Increasing the thermal efficiency of water heating boilers by improving design parameters

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Abstract. Currently, research is being conducted all over the world to create clearly defined operating, technological and design parameters that ensure the continuity of hydrodynamic and thermal processes, which will improve the energy efficiency of heat supply devices and the technical characteristics necessary for the development of control circuits. One of the most pressing problems in this area is the development of modern pipeline designs based on the values of the critical speed of the heat transfer flow, hydraulic resistance and solid particle concentrations relative to the calculated parameters along the line and their mathematical models, improvement of calculation methods and modification of the turbulizing elements of the heat transfer flow. The efficiency factor (COP) of water heating boilers used today in the country is 70-75%. This article presents an analysis of research on the creation of heating boilers by improving the hydraulic parameters of boilers and using effective structural elements to increase the energy efficiency of hot water boilers. The article presents a hydraulic calculation of improved parameters of a hot water boiler. It has been shown that the design of a finned heat-conducting pipe is more effective than a smooth one. As a result of research and calculations, it was possible to increase the thermal efficiency of the water heating boiler by 15-20%. This increases the efficiency of hot water boilers and saves resources used as fuel.

1 Introduction

In the world, there is a need to consistently implement measures to improve the quality and uninterrupted heat supply to consumers, update and modernize the fixed assets of the heat supply system based on the introduction of modern energy-saving technologies, as well as the efficient and rational use of fuel and energy resources. Heat supply systems make up a significant part of the national economy. Currently, when designing heat supply systems in our republic, it is important to improve the designs of hot water boilers using local raw materials. Research is being conducted around the world aimed at finding optimal modes, technological and design parameters, ensuring the continuity of hydrodynamic and thermal processes and developing control schemes that increase the energy efficiency of thermal

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power processes and devices. In this direction, considerable attention is paid to the production of modern energy-efficient hot water boilers based on improving methods for calculating coolant flow (flow), hydraulic resistance and design parameters that ensure continuity of heat transfer processes and changes in coolant flow elements [1].

### 2 Methods

Based on the results of a study of thermal energy and thermal devices in the republic, measures are being taken to improve their design and widespread implementation. The implementation of these tasks, including the reduction of modern technologies and their comparative energy efficiency indicators, is one of the important tasks. As a result of the study, the following diagram was adopted to represent the hydraulic model of the water flow passing through the pipe of the boiler device (Fig. 1), i.e. a hydraulic model of fluid flow moving between cylinders with diameters $d_1$ and $d_2$ and length $l$ was developed. (Fig. 1)

![Diagram of flow movement in the pipeline of the boiler device](image)

#### Fig. 1. Scheme of flow movement in the pipeline of the boiler device

We see the balance of forces acting on the fluid between two cylinders of radii $r_1$ and $r_2$ [2].

Cross-sectional surface 1-1 is in the direction of the $O_X$

$$P_1 = p_1 \pi (r_2^2 - r_1^2)$$  \hspace{1cm} (1)

where: pressure in section 1-1, $r_1$ and $r_2$ fluid flow radius. 2-2 affects the surface of the section

$$P_2 = p_2 \pi (r_2^2 - r_1^2)$$  \hspace{1cm} (2)

Paint the inner cylinder surface

$$T_1 = \tau_0 2\pi r_1 l$$  \hspace{1cm} (3)

where: frictional force on the inner cylinder surface, tensile stress, pipe length.

Paint the outer cylinder surface

$$T_2 = \tau 2\pi r_2 l$$  \hspace{1cm} (4)

Here: friction force on the outer cylinder surface, tensile stress.

We express the test voltage according to Newton's law as follows.

$$\tau = \mu \frac{du}{dr}$$  \hspace{1cm} (5)

Then the expression (2.4) is written as follows:

$$T_2 = \tau 2\pi r_2 l = \mu \frac{du}{dr} 2\pi r_2 l$$  \hspace{1cm} (6)
As in the previous problem, we get the following equation based on the equilibrium condition of the liquid volume.

\[
\frac{du}{dr} = -\frac{p_1 - p_2}{2\mu l} \frac{r_2^2 - r_1^2}{r} + \frac{\tau_0}{\mu r}
\]

(7)

The velocity of the fluid is zero at r = r_1. Therefore, by integrating the left side of this equation from O to u, and the right side from r_1 to r, we get this relation.

