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FIRING ESTONIAN OIL SHALE OF HIGHER QUALITY IN CFB BOILERS – ENVIRONMENTAL AND ECONOMIC IMPACT

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In this article environmental and economic impact of firing oil shale of higher quality is analyzed.

Fuel consumption, emission indicators (CO_2, SO_2, CO, NO_x, N_2O, particulates) and ash mass flow of a circulating fluidized bed (CFB) boiler firing oil shale of lower heating value (LHV) of 8.2–11.5 MJ/kg are presented. The investigation is based on full-scale firing tests.

Based on test results the impact of transportation and operational costs of oil shale and ash handling on electricity price is analyzed. The pollution charges and CO_2 emission allowances are considered when analyzing the environmental impact on costs.

Firing upgraded oil shale (10.5 MJ/kg) leads to substantial reduction of environmental impact and enables to save costs of electricity production. Reduction of CO_2 emission by 7%, ash mass flow by 25% and fuel consumption by 22% when firing upgraded oil shale instead of conventional one (8.4 MJ/kg) enables to save up to 3 EUR/MWh$_e$, achieving the major savings from environmental costs, especially from reduced need for purchasing CO_2 emission allowances.

Introduction

The European Union (EU) is working actively for a global agreement to control climate change, and since the early 1990s several steps have been taken to limit greenhouse gas emissions. In 2007 the EU started an integrated approach to climate and energy policy and committed to transforming Europe into a highly energy-efficient and low carbon economy. The commitment that Europe would cut its emissions by at least 20% of 1990 levels by 2020 was made. This commitment has a great impact on Estonia's electricity sector as up to 90% of electricity is produced in oil shale firing power plants.

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Narva power plants (AS Narva Elektrijaamad) with total capacity of 2380 MW_e consist of two oil shale firing plants – Baltic (Balti) and Estonian (Eesti), including 430 MW_e of CFB combustion technology based power units. Nevertheless, it is planned to introduce up to two new CFB units (2×300 MW_e). Thus, reduction in the CO_2 emission is a great challenge for the energy sector in Estonia.

At present, the LHV of oil shale fired at Narva power plants is approximately 8.3-8.4 MJ/kg (conventional oil shale). That fuel contains carbonate minerals (mineral CO_2 content up to 20%) resulting in high specific emission of CO_2 (in a range of 0.95–1.12 t/MWh_e depending on combustion technology) due to dissociation of carbonate minerals.

For minimizing CO_2 emission, oil shale of higher quality should be used. Enrichment reduces the content of carbonate minerals resulting in increased heating value and improved quality of oil shale.

Applying CFB combustion technology gives some advantages in utilization of oil shale of a higher quality. Because of lower combustion temperature and a large amount of circulating ash in the CFB boiler furnace it is possible to burn oil shale of higher quality more efficiently than in pulverized firing boilers.

Using the oil shale of higher quality adds some additional positive aspects to reduction of CO_2 emission enabling to reduce:

- fuel consumption per produced kWh of power;
- load of the fuel transportation and preparation system;
- expenses for ash handling and deposition.

Content of ash, mineral CO_2 and moisture are in a strong correlation with oil shale LHV [1, 2]. These fuel characteristics influence boiler emissions and economic indicators of the power plant.

To study the influence of oil shale quality on thermal efficiency and on environmental indicators of the CFB boiler the firing tests were carried out.

Experimental setup

The oil shale firing tests were carried out on the CFB boiler of the double power unit (215 MW_e) of the Balti Power Plant. The main steam parameters of the boiler (Fig. 1) were as follows: capacity (primary/secondary) – 95/76 kg/s, pressure – 12.7/2.4 MPa and temperature – 535/535 °C. Detailed description of the structure and the concept of boiler are given in [3].

