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RECOMMENDATIONS FOR DESIGN OF ESTONIAN OIL SHALE FIRED CFB BOILERS

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The following recommendations for designing new oil shale fired CFB boilers were worked out on the basis of the test burning of Estonian oil shale and following additional laboratory investigations [1-3]. Besides that, the experience of the long-term combustion of the pulverized (PF) oil shale at Estonian power plants was considered. Primarily the recommendations were thought for designing of the 100 MW_{th} CFB oil shale demo-boiler but they certainly do not lose their actuality at designing oil shale boilers based on the CFB technology in the future.

Arranging the recommendations, it was proceeded from the principal technological scheme of CFB boiler starting from the fuel bunker and finishing with the dust filter for cleaning flue gas and with ash handling. Besides recommendations also their motivation is presented. In case of need for a better elucidation of any question the materials of [1-3] were used in addition. It must be mentioned also that part of recommendations is provisional, done in particular for the planned demo-boiler, and they may be corrected in the future if the corresponding data will be available.

1. FUEL BUNKERS

Recommendation:

The devices to guarantee the normal feeding of oil shale (to avoid "hanging" of the fuel) for the oil shale bunkers of CFB demo-boiler should be foreseen.

Motivation:

According to the experience of Estonian oil shale power plants, "hanging" of oil shale in the fuel bunkers takes place sometimes. That disturbs the smooth and uniform feeding of the fuel into boiler. The same situation was observed at the CFB test boilers of Lurgi and Ahlstrom during burning tests.

In the Estonian power plants vibrators are in use to guarantee the uniform feeding of oil shale the, but also other methods are known. Obviously, for the bunkers of the oil shale CFB boiler the special devices should be foreseen to guarantee the normal feeding of oil shale.

2. FUEL PREPARATION

Recommendation:

The fuel preparation system should guarantee the maximal size of the fuel particle not more than 10 mm (pieces of higher size should be crushed).

Motivation:

Observation of the bottom ash from the test boilers has shown that large ash particles consist of unburned material. The latter fact was warranted by the laboratory analyses showing the presence of unburned carbon and sulfur in that ash (0.5-1.0% and 0.17-0.40%, respectively).

It may be supposed that, due to small dimensions of the test devices, part of the fuel has removed in the form of bottom ash before final burning of large pieces. Therefore the situation in the demo-boiler of greater dimensions, warranting longer staying of fuel in the burning zone, should become better. Considering the better staying of smaller fuel particles in the bed and their more rapid burning, the recommended size for feed oil shale should not exceed 10 mm.

Fuel feeding directly into the combustor is recommended.

3. COMBUSTION CHAMBER

Recommendations:

1. Using of the pneumatic system is obviously rational for fuel feeding into the combustion chamber. It guarantees the higher velocity of fuel particles at feeding and avoids their heating over 300°C.
2. The temperature 850°C must be considered most suitable for the operating of the combustion chamber in case of burning of Estonian oil shale.
3. It may be recommended to design the bottom part of the combustion chamber with a smaller cross section than the upper part.
4. Locating of the two-side radiated heat surfaces (tubular loop or platen) in the combustion chamber of the demo-boiler is unsuitable.
5. The devices for screening out from the bottom ash of large particles and for their additional crushing should be foreseen at designing of the demo-boiler. Large particles should be sent back into the combustor for final burning.

Motivation:

1. Estonian oil shale gets sticky and starts to release oil vapor and volatiles above 300°C. It was observed in first runs of the test device of Ahlstrom with feeding fuel into the combustion chamber by screws. The problem was avoided by over-pressurizing the screw with cooling air compared to combustor pressure at the feeding point. At LLB Lurgi test oil shale was fed with

a screw into a rotary valve and then blown pneumatically into the combustor at high velocity. That avoids heating as well as accompanying sticking of the softened fuel particles into the great lumps falling onto the bottom grid without staying in the fluid bed. The release of oil shale distillation products (oil vapours), favouring sticking, in the fuel feeding system will also be avoided by that.

