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THERMAL OPERATION OF OIL SHALE BOILER FURNACES

Abstract

In the operation of solid fuel boilers the main problem is the fouling of their heating surfaces by ash deposits and slag. The intensity of fouling process is estimated by the amount of mineral matter contained in the fuel and its chemical mineralogical properties, also by the character of combustion regime and the regime of cleaning heating surfaces.

The problems of the furnace thermal operation of oil shale boiler are discussed. The influence of the emissivity of furnace wall on its thermal efficiency is shown and some data on the emissivity of initial ash deposits formed in burning of shale oil with ash content over 0.5 % are given.

The burning of oil shale or ash containing heavy oil produced from oil shale causes the decreasing of the thermal efficiency of boiler furnace and this phenomenon cannot be fully removed by intensive cleaning. Due to this, the output power of boilers using oil shale or ash containing shale oil may be lower than designed.

The main problem in the operation of solid fuel boilers is the fouling of their heating surfaces by ash deposits and slag. The intensity of fouling process can be estimated by quantifying the amount of mineral matter contained in the fuel, and defining its chemical and mineralogical properties. The fouling is also a function of the combustion regime and the method used for cleaning the heating surfaces [1].

Intense soot-blowing methods like use of water jets, can clean the furnace water wall-tubes effectively [2], but this method can erode the tube metal and must not be used often. If the furnace uses such water-jet cleaning, the fouling process starts periodically again from the clean heating surface.

Due to this problem, a special interest is taken in the investigation of the thermophysical properties of initial ash deposits.

The boiler furnace thermal efficiency is an important parameter for comparing the thermal operation of different furnaces. A drop in efficiency can be used as a signal to initiate the furnace cleaning operation. A. Blokh [3] defines the thermal efficiency coefficient determined as:

$$\psi = \frac{q_{res}}{q_i} = \epsilon_f \cdot \epsilon_w \frac{1-\left(\frac{T_w}{T_f}\right)^4}{\epsilon_f + \epsilon_w \cdot (1-\epsilon_f) \cdot \left(\frac{T_w}{T_f}\right)^4}, \qquad (1)$$

where T_w - temperature of deposit surface, K;
T_f - temperature of flame, K;
ϵ_w - emissivity of deposits;
ϵ_f - emissivity of flame;
q_{res} - resultant heat flux, W/m^2;
q_i - incident heat flux, W/m^2.

Equation (1) shows that the thermal efficiency depends on the flame parameters and the emissivity (absorptivity - for the "gray" approximation) coefficient of the furnace water wall tubes (as covered by ash deposits). The efficiency is also dependent on the water wall tube temperature, which is controlled by the thermal resistance of the deposit layer.

One of the main parameters that is an idicator of furnace thermal operation quality is the exit flue gas temperature of furnace. If the water wall tubes are covered by a thin layer of initial deposits, this temperature depends on the radiatiative properties of the deposits (on its emissivity at the first).

To verify this thesis, the dependence of exit temperature on the furnace wall emissivity is developed. This work was performed at the 100 MW$_e$ Estonian oil shale boiler. Two values of the slag deposit layer thermal resistance *R* are shown in Fig. 1. Here, the flue gas temperature in the exit of boiler furnace is presented as a ratio between actual exit temperature and the same temperature of a furnace with absolute black walls.

The relationship in Fig. 1 is developed by a computer experiment using a known method: ВТИ–ЭНИН (VTI-ENIN) [4]. In order to implement those calculations, a special program for solving a nonlinear system of equations is created. An essential point of this calculation method is that it takes into account the physical phenomena of heat transfer at heating surfaces (water wall tubes covered by ash deposit). Radiation and thermophysical properties of ash deposits are needed for such calculations.

The furnace exit temperature defines the thermal efficiency of the furnace and the fouling conditions in the superheater. Due to this relationship, an optimal interval of flue gas temperatures exists for different fuels. This interval depends on the properties of the fuel and the burning regime. Several economical and technical problems for exploitation of boilers appear if the exit temperature is outside of this interval.

