EXPERIENCE OF ESTONIAN OIL SHALE COMBUSTION BASED ON CFB TECHNOLOGY AT NARVA POWER PLANTS

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Estonian basic power supply is over 90% covered by oil shale-fired thermal power plants. The original units, commissioned between 1959 and 1973, used pulverized firing (PF) technology. Because of their age and problems related to environmental and economical performance, it was decided to replace two old blocks with new ones applying a more advanced circulating fluidized-bed (CFB) technology. In 2001 AS Narva Elektrijaamad contracted Foster Wheeler to repower two blocks, Block No. 8 at the Eesti Power Plant and Block No. 11 at the Balti Power Plant. The first of the renovated blocks started commercial operation at the Eesti Power Plant near the town of Narva at the beginning of 2004.

Now, when the repowering project is virtually complete, it is time to review how well the new units have met expectations. Foster Wheeler's concept for oil shale combustion in CFB brings multiple benefits and opens up new opportunities for using oil shale as a clean-burning fuel capable of meeting today's emission standards. This paper will review Foster Wheeler's boiler concept for combustion of Estonian oil shale and the first operational experiences of the new units. The environmental and economical performance of the old PF and the new CFB units is compared.

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General

The first block to be repowered with new technology at power plants of *AS Narva Elektrijaamad* (Narva Power Plants Ltd., abbr. Narva PP) near the town of Narva, Block No. 8 at the Eesti Power Plant (Eesti PP), started commercial operation at the beginning of 2004, and was followed by launching of Block No. 11 at the Balti Power Plant (Balti PP) later the same year. Both of the new units employ CFB (circulating fluidized bed) combustion technology and are fitted with two identical CFB boilers providing steam to modernized and uprated 215-MW$_e$ steam turbines manufactured by LMZ.

The original blocks at Narva PP, which were equipped with boilers designed for PF technology, were commissioned between 1959 and 1973. Because of poor economical and environmental performance of these units resulting from their age, and serious problems of corrosion and fouling of their convective heat surfaces, Narva PP decided to repower two 200-MW$_e$ units using new environment-friendly and efficient combustion technology.

Fluidized-bed combustion has emerged as a growing challenger to PF combustion in recent decades, and is well known for its flexibility in terms of fuel quality and capability of firing difficult-to-burn fuels efficiently and with low emissions. Preliminary studies showed that fluidized-bed combustion offered similar advantages for firing oil shale at Narva and for replacing the depreciated PF boilers there.

Since there were no CFB boilers in operation firing Estonian oil shale, it was essential to carry out pilot-scale combustion tests to evaluate the performance of oil shale when subject to fluidized-bed combustion. Tests were carried out between 1993 and 1994 at Foster Wheeler's laboratory in Karhula, Finland, using a 1-MW$_{th}$ pilot plant. Several different types of fluidized-bed combustion were tested, and CFB combustion offered the best performance in terms of process behavior and gaseous emissions. Foster Wheeler's CFB technology, incorporating compact separators and INTREX^{TM} heat-exchangers, was selected, and an EPC contract to repower two blocks at Narva was signed between *AS Narva Elektrijaamad* and Foster Wheeler Energia Oy on May 25, 2001.

Description of Boiler Concept

While pilot-scale combustion tests showed very promising results, they also highlighted the need to make a number of modifications to the principles of a standard CFB boiler design to accommodate the special characteristics involved in firing Estonian oil shale.

To minimize the attrition of friable ash and the formation of soft deposits on convection heat surfaces, lower fluidizing velocities in the furnace were specified than for standard fuels, and the combustion temperature was

reduced to below 850 °C. A low combustion temperature – ideally around 800 °C according to the initial operating experience – reduces decomposition of $CaCO_3$ present in oil shale, thereby reducing CO_2 emissions and improving unit efficiency in comparison to PF units. The cross-sectional dimensions of the furnace designed for Narva PP are 19.3×6.4 meters, and the height 40 meters.

Alternative soot blowing methods were also specified to keep surfaces clean without excessive steam consumption. The convective superheaters are cleaned using patented spring hammers, and the economizers using a sonic cleaning system.