To compare the boiler performance, oil shale (LHV 8.2–11.5 MJ/kg) of various composition was used. In total 17 firing tests in two series were carried out according to EVS-EN 12952 – 15:2003 [4]. The same standard was applied for estimating the boiler efficiency and compiling boiler heat balance taking into account the peculiarity of the oil shale. The number of tests enables to analyze the impact of oil shale LHV in a large range on

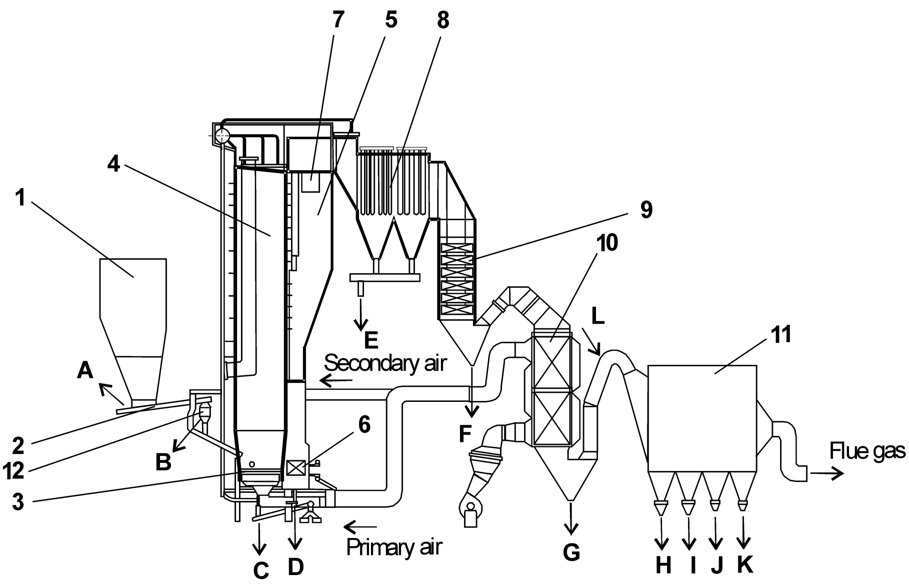

Fig. 1. Oil shale fired CFB boiler.

1 – raw fuel silo, **2** – fuel feeder, **3** – grate, **4** – furnace chamber, **5** – separating chamber, **6** – fluidized bed internal heat exchanger (INTREX), **7** – separator of solids, **8** – convective superheater and reheater, **9** – economizer, **10** – air preheater, **11** – electrostatic precipitator, **12** – secondary fuel crusher, **A – L** – sampling ports

the CFB boiler performance. The tests were run at boiler load of 85 kg/s of primary steam.

During the tests the following process data were collected. The location of ports for collecting solid samples is shown in Fig. 1. To determine the granular composition of the fuel, the samples were taken before (A) and after (B) the secondary fuel crusher. The fuel samples for ultimate and proximate analysis were taken from the main fuel conveyor (not shown in Fig. 1). The characterization of oil shale used is provided in Table 1.

For determining the chemical composition of ash the samples were taken from the following collection ports (Fig. 1): C – bottom ash, D – INTREX, E – convective superheater and reheater, F – economizer, G - air preheater and from four fields in electrostatic precipitator (ESP: H, I, J, K). Also, the ash mass flow rates from ash separation ports (C to K) were measured.

The main flue gas composition (O_2, CO_2, CO, NO_x, N_2O, SO_2, moisture) and temperature were measured in order to estimate the boiler combustion efficiency. Position L in Fig. 1 indicates the location in a boiler gas pass where the flue gas samples were taken for analysis.

In addition, the plant's own data logging system was used to register several boiler operation parameters.

Table 1. **Composition of oil shale as received, mass %**

Symbol	Parameter	Series 1	Series 2
Q_i	Lower heating value, MJ/kg	8.2–8.8	9.3–11.5
C	Carbon	20.06–21.94	22.64–27.40
H	Hydrogen	2.30–2.69	2.51–3.33
O	Oxygen	2.76–4.67	3.36–4.56
N	Nitrogen	0.04–0.06	0.04–0.07
S_o	Organic sulfur	0.39–0.54	0.41–0.60
S_p	Pyritic (marcasite) sulfur	0.76–1.07	0.89–1.16
S_s	Sulfate sulfur	0.06–0.09	0.04–0.12
Cl	Chlorine*	0.19–0.21	0.22–0.27
$(CO_2)_c$	Mineral CO_2	19.46–17.10	16.88–13.37
A_{co}	Ash content (corrected)**	41.83–39.54	41.19–37.89
W_{cr}	Crystal water	0.50–0.54	0.56–0.62
W	Moisture	10.40–12.75	9.30–11.95

* – chlorine is calculated on the basis of its average content (0.75% [1]) in organic matter of oil shale;

** – is calculated as $A_{co}=A_{lab} - \Delta A_{lab}$, where A_{lab} – content of laboratory ash; ΔA_{lab} – ash mass increase due to reactions (oxidation of marcasite FeS_2, formation of calcium sulfate $CaSO_4$ and incomplete decomposition of carbonate minerals) occurring during laboratory ashing of oil shale sample.

