Increase of energy efficiency in the low-pressure heater of PN-1100-25-6-1 type

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Abstract. Heat exchangers of various types (gas-gas, gas-liquid, liquid-liquid) are widely used in power plants of thermal power plants and nuclear power plants. Like any technical system, the heat exchange apparatus is estimated by the main quality indicator-energy efficiency. At present, most of the studies devoted to this issue are related to the determination of the intensification of the heat transfer process and the determination of the energy efficiency of convective heating surfaces. At the same time, both at the design stage, and especially for the functioning heat exchanger, it is required to determine its energy efficiency (further energy efficiency), which usually decreases with time. It is necessary to distinguish between the energy efficiency of the heat exchanger as a whole, in which the heat transfer occurs in the case of two-sided flow around the heat exchange surface and the energy efficiency of the surface on each side. (In the case of a heat exchanger with one-sided flow around the heat transfer surface, these concepts are often assumed to be identical, which is far from always correct). At the same time, after increasing the energy efficiency of the heat exchanger, due to the justified introduction of design changes, it is necessary to carry out a technical and economic calculation showing the means and time spent on the modernization of the apparatus. In the present paper, the existing design methods for increasing energy efficiency in low-pressure heaters of the PN-1100-25-6-1 type are considered and one of the promising ones is selected. The technical and economic calculation of this heater has been completed

1. Introduction
Like any technical system, the heat exchange system (heat exchanger) is estimated by the main quality indicator - energy efficiency. This indicator, laid down at the design stage, also characterizes the functioning apparatus.

The main element of the heat exchanger is the heat exchange surface, which in the case of recuperators is usually flowed from one side hot, with another cool coolant, (bilateral flow). Therefore it is necessary to distinguish:

• energy efficiency of the surface of heat exchange, washed by hot or cold medium;
• energy efficiency of the heat exchanger as a whole, in which heat transfer takes place from hot to cold heat carrier.
2. Energy efficiency of heat exchange surface and heat exchanger

These concepts are inextricably linked, but the energy efficiency of the heat exchanger is broader and, in general, represents the ratio of the actually transmitted heat flux in the heat exchanger to the maximum possible. The energy efficiency of the heat exchange surface is usually determined by the ratio of the heat flux to the energy costs for pumping the coolant along this surface.

When calculating the energy efficiency of heat exchangers during countercurrent, the method described in [1], wherein the dimensions of the heat exchange surfaces associated with heat capacity of coolant mass involved in the heat transfer process, it $\Delta T$, $\Delta T_{\text{max}}$ and is defined as:

$$
\hat{\varepsilon} = \text{NTU}_{\text{min}} \frac{\Delta T}{\Delta T_{\text{max}}}
$$

Where: $\text{NTU}_{\text{min}} = \frac{kF}{(Gc p)_{\text{min}}}$ - number of transfer units.

However, this definition of energy efficiency is acceptable at the design stage and is largely ideal, because Does not take into account the numerous factors of real devices (reliability, repairability, environmental friendliness, material cost, etc.). These factors must be taken into account when it comes to improving the efficiency of operating equipment. The definition of efficiency should end with a technical and economic calculation with an indication of the cost of modernization and the terms of its recoupment.

Convective recuperative heat exchangers with two-sided flow around the "liquid-liquid", "gas-liquid", "gas-gas", "gas-two-phase medium" have a wide application nowadays both in industrial (metallurgy, aviation, ship industry); And in power engineering.

The manufacture of such heat exchangers consumes a large amount of metal, and operation entails a large expenditure of energy, primarily for pumping heat carriers. At the same time, the growth in production volumes is accompanied by an increase in not only the mass and dimensions of heat exchangers, but also the costs of their operation. Therefore, the task of reducing the mass of heat exchangers (especially gas-liquid and gas-gas) on the one hand, and operating costs, on the other hand, is now also very relevant.

