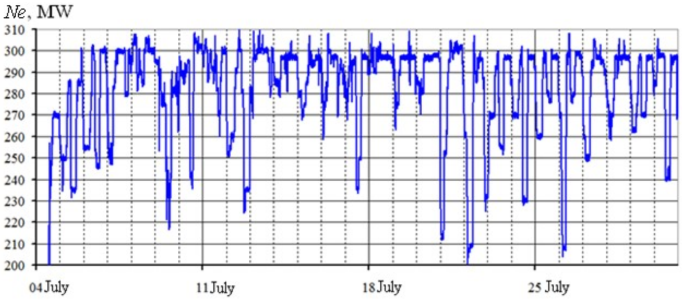

Fig. 1. Variation of electrical load of the turbine plant K-325-240 in summer

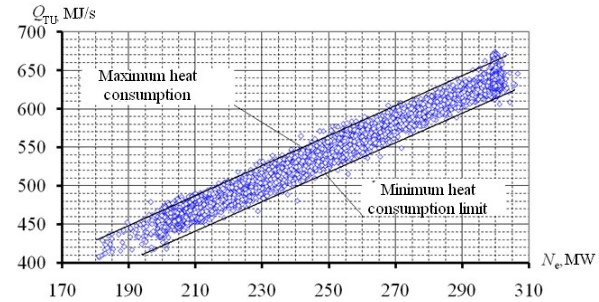

Fig. 2. Change in heat consumption for the K-325-23.5 turbine plant with a change in load in the conditions of Zmiivska TPP (January – April)

Regulation of the initial steam parameters in front of the turbine

Let's consider what impact these parameters can have on the economic performance of the turbine plant. First of all, we make a focus on the regulation of the initial steam parameters at the turbine inlet. Here, it is necessary to note the possibility of regulating live steam parameters in off-design modes. A sufficient amount of material and specific recommendations on the efficiency of turbine operation in the sliding pressure mode are given in the technical literature [5]. Numerous experiences in operating powerful turbine plants in such modes have shown that a rational decrease in the initial pressure with a decrease in the electrical load of the power unit leads to an increase in thermal efficiency by 1.5% or more. Considering that this technology is quite well-known and is already being used in the practice of operating power units, we will only declare the prospects of this approach, without discussing it in detail.

The expediency of a rational reduction in the temperature of live steam t_{ls} at partial loads for power units without reheating is considered in detail on the example of the T-37/50-8.8 turbine in [4]. It is shown that for this type of turbines, a decrease in the initial temperature by 5–10 °C in a mode of 70% of the rated one leads to an increase in the phase transition heat in the last stage zone, due to which the power increases by 1.2%.

As for reheated turbines, such a procedure can have a positive effect in some cases. A rational decrease in the live steam temperature t_{ls} in partial modes can lead to a decrease in pressure losses in the stop valve, which

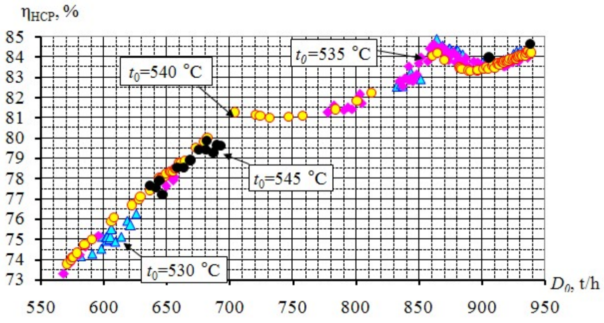

Fig. 3. HPC efficiency of turbine K-325-240, unit no. 8 at different values of fresh steam temperature

in turn increases the pressure in the flow part. Such an increase in pressure in front of the high pressure cylinder (HPC) and in the extractions, if it occurs by above reason, can compensate the initial decrease in the enthalpy of steam within certain limits due to a decrease in the temperature of live steam, which will ensure fuel savings. In this regard, an analysis of the relevant operational control data was carried out at the 325 MW unit. The result of the conducted researches is shown in Fig. 3.

The maximum efficiency of HPC is achieved at consumption of 865 and 920 t/h. The falling in efficiency at an initial temperature of 540 °C in the interval between these values of steam consumption is 1.1–1.5%. Fig. 3 shows that a decrease in t_{ls} leads to some (by 0.2–0.5 %) increase in efficiency. At the same time, it was found that a decrease in t_{ls} by 10 °C leads to an increase in pressure at the inlet to the low pressure cylinder (LPC) by 1.8 %, which probably allowed to increase efficiency and save fuel by 1.0% while maintaining an output of 300 MW. However, it should be noted that such a result, in the opinion of the author of the paper, can be considered as a special case associated with the design features of this turbine and cannot yet be recommended for using t_{ls} as a weighty adjustable parameter at variable load.