Test results and discussion

Based on the collected process data several CFB boiler parameters are analyzed. Concerning environmental indicators the fuel consumption and ash mass flow rates as well as emissions of the boiler are presented. In the current study the results of tests with conventional oil shale (8.4 MJ/kg) are compared with the results for the oil shale with LHV 10.5 MJ/kg, conditionally termed – upgraded oil shale.

In Balti Power Plant the produced heat is used for electricity generation and for district heating. In this article tests results for useful heat (MWh_{th}) are recalculated per electric energy (MWh_e) assuming that electricity is produced in condensing mode only. For that purpose the ratio 0.35/0.90 = 0.389 was used, where 0.35 is the average electricity production efficiency of the power unit working in condensing mode, and 0.90 is the boiler average thermal efficiency observed in tests. That ratio reflects the efficiency of energy conversion from the boiler thermal output to electric energy.

CO_2 emission from a CFB boiler

It is well known that total CO_2 emission (per one kg of fuel as received) when firing oil shale depends on two factors: burning of carbon and decomposition of carbonates:

$$V_{CO2} = V_{CO2\ carbon} + V_{CO2\ carb},\ nm^3/kg. \qquad (1)$$

The amount of CO_2 arising from burning of carbon in nm^3/kg is presented as $V_{CO2\,carbon} = 0.01853\,C$, where C – carbon content in oil shale in %. The amount of CO_2 arising from decomposition of carbonates in nm^3/kg is calculated as follows: $V_{CO2\,carb} = 0.00509\,k_{CO2}\,(CO_2)_c$, where k_{CO2} – extent of carbonate minerals decomposition (ECD) and $(CO_2)_c$ – content of mineral CO_2 in oil shale in % [1, 2].

The amount of CO_2 formed from burning of organic carbon per one kg of fuel depends on the carbon content of the fuel and also upon the completeness of combustion. When firing oil shale of higher LHV the emission of CO_2 formed from organic carbon increases due to higher organic carbon content in fuel. But when the fuel consumption rate decreases due to higher LHV, the amount of CO_2 from burning of carbon per produced heat (MWh_{th}) does not depend on LHV but only on the combustion efficiency.

The amount of CO_2 released from carbonate minerals depends on their total content $(CO_2)_c$ in fuel and their ECD during combustion which is influenced by the fuel combustion technology used. The ECD depends on the furnace temperature, fuel particle size and partial pressure of CO_2 in the surrounding medium [1] as well as upon operation load of boiler [5]. During oil shale combustion in industrial pulverized firing boilers, where combustion temperature is high (1400 °C and even higher) and fuel particles are extremely fine (median size of fuel, by mass R[0.5] = 35–60 μm), carbonate minerals decompose to a large extent, $k_{CO2} = 0.96–0.98$ [1]. In this case CO_2 from decomposition of carbonates is up to 18–22% from the total CO_2 emission. During oil shale firing in a CFB furnace at atmospheric pressure, carbonate minerals decompose to a smaller extent because of the lower combustion temperature (800–820 °C) and coarser particles. The extent of decomposition of carbonates k_{CO2} usually remains between 0.7–0.8 [1].

The test results for specific CO_2 emissions from the CFB boiler calculated per electric power are presented in Fig. 2. According to the results, total CO_2 emission was 1.01 t/MWh_e when firing conventional oil shale and 0.94 t/MWh_e in the case of upgraded oil shale, meaning reduction of CO_2 emission by 7%. The decrease in CO_2 emission was mainly achieved due to the reduction of CO_2 emission from decomposition of carbonates as oil shale with higher quality contains less carbonates.