2. The temperature 850°C must be considered as most suitable for burning of Estonian oil shale. In case of such temperature fluctuations in combustor temperature ±50°C do not evoke essential troubles in the boiler operation. At such temperature the binding of SO_2 of the flue gas by CaO is very intense. Binding of CaO by other ash components, decreasing the activity of CaO, is slow. (Decomposition of minerals of the sandy-clay part occurs at initial stage.) For combustion of CO such temperature is also sufficient. On other side this temperature is the most suitable concerning fouling and high temperature corrosion of heat transfer surfaces, economical and environmental aspects.
3. To avoid falling of large fuel particles onto the grid, in the bottom part of the demo-boiler higher gas velocity is needed. That may be reached using smaller cross section.
4. The possibility of some formation of ash deposits on heat transfer surfaces (in particular in case of the cross flow) located in the combustion chamber, during the long-term exploitation, must be kept in mind. It may cause troubles in operation of the combustion chamber. Therefore, until getting additional data of long-term tests placing of the two-side radiated heating surfaces (tubular loops or platens) in the combustion chamber of demo-boiler is unsuitable to solve this problem. However, for research work the problem can be solved by placing small heat transfer surface in the upper part of the combustion chamber.
5. Considering the circumstance that the bottom ash from combustor may consist of large "half-burned" particles, devices for screening and additional crushing of them should be foreseen at designing of the demo-boiler. These particles should be sent back into the combustion chamber for final burning after crushing of them.

4. CYCLONE

Recommendation:

At designing the recycling cyclone for the demo-boiler, the possibilities for its cleaning must be considered.

Motivation:

Long-term exploitation experiences of possible fouling of the recycling cyclone by ash deposits in case of Estonian oil shale, are lacking yet. Because of that the possibility that the long-time fouling takes place and cleaning of the recycling cyclone may prove absolutely necessary cannot be finally excluded. (Israeli experience constrains to guarded.) [1]

5. FLUIDIZED BED HEAT EXCHANGER

Recommendations:

1. Use of the fluidized bed heat exchanger (FBHE) is suitable, considering the possibilities to regulate the load and to preserve the operation stability of the boiler.
2. Obviously the installing of high-temperature heat transfer surfaces (last stages of super-heater and re-heater) into the FBHE, and increasing of the permissible steam temperature up to 540°C instead of 515-520°C, at the same time, is suitable.

Motivations:

1. This recommendation bases on the theoretical fundamentals worked out by the Lurgi for the CFB boilers and widely tested in practice during a long time ($FBHE^{LLB}$). $INTREX^{TM}$ is the corresponding Foster Wheeler technology.
2. $INTREX^{TM}$ or $FBHE^{LLB}$ can be recommended in particular for burning of Estonian oil shale when the corrosive activity of the circulating ash in the air media is significantly lower compared to that of the fine fly ash leaving recycling cyclone. So chlorine content in the circulating ash from the test units did not exceed 0.04-0.1%. Intermediate data of the laboratory corrosion tests made in TTU showed that the corrosion depth of test samples covered by the circulating ash was low [2]. It did not exceed the corrosion of not-covered samples in the air media at the same temperature. The heat exchange process in FBHE takes place in the air media, not in flue gas, and the possible influence of HCl on corrosion of heat transfer surfaces is avoided. The abrasive wearing at low air velocities (0.5-1 m/s) in FBHE probably is also very low. The tests made in TTU to estimate the abrasive influence of ash assured that conclusion. At these tests the circulating ash instead of wearing set on samples, differently to cyclone ash from the PF oil shale boiler used as a comparison material. It tells about the softness (very low abrasive influence) of circulating ash. All the above mentioned enables, in case when heat transfer surfaces are located in the FBHE, using of the higher temperatures of tube surface and besides that using of less expensive alloys with lower quality. Placing of high-temperature heat transfer surfaces into the FBHE enables to avoid very serious problems of fouling and high-temperature corrosion of conventional PF oil shale boilers.

[1] According to the latest experience of Foster Wheeler, the water-cooled square cyclone (Foster Wheeler Compact boiler) minimizes the cleaning needs.

6. CONVECTIVE HEAT TRANSFER SURFACES

Recommendations:

1. Installing of the demo-boiler with devices for intensive cleaning is necessary. Cleaning devices in any way do not crush the oxide film on the tubes and they should keep the heat surfaces continuously clean. It means that the formation of deposits should be avoided, not to confine oneself to removing of the formed deposits. Testing besides steam and air soot blowers less intensive vibration, gas-impulse and, in particular, the infra-sound with frequent operation on the demo-boiler is suitable. The combination of different cleaning methods may prove to be perspective. (Possibilities for placing of them on the boiler should be foreseen at designing of the demo-boiler.)
2. The wide-spaced corridor tube loops (not choking easily and better cleaned) should be used in the convective heat transfer surfaces of the demo-boiler.
3. The tubular-type air preheater with downstream gas flue should be preferred to the rotary-type air preheater, on the basis of the Lurgi test. Flue gas downstream avoids deposition of ash onto the tube-plate.

