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CONDITIONS AND METHODS OF DISSOLUTION OF SCALE IN BOILERS

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Three methods of dissolution (washing off) of deposits on the surface of heat-exchange channels have been considered.

Keywords: *heat-exchange channels, scale deposits, calcium carbonate, dissolution of deposits, reduction in the load, nucleate boiling.*

Introduction. Deposits of scale (hard salts as a rule) in tubes of boiler water walls are usually removed chemically by circulation of an acid solution. For this purpose one has to stop boilers for a certain period of time, to disconnect them from the mains, to organize a system for circulation of the solution, and to monitor the process of dissolution of deposits, preventing corrosion of the tube metals. This brings up the question of whether these labor-consuming operations can be avoided.

The possibility of washing surface deposits off without their chemical damage is assumed from the mechanism of the reversible process of scaling and dissolution of deposits in heat-exchange channels. Indeed, the process of deposition of the impurity from the aqueous solutions on the heat-exchange surface is the crystallization of the substance on condition that the solution is saturated and supersaturated near the surface, i.e., under the conditions where the solubility of the impurity turns out to be lower than its concentration in the solution: $S_w \le C_{wat}$.

For hard salts ($CaCO_3$, $CaSO_4$, and $MgCO_3$) dissolved in boiler water and having a negative temperature solubility coefficient, such conditions are often created in heated boiler tubes. In these cases we have the precipitation of the salt from a supersaturated solution and its fixation on the tube surface (crystallization). Thereafter the process of deposition continues, since the substance is delivered to the surface by concentration diffusion in the flow, and the motive force of the process is the concentration head ($C_{wat} - S_w$ vector). As the deposit layer grows, the hydrodynamic drift of the substance under the action of the flow increases and grows with flow velocity and layer thickness. The specific flux of the substance onto the channel wall is determined from the equation

$$\frac{dm}{dt} = \beta_w \rho \,(C_{wat} - S_w) - \frac{\Phi_{w,\delta}}{k}\,.$$

Stabilization of the deposit layer in the stationary regime is attained when the substance flux onto the wall $\beta_w \rho (C_{wat} - S_w)$ becomes equal to the growing hydrodynamic drift Φ/κ in value. Such an approach to description of the process of deposition (scaling) has been confirmed in [1–6]. In our experiments [4, 5], the appearance and accumulation of deposits have been determined from the increase in the wall temperature of the heated channel. The adhesion of the layers turned out to be low: the layers of the resulting deposits could move on the portions along the surface, e.g., with change in the angle of inclination of the channel or in vibration (impacts on the wall) [4].

Solution of the Problem. Formation of impurity deposits and their dissolution by a solution flow are considered as reversible processes [7]. If the solubility of the substance near the channel surface (tube wall) S_w turns out to be higher than C_{wat} (undersaturation of the solution), the inverse process, dissolution (washing off) of the substance from the surface of the deposit layer, i.e., its passage into solution, begins. Subsequent removal of the substance from the wall layer to the flow core is ensured by concentration diffusion.

Thus, the "undersaturation" of the solution at the wall is the condition of dissolution of the deposits: $C_{wat} < S_w$ [7]. The dissolution rate can be higher than the scaling rate, since both components of the substance flow

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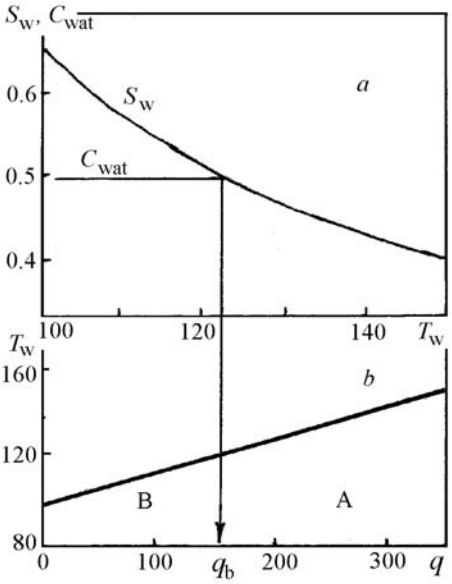