As it can be seen in Fig. 2 CO_2 emission from decomposition of carbonates has strong dependence on oil shale LHV and, as it was described above, it depends on mineral CO_2 content in oil shale and on the extent of carbonate decomposition – k_{CO2}. The k_{CO2} for the CFB boiler was calculated on the basis of ash composition as described in [6]. It was calculated as weighted average taking into account the ash mass flow rates (kg/s) from separation ports. As regards the calculation, the k_{CO2} value for CFB boiler in firing tests remained between 0.58–0.82. Herewith, k_{CO2} values were higher (0.75–0.82) when oil shale of higher LHV was fired. As boiler operated during the tests at the same heat load and furnace temperatures, the reason for higher k_{CO2} value when firing oil shale of higher quality can be found in

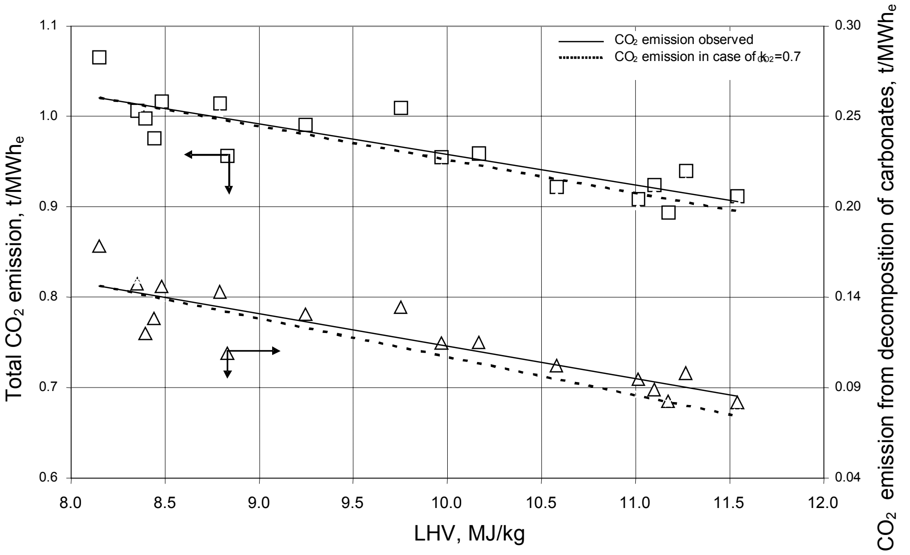

Fig. 2. Specific CO_2 emissions depending on oil shale LHV.

granular composition of fuel. Oil shale of higher quality (Series 2) was finer than oil shale used in test Series 1. Median size of fuel R[0.5] was 0.39–0.6 mm and 0.48–0.65 mm, respectively.

For estimating CO_2 emission from CFB boiler assuming the similar granular composition of oil shale for all tests, calculations were made taking $k_{CO2} = 0.7$ (the average value for tests when firing conventional oil shale) for all tests. The dashed line in Fig. 2 presents the results of that calculation. As it can be seen, additional reduction of CO_2 emission from decomposition of carbonates can be achieved resulting in total CO_2 emission reduction by 7.8% instead of 7.0%.

As regards CO_2 emission from burning of carbon, the firing tests indicated a weak dependence on oil shale LHV. Still, small reduction of CO_2 emission from burning of carbon was achieved as boiler efficiency increased by up to 1% when firing oil shale with higher quality (8.4 → 10.5 MJ/kg).

The ratio of carbonate CO_2 to total CO_2 emission depending on oil shale LHV is presented in Fig. 3. It can be seen that CO_2 emission from decomposition of carbonate minerals formed 14.4% (conventional fuel) and 11.2% (upgraded fuel) from the total CO_2 emission.

Estonian oil shale can be utilized more efficiently increasing electricity production efficiency of power unit applying higher steam parameters. For predicting total CO_2 emission (per MWh$_e$) for CFB combustion based power units with electricity production efficiencies of 0.38 and 0.41 additional calculations were made. The calculations are based on the test data (CO_2 emission from CFB boiler per MWh$_{th}$) using the recalculation ratios 0.38/0.90 = 0.422 and 0.41/0.90 = 0.456, accordingly. The results of calculations for upgraded and conventional oil shale are presented in Table 2. There