At the same time, since such a fact took place, during the operational analysis of the operation of other power units in variable modes, it is necessary to carry out appropriate control of the HPC parameters.

Vacuum control in the condenser by circulation water flow rate

No less important for increasing the efficiency of the turbine unit is the optimal choice of vacuum in the condenser, the value of which at a given load largely depends on the temperature and flow rate of the circulating water. Since the temperature of the circulating water is an external, non-controllable factor, one of the main parameters of influence on the rational vacuum is the flow rate of the circulating water. Information on determining the optimal flow rates of circulating water is quite widely presented in the literature, for example, in [7]. Therefore, in this paper, these issues are not considered in detail, but only fragments of experimental results of studies of the effect of vacuum in a condenser on the thermal efficiency of a power unit during its operation in winter are presented. In such cases, the controlled parameter to achieve the optimal vacuum in the condenser in terms of minimizing fuel costs is the circulating water flow rate.

The results of experimental studies carried out on a turbine plant with a capacity of 325 MW are given below. The data arrays of the dependences of the heat flow rate Q_{TU} on the temperature of the cooling water and the pressure in the condenser at rated flow rates of the circulating water are shown on Fig. 4.

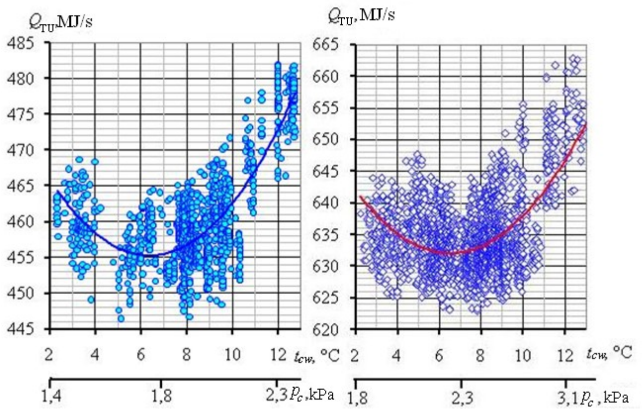

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Fig. 4. Dependence of the heat consumption for the K-325-23.5 turbine unit on the temperature of the cooling water and the pressure in the condenser at a constant load:
a – Ne=205 MW; b – Ne=300 MW

As can be seen from Fig. 4, the temperature of the cooling water when the load changes from 300 to 200 MW for a given turbine should not be lower than ~6 °C, despite the fact that the optimal pressures in the condenser differ significantly. When the temperature drops below this value, it is necessary to reduce the cooling water flow rate to the condenser in order to prevent pressure drops below 2.2 kPa at a load of 300 MW and below 1.6 kPa at a load of 200 MW.

An analysis of the obtained results shows that the desire to achieve a deep vacuum below the optimum leads to excessive fuel consumption and to a decrease in the efficiency of the turbine unit.

Turbine operation at non-optimal values of cooling water temperature and pressure in the condenser, usually in winter, leads to an increase in losses with the output speed and a decrease in the efficiency of the last stage due to an increase in volume flow to a value exceeding the optimal one. At the same time, the temperature of the condensate decreases, which leads to an increase in heat costs for its heating in the regeneration system, and an overestimated consumption of circulating water to the condenser requires unjustified additional costs for the operation of pumps, i.e. increased energy consumption for own needs.

Studies carried out on the K-325-240 turbine during 3 autumn-winter months showed that most of the time the turbine was operating at loads Ne=200 and 300 MW with p_c 3.1-1.4 kPa. During this time, it was mostly operating at a cooling water temperature below 6 °C and with a pressure in the condenser below the optimal (Fig. 4). As a result, the efficiency of the turbine unit decreased by 0.3–0.36%, and in three months the underproduction of electricity amounted to 0.3–0.5 million kW·h.

Thus, in order to prevent fuel reheat in the cold season, it is necessary to prevent excessive pressure reduction in the condenser. To do this, it is necessary to reduce the flow of cooling water to achieve optimal vacuum values and avoid the old concept – the lower the pressure in the condenser, the higher the efficiency of the turbine.