Motivations:

1.and 2. Intensive pulverizing of the oil shale ash takes place at combustion process in the system reactor/recycling cyclone (see Fig. 1 and 2). As the tests showed, the oil shale ash returned at the low-temperature burning (<900°C) was easily ground. Up to 50-60% of the total ash was collected as fines [2]. Such fine-grained ash had tendency to deposition onto heat transfer surfaces by the molecular and diffusion forces. This circumstance has great influence at fouling of convective surfaces by the loose unbound ash deposits. The sulphating (content of SO_2 in the flue gas is low), and sintering due to temperature, etc., do not play essential role at the formation of such deposits. Because of lack of the coarse ash fractions such dusty gas flow does not wear or thick the deposit decreasing so the possibilities for formation of hard, bound flue ash deposits [3]. Formed deposits may be easily removed but their staying on the heat transfer surfaces will significantly increase the thermal and aerodynamic resistance and decrease noticeably the heat absorbing. The design of the convective pass and flue gas dedusting system has to cope with these facts.

The tests of estimating the abrasive activity of ash were carried out in TTU. These tests showed that at boiler conditions the fine-grain fly ash flowing into the filter at different flue gas velocities practically does not cause wearing. On the contrary, in spite of high speed such ash tried to connect with samples and to form the deposit layer, so defending metal against wearing influence of ash flow. The above-mentioned shows a strong tendency of such ash to the formation of deposits. Formed in such conditions loose deposits may be easily removed but their staying on the heat surfaces will significantly increase the thermal resistance and decrease the heat absorbing. Basing on literature data, the heat transfer coefficients of such fine-grained loose deposits do not exceed the value λ=0.1-0.2 W/(m·K). In any case the latter fact should be considered at estimation of the necessary surface area of heat transfer surfaces. The intensive formation of deposits also will increase the aerodynamic resistance of the gas pass.