In calculating the furnace exit temperature, or the thermal efficiency of the boiler furnace (q_{res}/q_{in}), one must take into account the emissivity of the furnace walls, especially at low values of deposit thermal resistance. This is shown in Fig. 1.

Our investigations [5] of solid fuel boilers, and MHD power plant boilers, show that for a deposit thermal resistance of less than 0.007 m^2·K/W the thermal efficiency of the furnace depends mainly on the emissivity of furnace walls. For oil shale ash deposits in a furnace the expected thickness of deposits $\delta = R \cdot \lambda = 0.007 \cdot 1.0 = 0.007$ m or 7 mm. This emissivity depends on the state of deposits on the outer (fire-side) surface. Such deposits may be melted, solid or covered by melted slag particles.

The thermal conductivity coefficient λ of oil shale ash deposits depends on the conditions under which they are formed. According to E. Raask [6], the thermal conductivity coefficient of ash deposits may have values which vary over a wide range of values, as follows:

(1) initial ash deposit of submicron sized particles - λ=0.03 W/(m·K);
(2) inertially impacted particles - λ=0.1 W/(m·K);
(3) sintered deposit with a fused layer - λ=1.1 W/(m·K);
(4) dense iron-rich slag - λ=3 W/(m·K).

The direct, *in situ* measurement of λ of ash deposits, including their structure, is quite complicated. With oil shale ash deposits, their value of thermal conductivity coefficient is expected to be between 0.5-2 W/(m·K) [1]. During the fouling process the initial ash

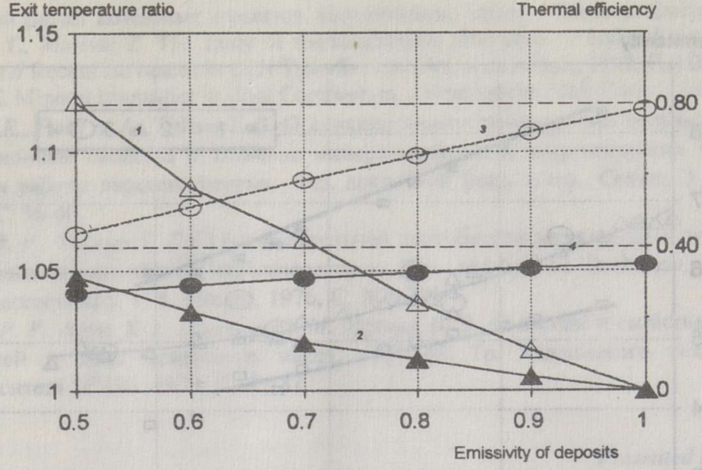

Fig. 1. The dependence of boiler furnace exit temperature ratio and thermal efficiency on the emissivity of covered by deposits furnace walls: *1* - temperature ratio at *R*=0.002 $m^2 \cdot K/W$ and 2 - at *R*=0.007 $m^2 \cdot K/W$; *3* - thermal efficiency at *R*=0.002 $m^2 \cdot K/W$ and *4* - *R*=0.007 $m^2 \cdot K/W$

deposits (which initially have low density) will become more dense and their thermal resistance will stabilize. As a result of these changes, the emissivity of the ash deposits will have a considerable influence on the furnace thermal efficiency.

Due to the high CaO content of oil shale ash, the initial oil shale ash deposits may have a very low emissivity [7]. Our investigations [8] show that white or gray colored oil shale ash deposits, formed on the upper zones of pulverized oil shale-fired boilers, have emissivity values of 0.5-0.7. The main component of oil shale ash deposits, which is formed during the fouling process, is gypsum (anhydrite) in various structural (mineralogical) forms. In Fig. 2 the total emissivity of crystalline $CaSO_4 \cdot 2H_2O$ and $CaSO_4$ sintered at 800 °C, is presented. The emissivity values of oil shale ash deposits [8] occur between the curves *1* and 2.