Choice of rational reheat temperature

Improvement of the economic performance of steam turbines operating at off-design loads can be achieved by regulating one regime parameter, however, as an analysis of the operation of existing power units has shown, their maximum efficiency is usually achieved with the simultaneous control of several regime parameters.

To illustrate what has been said, Fig. 5 shows the dependences of the specific heat consumption on turbine units K-325-23.5 on the temperature of the cooling water in modes both rated and different from rated, so-called rational modes.

These dependencies were obtained from the data array recorded by the auto-mated operational control system for a period of 6 months. On the basis of factor analysis, a selection of rated regime parameters and the corresponding specific fuel consumption, as well as parameters that give the minimum specific fuel consumption, was carried out. In particular, in the considered examples by the optimal combination of mode parameters it is possible to reduce the specific fuel consumption in the winter time on the mentioned unit by 0.5%, and in the summer with a deteriorated vacuum – by 2.0%. It should be noted that in these examples, the indications of rational values of the reheat temperature in summer were 20 °C less than the rated value and in winter – 10 °C less. Let's focus on the studies of the parameter t_r in order to determine its weight in achieving the fuel economy of the turbine unit.

Since the K-325-23.5 turbine unit was taken as the base for the study, an analysis of the influence of t_r on its main operational characteristics was made on its example. In the analysis, the results of measurements by the "Teleperm Me" system were used.

A turbine plant is a complex thermodynamic system with a large number of both positive and negative feedbacks. Therefore, the change in the reheat temperature cannot be considered only from the point of the change in steam moisture at the end of the expansion process and the decrease in the thermal efficiency of the cycle. A change in the reheat temperature is accompanied by a redistribution of temperatures, pressures and heat drops throughout the turbine and, in addition, has a significant impact on the operation of the regenerative feedwater heating system.

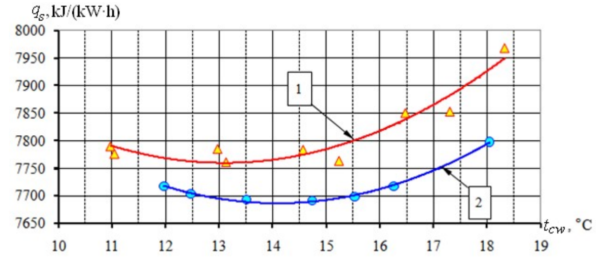

Fig. 5. Dependence of the specific heat consumption for the K-325-23.5 turbine unit on the temperature of the cooling water at Ne~300 MW:
1 – at the rated values of the operating parameters and the reheat temperature t_r (540±2 °C); 2 – at rational values of a number of regime parameters, including the reheat temperature t_r~(525–535 °C)

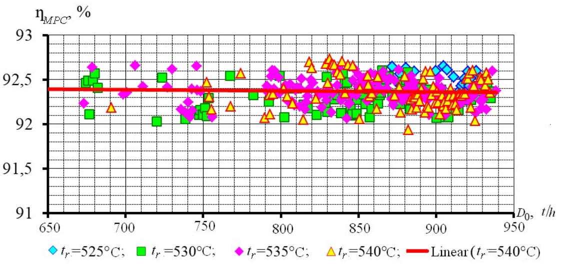

Fig. 6. Efficiency of the MPC turbine K-325-240, unit no. 8 in the flow range of 670-940 t/h at different reheat temperatures

Let's consider how the change in the temperature of the secondary steam affects the main parameters of medium pressure cylinder (MPC), LPC, efficiency and the performance of the turbine plant as a whole.

When t_r decreases, the enthalpy and entropy in front of the MPC decrease. In our case, it was found that at a load of 300 MW, a decrease in t_r from 539 to 533 °C leads to a decrease in the available heat drop in MPC by 7.6 kJ/kg. At the same time, despite the decrease in power at the MPC for the same reason, the power of the turbine plant remains constant (300 MW) due to an increase in the power of the LPC due to more efficient use of the phase transition heat in this compartment.

As for the efficiency of the MPC, it weakly depends on t_r (Fig. 6). Thus, the influence of t_r is displayed only in the change of the heat transfer and, accordingly, the power of the LPC.

When t_r decreases from 539 to 533 °C, the pressure at the LPC outlet decreases by 75 Pa, the steam humidity increases by 0.4%, and the available heat drop increases by 14 kJ/kg due to the above reasons, which is quite enough to compensate decreasing output of MPC and ensure a constant turbine 300 MW output. In this regard, it is important to know post-factorial changes in the basic characteristics of the entire power unit, which dominantly depend, as shown above, on changes in the operating parameters of the LPC.