\[
u = -\frac{p_1 - p_2}{4\mu l} \left[ (r_2^2 - r_1^2) - 2 \ln \frac{r}{r_1} \right] + \frac{\tau_0}{\mu} \ln \frac{r}{r_1}
\]

(8)

The velocity is also zero on the surface of the cylinder (r = r_2) [5,7,8,10]. That is why

\[
u = -\frac{p_1 - p_2}{4\mu l} \left[ (r_2^2 - r_1^2) - 2 \ln \frac{r_2}{r_1} \right] - 2 \ln \frac{r_2}{r_1} + \frac{\tau_0}{\mu} \ln \frac{r_2}{r_1}
\]

(9)

From this equation \( \frac{\tau_0}{\mu} \) we find

\[
\frac{\tau_0}{\mu} = \frac{p_1 - p_2}{4\mu l} \left[ (r_2^2 - r_1^2) \frac{1}{\ln \frac{r_2}{r_1}} - 2 \right]
\]

(10)

Thus, we get this relation for the cross-sectional distribution of speed.

\[
u = \frac{p_1 - p_2}{4\mu l} \left[ (r_2^2 - r_1^2) \frac{\ln \frac{r}{r_1}}{\ln \frac{r_2}{r_1}} - (r_2^2 - r_1^2) \right]
\]

(11)

When the value of \( r_2 - r_1 = c \) is much smaller than \( r_1 \), it can be deduced after some operations. This confirms the above-mentioned points once again. The maximum velocity of the liquid flowing through the annular slot does not correspond to the middle part of the slot height as before. Finding the maximum speed is complicated, so we won't give it.

3 Results

To improve the efficiency of this water heating boiler, changes have been made to its design. We know that heat transfer depends on the heat source surface and flow patterns. The design feature of the heat transfer boiler is that the steel pipe is placed in the outer part of the pipe and the heat transfer surface is increased. As a result, the energy-saving dimensions of the cross-sectional surfaces of the heat exchange pipes of the water heating system have been improved. Experiments showed that the efficiency of the improved water heating boiler was increased by 15%, and the fuel consumption for the boiler was reduced.
The heat transfer system in the boilers currently in production is shown in Figure 1.

In order to increase the efficiency of this heating boiler, changes were made to its construction. It is known that heat transfer is related to the surface of the heat source and the modes of motion of the flow. Steel pipe (diameter 50 mm) is a material that conducts heat well according to its physical properties. The design novelty of the improved heat transfer boiler is that a shell is placed on the outside of the steel pipe and the heat transfer surface is increased. As a result, the burned gas transfers more heat to the heat transfer medium.

In order to increase the efficiency of the water heating boiler, it was achieved by improving the hydraulic parameters of the heat supply devices and increasing their energy efficiency. To achieve these results, it is considered the change of the speed values of the heat transfer flow, hydraulic resistance and concentration of solid particles in relation to the design parameters, which provide continuous processes. The consumption of liquid flowing through the annular gap is calculated as follows [4]:

\[
Q = 2\pi \int^{r_2}_{r_1} u r dr = \frac{P_1 - P_2}{8\mu l} \pi (r_2^2 - r_1^2) \left[ r_2^2 + r_1^2 - \frac{r_2^2 - r_1^2}{\ln \frac{r_2}{r_1}} \right]
\]  

(12)

In this case, the average speed is determined from the flow rate formula, that is, by dividing the flow rate by the cross-sectional area:

\[
\mathcal{Q} = \frac{P_1 - P_2}{8\mu l} (r_2^2 + r_1^2) - \left( \frac{r_2^2 - r_1^2}{\ln \frac{r_2}{r_1}} \right)
\]  

(13)

The hydraulic loss is calculated as follows.
Hydraulic radius

\[
R = \frac{\omega}{\chi} = \frac{\pi(r_2^2 - r_1^2)}{2\pi(r_2 - r_1)} = \frac{r_2 - r_1}{2}
\]

Hence the Reynolds number

\[
\text{Re} = \frac{\frac{94R}{\nu}}{\nu} = \frac{92(r_2 - r_1)}{\nu}
\]

Given this,

\[
H_e = \frac{\frac{64(r_2^2 - r_1^2)\ln\frac{r_2}{r_1}}{\text{Re} \left[ (r_2^2 + r_1^2)\ln\frac{r_2}{r_1} - (r_2^2 - r_1^2) \right]}}{2(r_2 - r_1) \frac{g^2}{2g}}
\]