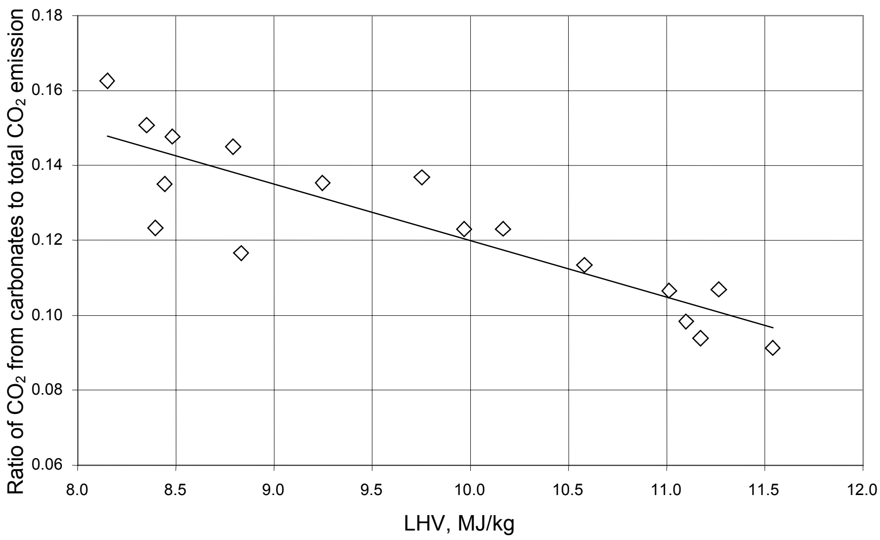

Fig. 3. The ratio of carbonate CO_2 to total CO_2 emission depending on oil shale LHV.

can be seen that if firing conventional oil shale in power units with efficiencies of 0.38 and 0.41, the total CO_2 emission would be 0.93 t/MWh$_e$ and 0.87 t/MWh$_e$, respectively instead of 1.01 t/MWh$_e$ observed in the tests for current power units with efficiency of 0.35.

Other emissions

The results for flue gas components (SO_2, CO, NO_x, N_2O*)* are presented for dry flue gas and $O_2 = 6\%$. As the gas analysis showed, carbon monoxide emission varied during the tests in the range of 20–45 mg/nm^3 and had no significant correlation with fuel quality. The CO emission depended rather on combustion efficiency than on fuel LHV.

Concentration of nitrogen oxides in flue gas had a slight tendency to increase with higher oil shale LHV. The concentration of NO_x in flue gas is proportional to the nitrogen content of the fuel [1]. Still, the NO_x emission for upgraded oil shale stayed below the level of 200 mg/nm^3.

SO_2 and N_2O concentration in flue gas during all the tests stayed below 15 mg/nm^3. That is below measurement level of the gas analyzer. Due to large amount of free lime available in oil shale (usually molar ratio of Ca/S = 8–10 [1]) and low combustion temperature, the SO_2 formed during combustion is bound totally into ash and therefore practically no SO_2 is emitted.

Concentration of particulates in flue gas after ESP was not measured during the tests. For economic calculations it was assumed that the concentration stayed below 30 mg/nm^3.

Fuel consumption and ash mass flow rates

As it was expected, firing oil shale with higher quality resulted in reduction of fuel consumption rate. Due to higher LHV the fuel consumption decreased by 22% when firing upgraded oil shale instead of conventional one. Even greater reduction of ash mass flow was achieved – up to 25% due to reduced fuel consumption rate and lower ash content of upgraded oil shale. The results for fuel consumption and ash mass flow rates per electric power are presented in Fig. 4. Herewith, the fuel consumption rate is calculated via boiler indirect heat balance. The ash mass flow rate is calculated based on fuel consumption rate and real ash content of fuel (kg/kg). Real ash content takes into account ash mass increase due to reactions occurring in the furnace during combustion process – marcasite (FeS_2) oxidation, calcium sulfate ($CaSO_4$) formation and incomplete decomposition of carbonate minerals.

