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# WEAR OF THE FUEL SUPPLY SYSTEM OF CFB BOILERS

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*The advantages of circulating fluidized bed (CFB) boilers over other boiler types include the possibility to fire fuels of low calorific value and rich in mineral matter like oil shale. However, particle-surface interactions may cause wear of surfaces submerged in ITREX, of the walls inside the furnace, of chrome-plated panels in separators, and of heat surfaces in boiler convection passes. This takes place directly in the boiler, but particle-surface interactions begin in the fuel supply system already and end in the ash removal system. The present article deals with wear in the fuel supply system on the basis of practical experience.*

## Abrasive characteristics of fuel mineral part

Wear of fuel system parts depends on mineral composition of fuel. Rates of both abrasive wear and erosive impact of particles are influenced by abrasive characteristics of the wear-causing particles. The useful criterion for abrasive action of particles, which characterizes their erosion-causing property, is hardness [1]. In the case of coal, Vickers hardness of the bulk of fuel is equal to 10–70 kg/mm$^2$. The corresponding values for erosive minerals like quartz and pyrite are 1200–1300 kg/mm$^2$. Most of the other constituents like kaolinite and carbonates are softer, their Vickers hardness varying between 30–500 kg/mm$^2$.

Organic matter content of Estonian oil shale is approximately 30–40% and that of the mineral part 65–70%. According to Vickers hardness test,

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the hardness of organic matter (carbon content of organic part 77.5% [2]) is as low as 10–70 $kg/mm^2$ [1]. The mineral part as the main wearing agent of oil shale consists of carbonate and clayish sandstone compounds [3]. In the mineral part carbonates form more than 32–40%, unlike the other fuels, and the surplus part is clayish sandstone containing 75% of quartz, orthoclase and hydromuscovite compounds [3]. The value of Vickers hardness of the constituents of fuel mineral part are presented in Table 1 [1].

*Table 1.* **Hardness of main components of fuel mineral part**

| Constituent | Vickers hardness |
|---|---|
| Quartz | 1200–1300 |
| Orthoclase | 700–800 |
| Hydromuscovite | 40–80 |
| Calcite | 130–170 |
| Magnesite | 370–430 |

Both compounds – carbonate and clayish sandstone – are the compounds of relatively low abrasive ability. Abrasivity of quartz is particularly high [1]. Many investigators have found a relationship between the wear of elements of a device and size of abrasive particles.

## Route and conditions of fuel supply

Foster Wheeler boiler operates using the principles of a CFB and can fire a low-calorific solid fuel of high ash content. The boilers at Narva Power Plant are operating on oil shale whose granular composition given in Table 2.

*Table 2.* **Typical granular composition of oil shale fuel**

| Sieve aperture, mm | Residue on the sieve (cumulative oversize), % | |
|---|---|---|
| | Fuel in silo | Fuel after crusher |
| 31.5 | 0.3 | – |
| 14 | 6.6 | 4.6 |
| 10 | 13.2 | 9.3 |
| 5 | 27.3 | 19.7 |
| 1 | 55.3 | 43.3 |
| 0.5 | 65.6 | 54.6 |
| 0 | 100 | 100 |

Figure 1 shows the route of fuel through feeding devices before the combustion chamber. Fuel falls from the silo (1) through pneumatic slide gates onto the oil shale feeder (2) that is a part of the conveying fuel line. The next device on the fuel line is the crusher (3); after that the oil shale flow is distributed between two chutes. The vertical line after the crusher