The PF boilers at Narva PP have suffered from high levels of fouling and corrosion in the convective superheater area, negatively impacting unit availability. As a result, at designing new units a lot of attention was paid to selecting the optimum steam temperature for each superheating stage. The final superheating/reheating stage employs Foster Wheeler's proprietary Integrated Recycle Heat Exchangers INTREX^{TM}. This enables steam temperatures used for the convective superheaters/reheaters in the convective pass to be kept below 450 °C, the point at which, according to the studies, an intensive high-temperature corrosion begins. Steam-cooled separators are used as second-stage superheaters for the same reason.
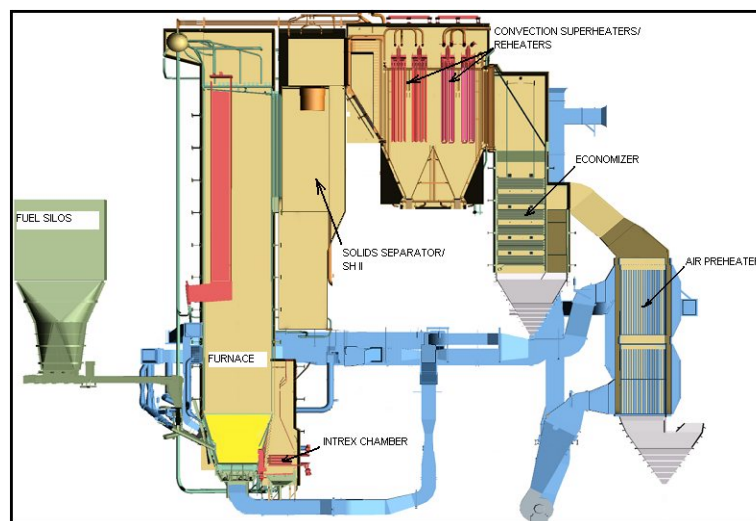

Fig. 1. Cross-section of Foster Wheeler's CFB boiler for firing Estonian oil shale

Pneumatic fuel feeding to the front wall of the lower furnace is provided through eight feeding chutes, guaranteeing good mixing of the fuel in the bed and favorable conditions for binding sulphur in the lower furnace and preventing the sulphation process from taking place after the furnace on the surface of the convective heat exchangers, where it is likely to cause the formation of hard deposits.

The design of the Narva PP boilers is based on Foster Wheeler's second-generation CFB technology. Process flow scheme includes separators of solids, constructed from water- or steam-cooled panels, integrated with the combustion chamber (Fig. 1). Such a design of cooled separators offers the advantage of not requiring heavy refractory linings which limit unit operation and increase maintenance costs, as happened in the case of the first-generation uncooled separators. Both versions of separators are given in Fig. 2.
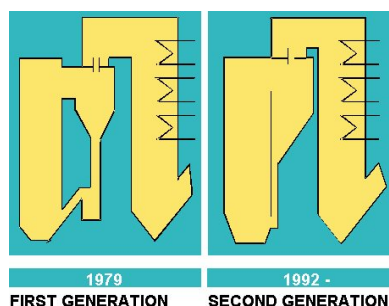

Fig. 2. The design of Foster Wheeler's first- and second-generation separators of solids

Three separators of solids were specified for the back wall of each boiler furnace in parallel, and comprise the second superheating stage (SH II). Prior to entering the separator walls, steam passes through the convective superheating stage, which includes superheaters IA and IB. One of the three INTREX^{TM} heat exchangers *per* boiler is used as a final superheating stage (SH III).

The reheat steam path in the boilers begins with the convective reheaters (RH IA and IB) located in the flue gas path after the first superheater. Two INTREX^{TM} heat exchangers in parallel make up the final reheating stage. Reheat steam temperature is controlled by spray water injection, INTREX^{TM} fluidizing velocity, and the RH 1 by-pass. The latter is a patented reheat steam control method, in which a part of the steam bypasses RH I, reducing the reheater's heat duty. By using the by-pass as a primary reheat steam controller, the water flow used in the reheat spray can be minimized, helping to optimize plant efficiency.

The economizer located after the convection cage in the flue gas path heats the feedwater *prior* to entering the steam drum. The final heat surfaces in the flue gas path are in the air preheater, which heats combustion air close to 300 °C.

Description of the Main System

INTREX^{TM}

A number of technical innovations incorporated in Foster Wheeler's CFB concept, such as the use of INTREX^{TM} units, enhance the capability of the boiler to burn difficult-to-fire fuels and offer greater flexibility. INTREX^{TM}

units are steam-cooled heat exchangers located in the lower part of the combustion chamber. They are not a part of the main furnace, however, and form a separate water-cooled chamber adjacent to the main combustion chamber. Solids coming down from the separator of solids are led through this very efficient heat exchanger on their way back to the bottom of the furnace. Cross-section of INTREX^{TM} heat exchanger is given in Fig. 3.