Below are the results of studies conducted on the basis of a factor analysis of the influence of t_r on the main operational indicators of the K-325-23.5 MW turbine unit.

Fig. 7 shows the influence of the feed water temperature on the reheat temperature. With a turbine output Ne=300 MW, the feed water temperature varies within ±0.1 °C, and at output of 204 MW, a decrease in the reheat temperature from 547 to 530 °C leads to an increase in the feed water temperature by 0.5 °C. Based on this, we can conclude that a decrease in the reheat temperature does not cause a deterioration in the operation of feed water heaters.

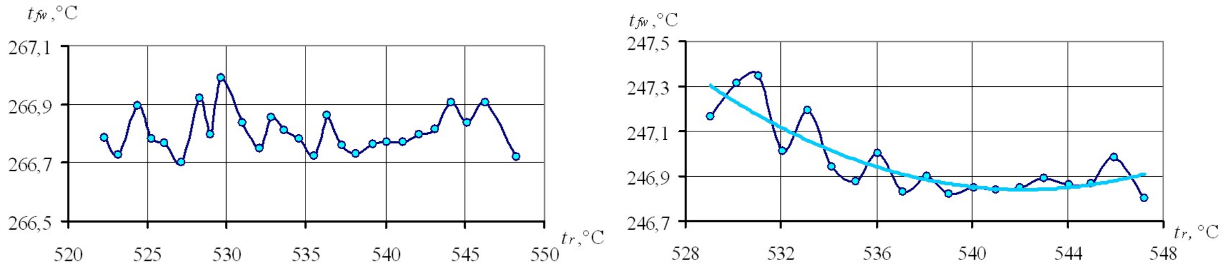

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Fig. 7. Dependence of feed water temperature on reheat temperature at turbine output:
a – 300 MW; b– 204 MW

As the reheat temperature decreases, the steam temperature at the inlet to the LPC decreases, which leads to a shift in the process of steam expansion towards a decrease in entropy. As a result, the amount of condensation heat used in the flow part of the LPC increases and the enthalpy of steam in the condenser decreases. Fig. 8 shows the dependence of the enthalpy in the condenser on the turbine output at various reheat temperatures.

It can be seen from Fig. 8 that when the reheat temperature decreases from 545 to 533 °C, the enthalpy of steam in the condenser decreases by 10–14 kJ/kg, which increases the efficiency of using the heat supplied to the turbine unit.

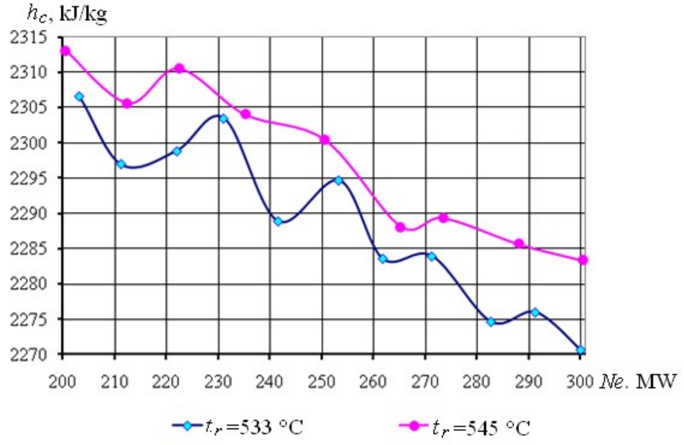

Fig. 8. Dependence of steam enthalpy in the condenser on turbine output at different reheat temperatures

Fig. 9 shows the dependence of the specific fuel consumption on t_r for the K-325-23.5 turbine unit.

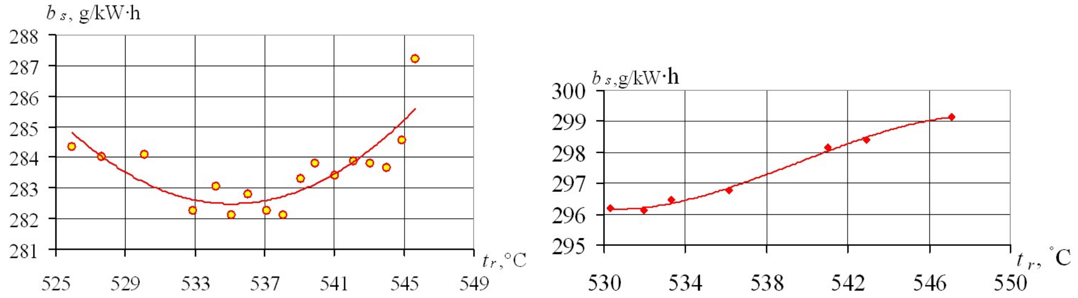

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Fig. 9. Dependence of the unit fuel consumption of the K-325-240 power unit on the reheat temperature at constant output:
a – Ne=300 MW; b – Ne=204 MW