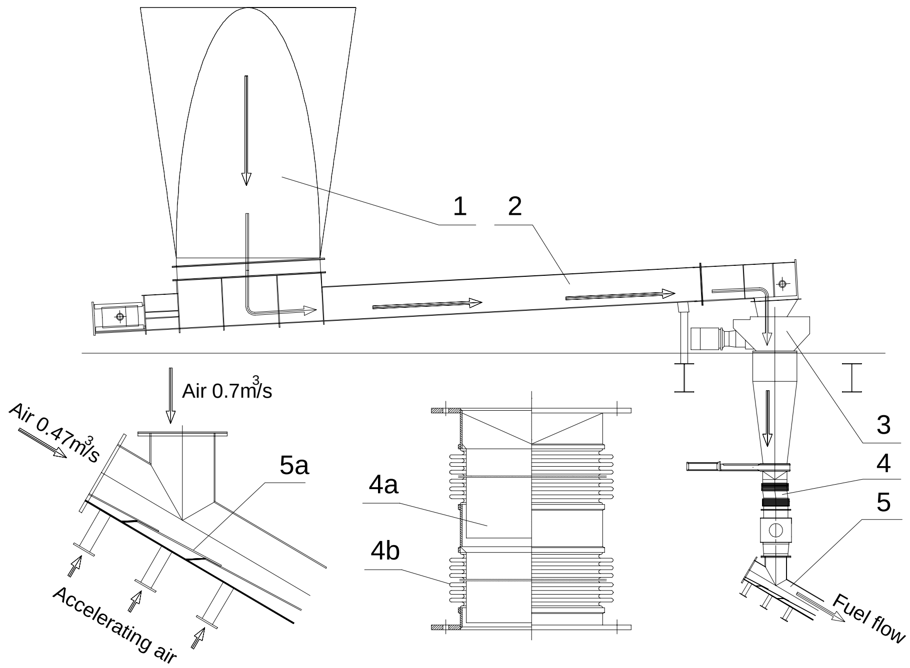


*Fig. 1.* Fuel feeding system and its elements. 1 – oil shale bunker, 2 – feeder, 3 – crusher, 4 – expansion bellows, 4a – internal straight tube of the bellows, 4b – external stainless bellows, 5 – fuel tube, 5a – plates of the tube.

consists of pneumatic slide gates, the expansion bellows (4), and the air bustles, the both last-mentioned being intensively wearing parts of the line.

The expansion bellows consist of an internal straight tube (4a) and external stainless bellows (4b). The internal straight tube through these two parts protects the bellows against wearing caused by oil shale falling, and its upper end is rigidly fixed with the channel. The open lower end of the straight tube enables the bellows to operate as compensator. Under hot conditions the bottom of the boiler moves downwards, and the bellows compensate this vertical movement by up to 250 mm, while some parts of the fuel system are rigid.

Fuel of the composition as given in Table 2 is fed into the crusher where it is crushed between the counter knife and the rotating knife disc. Finer particles continue the movement towards the furnace.

The last section of the fuel route is the chute-like tube (5) that slopes down towards the furnace by 30°. Stepwise bottom of the tube has been formed by 7 plates (5a). Crushed oil shale falls by gravity onto the second plate of the chute and continues moving towards the lower combustion chamber.

As the stepwise plate is installed significantly lower than the center level of the inclined tube, not only the surface of the plate but also side walls of the inclined tube are subjected to the falling fuel flow.

The role of air in the fuel feeding system is considerable at mixing, at transportation and blocking the fire from the furnace after the pneumatic gate feeder. Hot primary air (~245 °C) is introduced to the air bustle which has a double-casing construction – external and internal tubes. The air introduced between the tubes blows downwards in the direction of the combustion chamber preventing flowing of combustion gas backwards into the fuel feeding system. Further the air-fuel mixture added to the transportation air at the end of the inclined chute continues moving on the plates in the chute towards the furnace. For decreasing the contact surface between oil shale and stepwise plates, the air is given through eight air feeding places underneath the chute.

It is well known [4] that the particles smaller than 300 µm, especially those < 100 µm, are more abrasive than 500 µm particles. Erosive ability of larger particles quickly goes down. As seen from Table 2, ~55% of the oil shale mass passing through the whole fuel supplying system is larger than 500 µm. The share of particles of erosive size (100–300 µm) is about 30% by mass.

## Erosive wear

Through the whole path of oil shale in the horizontal and vertical directions, vertical or slightly declining parts have been subjected to erosive wear.

Among numerous parameters influencing the wearing process the rate and concentration of fuel flow are the main ones.

Erosive wear taking place in oil shale path can be classified according to the size of attack angle in places subjected to wear. The angle between the axis of flow and tangent line of the surface is called attack angle. Depending on the angle of fuel moving with respect to contact surfaces, the attacks are classified as straight line attacks (impact to 90º) and oblique or slipping attacks (less than 90º).

Significantly damaged places have been observed on slightly inclined walls of the channel after the crusher, on the corrugated walls of the bellows and on the second plate of the sloping chute (5a) (Fig. 1).

Impacts on slightly inclined walls are slipping attacks. Due to abrasive wear a 5-mm wall wears out during 2000–3000 h. Thereafter the holes in walls are to be covered by welding patches on some places.

Frequently the penetrating holes form in the external corrugated walls of the lower section of the bellows (compensator). Wall thickness of the corrugated wall is 2 mm. To protect the wall against falling oil shale, the internal straight tube (4a) consists of two parts which must cover the free slit between the upper and lower parts of the straight tube. Obviously under hot conditions the boiler's lower end moves downwards because of heat expansion. As for the original design, the inner tube length was insufficient for complete closing the slit between tube parts, and fuel falling through the slit weared a hole through the corrugated wall. After correction of the bellows construction, abrasive wear of the corrugated tube was not observed.

Penetrating holes in the wall of the fuel supply channel after the air bustle appeared after 3000–4000 working hours. Fuel flow falling through the conical channel (wall angle 2–3º) contacted with metal surface (thickness 4 mm) wearing the holes.

Side walls of the second plate of the inclined chute (5a) are stricken by a straight line attack. Forces that affect the surface directly are inclined with respect to the surface at an angle of 30º. Inclined attack forces can expand in two directions: perpendicularly and tangentially. Tangential attack can promote abrasive wear of the plate. Thus the plate is attacked simultaneously by both inclined and straight line forces causing abrasive wear, their share depending on attack angle and properties of both the surface and shale particles [1].