INTREX^{TM} units operate in the bubbling-bed mode, at low fluidizing velocities to prevent the erosion of heat exchanger tubing. INTREX^{TM} units are used as final-stage superheaters/reheaters because of less hazardous conditions they offer in terms of fouling and corrosion resulting from low chlorine content of recirculated ash. This enables lower steam temperatures to be used in convective superheaters, where the risk of fouling and corrosion is higher. The benefit of INTREX^{TM} units is particularly highlighted when firing fuels that contain components contributing to high-temperature corrosion or extensive fouling of convection heat surfaces.
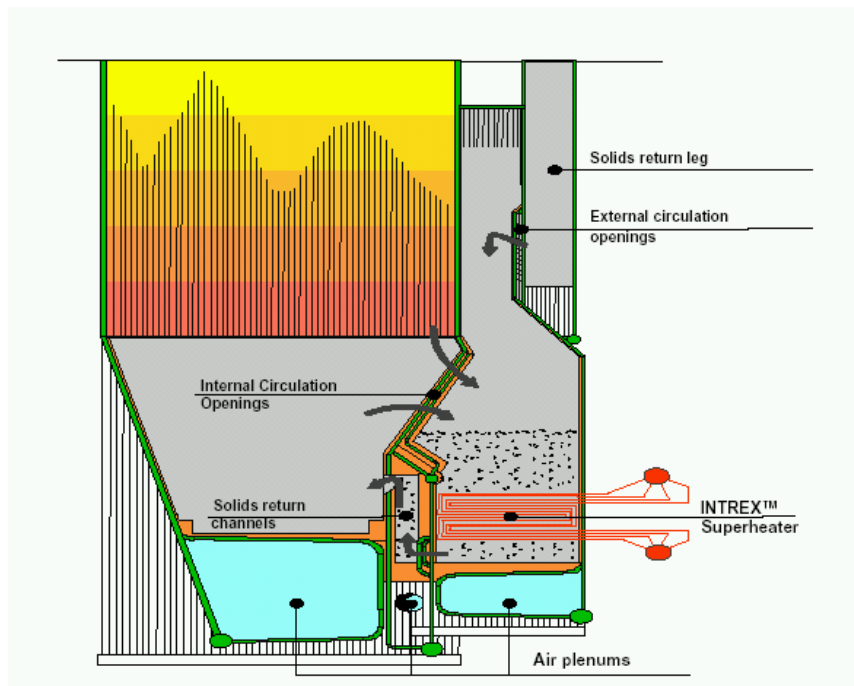

Fig. 3. Foster Wheeler's INTREX^{TM} heat exchanger

Separator of Solids

The separator of solids, which separates coarse and heavy ash particles from the flue gas flow after the furnace for recycling back to the bottom of the combustion chamber, is an important feature of CFB boilers. Foster Wheeler introduced a second-generation compact separator of solids, built from

water- or steam-cooled panels some time ago. This separator is an integral part of the combustion chamber, and does not require any heavy refractory lining called for the first-generation uncooled separators. Heavy refractory increases maintenance costs and restricts operational flexibility when longer start-up times are needed. The footprint of the second-generation design is also smaller, and only simple expansion joints are needed to compensate for the small movements encountered.

The design of the second-generation separator offers the benefit of simple construction and prolongs the residence time of fuel and limestone particles in the furnace, giving them time to react completely. The separators of solids specified for the Narva CFB boilers are steam-cooled, and utilized as second-stage superheaters, enabling lower steam temperatures to be used in the boiler convective superheaters. The separators of solids employ thin refractory linings, anchored with dense studding.

Combustion Air System

Combustion air in CFB boilers can be divided into three categories: primary air, secondary air, and high-pressure air.

Primary air in the Narva CFB boilers is utilized for bed fluidizing and fuel feeding purposes, and it comprises more than half of the total input of combustion air. The majority of the primary air is introduced to the furnace through a cooled grid.

Secondary air, introduced to the furnace through the openings of the start-up burner and secondary air nozzles, accounts for around one third of the total input of combustion air. Secondary air ensures proper staging and results in lower emissions of nitrogen oxide.

The remainder of the combustion air is high-pressure air used for the INTREX^{TM} units and wall seal fluidizing.

Ash Handling

Due to high ash content of Estonian oil shale – up to 50% on an as received basis – the ash discharge system is one of the most important subsystems of a power plant fired on this fuel. The bottom ash-fly ash-ratio in the Narva CFB boilers is approx. 40 to 60%. Bottom ash is discharged from the furnace *via* 16 dropping chutes, which feed the ash to eight water-cooled screw conveyors. Two chain conveyors and elevators are used to convey bottom ash to the bottom ash silo, from where most of the ash is pneumatically transported to the ash silo for wet ash removal.

Small and light ash particles (d < 50 μm) not separated by the separators of solids comprise fly ash. Fly ash is removed from the boiler from the hoppers under the convection cage, the economizer, the air preheater, and the electrostatic precipitator. Fly ash is transported from the hoppers pneumatically, with the exception of convection cage ash, which is discharged to the bottom ash silo using water-cooled screws and chain

conveyors. All the ash from each pair of boilers that ends up in the ash silo is fed to the wet ash removal station, where it is mixed with water, and the resulting pulp is pumped to the site's ash evaporation basin.

Fuel Feeding

In the Narva CFB boilers fuel is pneumatically fed to the front wall of the furnace through eight dropping chutes. Primary air is used as the conveying air for fuel feeding. The velocity of the fuel-air mixture at the end of each feeding chute is over 20 m/s, guaranteeing that the fuel enters the furnace safely without the risk of backfire. The granular composition of the fuel in the day silo is 0–40 mm, but is reduced to 0–15 mm prior to entering the furnace using secondary crushers located at the end of each pressurized chain conveyor conveying oil shale from the four-day silos to the furnace.

Operational Experience

The early operational experience of firing oil shale in the new CFB boilers has been very positive. All the basic problems encountered with firing the fuel in PF boilers appear to have been solved by introducing CFB combustion. The new boilers have operated reliably, with good efficiency and low gaseous emissions. The combustion process has been stable and easy to operate over a wide load range, and dynamic requirements have been met easily.