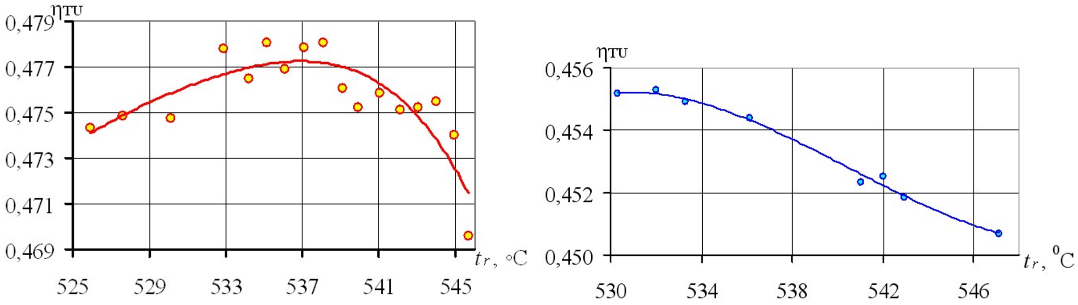

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Fig. 10. Dependence of the absolute efficiency of the turbine unit on the reheat temperature at constant power:
a – Ne=300 MW; b – Ne=204 MW

As can be seen from Fig. 9, a decrease in t_r leads to a decrease in the unit consumption of equivalent fuel by ~3 g/kW·h. At a load of 300 MW, reducing the reheat temperature to a rational value leads to an increase in the thermal efficiency of the turbine by 1.5%, and at a load of 205 MW – by 1.0%.

Fig. 10 shows the dependence of the turbine unit efficiency on the reheat temperature at constant output.

As can be seen from Fig. 10, a, with an output Ne=300 MW a decrease in the reheat temperature from 545 to 535 °C leads to an increase in the efficiency of the turbine unit by ~0.6%. With a further decrease in the reheat temperature, the efficiency of the turbine unit begins to decrease. With an output Ne=204 MW, a decrease in the reheat temperature from 546 to 530 °C also leads to an increase in the efficiency of the turbine unit by ~0.4%.

The performed analysis showed that when the K-325-240 turbine operates in off-design modes, the reheat temperature of 545 °C adopted in operation is not optimal from the point of view of efficiency. To increase the efficiency of the turbine unit in off-design modes, it is necessary to ensure the optimal distribution of heat flows supplied to the turbine by reducing the reheat temperature to an optimal value of ~530–537 °C.

To verify the conclusion about the possibility of increasing the efficiency of a turbine unit by reducing the temperature of the secondary steam at partial loads obtained as a result of statistical analysis, direct tests were performed on the K-325-23.5 turbine. The research was carried out by employees of the Institute of Mechanical Engineering Problems of the National Academy of Sciences of Ukraine (Kharkiv), the Institute of Coal Energy Technologies of the National Academy of Sciences of Ukraine (Kyiv) and the Zmiivska TPP [3].

During the tests, the output at the generator terminals was maintained within the range of 205.2–205.5 MW. At fixed values of the secondary steam temperature (545, 540, 535, 530 °C), the main parameters of the boiler, turbine and output at the generator terminals were measured for 50 minutes in each mode (relative accuracy of output measurement at the generator terminals is ±0.01 MW). The temperature of the secondary steam was reduced using a steam-steam heat exchanger. The controlled parameters were recorded at intervals of 5 minutes.

Tests have confirmed the possibility of increasing the efficiency of a turbine unit in off-design modes by reducing the temperature of the secondary steam to an optimal level. This reduction leads to an increase in heat consumption for regeneration by 0.3% and a decrease in heat loss in the condenser by 0.8%. As a result, the efficiency of the turbine unit increases by 0.3–0.4%, and the specific consumption of equivalent fuel decreased by 3–4 g.e.f./kW·h. Reducing the temperature of the secondary steam leads to a decrease in the temperature of the outgoing gases and to more efficient use of heat. At the same time, the boiler efficiency increases by ~1%.

