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To cite this article: E V Kocharyan et al 2017 J. Phys.: Conf. Ser. 891 012048

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Influence of scale deposit and its thickness on the heat exchanger operational efficiency

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Abstract. Materials submitted provide for the research results of the problem of scale formation in heat exchangers and show results of calculations of scale type and thickness impact on heat transfer factor and on heat exchanger overall energy efficiency with regard to heat exchanger hydraulic resistance increase. Calculations have been carried out using the example of heat exchanger PV1 (IIBI) 219-2-G-1,6-6-UZ, manufactured as per State Standard (GOST) 27590-2005. On the basis of calculations performed recommendations on maximum allowable thickness of scale crust of different type, after scaling of which the heat exchanger operation may infringe the technological process, have been elaborated.

Reliability of Russian heat supply systems is significantly lower than that in European countries. The main reason for damage of heating networks and heat exchangers is pollution (primarily boiler scale deposit) and corrosion of heat transfer equipment. Due to imperfection of the applied water treatment methods or irregularities in the procedure, the thermal resistance of heat transfer surfaces increases and thus heat exchanger characteristics reduce. The composition of treatment water significantly influences the dynamics of main heat exchanger characteristics, and consequently on the composition of deposits generated on heating surfaces.

This work provides for the analysis of impact of thickness and type of boiler scale on operational efficiency of the heat exchanger PV1 219x2-G-1,6-6-UZ (State Standard 27590-2005). Shell and tube type of the unit has been chosen for calculations as the most commonly used one.

Academician’s M.V.Kirpichev energy factor has been accepted as the criterion of heat exchanger operational efficiency [1]:

\[ E = \frac{Q}{N} \]  

where \( Q \) is the heat exchanger heating capacity and \( N \) is the power for heat exchanger pumping.

We evaluated both individual influence of pollution on heat capacity of the unit through relative decrease of heat transfer factor (Fig. 1) and on operation in general through relative decrease of energy factor:

\[ \bar{E} = \frac{E}{E_0} \]  

(2)
where $E$ is the energy factor of the heat exchanger without deposits and $E_H$ is the energy factor of the heat exchanger with deposits.

The calculation was made for several types of boiler scale with different thickness from 0.5 to 3 mm (Table 1).

<table>
<thead>
<tr>
<th>Type of scale and its chemical composition</th>
<th>Heat conductivity factor (W (m·K)$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oiled boiler scale</td>
<td>0.116…0.175</td>
</tr>
<tr>
<td>Silicate boiler scale (with content of silicon compounds up to 20 – 25 % and more)</td>
<td>0.038…0.232</td>
</tr>
<tr>
<td>Gypsum boiler scale (with content CaSO$_4$ up to 50 %)</td>
<td>0.58…2.9</td>
</tr>
<tr>
<td>Carbonate boiler scale (with content of CaCO$_3$ + MgCO$_3$ more than 50 %)</td>
<td>0.58…7.0</td>
</tr>
<tr>
<td>Mixed boiler scale containing gypsum, carbonates and silicates of calcium and magnesium</td>
<td>0.8…3.5</td>
</tr>
</tbody>
</table>

On the basis of boiler scale heat transfer analysis, we can conclude that silicate boiler scale and oiled boiler scale are the most dangerous ones. For such types of boiler scales the thickness of already 0.5 mm is critical (heat transfer factor decreases by 5 times; energy factor decreases by 85 %). Thus these types are not shown in Figures 1 and 2.

**Figure 1.** Dependence of heat transfer factor decrease on thickness of boiler scale layer and type of deposits.

1 – Gypsum boiler scale (with content of CaSO$_4$ up to 50 %);
2 – Mixed boiler scale, consisting of gypsum, carbonates and calcium and magnesium silicates;
3 – Carbonate boiler scale (with content of CaCO$_3$ + MgCO$_3$ more than 50 %);
$k/k_n$ – relation of heat transfer factor of “clean” heat exchanger to the heat transfer factor of scaled heat exchanger;
$\delta_n$ – boiler scale thickness, mm.
Figure 2. Dependence of energy factor decrease on the thickness of boiler scale and type of deposits.

1 – Gypsum boiler scale (with content of CaSO₄ up to 50%);
2 – Mixed boiler scale, consisting of gypsum, carbonates and calcium and magnesium silicates;
3 – Carbonate boiler scale (with content of CaCO₃ + MgCO₃ up to 50%);

E/Eₜ – relation of Academician Kirpichev’s energy factor of “clean” heat exchanger to Kirpichev’s energy factor of scaled heat exchanger;

δₜ – boiler scale thickness, mm

On the basis of obtained results we can conclude that the most important parameter defining the dynamics of heat exchanger efficiency decrease is the type of boiler scales, due to the fact that at one and the same thickness of the layer the decrease of the energy factor may differ by 10 % and more for different types of deposits. Taking into account that during selection of the heat exchanger the free allocated area of about 10 % for contaminants depositing is accepted, this reserve should be considered at defining maximum allowable thickness of boiler scale. Based upon these factors it is required to define frequency of heat exchange surfaces’ cleaning.

References