The solution of the problem of increasing the energy efficiency of the heat exchanger reduces to creating a physical situation for a given area and average velocity of heat carriers, in which heat transfer takes place with the greatest intensity, and the process of transferring the amount of motion is the lowest; Through the intensification of heat transfer from each of the heat carriers. Here, when the heat transfer from one of the heat transfer is much less than from the other, as in the case of the heat exchanger "gas-fluid", the task is simplified and the energy efficiency of the apparatus is often taken equal to the surface energy from the gas, which is not always correct. In general, the higher the efficiency of the convective surface in the apparatus on the side of the coolant with the lower heat transfer coefficient, the higher is its energy efficiency usually.

2.1. Determination of energy efficiency of convective surfaces and apparatus

Currently, most studies, starting with prof. Gukhman A.A. [2], akad. Kirpichova M.V., prof. Kalafati D.D., prof. Pronina V.A., Etc., is associated with the determination of the energy efficiency of convective heating surfaces.

The absolute value of the energy efficiency of the heat exchange surface is $\varepsilon$, [2].

$$
\varepsilon = \frac{St}{(\Delta P / \rho W^2)}
$$

Heat exchange surface can be characterized as a heat flux $Q$ [W], the power for pumping coolant $N$ [W], the area of heat transfer surface $F$ [m²], volume of the heat exchange surface $V$ [m³] In the transition to obtain specific characteristics: $q = Q / F$ [W / m], $n = N / F$ [W / m], $1 / \beta = V / F$ [M], where $\beta$ is the compactness of the heat exchange surface. These specific characteristics quite fully characterize the intensity of the processes taking place on the heat exchange surface, and from them one can judge its energy efficiency.
Relative indicators are usually used to select, evaluate and compare heat exchange surfaces for their energy efficiency. These indicators include the heat exchange efficiency of the surface coefficients \( K_d = F_2/F_1 \), the number of heat transmitted \( K_\varnothing = Q_2/Q_1 \), power consumed for pumping coolant \( K_N = N_2/N_1 \). Similarly, these indicators can be used to determine the energy efficiency of a heat exchanger, [3].

The magnitude of these parameters depends on \( F_1, Q_1, N_1 \), i.e. the choice of a reference surface with which compares investigated \( (F_2, Q_2, N_2) \).

As noted above, for a heat exchanger, in general, the number of variables that determine its efficiency is much larger. Thus, for a shell-and-tube heat exchanger, a large role is played by the method of placing the tube bundle, the construction of the partitions, and also the output and input devices. In addition to the correct choice of the method of intensification and the geometry of the intensifying elements, we must take into account the costs of their manufacture, take into account the accumulation of harmful deposits, erosive and corrosive wear of the intensifying elements, and so on. There is a need to select an optimal method to improve the efficiency apparatus with the position long-term use of the machine, periods and methods of its purification and the like, that is, from the standpoint of the reliability of the heat exchanger and the value of its modernization. Therefore, the calculation of increase of efficiency should always end with a technical and economic calculation showing the time and money needed for the modernization of the machine in terms of its operation.

2.2. Ways to increase energy efficiency in heat exchangers with two-way flow around

For this purpose can be used rough tubes, tubes with circular protrusions convergent-diffuser, with undulating axis of the tube holes with spherical surface. [4].

The use of differently profiled tubes is considered now as one of the most accepted directions of increasing the efficiency of heat exchangers with both one-sided and two-sided flow in the event of the presence of steam condensation in it. Real applications in condensed heat exchangers are pipes in which the artificial roughness formed by the rolling profile takes place both from the outside and from the inside. The intensification of heat transfer from the steam side is determined by the change in the hydrodynamics of the film of the draining condensate, the average thickness of which decreases due to the action of the surface tension forces, the trajectory of its movement changes, and the turbulence increases. The intensification of heat exchange on the other hand is also determined by the flow hydrodynamics - the ordered fluid flow in the viscous sublayer is disturbed due to its turbulence and twist. Thus, when using heat exchange surfaces formed from profiled tubes, there are a number of advantages:

- heat exchange is improved both from the inside and from the outside of the surface;
- the rolling technology in some cases is quite simple;
- when using profiled tubes, as a rule, there is no need to change the existing technology of assembly of shell-and-tube heat exchangers.