It was found at an early stage of boiler commissioning that the particle size of original fuel was too coarse, which caused problems with bed fluidization during low-load operation under conditions of low fluidizing velocity. Coarse particles in bottom ash also disrupted the pneumatic transport of bottom ash by blocking the lines. Secondary crushing of the fuel was added to maintain good availability and low gaseous emissions at low load.

Following the installation of secondary crushing during the summer outage in 2004, the boilers have worked reliably, with low gaseous emissions across the entire load range. It has been determined on the basis of this experience that the ideal maximum particle size for oil shale when fired in a CFB unit is approx. 15 mm. Observing this parameter results in correct fluidization even at lower fluidizing velocities, and keeps the amount of fly ash low, reducing dust levels in the back pass.

The generating efficiency of the repowered blocks has improved, in comparison to the old blocks, from 30 to 36%[*]. There are a number of reasons for higher thermal efficiency of CFB combustion compared to PF firing:

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[*] Efficiency characteristics of boiler and energy unit of PF and CFB processes are difficult to compare, because of different methods used at estimation (Editor's comment).

- A low combustion temperature results in the extent of carbonate decomposition (ECD) of 60–75%, compared to approx. 98% at PF.
- The extent of sulphation in a CFB unit is almost 100%, compared to only approx. 80% in a PF unit.
- Lower ECD and higher sulphation rate result in a significantly lower specific fuel consumption and reduced CO_2 emissions compared to a PF-based system.
- Probably the most serious environmental problem encountered with firing oil shale in PF boilers has been a high level of SO_2 emissions. Despite the extent of sulphation of 80%, emissions have been 1,500–2,000 mg/Nm^3. Due to more favorable conditions for sulphur binding offered by CFB combustion, practically all sulphur is bound by limestone in oil shale ash, resulting in virtually zero SO_2 emissions at all loads.

Combustion temperature of oil shale in new CFB boilers has been lower than estimated initially, which has helped to keep heat surfaces clean without any negative impact on the combustion process. Combustion temperatures have been at the level of 800 °C. Despite this slightly reduced temperature, combustion efficiency of the reactive fuel has remained high at all loads, basing on the low content of unburned carbon of ash samples that have been analyzed.

NO_x content of flue gas has been 130–160 mg/Nm^3 at 6% O_2, dry matter. Lower temperature and more uniform profile of furnace temperature typical of CFB combustion reduce the formation of NO_x from atmospheric nitrogen compared to PF combustion.

Fig. 4. The superheater I tubes in Block No. 8 at the Eesti PP

Poor availability of the old PF units at Narva PP has largely resulted from intensive fouling and corrosion of convective heating surfaces. As practically all SO_2 is bound by the ash in a CFB furnace when firing oil shale, the temperature of convective heating surfaces is low, and the methods of continuous cleaning fitted at Narva work efficiently, there has been no sign of significant fouling or corrosion of convective surfaces in the repowered blocks. The location of the INTREX^{TM} heat exchangers outside the main combustion area has also resulted in no fouling or corrosion being detected in these units either. Inspections of the convective heat exchangers at Narva PP have been carried out regularly, and only easily removable loose deposits have been detected (Fig. 4).

The reliability of the systems of fuel feeding and ash removal is another factor impacting the availability of boilers fired on oil shale. Reliable operation is very important when using a fuel like oil shale with an ash content of up to 50% on as received basis. Experience with the old units has shown that oil shale can be sticky and has a strong tendency to arc in fuel silos. To reduce this problem, the day silos in the repowered units have been lined with a sheet plate of stainless steel. Silo hammers have been installed in every fuel silo at Block No. 8 at the Eesti PP, and air cannons in every silo at Block No. 11 at the Balti PP to reduce arcing. Both methods, hammers and cannons, have proved effective in minimizing the problems with fuel supply, enabling the boilers to be operated continuously without any need to further control.

Because of the combustion temperature lower than the designed one and lower level of carbonate decomposition, together with low initial fluidizing velocity, grindability of oil shale ash proved to be lower than initially estimated, causing problems with transportation of bottom ash during the initial stage of boiler operation. Large ash particles in the bottom ash blocked the pneumatic transporter lines. Following the installation of secondary crushers in each fuel feeding line and the addition of further air nozzles to bottom ash transportation lines, blocking problems were resolved.

High efficiency, good availability, and low emissions: for decades, these features were rarely, if ever, associated with power plants firing oil shale. Now the situation has changed. A new era of oil shale firing has started thanks to the introduction of CFB combustion technology at Narva PP. Block No. 8 at the Eesti PP has been in operation for over a year now, and Foster Wheeler's design has proved very successful, with only minor modifications being needed. Gaseous emissions have fallen dramatically compared to the old PF-based units. SO_2 emissions are practically zero, due to the inherent sulphur capture provided by limestone in fuel.