Fig. 1. Solubility of calcium carbonate S_w vs. tube-wall temperature T_w (a) determined by the heat-flux density q (b) at T_{wat} = 100°C and C_{wat} = 0.5. A, region of scaling regimes ($q \geq q_b$), B, region of dissolution of deposits ($q \leq q_b$). S_w and C_{wat}, mg-eq/kg; T_w, °C; q, kW/m^2.

point in one direction and are summed up. Creation of such conditions is ensured in two proposed methods of dissolution of deposits on the tube surface (methods 1 and 2).

Method 1. Reduction in the Thermal Load or Unloading the Boiler without the Cessation of Water Circulation. In this method, the wall temperature is reduced (to the level of the water temperature for the density of the heat flux absorbed by the tubes $q = 0$), because of which solubility in the wall (boundary) layer grows; the solution becomes unsaturated and capable of dissolving the substance from the layer surface. Head ($C_{wat} - S_w$) becomes the motive force of the process.

The reversible processes of formation and dissolution (washing off) of deposits are shown in Fig. 1. Here the operating conditions of water-wall tubes of a heating boiler at a water temperature of 100°C and concentration of calcium carbonate $CaCO_3$ C_{wat} = 0.5 mg-eq/kg are considered as an example. The wall temperature of a water-wall tube, which is dependent on the heat-flux density (Fig. 1b), determines the solubility of calcium carbonate (Fig. 1a). In the region of regimes A (wall temperature higher than 130°C, solubility at the wall S_w lower than the content of salt C_{wat}), the process of formation of a scale layer occurs. The wall temperature decreases with heat flux; for heat-flux values lower than q_b, T_w is no higher than 130°C. The solubility of the impurity exceeds the concentration of the solution C_{wat} and the process of washing off begins (region of regimes B). The lower the wall temperature, the higher the salt's solubility and the concentration head and the higher the washing-off rate.

Such a process has been established visually in experiments with a glass portion of the "tube-in-tube" type. With the solution of sodium sulfite Na_2SO_3 with a temperature of 40–42°C, whose velocity was 0.1 m/sec, we first accumulated a deposit layer on the heated internal tube to a thickness of 1 mm and then dissolved it. After reducing the thermal load, the layer dissolved in 25–28 min. Selection of sodium sulfite of high solubility in water turned out to be quite appropriate, since it became possible to produce large concentration heads and to sharply reduce the duration of the experiments.

In experiments with the model of a boiler section [4], we measured the temperature regime of the heated lateral side of length 350 mm in 14 cross sections with the use of a sodium-sulfite solution. At a solution temperature of 40–42°C, an average flow velocity of 0.07 m/sec, and heat-flux density q = 84 kW/m^2, the temperature of the heat-exchange surface began to grow from the level of 100°C when the concentration of the solution C_{wat} was brought to 0.225. For the head $C_{wat} - S_w$ = 0.225 − 0.19 = 0.035, the growth in the temperature of this surface was 200–240°C over an operating period of 3 h.

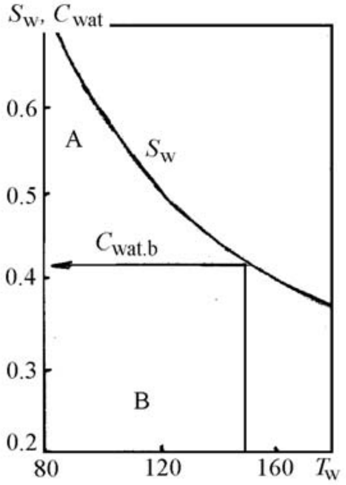

Fig. 2. Formation and dissolution of deposits in the tubes of a boiler operating with a constant load at $C_{wat.b} = 0.4$ mg-eq/kg. A, region of scaling ($C_{wat.b} > S_w$), B, region of dissolution of deposits ($C_{wat.b} < S_w$). S_w and C_{wat}, mg-eq/kg; T_w, ^oC.