In a series of profiled tubes most studied and passed industrial tested in serial heat exchangers in power plants are profiled twisted tubes, longitudinally profiled , tubes double profile, tubes with counter - helical profiling [5]. These tubes are made of conventional smooth at their run-on special devices rolling mill planetary running s method.

So, as shown by the results of the research, the guaranteed effect of the increase in the heat transfer coefficient in devices with PT with a rationally chosen tube geometry and corresponding to the RoTO norms under operating conditions at the nominal operating mode of the apparatus is: for capacitors - 15%, for LPH- 35-40% for heaters network water - 20-40%. The hydraulic resistance of the apparatus increases by 40-70% [5]. Similar results are also observed for other types of profiled tubes.

The disadvantage of the above methods of heat transfer intensification is:

- complexity of manufacturing the profiled surface and its cost;
- complexities in cleaning surfaces from deposits.
2.3. Technical and economic calculation of energy efficiency in heaters

In the present paper, an increase in energy efficiency in low-pressure heaters of the PN-1100-25-6-1 type was considered, and a feasibility study was carried out under the conditions of its operation in the thermal circuit of the N = 730 MW unit.

For upgrading apparatus used profiled tubes with annular protuberances, manufactured by our industry [6].

![Figure 1. Profile annular tube.](image)

The results of thermal calculation showed that after the modernization of the pipe system:
- the heat transfer coefficient of condensing steam to the tube walls has increased by 33.8% [7];
- the heat transfer coefficient from the pipe walls to the heated water increased by 277.5%;
- the heat transfer coefficient in the apparatus increased by 69%.

In the work it was assumed that the amount of heat transmitted to the heating steam Q in the machine and F surface remain the same (as in smooth pipes), i.e. performance indicators $K_F = 1.0$ and $K_Q = 1.0$.

As a result:
1. The heat transfer in the preheater on the side of the heating steam increases and the resulting condensate is supercooled.
2. The steam consumption in the selection of the turbine for the preheater is reduced.
3. The heat transfer from the side of the heated water increases and its temperature at the outlet from the apparatus increases.

The results are shown in Table 1.

| Options | Before the modernization of the pipe system | After the modernization of the pipe system |
|---------|---------------------------------------------|------------------------------------------|
| H, kJ / kg | 1256.67 | 1262.64 |
| $D_h$, kg / s | 589.72 | 587.11 |
| Gross efficiency | 0.422 | 0.424 |
| $E_{own needs}$ | 0.032 | 0.032 |
| Net efficiency | 0.409 | 0.410 |
| $b$, kg.s.f / kWh | 0.301 | 0.300 |
| $V$, m$^3$/s | 49.346 | 49.226 |

**Table 1.** Change of key parameters after modernization of the pipe system
Thus, the savings in the specific consumption of conventional fuel in 1 g.s.f / kW*h were achieved. While maintaining the same generation of heat and electricity.

However, the capacity of pumps for pumping water in the tubes with an annular knurling increases by 9.9%, the power of the fans for products combustion, as compared with one heater with smooth pipes is considerably reduced, and the power efficiency index for power in the apparatus $K_V = N_2/N_1$ decreases, and the energy efficiency itself ceteris paribus increases: $K_T = 1.0$, $K_P = 1.0$, $K_N < 1.0$.

According to preliminary technical and economic calculations, an approximate payback period was set for the modernization of the pipe system (production of new pipes and their installation), which was 33 days, due to fuel savings.

The calculation was carried out at the average existing prices for gas fuel 0.45 RUB/m³, a knurled pipe 1558/l RUB/m. [6]

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