NO_x emissions have been in the range of 130–160 mg/m^{3}n (as NO_2, dry, 6% O_2). CO_2 emissions have fallen owing to the improved efficiency of the new units and partial decomposition of carbonates during CFB combustion. Dust is captured by efficient electrostatic precipitators. Emissions easily meet the limits set by the latest EU standards. Good availability has been

achieved by using low steam temperatures in the convective superheating stages, preventing fouling and corrosion of the convective heat exchangers. The reliable operation of the new systems of fuel feeding and ash removal has also been a key factor contributing to good availability of the new units.

All in all, many of the traditional problems associated with oil shale combustion have been solved using CFB-based technology.

Results of the first full operation year

2004, the first full operation year of the 8th CFB Power Unit at the Eesti PP was successfully completed, and now is the time to draw conclusions about the environmental effect of the introduced CFB technology basing on the plant's official and provided data of operational tests.
In Fig. 5 the effect of the CFB technology on air emissions during combustion of Estonian oil shale is illustrated on the basis of yearly figures of the Eesti PP.
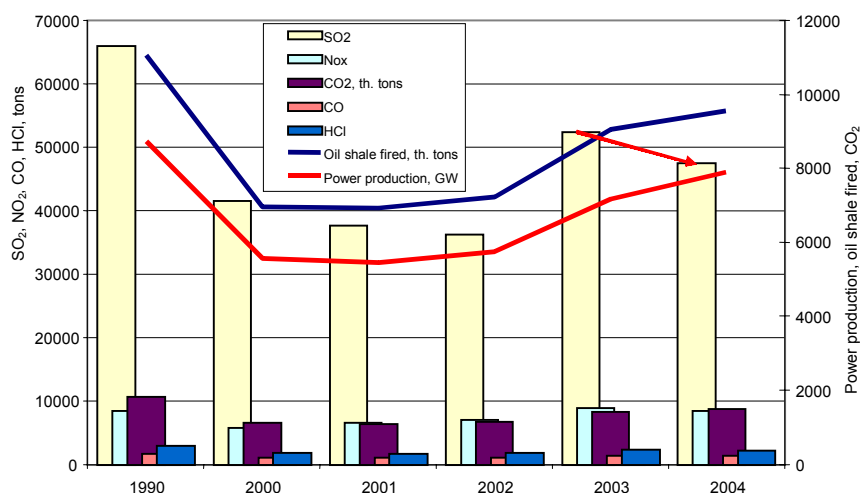

Fig. 5. The Eesti PP – power production, oil shale fired, and emissions

During 2004, the average operating power of the Block No. 8 during 6,333 hours was 187 MW. The corresponding average operating power of the whole plant was 856 MW. In the conditions of power production 10% higher than that of the previous year, the operation of new power unit resulted in the reduction of the total SO_2 emissions of the power plant for about 10% in 2004.

The comparison of emission factors of different components at pulverised firing and circulating fluidised bed firing of Estonian oil shale is given in Fig. 6. Emissions are calculated on the final production unit – kWh released to the grid.
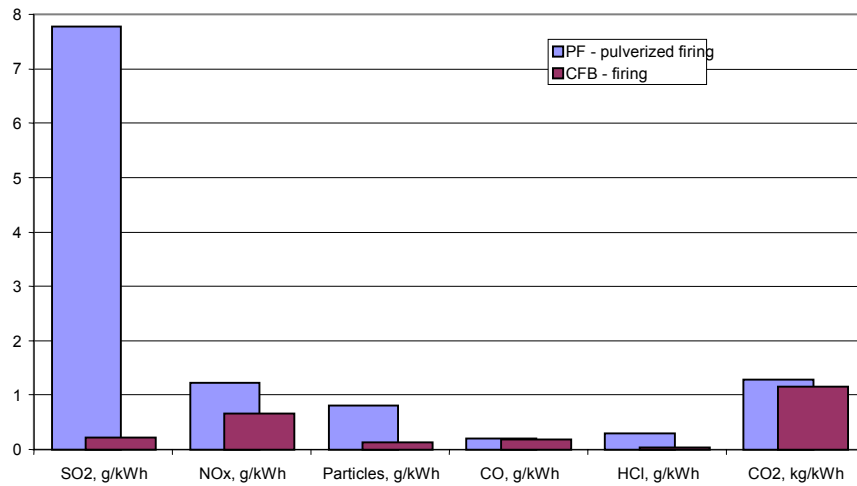
Fig. 6. Emissions at Estonian oil shale combustion

