CALCULATION OF COMPOSITION OF ESTONIAN OIL SHALE AND ITS COMBUSTION PRODUCTS ON THE BASIS OF HEATING VALUE

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The method for calculation of composition of Estonian oil shale and its combustion products, as well as product amounts on the basis of lower heating value of the fuel as received is presented. The method is fast and enables an operative estimation of changes in boiler and its elements during burning of oil shale of different heating value. The need for such a model has arisen in connection with the choice of suitable fuel at design of new oil shale boilers.

1. Background

New circulated fluidized bed (CFB) boilers will be taken into use at Estonian oil shale power plants in the nearest years. Economical considerations focus the attention in the future use of oil shale of lower heating value in power plants. It is clear that at design of oil shale boilers operating with new technology, it is important to consider correctly the properties of oil shale to be taken into use, because the reliability and economy of boilers greatly depend on fuel properties. Estonian oil shale known as a problematical fuel has caused great troubles in boiler operation. Considering that possible changes of oil shale heating value in the future may also cause some changes in the boiler operation conditions, it is necessary to consider all possible changes beforehand.

So the optimal solutions at design of boilers and their single elements may be found only in case of the possibility to prognosticate the composition and properties of oil shale depending on its heating value. The operative prognostication is very necessary, because experimental researches to estimate the composition and properties of oil shale of different heating value as well as of their combustion products are expensive and time-consuming. Their use in given case at various calculations is practically excluded.

Investigations [1, 2] of Thermal Engineering Department of Tallinn Technical University (TED TTU) have shown the interrelation between oil shale heating value and composition as well as between characteristics estimated by technical analyses

and composition. Basing on these data, determination of the composition of oil shale and its combustion products with sufficient accuracy for boiler calculations is possible knowing only ash (A^d) and carbonate CO_2 (CO^d_M) content of the dry mass. This is due to the circumstance that relationship between three main components (organic, sandy-clay and carbonate) which determine the composition of Estonian oil shale as well as average composition of these components is quite stable [3]. The use of calculation method makes the prognostication considerably easy and handy. Investigations have shown that oil shales with the same heating value may somewhat differ in composition. Therefore, computational prognostication should even be preferred to a single casual prognosis made on the basis of a number of analyzed samples insufficient for authentic statistical calculations.

The results of later analyses of fuels used in power plants showed that the relationships between composition and heating value given in [1, 2]. need some correction. The results of analyses of two main oil shale characteristics (content of ash and carbonate CO_2) obtained at oil shale power plants during 1960-1990 versus heating value are plotted in Figs. 1 and 2 (yearly average data). Besides other factors, also oil shale moisture depends on heating value (Fig. 3).

Considering the facts given above, a more exact method for calculation of composition and amounts of oil shale and its combustion products was worked out in TED TTU. The method was worked out on the basis of relationships given in Figs. 1-3 and data on the composition of the main components of Estonian oil shale (Table 1), according to new results of later investigations. The methodology somewhat differs from that given in [3].

Table 1. **Average Composition of Oil Shale Main Components, %**

Organic part		Sandy-clay part (with crystal water)		Carbonate part	
C	77.45	SiO_2	59.8	CaO	48.1
H	9.70	CaO	0.7	MgO	6.6
S	1.76	Al_2O_3	16.1	FeO	0.2
N	0.33	Fe_2O_3	2.8	CO_2	45.1
O	10.01	TiO_2	0.7		
Cl	0.75	MgO	0.4		
		Na_2O	0.8		
		K_2O	6.3		
		FeS_2	9.3		
		SO_3	0.5		
		H_2O	2.6		
Total:	100.00	Total:	100.0	Total:	100.0

The calculation is made according to the scheme described below (see Calculation Sample in Table 2).
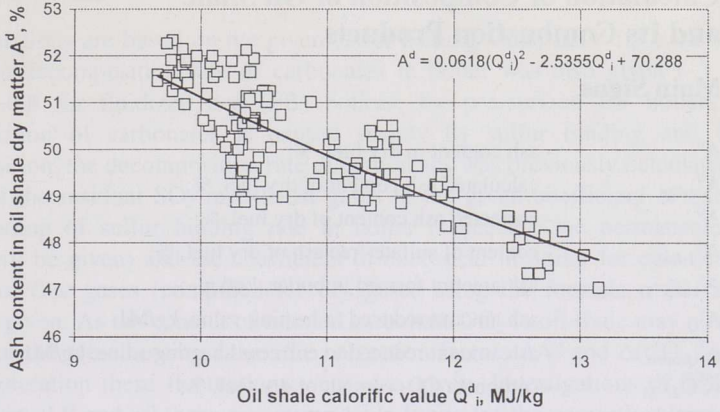
Figure 1. Ash content of dry oil shale versus heating value (for notation see next page)
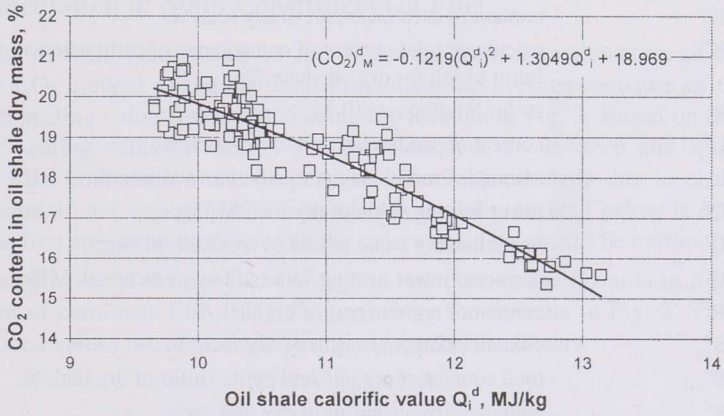
The equation shown in Figure 1: $A^d = 0.0618(Q^d_i)^2 - 2.5355Q^d_i + 70.288$

