Oil Shale, 2011, Vol. 28, No. 1S, pp. 162–168
doi: 10.3176/oil.2011.1S.08

ISSN 0208-189X

CATASTROPHIC WASTAGE OF TUBES IN FLUIDIZED BED BOILER

H. SUIK[(a)*], T. PIHU[(b)], A. KONIST[(b)]

(a) Tallinna Elektrijaam OÜ
Väomurru 1/Tooma 14, Tallinn, 11415, Estonia

(b) Department of Thermal Engineering
Tallinn University of Technology
116 Kopli St., Tallinn 11712, Estonia

Fluidized-bed (FB) and circulating fluidized-bed (CFB) boilers have some advantages compared with pulverized firing (PF) boilers. Advantages of fluidized-bed boilers are related to fuel properties, composition of exit flue gas, boiler efficiency and capital and O&M costs.

Special attention in this field must be paid on comparing maintenance cost of boilers operating in different combustion modes. On the one hand, the cost of fluidized boilers is not high due to lack of rotation facilities, and corrosion intensity is low due to low combustion temperature, but, on the other hand, the maintenance cost can increase due to intensive wastage of both heat surfaces and canals supplying fuel and exiting flue gas.

The present article deals with the wear problems in the boiler furnace. As a result of this work the dependence of erosion on the velocity of the mass flow during different operation times by moderate concentration of particles is given.

Introduction

FB and CFB combustors facilitate burning of a wide variety of fuels with high combustion efficiency while meeting pollutant emission requirements for SO_2 and NO_x. Wastage of materials, both metallic and refractory, is a major source of concern because it can be responsible for shutdowns and high maintenance costs. Usually the wastage of tubes and other materials can occur anywhere along the fuel and gas path due to entrained solid particles passing through the boiler. Wastage rates of tubes of FB and CFB boilers are acceptable and do not exceed those of PF boiler tubes. Reasonable wastage rate for fluidized-bed boiler tubes is 0.3–1.0 μm/h and may be as high as 3.0 μm/h [1]. Wastage in FB and CFB boilers has been a continuing

---

[*] Corresponding author: e-mail *Heinrich.Suik@elektrijaam.ee*

problem, and as long as there is no better alternative, both FB and CFB combustion are considered risky technologies [2].

Is fluidized-bed combustion a risky technology?

In PF boilers wear and wastage of tubes and facilities have been caused by ash, whose behavior and quantities determined their damages. However, in addition to metal wastage depending on ash, the fluidized environment causes significantly more damages in boilers. The large extent of metal wastage is caused by relatively high velocity of bed material and by its special composition. Typical granular compositions of FB and CFB boiler bed material are given in Tables 1 and 2. The rates and mechanism of the metal loss are complex functions of the particle characteristics, i.e. composition, shape, size and strength [2], and also on the conditions inside the combustors, and the characteristics of metal [3, 4].

Sand material contains more than 80% of SiO_2, it means that it is quartz sand which has high abrasive properties [5]. The initial sand fill is natural sand, and it should not be crushed or should not contain a high proportion of quartos which decays due to thermal shock.

Oil shale ash properties suit for creating fluidizing bed and therefore no additional sand is needed. Eroding by oil shale ash is many times weaker compared to quartz sand. After start-up oil shale CFB bottom ash screened through the sieve 1.6 mm will be used as the bed material and it is blown pneumatically into the boiler. Abrasive properties of CFB oil shale ash have not been studied yet and need future investigation in order to determine erosion coefficient needed for calculations.

Table 1. **Granular composition of bed material of FB boiler operating on biomass**

Sieves, mm	R(x), %
2	0.63
1.4	1.60
0.71	59.21
0.355	99.74
0.18	99.83
0	100.00

Table 2. **Granular composition of bed material in oil shale CFB boilers**

Sieves, mm	R(x), %
2	48.63
0.5	61.82
0.18	80.51
0.125	88.39
0	100.00

The velocity of fluidization environment is a decisive factor in erosion of tubes in furnace and flue gas ducts and fuel supplying routes. In the furnace of CFB boilers gas velocity is 5–7 m/s [4], 4.5–5.0 m/s [6], in the furnace of FB boilers 1–2 m/s [7].