The decrease in the emission factors during CFB firing stemmed from different factors. Firstly, the formation of some flue gas components (NO_x, CO_2) under the CFB conditions was lower. Secondly, the absorption of acidic flue gas components (SO_2, HCl) by alkaline particles of fly ash was much more complete owing to favourable conditions of time and temperature. And lastly, thermal effect of incomplete calcination of carbonates and almost full sulphation of SO_2 reduced the emission of all components. The above-mentioned thermal effect was estimated to be about 0.36 MJ per kg oil shale, and the corresponding reduction factor was about 4%.
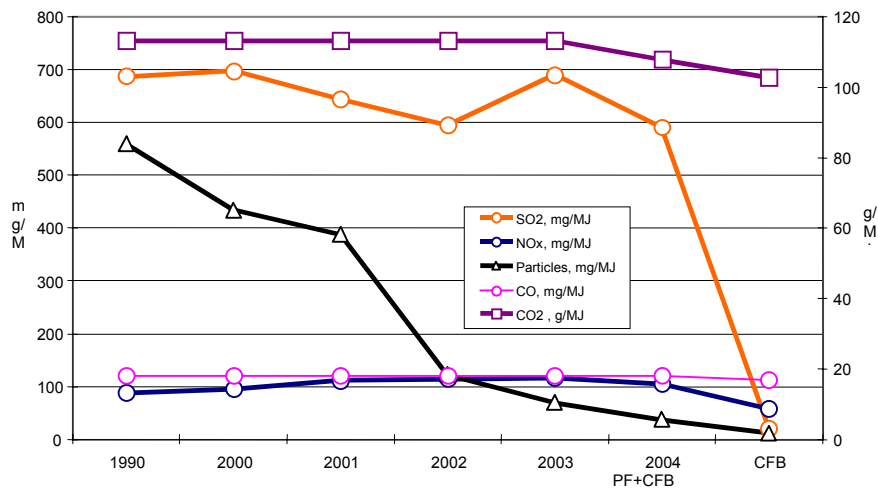

Fig. 7. Emissions from the Eesti PP (1990–2004) and from the new CFB power block

The dynamics of air emission factors of oil shale combustion based on the emission report of the Eesti PP is presented in Fig. 7.

Comparison: PF *versus* CFB

The comparison of PF and CFB boilers clearly shows the winning technology – CFB. This is confirmed by the data on emission amounts, functioning conditions of the heating surfaces and heat rate. The comparative data for PF boilers and the renovated energy Block No. 8 of the Eesti PP are presented in the Table.

Block No. 8 of the Eesti PP and Old PF Blocks[*]

Indices	CFB block	PF block (TP-101)
Operational capacity, MW_{el}	215/187	180
Self-consumption, %	–/9.13	8.93
Net efficiency factor, %	34–36/35	30
Heat rate, kJ/kWh	9230/10256	11737
CO_2 emission, kg/kWh	0.9744	1.2985
SO_2 emission, mg/Nm^3	5–20	*ca* 2000
NO_x emission, mg/Nm^3	90–120/140–160	*ca* 300
Fly ash emission, mg/Nm^3	25–30/20	*ca* 100
Boiler gross efficiency factor, %	93.3–94.9	82.28
Fuel consumption as coal equivalent, g/kWh	350	401

[*] Double data sets (x/y): the first set is the data obtained on the basis of the Elektrowatt-EKONO performance test results, and the second set is the average data for Block No. 8 of the Eesti PP in 2004.

The data in the table are approximate. For instance, heat rate figure for energy blocks with CFB boilers is the average rate measured at testing of Block No. 8 at the Eesti PP at the block's capacity of 216–217 MW_{el}. As for the heat rate figure for energy blocks with PF, it was based on the average consumption of fuel in coal equivalent of energy blocks of the Eesti Power PP equipped with TP-101 boilers in 2002. CO_2 emission figures were calculated on the basis of heat rate. The lowest heating value of the fuel in these calculations is 8.400 MJ/kg, and the extent of carbonate decomposition is 97% for PF boilers but 72.8% for CFB boilers (average data) determined during testing of the boilers of Block No. 8.

As for the efficiency factor of CFB boilers, the data given in the Table is the "apparent" efficiency determined at testing, without considering the fact that the actual heating value of oil shale in CFB boilers is somewhat higher than the lowest heating value established in the calorimetric bomb where the extent of carbonate decomposition is smaller and sulphur binding practically complete. The efficiency of PF boilers as given in the Table is the average efficiency of TP-101 boilers at the Eesti PP in 2002.

The co-workers of the Department of Thermal Engineering at Tallinn University of Technology have analysed ash fractions of CFB boilers. The

results allow pointing out the following differences compared to the PF boilers: the total ash from CFB boilers contains up to 2% coarse (>10 mm) particles (such coarse particles can be found in the bottom ash) while the free lime content is lower than that in PF ash. Free lime content of all ash fractions examined remained below 10% (fluctuating between 5.7–8.4%). Free lime content of different fractions of the ash from PF boilers differs quite considerably; the average range is 10–30%.

Lower free lime content of the ash from CFB boilers is confirmed by the data on the extent of carbonate decomposition calculated basing on ash analyses, that corresponds well with the results of the Elektrowatt-EKONO tests conducted at Block No. 8 of the Eesti PP – according to these, the extent of carbonate decomposition in CFB boilers fluctuates on average at 70–75%.

It should be noted that in coarse fractions of the bottom ash the extent of carbonate decomposition can even be less than 15%. This is caused by relatively large limestone particles in the fuel – due to their substantial density, they quickly subside through the fluidised bed. These particles experience low thermal effect – exposition time is short and their temperature remains low. The sulphur present in fuel is completely bound by ash.

