

## CIRCULATING FLUIDIZED BED COMBUSTION – THE TECHNOLOGY EXACT FOR ESTONIAN OIL SHALE

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*The development of conventional bubbling fluidized bed (BFB) combustion between 1950 and 1960 led to the workout of a new type of fluid-bed process – circulating fluidized bed (CFB) combustion.*

*The circulated fluidized bed combustion owns its name from the idea of rapid continuous circulating of ash particles in the system combustor – recycling cyclone.*

*Due to the considerably fine particle size of fuel and high gas velocity the ash, the product of fuel burning, is carried out from the combustor with flue gases. Hot flue gases and fly ash are separated from coarse ash particles in a recycling cyclone. Coarse ash particles, the “circulating ash”, captured by the recycling cyclone are returned into the combustor.*

*Leadership in the development of CFB technology between 1975 and 1985 belonged to the European firms Lurgi Lentjes Babcock (LLB, Germany) and Research and Development Center of Ahlstrom (Hans Ahlstrom Laboratory, Finland; since 1995 Foster Wheeler).*

### COMBUSTION

The fuel is burnt at a low, considering the conventional pulverized firing (PF), temperature, at about 850°C.

Fuel is fed directly into the combustor. The combustion air is fed in two stages. Primary air is fed through the nozzle grid at the bottom of the combustor and secondary air, depending on boiler design, at various levels above the fuel feed point to provide a staged combustion and to ensure the complete burning of fuel (Fig. 1).

The limestone, required for desulphurization of flue gas, is added near the bottom grid of the combustor. In the combustor the fuels burning and sulphur caption reactions take place simultaneously. The high turbulence in the circulating bed causes the fuel and limestone to mix quickly and uniformly with the bed material.

The advantage of the CFB combustor is that it can burn, besides high-grade coals, a wide range of cheap fuels with variable particle size and high ash, moisture, volatiles and sulphur content. Such fuels as anthracite, different cokes, brown coals,

lignite, oil shale and other solid fuels, oil and gas, different industrial sludge, biomass, slurry, different wastes and other can be burned.

*Estonian Oil Shale.* Such a low burning temperature is recommendable particularly in case of burning of Estonian oil shale keeping in view the fouling and high temperature corrosion of heat transfer surfaces.

The limestone addition is not required in case of fuels containing the necessary amount of carbonates as, for example, Estonian oil shale.

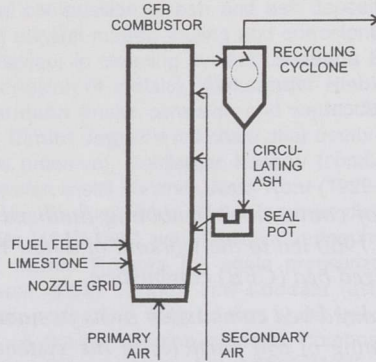


Figure 1. CFB combustor, recycling cyclone and seal pot

In comparison with the BFB the advantages of the CFBC are:

- stable combustion at moderate temperatures,
- higher combustion efficiency,
- higher heat transfer intensity,
- better load reduction with faster turndown rate,
- high sulphur capture rate,
- lower  $\text{NO}_x$  emissions,
- lower  $\text{O}_2$  level in the flue gas.

### FLUIDIZED BED HEAT EXCHANGER (FBHE)

If the development of BFB led to the CFBC then fluidized bed heat exchanger is a next step in the development of the last.

INTREX<sup>TM</sup> and FBHE<sup>LLB</sup> are the technical solutions for fluidized bed heat exchangers of Foster Wheeler and LLB Lurgi, respectively.

In fluidized bed heat exchanger a portion of hot circulating ash is cooled as it passes over the heat transfer surface before returning into the combustor. Captured in cyclone circulating ash is returned into the combustor through the seal pot or/and through the fluidized bed heat exchanger (Fig. 2).

The advantages of the INTREX<sup>TM</sup> and FBHE<sup>LLB</sup> are:

- ability to control and regulate combustor temperature with changing fuels and loads,

- the air media, low gas velocity and absence of finest ash particles in the circulating ash make FBHE suitable for placing high temperature sections of the superheater in that,
- using of a single combustor chamber at larger boiler sizes by placing necessary additional heat transfer surface in the FBHE,
- ability to place heat transfer surfaces in more than one FBHE to control steam temperatures at different points,
- placement of reheat surface in large industrial and utility units. Solids flow through the FBHE can be varied to control reheater temperatures without spray-water.

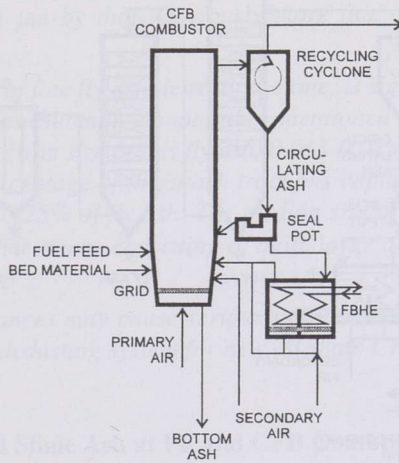


Figure 2. CFB boiler with fluidized bed heat exchanger (FBHE)

*Estonian Oil Shale. INTREX<sup>TM</sup> or FBHE<sup>LLB</sup> can be recommended in particular at 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. In case of Estonian oil shale the corrosive activity increases significantly with decreasing of ash particle size.*

## STEAM GENERATION

Depending on the operation mode of the boiler as well as on the boiler size and type of fuel, the CFB boiler may be designed either with or without FBHE.