It is known that the smaller the attack angle, the intensiver the wear, reaching its maximum at an angle of 30–50º [1]. In the present case attack angle is 30º, which explains very intensive wear of the plate at operation during less than 8000 h (Fig. 2). As particles' distribution in the falling fuel flow had been uniform, the plate was damaged basically by the fuel flow core, and erosion of the side wall of the chute was much less.

*Fig. 2.* The penetrating hole in the chute of the fuel supply canal.

The amount of damaged metal is proportional to the energy of particles that attack the surface of the plate. If kinetic energy of particles is higher and number of attacks greater, the wear of metal is more extensive. Both kinetic energy and number of attacks depend on the velocity of fuel flow. Kinetic energy is proportional to the rate in the square power, and quantities of attacking particles at a given concentrations in the fuel flow are proportional to the rate in the first power.

## Determination of abrasion index

At first approximation the wear is proportional to the rate of fuel flow in the third power [5]. Raask proposes to use power index 2.3–2.5 [1].

According to [5], the maximum intensity of wear can be expressed

$$\delta_{pl} = \alpha \cdot \eta \cdot k \cdot m \cdot \omega^3 \cdot \tau, \quad \text{mm}, \tag{1}$$

where:

$\delta_{pl}$ – maximum intensity of plate wear, mm. The second plate in the inclined chute is made from steel AISI 304, and its thickness was 12 mm;

$\alpha$ – abrasion index, $mm \cdot s^3/g \cdot h$;
(abrasion index for oil shale – $\alpha_{\text{oil shale}}$ – is not determined);

$\eta$ – coefficient, determining the number of probable attacks on the plate surface.

Assuming that all fuel particles contact with the second plate falling on it by gravity $\eta = 1$;

$k$ – concentration of fuel in flow, $g/m^3$;
Calculation of fuel flow concentration is performed as follows. The amount of oil shale passing through the crusher is equal to 30 t/h or $8.4 \cdot 10^3$ g/s. The amount of air given directly at cross section of the chute from the air bustle is 0.7 $m^3/s$, and that of the air entering at the end of the inclined chute before the furnace is 0.47 $m^3/s$ (Fig. 1). Considering that the amount of air entering through the slot between the first and the second plates is negligible, the whole amount of air is 1.17 $m^3/s$. Consequently, the concentration of fuel in the flow is $7.2 \cdot 10^3$ $g/m^3$.

$m$ – coefficient of wear resistance of metal;
Wear resistance is a relative value – wear intensity of metal is compared with that of the standard material St 45. Wear intensity depends on the attack angle. Relative intensity of alloy austenitic steel 12Cr18Ni10T at the attack angle of $30^\circ$ determined by Mägi is 0.88 [4]. Relative wear intensity is the measure of wear resistance of material. On these assumptions and since AISI 304 belongs to the austenitic class of metals, coefficient of its wear resistance is 0.88.

$\omega$ – velocity of fuel flow, m/s;

In the vertical part of the fuel route particles fall down onto the inclined chute by gravity force. The velocity of falling is affected by two factors.

The first factor that affects velocity of falling is small size of fuel particles after crushing (Table 2). At falling of particles by gravity, the resistance of the surrounding air affects the velocity only by up to 1% [6], but when the size of particles is very small (for example 100 μm), the resistance of the air increases, and velocity of particles' falling remains stable with no increase. The change from steadily increasing motion of particles to a stable one is explained by gravity force (G) equalled by air resistance (S), S = G [6].

The second factor affecting velocity of falling the particles is the air entering from the air bustle (Fig. 1). The velocity of the air in the channel behind the air bustle is 3.5 m/s. The velocity of fuel flow falling by gravity into the air flow is 9.9 m/s. The air flow falling in the same direction with gravity force affects small-size particles so that air resistance S is much less than gravity force G in conditions existing in the vertical part of the route. The effect of the same direction air flow on velocity of bigger particles is insignificant because G >> S.

The above-mentioned explanation allows to take the velocity of fuel flow for gravity velocity in the contact place of wearing. Velocity of flow on the plate surface is equal to 11.0 m/s.

$\tau$ – operation time, h;

Many holes penetrating the second plate were observed after 8000 h of boiler operation.

The equation (1) was solved using the values given above, and that gave the value of abrasion index of oil shale $0.162 \cdot 10^{-9}$.

## Conclusions

Comparison of abrasion index of oil shale with abrasion indexes of ash of other fuels [1] shows that abrasiveness of oil shale is lower than that of ashes. That is explained by the fact that the few abrasive minerals in the oil shale fuel are diluted by comparatively nonabrasive organic matter and relatively nonabrasive mineral matter (as in the case of coal-fired boilers) [1]. This work is a first attempt to determine abrasion index of oil shale basing on industrial practice.

As shown in practice, there are two ways for decreasing the wear of the elements of the fuel supply system in existing CFB boilers:

1. Changing the design of elements.
2. Using materials with higher wear resistance in the elements subjected to erosion.

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