The interesting indicators from the viewpoint of the environmental impact are the content of sulphides and hazardous organic compounds in ash. In the laboratory-tested ash samples from the CFB boilers of the Eesti PP, the content of sulphides fluctuated at 0–0.28%, with smaller figures found in finer ash fractions (0–0.17%). This indicator is the same for ashes from CFB and PF boilers. An analysis on the content and composition of organic compounds in different ash size fractions from CFB boilers was conducted at the Institute of Chemical and Biological Physics. The results showed that the content of hazardous organic compounds, primarily polycyclic aromatic hydrocarbons (PAH), in the CFB boiler ash was even lower than in ash from PF boilers.

The main aspect that determines operating conditions of the boiler is the state of its heat-transfer surfaces. When we compare the operating conditions of CFB and PF boilers, the latter are characterized by intensive fouling of heating surfaces with hard, sulphate-bound fly ash particles, as well as by the high-temperature corrosion due to aggressive components present in ash particles, mainly KCl. The fouling of heating surfaces results in a decrease of heat transfer and in the need for intensive cleaning of heat-transfer surfaces. Corrosive wear caused by such cleaning of heating surfaces forces the operators to reduce the overheated steam temperature from 540 °C, as specified in the design, to 515–520 °C. This temperature lowers the operational availability of the energy blocks from 200 MW_{el}, as specified in the design (boilers TP-67 and TP-101), to only 180 MW_{el}. Despite of high-alloy steels used in high-temperature heating surfaces, the volumes of boiler repair are considerable (during each general maintenance thousands of worn-

out parts of tubes must be replaced). As a result of the problems described above, operational and repair expenses are huge. Due to intensive fouling and corrosion of boiler heating surfaces, oil shale power plants have never reached the designed capacity and their efficiency factor has remained at 28–30%.

The initial operation experience of the renovated energy blocks indicates that operational conditions of heating surfaces of the CFB boilers are much better than those of the old units. Because SO_2 is bound by ash predominantly already in the furnace and the separators after the furnace remove coarser fractions from ash, only deposits of fine ash particles on heating surfaces of the convective gas pass are detected, the cleaning devices installed to the boiler can easily manage with them. This is proved by the research data: gas temperatures on the convective heating surfaces have remained constant (see Fig. 8).
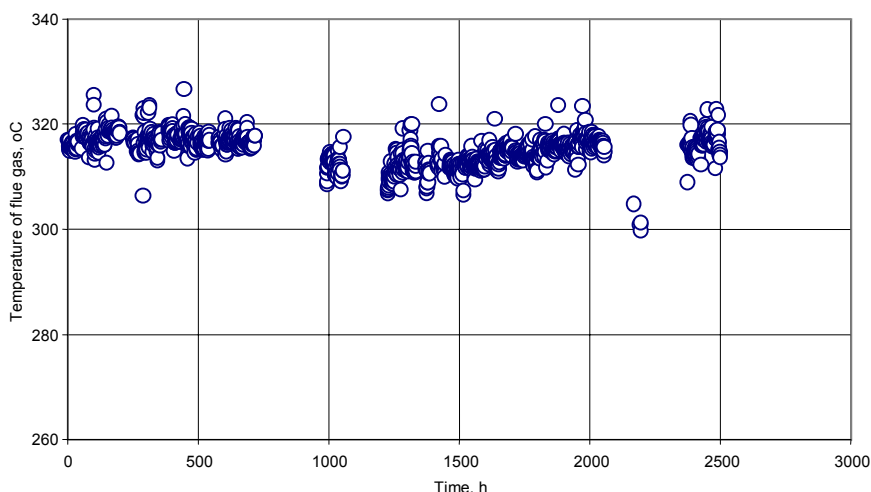

Fig. 8. The Eesti PP, boiler 8-1. Changes in average temperature of flue gas after economizer during 09.12.2004–23.03.2005 at boiler steam production 85–95 kg/s

Regarding high-temperature corrosion of the heating surfaces – the data obtained so far allow to make the forecast that no serious problems are to be expected in CFB boilers. Although the deposits on convective heating surfaces contain up to 2% chlorine, as shown by analyses, the data obtained in the long-term studies of PF boilers indicate that corrosive influence of chlorine decreases noticeably when the temperature of the heating surface metal is below 450 °C. In the CFB boilers the last stages of high temperature of the steam superheaters are in the INTREX. Owing to the air environment and low chlorine content (<0.17%) of INTREX ash, the corrosion risk is low.

Problems Related to Ash Handling and Landfilling

When speaking of the environmental hazard of oil shale power plants, one main question that arises is the problem of ash field water. At the moment, a hydraulic ash removal system is used, and the basic environmental problem is possible release of that water into the environment. In the case of the hydraulic ash-removal system, the amount of water is 10–20 cubic metres per 1 tonne ash. The water amounts in the ash-removal system (together with the sediment ponds) are huge, reaching at the Balti and Eesti power plants about 8–9 millions of cubic metres yearly. More than 11 millions of cubic metres of rainwater fall onto the ash fields every year. A part of that evaporates; another part is bound with the land-filled ash.