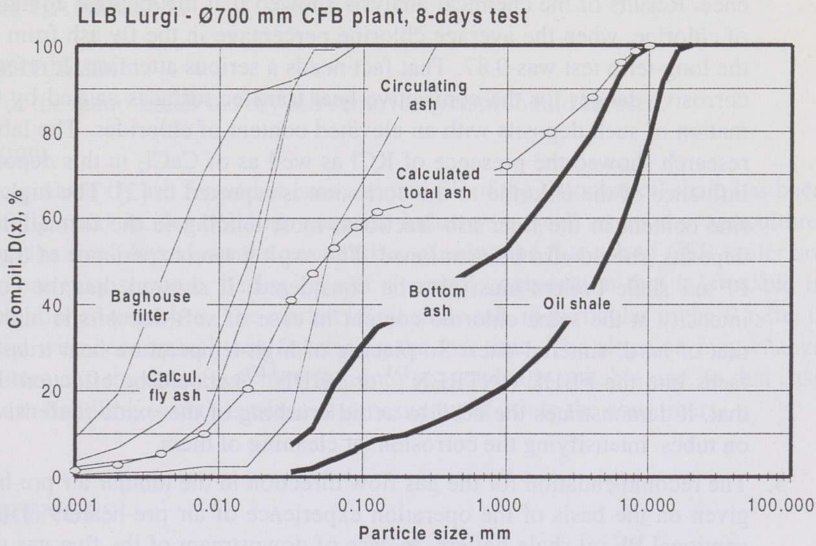

Figure 1. Grain composition of oil shale and ashes

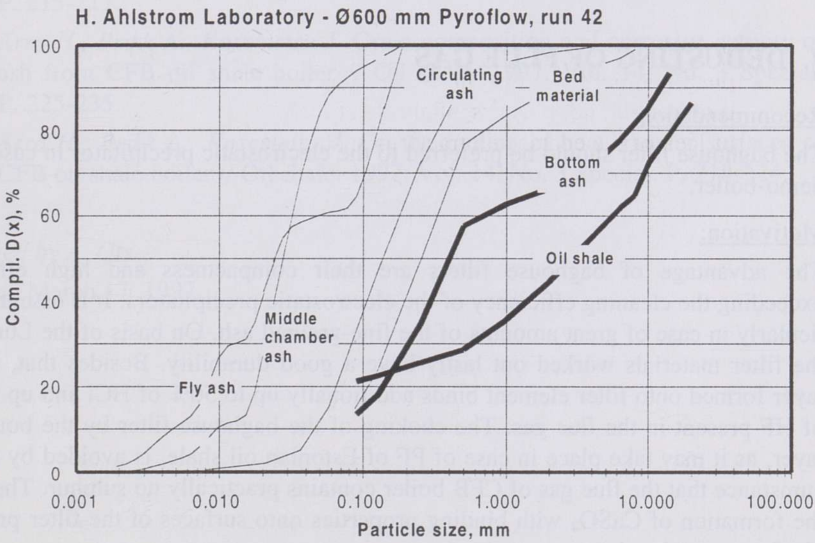

Figure 2. Grain composition of oil shale and ashes

The test at LLB Lurgi confirms the above-mentioned. Observing of not-cooled tube-sample placed in the convective pass at temperature ~550°C, showed the formation around it of the deposit layer of up to ~1 cm thickness after 8-days exposition. It was a loose deposit, particles of which were not bound with themselves as well as to the metal surface and all the deposit may be easily removed. The uniform thickness of deposit around the sample tells quite clearly that the dusty gas flow around the sample had no wearing influence. Results of the chemical analysis showed that this deposit contains ~2% of chlorine, when the average chlorine percentage in the fly ash from filter at the long-term test was 0.87. That fact needs a serious attention. It refers to the corrosive danger for the convective heat transfer surfaces caused by the formation of such deposits with an elevated content of chlorides. The laboratory research showed the presence of KCl as well as of $CaCl_2$ in this deposit. The influence of the chlorine to the corrosion is reported in [2]. The higher chlorine content in the finer ash fractions, most tending to the formation of the deposits, should also be mentioned. The exploitation experience of traditional PF oil shale boilers must also be considered. It showed that the corrosion intensity at the same chlorine content in case of soft deposits is higher than that of hard, sintered ones. So placing of high-temperature heat transfer surfaces into the FBHE (INTREX^{TM} or FBHE^{LLB}) should be effectual. Besides that, it demonstrates the need to avoid crushing of the oxide (defensive) film on tubes, intensifying the corrosion, at cleaning of them.

3. The recommendation for the gas flow direction in the tubular air pre-heater is given on the basis of the operation experience of air pre-heaters of the conventional PF oil shale boilers. In case of downstream of the flue gas the tube plates are clean but in case of upstream they are covered with the ash deposits.

7. DEDUSTING OF FLUE GAS

Recommendation:

The baghouse filter should be preferred to the electrostatic precipitator in case of the demo-boiler.

Motivation:

The advantage of baghouse filters are their compactness and high efficiency exceeding the cleaning efficiency of the electrostatic precipitators. It is essential particularly in case of great amounts of the fine-grained ash. On basis of the Lurgi data the filter materials worked out lastly have a good durability. Besides that, the ash layer formed onto filter element binds additionally up to 50% of HCl and up to 90% of HF present in the flue gas. The choking of the baghouse filter by the bound ash layer, as it may take place in case of PF of Estonian oil shale, is avoided by the circumstance that the flue gas of CFB boiler contains practically no sulphur. Therefore, the formation of $CaSO_4$ with binding properties onto surfaces of the filter presumably does not take place.

The oil shale ash received from the PF boiler has a tendency be cemented also at action with water. The ash from CFB boiler is somewhat another kind of material. The test made in TTU with ash from filter held last more than a week in the air flow saturated by water vapour showed that hardening of ash layer did not take place.

However, it should be considered how to avoid the ash layer hardening on the filter material by the moisture of air or gas in conditions where the dew point may cause it. The latter may take place, for example, along the boiler start up or shut down, etc.

8. ASH HANDLING

Recommendation:

In case of the demo-boiler the dry ash-removal system should be used.

Motivation:

The fine-grained fly ash formed at conventional PF of the Estonian oil shale has been successfully used in the building material industry as well as in the agriculture. Although the final data about the possibilities of using the flue ash of CFB boiler are lacking, one may suppose, basing on ash chemical composition that it is usable in above mentioned branches. The market of oil shale ash, in particular in the Russia, is connected with economical troubles during the last time. The situation may change in the future and the use of ash may turn into economically suitable one. In that case the dry ash-handling system is necessary for output of ash to the consumers.

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