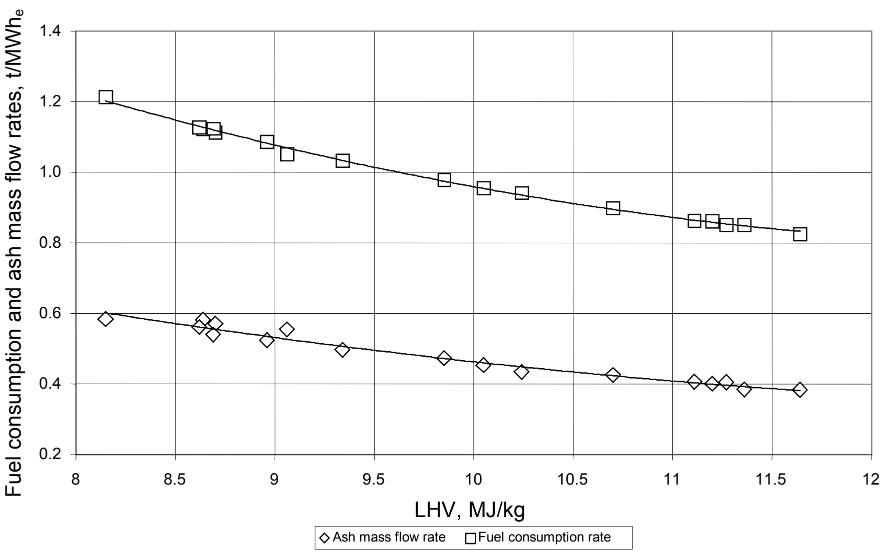

Fig. 4. Specific ash mass flow and fuel consumption rate depending on oil shale LHV.

As there is a strong correlation between oil shale characteristic composition and LHV, it is possible to present the test results for CO_2 emission and for ash mass flow (in Fig. 2 and Fig. 4) depending on oil shale LHV.

Major test results for the CFB boiler are presented in Table 2.

Table 2. **Test results for CFB boiler**

Parameter	LHV, MJ/kg	
	8.4	10.5
Fuel consumption rate, t/MWh_e	1.16	0.91
Ash mass flow rate, t/MWh_e	0.57	0.43
CO_2,, t/MWh_e	1.01	0.94
CO_2, t/MWh_e (calculated for 0.38*)	0.93	0.87
CO_2, t/MWh_e (calculated for 0.41*)	0.87	0.80

* power unit efficiency

Economic aspects

The firing tests with upgraded oil shale indicated significant reduction of fuel consumption and ash mass flow rates as well as air emissions from the CFB boiler. The results of tests described above were used for analyzing the potential extent of cost reduction in Narva power plants. The economic analysis was made for the case of replacing oil shale of 8.4 MJ/kg (LHV) with the one of 10.5 MJ/kg heating value. Cost calculations were made for the CFB units installed in Eesti and Balti power plants for the current capacity: 215 MW_e CFB units are operated in both power plants. Also, the calculations of potential savings were made for the year 2015, assuming that two units of 215 MW_e are operating and a new CFB-based capacity of 300 MW_e, or 600 MW_e will be commissioned resulting in total capacity of 730 MW_e, or 1030 MW_e as an option. The following annual electricity production was assumed: 2.92 TWh_e in 2010 and 4.96 TWh_e or 7.00 TWhe in 2015. In economic calculations for the new power units the production costs were taken similar to these of Eesti Power Plant.

The costs analyzed in regard to impact of introducing upgraded oil shale were: fuel costs, transport costs, operational costs and costs related to the environmental impact.

Fuel costs

The fuel cost is an important component of electricity production expenditures. In Estonia, according to the *Electricity Market Act* the price of the oil shale sold to large (with capacity of at least 500 MW_e) power plants must be regulated. At present, the Competition Authority has set a price cap of 1.26 EUR/MJ for oil shale (8.4 MJ/kg) supplied to Narva power plants. In the current analysis it is assumed that the price of oil shale is proportional to the heating value. Therefore, as the price of energy in fuel (EUR/MJ) is assumed to be the same for conventional and upgraded oil shale, the prices of fuel are 10.55 EUR/t and 13.24 EUR/t, respectively. Nevertheless, due to the higher combustion efficiency 0.21 EUR per every MWh_e of produced electricity can be saved.

Transport costs

The use of upgraded fuel enables to reduce oil shale transport costs from mines to power plants. Assuming the current level (2010) of railway tariffs and installed generation capacity of 430 MW_e the cost paid for transportation of oil shale to Balti Power Plant and to Eesti Power Plant can be reduced by EUR 0.56 and by EUR 0.26 million a year, respectively. As the result, the total reduction of transportation costs is approximately EUR 0.82 million. By 2015, in the case of total installed capacity of 1030 MW_e the annual savings can reach EUR 1.89 million, assuming 5% annual increase of transport costs since 2010.