Despite the fact that the ash when stored binds water (~0.6–0.7 cubic metres per ton of ash) and at the same time evaporation takes place, there might be cases when the amount of water in sediment ponds can increase to the extent that it would be necessary to let the excessive water to flow into the Narva River, which always means getting a special permission and a big pollution tax. In different years the Balti PP let about 0–2 million cubic meters of water from its sediment ponds to the Narva River.

The main environmental hazard caused by ash fields is the high-alkali (pH = 12–13) water circulating in the ash removal system. High alkalinity of the water is caused by the contact between water and oil shale ash containing free lime. Formed at such contact $Ca(OH)_2$ is able, as shown in calculations, to contaminate huge amounts of water – some hundred tons of ash may theoretically contaminate all rainwater falling onto the ash fields during the year.

In accordance with the EU directives and the decree of the Estonian Ministry of the Environment, the transition to a dry or semi-dry ash removal should be completed not later than by the summer of 2009. The investigation to obtain a new ash-removal technology was started at oil shale power plants several years ago.

Because of the lack of a new technology today, also dry ash from the new CFB boilers is transported to the ash fields *via* the existing hydraulic ash removal system. A new problem has arisen due to the presence of coarse-grained (>10 mm) particles in the bottom ash of the CFB boilers. Despite a small amount of such particles in the total ash, they can clog the pulp tubing and stop the ash removal from the boiler completely due to a low velocity of the pulp, especially in places where the pulp tube turns up to the landfill. Also, reducing granular composition of oil shale to 0–15 mm by using secondary crushers has not solved the problem.

In addition to clogging of tubes by coarse-grained pulp, the dispersal of ash at the landfill has worsened. Coarse ash particles are not carried on with the pulp along the ash field as it takes place with the fine-grained ash from PF boilers at the ash field slope of 0.005–0.008. Stacks of coarse ash particles are formed at pulp outflows, and bulldozers are needed to handle

them. Because of that, an intensive search for ways to solve the problem has been started. Two ways forward have been proposed – 1) increasing of pulp velocity in the tube line to avoid falling out of coarse ash particles and 2) additional crushing of bottom ash before feeding it into the hydraulic ash removal system.

The first way has been used at the Eesti PP, where the diameter of the 15th tube line has been decreased from 630 to 500 mm and a bypass-tube with a slide-valve has been added. It enables high-speed blowing of the tube line in case of its clogging. At the Balti PP, the blowing of compressed air into the tube line to increase pulp velocity was used. By using these measures, clogging of tube lines was avoided, but the formation of ash cones at ash fields has continued. The second way has not been implemented yet. The used measures are only temporary solutions, but the main attention in the near future should be paid on finding a new dry or semi-dry ash-removal system with small content of water.
Today's attempts of oil shale power plants to find a new technology of ash removal are oriented towards technologies that use small amounts of water, e.g. "dense pulp" technology. The processes of designing, building and testing of a utility to obtain "dense pulp" and working out a new ash removal technology are going on at the Balti PP.

Here we should note that the transition to a dry or semi-dry ash removal is not enough to raise the safety of the environment due to the pollution of millions of cubic metres of rainwater at the ash fields. Though the ash from the CFB boilers contains less free lime than PF ash, its polluting effect remains. The process of dry ash removal does not solve the question. As shown by laboratory studies, even the formation of the so-called "ash-rock" at the ash field does not solve the problem because $Ca(OH)_2$ formed on the basis of CaO will remain there to a large extent. The best solution will be the conversion of $Ca(OH)_2$ to neutral $CaCO_3$. Unfortunately, the technology to carbonise such huge amounts of ash that we have at oil shale power plants has not been developed yet.

To get even a least satisfactory result, we have to solve many fairly complicated problems. In addition to these problems that are strictly related to the ash removal (transportation, spreading of the ash and binding it into a monolithic mass) we have to find a solution to the question how to neutralise free lime in oil shale ash as one of its most hazardous components. The amount of water needed for ash removal does not play any important role here. Whatever technology we use for ash removal, ash fields come into contact with millions of cubic meters of rainwater a year, and rainwater becomes polluted with soluble components of the ash field material to such an extent that, according to the environmental requirements, it is unacceptable to be released into the nature.

Conclusions

- The first operational experience of firing oil shale in the new CFB units is very promising. The basic problems of oil shale pulverized firing like high air emissions, fouling and corrosion of heating surfaces, low efficiency and low operational reliability seem to be solved. The new boilers have operated reliably, with good efficiency and low gaseous emissions. The combustion process has been stable and easy to operate over a wide load range, and dynamic requirements have been met easily.

- The basic environmental problem at the moment is hydraulic ash removal system in use, due to which ash field water is highly alkaline. Possible solutions include neutralization of water and renovation of the whole ash removal system, both being at the research stage at the moment.

- The very first analyses of new boilers are presented in [1–3].

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