To check and confirm the obtained effect on heating turbines, studies were carried out on the T-250/300-240 turbine unit in the warm and cold seasons in a wide range of electrical loads.

At the first stage of these studies, it was discovered (Fig. 11) that with a gradual decrease in the reheat temperature from 545 to 509 °C within thirty minutes, a temporary increase in the output of the turbine unit by ~1% was recorded.

At the second stage of research, the influence of the reheat temperature on the change in output was carried out taking into account the change in pressure in the condenser. These results are shown in Fig. 12.

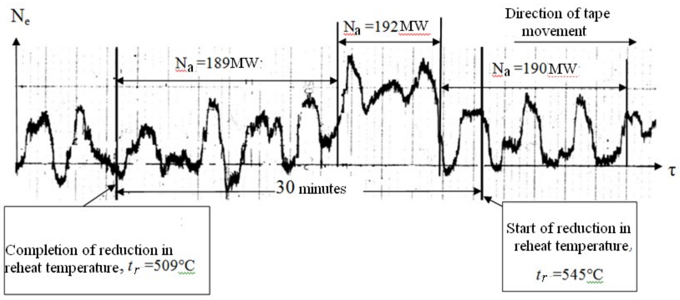

Fig. 11. Variation in output of the T-250/300-240 turbine unit with a decrease in the reheat temperature

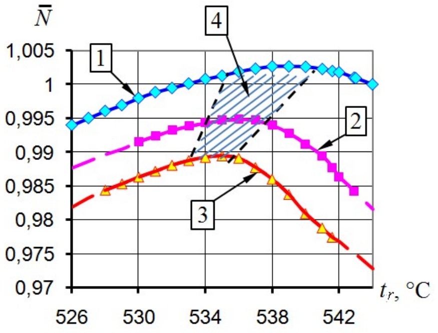

Fig. 12. Dependence of the relative output of the T-250/300-240 turbine unit on the intermediate superheat temperature at various pressure values in the condenser:
1 – p_c=5.6 kPa; 2 – p_c=8.2 kPa; 3 – p_c=11.5 kPa;
4 – region of optimal reheat temperatures

When the reheat temperature decreases from ~545 to 534–538 °C, the efficiency of the turbine unit reaches a maximum, and with a further decrease in the secondary steam temperature it decreases [4].

As a result of these tests, it was found that the maximum increase in the efficiency of this turbine unit is achieved by reducing the reheat temperature to 535 °C when operating in cogeneration mode and is more than 1.5%.

Similar tests were carried out at other power units and also showed similar results. Thus, tests at the K-210-130 turbine unit of the LMZ "Kurakhivska TPP" showed that when the load is reduced to 145 MW and the reheat temperature is reduced to 530–525 °C, depending on the time of year, the saving in unit fuel consumption is 1–2%, and the efficiency increases by 0.6–1.0%.

The same results (1–1.5%) of fuel saving were obtained when conducting similar experiments at the K-300-240 turbine unit No. 7 of the Zmiivska TPP.

Thus, we can summarize that reducing the industrial superheating temperature to a rational value (depending on the load and pressure in the condenser) by 10–25 °C leads to an increase in the thermal efficiency of a turbine unit operating at variable loads by 1–2.0% with efficiency increasing by 0.5% or more.

The efficiency factor observed in such processes is explained by an increase in the actual humidity in the LPC and a more rational use of the heat of phase transition. When the reheat temperature decreases, the initial phase transition zone shifts towards the flow, which expands the active size of condensed steam, thereby increasing its humidity. We can add to the mentioned above that a shift in the beginning of steam condensation to a zone of high pressures, as is known from [8], leads to an increase in the rate of nucleation by one or two orders of magnitude in nonequilibrium processes. All this in total contributes to a high increase in humidity and a decrease in the level of steam supercooling and increase in the efficiency of the LPC. In this case, with a slight change in the temperature of the secondary steam, intense condensation leads to a significant decrease in the enthalpy behind the last stage of the LPC, while the enthalpy in front of the MPC and LPC decreases slightly, which ensures constant output and increase in the efficiency of the turbine unit.

Unfortunately, it should be noted that the recommendations for choosing the optimal reheat temperature introduced above, tested on real turbine units, differ from the currently existing amendments to standard energy characteristics, which provide for an increase in steam consumption, and therefore fuel consumption. It is presupposed that such a procedure compensates for the loss of power due to a decrease in the reheat temperature (Fig. 13). Namely, that the mode of reducing the reheat temperature under variable loads appears to be a negative effect and it is recommended to avoid it, while maintaining the maximum reheat temperature parameters.