In FBHE-equipped boilers the heat transfer surfaces for steam generation are located both in the combustor and in FBHE. As it was mentioned above, in FBHE a portion of hot solids is cooled as it passes over several sections of heat transfer surface before returning into the combustor. Part of secondary air needed for keeping fluidized bed is heated in the INTREX<sup>TM</sup> or FBHE<sup>LLB</sup> before turning into the combustor (besides above mentioned).

Hot flue gas together with fine ash leaves the recycling cyclone and flows into the convective pass of the boiler, where typically economizer as well as air preheater and sections of superheater are placed.

In CFB plants without a FBHE the entire evaporating surface is distributed over the combustor and the convective pass.

From the convection zone flue gases pass through a gas dedusting system into the stack (Fig. 3).

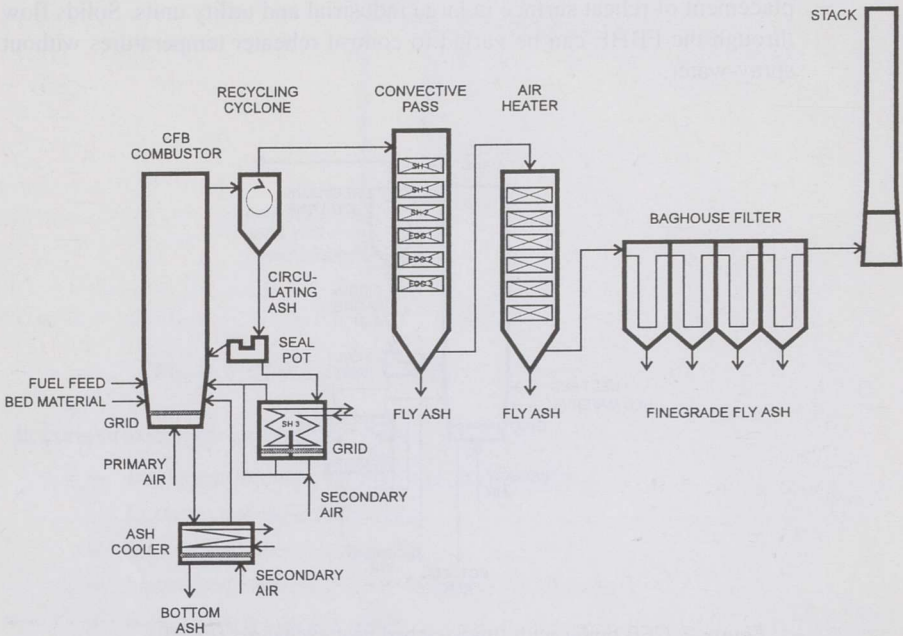


Figure 3. CFB power plant

## CLEANING OF FLUE GAS

### Dedusting

The flue gas in CFB boilers is cleaned from ash particles either in electrostatic precipitators or in baghouse filters. Emission limit does not exceed  $50 \text{ mg dust/m}_n^3$ .

The selection of optimum type of dust collectors depends on various factors such as flue gas temperature, composition and dust load, the required dust collection efficiency, electric dust resistivity and other.

The electrostatic precipitator (ESP) in CFB boilers may be arranged on the hot-gas side upstream of the air preheater at flue gas temperatures of  $300\text{--}350^\circ\text{C}$ , or on the cold-gas side downstream of air preheater at flue gas temperatures of  $130\text{--}310^\circ\text{C}$ . Maximal dust collection efficiencies of ESP are up to 99.99%.

Besides ESP, the baghouse filters (BHF) are employed for flue gas dedusting in CFB boilers. When limestone is added to the combustion process for  $\text{SO}_2$  control as well as when fuel consists carbonates, the fly ash retained on the filter bags contains

a certain amount of free calcium oxide. Ash layer containing free CaO absorbs additionally 40-50% of HCl and up to 90% of HF present in flue gas as well as part of remaining SO<sub>2</sub>. The guaranteed operating time of the BHF is 12-16 thousand hours.