The physical properties of fuel vary depending on the wood/waste fuel added to fossil fuels. The effect of erosive properties directly depends on the fuel applied.

Catastrophic wastage in FB boiler

Against erosion the tubes in the furnace of FB have been covered by wear-resistant refractory; that is why wearing takes place in the interface between the covered and bare surface. Under operating conditions with unanticipated factors the moderate erosion can achieve catastrophic extent due to fluidization technology. Direct flow of the bed material is the reason of intensive erosion of tubes. Figure 1 shows the arrangement of piping of the bed sand recirculation back to the furnace, leading to catastrophic wearing of furnace tubes after 5051 hours of operation.

A pneumatic transmitter blows the sieved bed material back to the furnace against the front wall. Blowing capacity of the system is 20 m^3/h, size of sieved particles <1.6 mm, and specific weight 1 000–1 500 kg/m^3. The transmitter is working periodically. The cycle of sand return consists of two stages: the fulfilling of the transfer cone of the capacity 0.25 m^3 and the blowing cycle. Duration of the blowing cycle, that means exhausting the cone, is approximately 45 s. Three returning cycles are executed consecutively, after which the bed material is collected into the sieving system. The complete cycle – sieving, three fulfilling and blowing stages occur approximately in one hour.

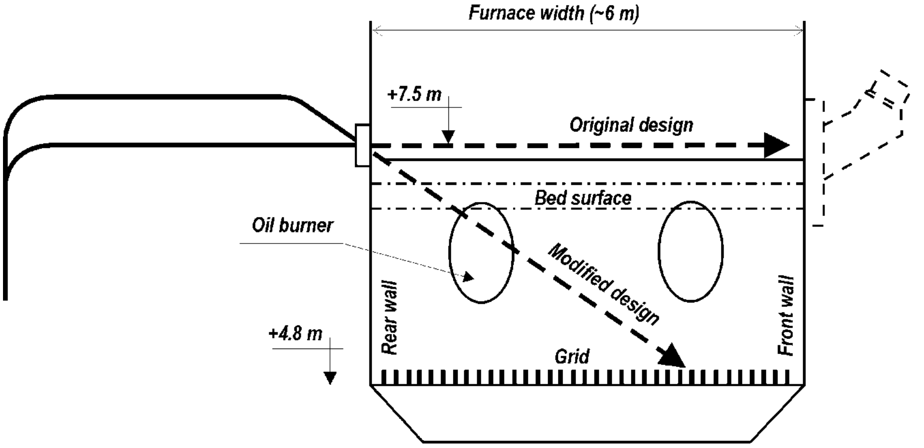

Fig. 1. Original and modified circulation pipings of bed sand.

During operation of more than 1 500 returning cycles returning particles impacted the front wall thinning tube wall thickness to failure such as fish-mouth rupture (Fig. 2). This ultimate failure results from rupture due to increasing strain caused by tube material erosion. The thickness of the edge of tube wall around the rupture was 2 mm, but wall tubes were slightly thinned in the radius 0.3 m on the front wall across the blowing nozzle of the returning tube. Velocity of particles at collision with the front wall tubes was ~71 m/s at the collision angle 90°.

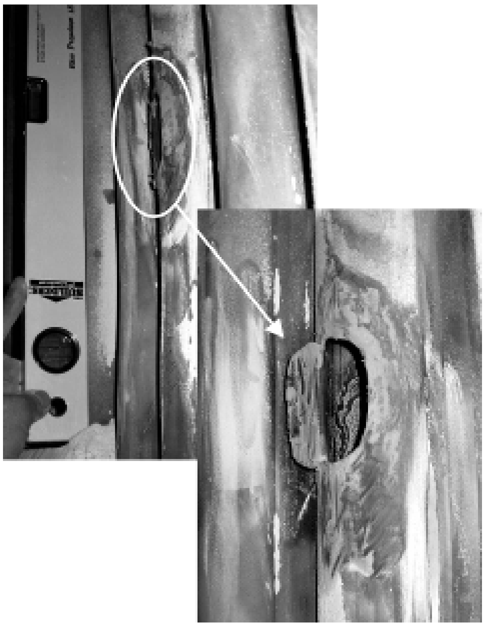

Fig. 2. Knife-edged (fish mouth) type slit caused by erosion.