At a fourfold reduction in the thermal load (to $q = 21$ kW/m^2), the surface temperature in all cross sections sharply dropped. The reduction in the temperature heads ($T_w - T_{wat}$) was disproportionally larger than the decrease in the heat fluxes, which points to washing the deposits off. But two hours of washing off turned out to be not enough for the deposits to be washed off completely, since the concentration head was small: $C_{wat} - S_w = 0.225 - 0.24 = -0.015$.

Method 2. Washing off with "Pure" Water (Boiler Water with a Low Concentration of Hardness Salts) without Reduction in the Thermal Load. In this case, too, the solubility of the salt in the wall layer S_w can turn to be higher than its concentration in the solution, and the flow will turn out to be capable of dissolving the solid substance from the layer surface. Figure 2 illustrates such conditions for the water-wall tube of a heating boiler operating with a constant load. At $T_w = 150^oC$, the corresponding solubility of calcium carbonate in the wall layer is equal to $S_w = 0.4$ mg-eq/kg. The $CaCO_3$ deposits were formed on the tube wall only when C_{wat} was higher than the boundary value (region of regimes A at $T_w > 150^oC$, solubility S_w lower than 0.4 mg-eq/kg). When the concentration of the salt in the solution was lower than $C_{wat.b}$ the solubility of the solid substance in the wall layer turned out to be higher that C_{wat}, the concentration head changed its direction, and dissolution of the scale began (region B).

Such a case of "washing off in operation" was recorded in the initial operating period of the PK-41 supercritical-pressure boiler of a 300 MW power-generating unit of the Konakovo State Republic Electric-Power Station. On disturbance of the unit's operating regime (suction of cooling water into the condenser), which led to an increase in the hardness of boiler water, the wall temperature in all cross sections of the water-wall tube on which the measurements were performed increased 40^oC from 520–530^oC during 4 h. On elimination of the suctions and restoration of the normal quality of water without changing the operating regime of the boiler, the tube-wall temperature returned to its initial value.

"Self-washing" of deposits was investigated in the experiments of the G. M. Krzhizhanovskii Institute of Power Engineering in metering out Volga water and solutions of hard salts into one water-wall tube of this boiler [8]. For a content of the $CaSO_4$ salt of ~ 4.7 mg-eq/kg, the growth in the tube-wall temperature in the zone of maximum heat fluxes was 17^oC/h. When the metering out of the salt solutions was discontinued and the boiler's operating regime was virtually constant, a reduction in the tube-surface temperature, demonstrating the process of reverse passage of the substances from the deposits into the heat-transfer agent, was observed in all experiments.

Method 3. Washing Deposits off Nonchemically. The operation of the heat-exchange surface is switched to the regime of nucleate boiling. On initiation of boiling, growing and separating steam bubbles are formed on the surface of the scale layer; they destroy the accumulated deposit layer. These regimes have been described in [4, 5] for flow in vertical and horizontal channels and for pool conditions.

Conclusions. We have considered three methods of washing off (dissolution) deposits in heat-exchange channels nonchemically. All the given results on dissolution of scale layers have been obtained in the experiments with "fresh" deposits. The scale layers are strengthened with time (adhesion grows), which makes it difficult to dissolve the substance from the layer surface.

NOTATION

C_{wat}, concentration of the impurity in boiler water, mg-eq/kg; k, (dimensionless) adhesion coefficient; m, mass of the deposited substance, kg/m^2; q, heat-flux density, kW/m^2; S_{w}, solubility of the impurity in the wall layer, mg-eq/kg; T, temperature, $^{\circ}$C; t, time, sec; β_w, mass-exchange coefficient dependent on the hydrodynamics of the flow, m/sec; ρ, density of the deposit layer, kg/m^3; Φ, hydrodynamic drift of the substance from the layer surface, kg/(m$^2\cdot$sec). Subscripts: w, wall; wat, water; b, boundary value; w, velocity of the water flow in the channel, m/sec; δ, thickness of the deposit layer, m.

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