*Estonian Oil Shale. Test burning in different ~1 MW<sub>th</sub> boilers of Ahlstrom (Finland) and LLB Lurgi (Germany) showed very intensive pulverizing of oil shale ash in CFB. As the result of that the part of very fine fly ash rises significantly compared to PF burning.*

*One of the main problems at conventional PF burning by using four-field ESP is great emission of solids (1.5-2% of total ash or 1-2 g/m<sub>n</sub><sup>3</sup>). Amount of fly ash received in ESP of boiler TP-101 (100 MW<sub>th</sub>) of the Estonian Power Plant makes 19.2%, and median grain size is 0.015 mm (see the following Table). Percentage of finest ash from the IV field of ESP is only 0.1 at median size 6.5 μm by that. Obviously more fine ash particles are flowed through ESP.*

*The percentage of fine fly ash, leaving cyclone, is significantly higher at CFB burning - 40% as minimal, compared to mentioned above PF burning. Calculated median grain size of this fly ash, 0.013-0.02 mm, is near to that at PF burning, but percentage of finest ash fractions captured in the material filter is very high – 10-25% of fly ash. The median size of these fractions of ash is only 3-4 μm. That means consisting of quite large amount of the particles of sub-micron sizes.*

*These circumstances may cause serious problems and should be considered at designing of dedusting system for new oil shale CFB boiler.*

### Oil Shale Ash at PF and CFB Combustion

Ash flow	Ash percentage	Median Grain Size, mm
<b>PF technology, boiler type TP-101 of the ESTONIAN POWER PLANT</b>		
Total ash of ESP	19.2	0.015 (calculated)
Pre-chamber	13.5	0.041
IV field	0.1	0.0065
<b>CFB technology, Ø600 mm test boiler of the AHLSTROM</b>		
Fly ash leaving cyclone	66-92	~0.02 (calculated)
Middle chamber ash	1-8	0.019-0.039
Ash from material filter	65-85	0.018-0.026
<b>CFB technology, Ø700 mm test boiler of the LLB LURGI</b>		
Fly ash leaving cyclone	39-60	0.013-0.016 (calculated)
Ash from the second cyclone	30-53	0.019-0.022
Ash from material filter	8.3-14.3	0.003-0.0046

### ***Sulphur Dioxide (SO<sub>2</sub>) Reduction***

Control of sulphur dioxide (SO<sub>2</sub>) and nitrogen oxide (NO<sub>x</sub>) emissions from power plants is one of the main environmental problems. The CFB process is an important step towards solving this problem. Addition of the gas desulphurization or/and NO<sub>x</sub> removal systems are not required in CFB boilers.

CFB boilers can achieve over 90-95% of SO<sub>2</sub> reduction "in situ" by mixing limestone (Ca/S molar ratio approximately 1.5-2.0) with fuel in the combustor or by carbonate part of the fuel. Desulphurization takes place directly in the combustion zone. Due to a sufficiently long residence time, limestone reacts with the sulphur of the fuel finally forming gypsum that is removed from the combustor in solid form with ash. The reaction steps are as follows: oxidation of the fuel-bound sulphur, calcination of limestone to form calcium oxide and final gypsum formation. SO<sub>2</sub> emissions are low even when burning high-sulphur fuels.

*Estonian Oil Shale.* Sulphur content in the Estonian oil shale is approx. 1.5%. At PF of oil shale 70-80% of SO<sub>2</sub> is bound with ash – emission with flue gas is about 1.4-2 g/m<sub>n</sub><sup>3</sup>. At burning in CFB free CaO, formed at decomposition of the carbonate minerals of oil shale, is very active and effectively binds SO<sub>2</sub> from flue gas. On the basis of test burning in different 1MW CFB boilers of Ahlstrom and LLB Lurgi remaining SO<sub>2</sub> content in flue gases is only some ppm.

### ***Nitrogen Oxide (NO<sub>x</sub>) Formation***

The combustion temperature 850°C in combustor of CFB boiler is generally too low to allow significant oxidation of atmospheric nitrogen. Besides that, the formation of nitrogen oxides from bound in the fuel nitrogen compounds is suppressed by staged combustion air addition.

Above mentioned conditions give extremely low NO<sub>x</sub> emission – lower than 200 mg/m<sub>n</sub><sup>3</sup>.

*Estonian Oil Shale.* Content of nitrogen compounds in the Estonian oil shale is low (about 0.1% nitrogen). At test burning in CFB NO does not exceed 150-170 ppm and N<sub>2</sub>O 10-15 ppm (NO<sub>x</sub>=160-180 ppm at LLB Lurgi tests & 87-129 ppm at Ahlstrom tests).

### ***Reduction of Chlorine and Fluorine Compounds***

Chlorine and fluorine compounds are largely retained in the ash.

Using baghouse filter, the layer of fly ash on the filter bags consisting free CaO absorbs additionally 40-50% of HCl and up to 90% of HF present in flue gas.

*Estonian Oil Shale.* At test burning of oil shale in Ø700 CFB test boiler of LLB Lurgi with baghouse filter HCl=179-245 mg/m<sub>n</sub><sup>3</sup> (dry).

At test burning in Ø600 test boiler of Ahlstrom HCl content before the baghouse was 60-70 mg/m<sub>n</sub><sup>3</sup> and after the baghouse <5 mg/m<sub>n</sub><sup>3</sup>.

### ***Carbon Oxides (CO<sub>2</sub> and CO) Formation***

*Estonian Oil Shale.* LLB Lurgi (850°C, O<sub>2</sub>=4%): CO<sub>2</sub>=14.2-15.5 Vol.%; CO=15-50 ppm.

Presented by A. Ots

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