Basing on the data of operation experience, the intensity of erosion can be determined by the following equation [5]:

$$T = \delta/3.6\times10^{-2}\times\psi\times k, \quad (1)$$

where,

- T – durability (working age, lifetime) of tube till rupture, h. During boiler operation for 5051 hours, the front tubes were impacted by particles during 189 hours;
- δ – worn thickness of tube which has been impacted by particles for 189 hour during 5051-hour operation of boiler;
- ψ – concentration of particles, g/(cm^{2}s). Mean specific weight of the blowed material is 1200 kg/m^3, quantity of the blowed material during one cycle is 300 kg, and the blowing lasted for 45 s. Using these data for calculation, the concentration of particles is equal to 85.4 g/cm^{2}s.

k – erosion intensity of the material, mm^3/kg. As k is the relative erosion intensity of standard material [5], the $k = k_0 k_\psi$. k_ψ is the correction coefficient taking by consideration erosion by high velocity of the particles. As shown in Fig. 3 [5], according to the line under $\psi =$ 85.4 g/cm^{2}s, k_ψ equals 0.73. In the present paper k_0 expresses the relative erosion intensity of the tube material used in the boiler.

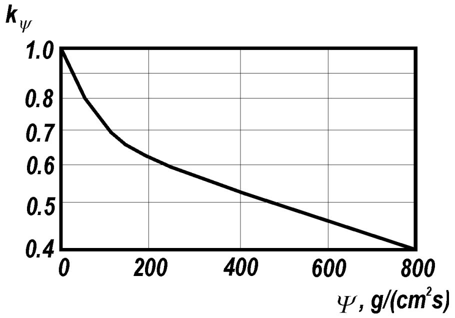

Fig. 3. Coefficient k_ψ depending on the concentration of particles [5].

Erosion intensity k in equation (1) is expressed as:

$$k = \delta / T \times \psi \times k_\psi, \quad (2)$$

and in given conditions, (velocity of particles 71 m/s), k equals 0.0109 m^3/kg.

For calculation of the erosion of the tube in boilers it is suggested to use the following equation [5]:

$$k = C_a v^2, \quad (3)$$

where

k – erosion intensity of the material, 0.0109 m^3/kg;

v – velocity of the erosion flow, m/s, in given conditions $v = 71$ m/s;

C_a – empirical coefficient dependent on abrasive properties of the erosion flow.

Using Eq. 3 one can get C_a equal to 2.16×10^{-6}. As empirical coefficient C_a depends only on abrasive properties of the flow [5] we can insert the equation 3 into the equation 1. As C_a depends on abrasive physical properties and concentration of the particles, it is possible to calculate the tube wastage in the conditions of different velocities and flow concentrations.

In the following way it is possible to estimate the erosion wastage during 10^5-h operation as a standard time calculated for boiler metal.

The possibilities of using this method have been given in two examples – the calculated one, and the one in Fig. 4. For example – at moderate concentration of particles [8–11], $\psi = 100$ g/(cm^{2}s), in the first case when $v = 2$ m/s the tube wastage is 3.11 mm, and in the second case when $v = 5$ m/s the wastage is 15.43 mm during 10^5-h operation.

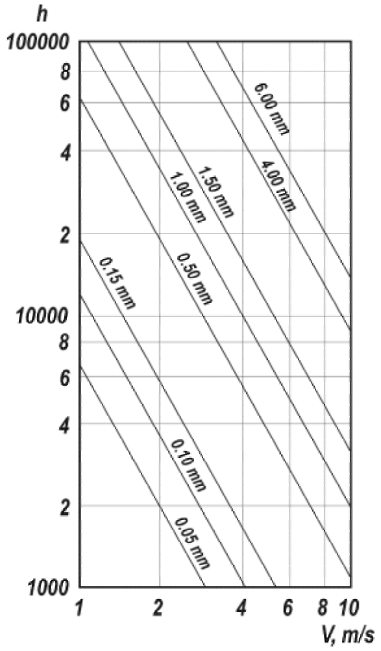

Fig. 4. Dependence of erosion on the velocity of the mass flow.