In the previous cases, we introduce the notation and the hydraulic friction is defined as:

\[
\lambda = \frac{64}{\text{Re}} \frac{(r_2^2 - r_1^2)\ln\frac{r_2}{r_1}}{(r_2^2 + r_1^2)\ln\frac{r_2}{r_1} - (r_2^2 - r_1^2)}
\]

In that case, the pressure lost in the pipeline;

\[
H_e = \frac{\lambda}{2(r_2 - r_1)} \frac{g^2}{2g}
\]

When evaluating the flow behavior in water heating boilers, it is necessary to evaluate two surface geometric measurements D/d and the complex Reynolds criterion. The process that occurs in the flow under the influence of temperature is reflected in the Reynolds criterion. On the basis of theoretical studies, hydraulic processes in the existing heating boiler were analyzed. According to it, the Reynolds number was determined to change as follows.

\[
\text{Re} = \frac{\frac{94R}{\nu}}{\nu} = \frac{92(r_2 - r_1)}{\nu}
\]

**Table 1.** Mode of flow and Reynolds number in an existing heating boiler

<table>
<thead>
<tr>
<th>№</th>
<th>t, °C</th>
<th>v, sm²/s</th>
<th>9, sm/s</th>
<th>r₂, sm</th>
<th>r₁, sm</th>
<th>Re</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>0.0131</td>
<td>0.5</td>
<td>55</td>
<td>12</td>
<td>1641</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>0.0114</td>
<td>0.5</td>
<td>55</td>
<td>12</td>
<td>1886</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>0.0081</td>
<td>0.5</td>
<td>55</td>
<td>12</td>
<td>2654</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>0.0068</td>
<td>0.5</td>
<td>55</td>
<td>12</td>
<td>3162</td>
</tr>
<tr>
<td>5</td>
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<td>0.0054</td>
<td>0.5</td>
<td>55</td>
<td>12</td>
<td>3981</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td>0.0048</td>
<td>0.5</td>
<td>55</td>
<td>12</td>
<td>4479</td>
</tr>
</tbody>
</table>
As a result of the research, the change of the mode of action and the Reynolds number was determined in accordance with the temperature of the flow in the heating boiler (Figure 4).

![Fig. 5. Mode of operation of the current in the heating boiler](image)

Using the formula (18) given above, the coefficient of hydraulic friction of the water flow in the existing heating boiler was determined. According to it, the value of the coefficient of hydraulic friction was found to change from 0.034 to 0.008 (Table 2, Figure 6) [1,2,3].

<table>
<thead>
<tr>
<th>№</th>
<th>t, °C</th>
<th>ν, sm²/s</th>
<th>g, sm/s</th>
<th>r2, sm</th>
<th>r1, sm</th>
<th>Re</th>
<th>λ</th>
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<tr>
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<td>0.5</td>
<td>55</td>
<td>12</td>
<td>6719</td>
<td>0.008</td>
</tr>
</tbody>
</table>

![Fig. 6. Coefficient of hydraulic friction of the boiler pipe](image)
As a result of the research, in order to increase the thermal efficiency of existing water heating boilers, improved design parameters of the boiler were developed and hydraulic calculations were performed. In particular, the cross-sectional surfaces through which the heat flow moves were increased due to additional ribs, as a result of which an increase in the thermal efficiency of the water heating boiler was achieved. As a result of the conducted studies, it was found that the flow mode and Reynolds number in the existing heating boiler is in the range of 1641-6719, and the coefficient of hydraulic friction is in the range of 0.008-0.0034. This increases the efficiency of water heating boilers used in social facilities and helps to save resources used as fuel.

4 Findings

1. As a result of the research, in order to increase the thermal efficiency of existing hot water boilers, improved design parameters of the boiler were developed and hydraulic calculations were carried out.
2. In particular, the surfaces of the area along which the heat flow moves were added to the fins, as a result of which the thermal efficiency of the boiler was increased.
3. Based on a study of hydrodynamic and heat transfer processes in the pipes of a domestic boiler, a functional dependence of the heat transfer coefficient of the flow on the operating mode was derived. As a result, it was found that the efficiency of heating boilers depends on the flow regime.
4. Hydraulic processes and heat exchange processes occurring due to an increase in the radius of interaction of the pipe wall in the working water heating chamber were assessed.

As a result, it was possible to create an energy-efficient boiler.

References

4. S. Xoshimov, D. Atakulov, O. Yalgashev, S. Komilov, J. Boykulov, E3S Web of Conferences 365 (2023) https://doi.org/10.1051/e3sconf/202336503033