Operational costs in power plants

In power plants the use of upgraded oil shale enables to reduce the operating costs for oil shale as well as for ash. The consumption of oil shale and the ash flow rates depending on LHV is presented in Fig. 4.

As the introduction of upgraded oil shale results in smaller volumes of fuel, it enables to reduce 22% of the variable part of the fuel and 25% of the ash operational costs. Nevertheless, in Narva power plants the value of savings in absolute terms is rather modest – at the current level (2010) the annual savings can be EUR 0.28 million. In projections of operational costs of handling oil shale and ash for 2015 the annual increase of 6% was assumed. So, in 2015 approximately EUR 0.77 million can be saved annually in the case of installed capacity of 1030 MW_e.

Environmental impact costs

An impact greater than direct cutting of operational costs is achieved due to substantial reduction of environment costs. According to Estonian legislation the harmful impact on environment has to be compensated following the 'polluter pays' principle. Since 1991 the environmental charges have been in use to compensate the use of natural resources and release of waste or pollutants into soil, water or ambient air. The charges together with the relevant rates are stipulated by the *Environmental Charges Act*. The air pollution charge on the release into ambient air from a stationary source of pollution is applied for emission of:

- sulfur dioxide (SO_2) or other inorganic sulfur compounds;
- carbon monoxide (CO);
- carbon dioxide (CO_2);
- particulates;
- nitrogen oxides or other inorganic nitrogen compounds;
- volatile organic compounds (except methane)*;
- mercaptans*;
- heavy metals or compounds of heavy metals*.

* were not considered in this article

Also, the pollution charge is applied for waste disposal, including oil shale fly and bottom ash landfilled at the ash fields.

In the present study the reduction in emission of carbon dioxide and particulates as well as ash disposal was analyzed and economic effect of these reductions assessed.

In Estonia, the pollution charge for release of carbon dioxide into ambient air was introduced in 2000. As since 1 January 2008 Estonia has introduced excise duty on electricity, from the same date the electricity producers do not have to pay the pollution charge on CO_2 emission. As a result, at present, the CO_2 charge has to be paid by all enterprises producing heat, excluding the ones firing biomass, peat or waste.

According to the *Environmental Charges Act*, the rates of pollution charges will be increased gradually in the following years up to the 2015. The rates relevant to the present study are presented in Table 3.

The calculations indicated that at the level of CFB-based capacities installed in 2010, the replacing of conventional oil shale (8.4 MJ/kg) with the upgraded one (10.5 MJ/kg) would reduce the pollution charges (for emission of particulates and for ash landfilling) paid by Narva power plants by EUR 0.52 million. In 2015, assuming installed capacity of 1030 MW_e, the annual savings of pollution charges would be EUR 2.98 million.

As described above, in Estonia the utilities producing electricity are not obliged to pay pollution charge for emitting CO_2 into ambient air. Still, the emission of CO_2 has an increasing impact on the environmental performance as well as on economic results of power plants. Estonia has no problems of meeting targets set by Kyoto Protocol. Nevertheless, the EU has set several challenging climate and energy targets to be met by 2020, among these there is a goal to reduce greenhouse gas (GHG) emissions in the EU member states by at least 20% below 1990 levels. To promote reaching this target in a cost-effective and economically efficient manner the European Parliament and the Council established in 2003 a scheme for greenhouse gas emission allowance trading (EU ETS) within the Community [7].

Estonian enterprises, including Narva power plants, had no problems with meeting GHG emission reduction targets set for the first period (2005–2007) of the EU ETS. The situation during the second period (2008–2012) will be more difficult as the allocated amount of CO_2 allowances is by 47.8% smaller than Estonia had applied for. Data on Narva power plants for the first two periods of EU ETS are presented in Table 4.