Figure 4 shows the dependence of erosion on the velocity of the mass flow during different operation times and at the moderate concentration of particles $\psi = 100$ g/(cm^{2}s). If the calculated lifetime of the boiler tubes is 100,000 hours, the metal wastage cannot be more than 4.00 mm, the particle flow velocity has to be less than $v = 2.4$ m/s according to Fig. 4. If the concentration of particles is more than $\psi = 100$g/(cm^{2}s), wastage will increase proportionally, and if less, inversely.

The relation between the concentration and velocity of particles is inversely proportional. Because the concentration of particles in the CFB is less than in FB boilers, the velocity of particles in these boilers are inversely proportional as well.

Conclusions

The boiler design fault allowed to calculate the intensity of erosion in FB boiler caused by quartz sand particles hitting the surface at an angle of 90°.

As a result of the present study the dependence of erosion on the velocity of the mass flow has been defined. This can be taken into account while designing or modifying FB boilers.

According to the given examples both the velocity and concentration of particles are decisive relevant factors which enable the fluidized-bed combustion technology to be called risky.

REFERENCES

1. *Stringer, J., MacAdam, S. S., Wright, I. G., Seth, V. K.* Effect of process variables on wastage in fluidized bed combustors: criteria for test procedures // J. Phys. IV. 1993. Vol. 3. P. 797–805.
2. *Hristov, J. Y.* Fluidized Bed Combustion as a Risk-Related Technology. Part 2: Problems relevant to the equipment damage due to the fuel properties // Fluidized Beds in Energy Production, Process Engineering and Ecology / 4-th Int. Symposium of South-East European Countries(SEEC), Thessaloniki, Greece, April 3–4, 2003. P. 135–140.
3. *Belin, F., Babichev, L. A., Levin, M. M., Maystrenko, A. Yu.* CFB Combustion of high-ash Ukrainian anthracite – test results and design implications // Ukraine/U.S Joint Conference on Ukraine Clean Coal Power Plant Upgrade Opportunities, April 21–24 1998, Kiev, Ukraine. 10 pp.
4. *Ryabov, G. A., Nadirov, I. I.* The implication of CFB technology for repowering of old pulverized coal boiler in Russia // 15-th International Conference on Fluidized Bed Combustion, May 16–19, 1999, Savannah, Georgia. 9 pp.
5. *Kleis, I., Uuemõis, H.* Wearing-Resistance of Elements of the Refiners by Impacts. – Moscow: Mashinostroenie, 1986. 157 pp. [in Russian].
6. *Wang Oing, Bai Jingru, Zhao Lixia, Sun Baizhong, Liu Hongpeng*. Validity of an expert system for oil shale-fired CFB boiler design and performance analysis // Oil Shale. 2008. Vol. 25, No. 4. P. 400–411.
7. *Yamamoto, K.* Biomass Power Generation by CFB Boiler // NKK Technical Review. 2001. No. 85. P. 29–34.
8. *Goidich, S. J., Wu, S., Fan, Z., Bose, A. C.* Design aspects of the ultra-super-critical CFB boiler // Internat. Pittsburgh Coal Conference, Pittsburgh, PA, September 12–15, 2005. P. 1–12.
9. *Franke, J., Kral, R.* Supercritical boiler technology for future market conditions // Parsons Conference, Oct. 2003. P. 1–13.
10. *Psik, R., Slomczynski, Z.* Final stage of first supercritical 460 MW_e CFB boiler construction – project update // Power Gen International, Orlando, Florida, December 2–4, 2008. P.1–13.
11. *Lundqist, R., Schrief, A., Kinnunen, P., Myöhänen, K., Seshamani, M.* A major step forward – the supercritical CFB boiler // Power Gen International 2003. P. 1–22.

Received December 2, 2010