Let's consider the reasons that currently limit the more effective use of the rational reheat temperature t_r as a regulating operating parameter.

When operating condensing turbines, recommendations for maintaining the intermediate reheat temperature at the maximum permissible level are justified, first of all, by the need to prevent an increase in the humidity of the exhaust steam due to the danger of erosive destruction of the working blades of turbine's last stages and a decrease in the efficiency of the unit. However, there are a number of papers [9, 10, 11] showing that the intensity of erosive wear of the last stages of turbines is determined mainly by the concentration of coarse moisture in the steam flow. It depends on the operating mode of the turbine and, to a lesser extent, depends on the total moisture content of the steam.

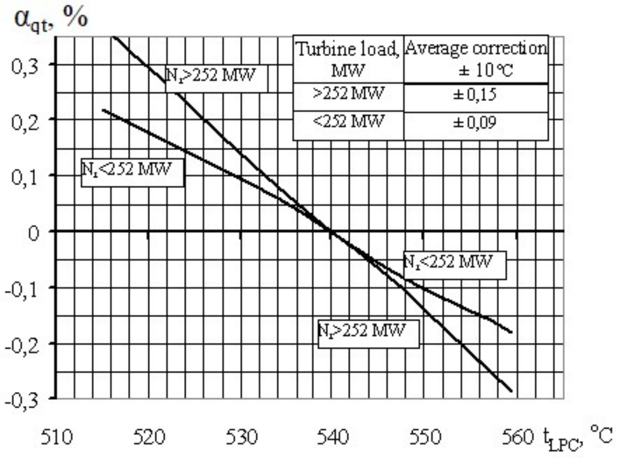

Fig. 13. Typical correction to fresh steam consumption for deviation of the steam reheat temperature from the rated one for a 300 MW turbine unit

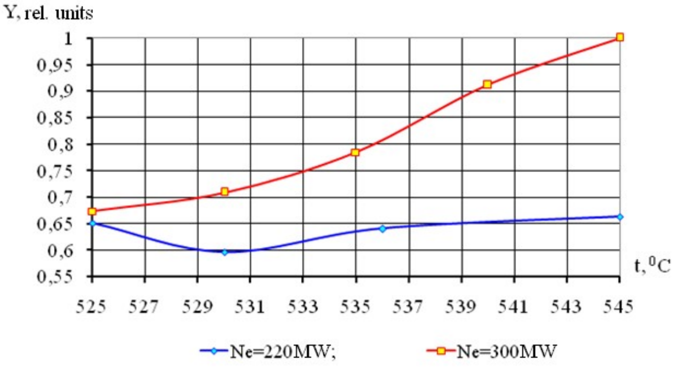

Fig. 14. Change in the total relative amount of coarse moisture at the top of the last stage blade of the K-325-240 turbine in the area of 30–100 mm at constant output and a decrease in the industrial superheat temperature

Specially conducted studies on a 325 MW turbine showed that a decrease in the reheat temperature does not always lead to an increase in coarse moisture, although it leads to an increase in the diagrammatic humidity (Fig. 14). For these studies, a diagnostic probe specially developed at IPMach was used, which makes it possible to determine the intensity of changes in coarse moisture in the flow [11].

The results of the experiment showed that a slight decrease in the reheat temperature does not increase, but even reduces the proportion of coarsely dispersed moisture, which should reduce erosive wear of the working blades, although it leads to an increase in the moisture content of steam due to the expansion of the active volume of finely dispersed process moisture.

As for the efficiency of the unit, specially carried out full-scale tests on various units of TPPs and CPPs showed that a rational decrease in the reheat temperature does not lead to a decrease, but to an increase in the efficiency of the turbine unit.

To be fair, it should be noted that back in the 80s there were some papers, for example [5], which showed that in certain cases it may turn out that the maximum level of reheat temperature increases the thermal efficiency of wet steam turbines at rated mode, but reduces it at partial loads. However, all these recommendations have not found wide application, probably by the reason stated above (the prevailing ideas about the unambiguous negative effect of humidity on efficiency), and to a greater extent due to the lack of a physical explanation for this effect and insufficient convincing and correctness of field tests on power units of various capacities. Therefore, unfortunately, the regulatory documentation on operating modes of a turbine unit to this day recommends maintaining the reheat temperature at the maximum permissible level in all operating modes.