The problem of low thermal efficiency also appears when burning heavy oil produced from oil shale. This heavy oil has an ash content 0.5-1 %. Some ash deposits total emissivity data are presented in Fig. 2. These results are from an experimental plant in Kohtla-Järve burning shale oil from УТТ-500 (UTT-500) [9]. The measurements were taken on samples collected by a special air-cooled probe. The surface temperature of the probe was 600 °C, with an exposition time of 5.5-65 hours. Emissivity measurements were taken using two independent methods. First - the total emissivity was measured directly by a radiation detector, and second - the total emissivity was calculated by integrating the spectral emissivity, as measured by a spectral emission instrument [5].

The sample deposits have properties of a selective surface and their emissivity level is very low. For a high-power boiler furnace, with a temperature of 400-450 °C (as expected for the outer surface of the water wall tubes) the expected emissivity values of heavy oil deposits are 0.5-0.55. As pointed out in other research [9], the deposits of УТТ-500 (UTT-500) oil ash consist of up to 33 % CaO, 36 % SiO_2, 5 % Fe_2O_3 and 15 % Al_2O_3. Due to the low content of Fe_2O_3 and high content of CaO and SiO_2, (according to the data in [7]), the emissivities of those deposits have low values. The deposits are quite dense and their thermal resistance is quite low - 0.002 $m^2 \cdot K/W$.

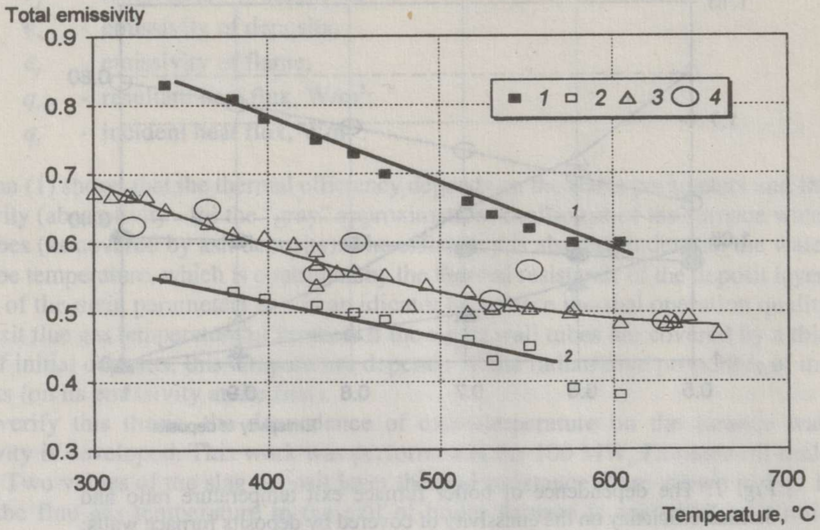

Fig. 2. Total emissivity of anhydrite and ash deposits from shale oil experimental plant furnace: 1 and 2 - $CaSO_4$ (1- sintered, 2- crystalline); 3 and 4 - shale oil ash (3 - direct measurement, 4 - integrated spectral measurements)

Due to the low emissivity of the heavy oil ash deposits, the expected boiler furnace thermal efficiency for heavy oil produced from oil shale is less than 0.35. The low efficiency of furnace is the reason for increased furnace exit temperature. A frequent cleaning of furnace surfaces (especially for small-scale boilers) is not economical. Also, Tiikma and Micevic have shown that the deposits with low emissivity appear after only 2-3 hours of furnace operation with newly-cleaned surfaces [5]. As a result, the frequent cleaning may "generate" heating surfaces with very low emissivity.

In conclusion, it must be mentioned that burning oil shale, or heavy oil produced from oil shale, causes a decrease in the efficiency of the boiler furnace. This phenomenon cannot be fully mitigated by intense cleaning. As a result, the power output of boilers using oil shale, or shale oil with an ash content over 0.5 %, may be lower than designed.

Acknowledgements

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