As there is a great difference between applied and allocated quantities of emission allowances the lacking allowances must be purchased paying the

Table 3. **Rates of pollution charges (EUR/t)**

Pollutant	2010	2015
Particulates (air emission)	39.37	146.17
Oil shale ash (landfilling)	1.20	2.98

Table 4. **CO_2 emission allowances for Narva power plants (2008–2012), 10^3 t**

Power plant	Applied	Allocated
Balti	2 974.8	1 454.3
Eesti	11 679.2	7 214.5

market price. In the EU it has been decided that full auctioning of allowances shall be the rule for the power sector since 2013, as well no free allocation shall be made in respect of any electricity production by EU ETS new entrants [8]. This means that the CO_2 emission level would be the factor of increasing importance for electricity producers.

In the current analysis the basic cost calculations were made applying the emission allowance price of 15 EUR per ton of CO_2. The use of upgraded oil shale would save EUR 4.2 million (installed capacity of 430 MW_e), EUR 6.92 million (730 MW_e) or EUR 9.63 million (1030 MW_e). Hence, the cost of CO_2 allowance is the main contributor to economic savings in the current analysis. Therefore, the sensitivity analysis was carried out to determine the impact of higher price level of CO_2 emission allowance. The results for 20 EUR/t indicate that the annual savings (in 2015) could reach up to EUR 9.22 million (730 MW_e) or even to EUR 12.84 million in the case of 1030 MW_e installed capacity.

The potential specific savings of production costs in Narva power plants are presented by cost elements in Tables 5 and 6. In these tables the savings are calculated per produced electricity (gross).

Today, in Estonia the rates of environment-related charges are at low level, also there is no need to purchase allowances for CO_2 emission. As the result, the share of environment related potential savings is low: in 2010 0.18 EUR per MWh_e of produced electricity. In Estonia, the gradual increase of pollution charge rates is stipulated in the relevant law. Therefore, in 2015 the level of potential savings is already quite significant.

The major effect of cost reduction can be gained due to smaller emission of CO_2. The sensitivity analysis indicated that raising price on CO_2 emission allowances would increase the relevant specific savings essentially (Table 6).

Table 5. **Specific savings of electricity production costs**

Cost article	EUR/MWh_e	% of the current price*
Fuel	0.21	0.81
Transport	0.27	1.05
Operations	0.10	0.36
Total	0.58	2.22

* – savings are compared with price cap (29.41 EUR/MWh_e) set by the Competition Authority for the electricity supplied from Narva power plants

Table 6. **Specific savings of environment related electricity production costs in 2015**

Cost article	EUR/MWh_e	% of the current price*
Pollution charges	0.43	1.6
CO_2 allowances		
if 10 EUR/t	0.92	3.5
if 15 EUR/t	1.38	5.2
if 20 EUR/t	1.83	6.9
Total	1.35–2.26	5.1–8.5

* – savings are compared with price cap (29.41 EUR/MWh_e) set by the Competition Authority for the electricity supplied from the Narva power plants

During the period of 2010–2015 the use of upgraded oil shale in CFB based power units of Narva power plants would enable to avoid 2.04 million tons CO_2 emission and save from EUR 20 million (10 EUR/t CO_2) to EUR 40 million (20 EUR/t CO_2) of allowance purchases. Additionally, EUR 19.1 million could be saved due to lower operational costs and smaller pollution charges.

Conclusions

Firing upgraded (10.5 MJ/kg) oil shale in the CFB boilers would enable to decrease the environmental impact of power production significantly. The main effect was expressed in reduction of CO_2 emission by 7% compared to conventional (8.4 MJ/kg) oil shale. Also, much lower rates of fuel consumption (~22%) and ash mass flow (~25%) were observed. CO_2 emission from decomposition of carbonate minerals formed 14.4% when firing conventional and 11.2% when firing upgraded oil shale from the total CO_2 emission. Total CO_2 emission was 1.01 t/MWh_e for conventional oil shale and 0.94 t/MWh_e in the case of upgraded oil shale.

The economic calculations indicate clearly that introduction of upgraded oil shale in power plants has positive effect on electricity production costs, especially on environment-related expenditures. Potential specific saving of production costs (fuel, transport and operations) will be 0.58 EUR/MWh_e. The significant environmental benefit – avoided emission of CO_2 – would translate into essential economic effect as well. In 2015, 2.26 EUR/MWh_e of environment related costs can be saved in the case of CO_2 allowance price of 20 EUR/t, the total savings reaching up to 3 EUR/MWh_e. In the latter case the total annual savings (all costs) in CFB based units of Narva power plants could reach EUR 19.5 million.

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