Thus, numerous field studies carried out by employees of the Anatolii Pidhornyi Institute of Mechanical Engineering Problems of NAS of Ukraine at various power units in Ukraine have shown the advisability of using reheat temperature as an effective operating parameter at reduced loads. The author of the paper hopes that the facts of real reduction in fuel consumption, documented in the form of reports of regime tests at thermal power plants and combined heat and power plants, as well as a reasoned theoretical justification for such thermophysical processes, can become a significant basis for the revision of the relevant regulatory documentation both directly by the turbine manufacturer and at the level of the relevant departments.

Conclusions

On the basis of experimental studies and literature analysis, it has been established that for regulating modes when operating turbines at variable loads it is recommended to consider the following as rational parameters: the pressure of the live steam of the high-pressure cylinder (p_{os}), the pressure in the condenser (p_c $f(t_{\text{circ.water}})$), as well as reheat temperature t_r.

Rational choice of all these parameters in combination leads to a reduction in heat consumption by 2.5–3.5%.

It has been established that one of the main reasons for the decrease in the efficiency of turbine units when operating in variable modes is the irrational use of the reheat temperature and the heat of phase transition in the flow part of the LPC.

It is shown that as a result of analyzing the operation of turbine units of various capacities, a rational choice of reheat temperature (reducing t_r by 10–20 °C) increases thermal efficiency by 1–2%, and efficiency by 0.4–0.7%.

To prevent fuel burnout in winter, it is necessary to reduce the flow of cooling water to achieve a rational vacuum value.

In order to increase the economic efficiency of the turbine unit operation of TPPs and CPPs at reduced loads, it is recommended to revise the regulatory documentation on the current amendments for changes in the reheat temperature.

With the strict compliance with the above-mentioned recommendations as for the mode parameters of turbine units operating on variable loads, fuel savings at TPPs and CHPs of Ukraine can be in amount up to 250–300 thousand tons of coal per year.

The author expresses special gratitude to Dr. Tech. Sciences V. P. Skliarov for his significant scientific and practical contribution to the study of the influence of operating factors on the efficiency of turbine units of TPPs and CPPs at variable loads.

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Received 21 November 2023

Раціональні режимні параметри енергоблоків, що працюють у сучасних умовах енергоринку

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У статті проведено аналіз роботи конденсаційних і теплофікаційних турбін у сучасних умовах енергоринку з оцінкою впливу на економічні показники режимних параметрів гострої та вторинної пари. Показано, що при роботі на змінних навантаженнях найбільш ефективними в частині високого тиску турбіни є раціональне зниження початкового тиску $p_{ос}$ *(ковзного тиску), що приводить до підвищення теплової економічності на 1–1,5%. Представлено експериментальні результати дослідження впливу вакууму в конденсаторі на витрату палива. На конкретному прикладі турбоустановки К-320-26,5 доведена необхідність раціонального вибору витрати охолоджувальної води в зимовий час для забезпечення оптимального вакууму. Найбільш детально розглянуто питання вибору раціональної температури промперегріву пари* $t_{пп}$*. Встановлено, що однією з основних причин зниження ефективності турбоагрегатів під час роботи на змінних режимах є нераціональне використання температури промперегріву й теплоти фазового переходу у проточній частині циліндра низького типа. Наведено фізичне пояснення цих процесів у турбіні при зниженні* $t_{пп}$*, а результатами аналізу роботи турбоустановок різної потужності встановлено, що раціональний вибір температури промперегріву (зниження* $t_{пп}$ *на 10–20 °C) підвищує теплову економічність на 1–2%, а коефіцієнт корисної дії на 0,4–1,0%. Рекомендується як раціональні параметри пари при роботі на змінних режимах розглядати тиск гострої пари циліндра високого тиску (*$p_{ос}$*), тиск у конденсаторі (*$p_к=f(t_{цирк.води})$*), а також температуру промперегріву* $t_{пп}$*, що в комплексі дозволяє знизити витрати тепла на 2,5–3,5%. З метою підвищення економічної ефективності роботи турбоблоків ТЕЦ і ТЕС на знижених навантаженнях пропонується переглянути нормативну документацію щодо чинних поправок за змін температури промперегріву. Зазначено, що за суворого дотримання розглянутих вище рекомендацій економія палива на ТЕС і ТЕЦ України може становити 250–300 тисяч тонн вугілля на рік.*

Ключові слова*: парова турбіна, змінні навантаження, режимні параметри, витрата палива, коефіцієнт корисної дії.*

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