Figure 2. Carbonate CO_2 content of oil shale dry matter versus heating value

The equation shown in Figure 2: $(CO_2)^d_M = -0.1219(Q^d_i)^2 + 1.3049Q^d_i + 18.969$
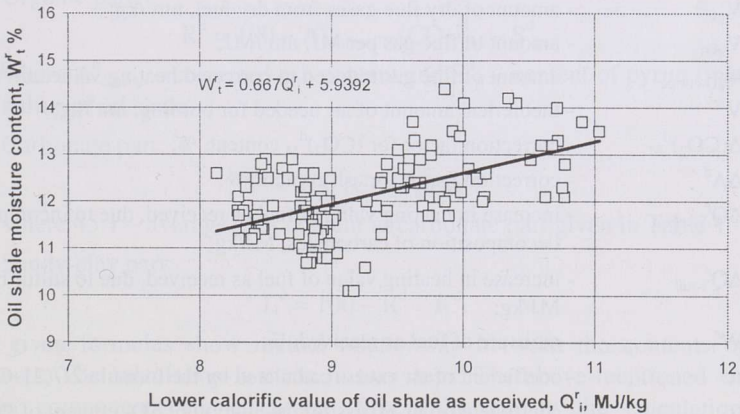
Figure 3. Oil shale moisture content versus heating value

The equation shown in Figure 3: $W^r_t = 0.667Q^r_i + 5.9392$

2.   Calculation of Composition of Oil Shale and Its Combustion Products

2.1.   Main Signs

A^d - ash content in dry fuel, %;

A^d_{calcul} - calculated ash content of dry fuel, %;

A^d_{correc} - corrected ash content of dry fuel, %;

$A^d_{S\text{-}free}$ - content of sulfate-free ash of dry fuel, %;

A^r_{boiler} - ash amount formed in boiler, kg/kg;

A^r_Q - ash amount reduced to heating value, kg/MJ;

$A^r_{Q\text{-}correc}$ - ash amount reduced to corrected heating value, kg/MJ;

$(CO_2)^d_M$ - carbonate CO_2 content of dry fuel, %;

$(CO_2)^d_{M\,calcul}$ - calculated carbonate CO_2 content of dry fuel, %;

$(CO_2)^r_M$ - carbonate CO_2 content of fuel as received, %;

k_{CO2} - carbonates decomposition rate in boiler (0-1);

$k_{CO2\text{-}min}$ - minimal carbonates decomposition rate;

K^d - content of carbonate part of dry fuel, %;

K^d_{ash} - calculated total content of components of carbonate part to be burnt to ash for dry oil shale, %;

k_S - sulfur binding rate (0-1);

L^d - content of sandy-clay part of dry fuel, %;

L_{ash} - amount of sandy-clay part to be burnt to ash, %;

Q^d_i - lower heating value of dry fuel, MJ/kg;

Q^r_i - lower heating value of fuel as received, MJ/kg;

$Q^r_{i\text{-}correc}$ - corrected lower heating value of fuel as received, MJ/kg;

R^d - content of organic part of dry fuel, %;

S^d_o - content of organic sulfur of dry fuel, %;

S^d_{o+p} - total content of organic and pyrite sulfur of dry fuel, %;

S^d_p - content of pyrite sulfur of dry fuel, %;

$SO_{2\text{-}given}$ - given SO_2 content of flue gas, nm^3/MJ;

V_g - total amount of flue gases from fuel as received, nm^3/kg;

V_{gk} - amount of dry flue gases from dry fuel, nm^3/kg;

V_{gQ} - amount of flue gas per MJ, nm^3/MJ;

$V_{gQ\text{-}correc}$ - amount of flue gas reduced to corrected heating value, nm^3/MJ;

V^o - theoretical amount of air needed for burning, nm^3/kg;

$\Delta(CO_2)^d_M$ - correction factor for $(CO_2)^d_M$ content, %;

ΔA^d - correction factor for ash content, %;

$\Delta Q^r_{i\text{-}carbon}$ - increase in heating value of fuel as received, due to incompleate decomposition of carbonates, MJ/kg;

$\Delta Q^r_{i\text{-}sulf}$ - increase in heating value of fuel as received, due to sulfur binding, MJ/kg;

W^r_t - moisture of fuel as received, %;

α - coefficient of air excess calculated by the formula $21/(21\text{-}O_2)$;

α_1 - coefficient of air excess for calculation of SO_2 content of flue gas.

2.2.   Basic Data

The calculations are based on the given lower heating value LHV (Q^r_i). In addition to that the decomposition rate of carbonates in boiler was also given (~1 for PF boilers; ~0.8 for fluidized bed (FB) boilers; for pressurized FB boilers where decomposition of carbonates is caused mainly by sulfur binding and $MgCO_3$ decomposition, the decomposition rate of carbonates was previously calculated). The content of the residual SO_2 in exhaust gases at the given coefficient of excess air (when finding of sulfur binding rate in boiler is needed, the permissible sulfur content will be given) and the coefficient of excess air in boiler for calculation the amounts of flue gases (computed for dry gases using the formula $\alpha=21/(21-O_2)$) were also given. As the content of ash and carbonate CO_2 in oil shale may noticeably fluctuate at the same heating value, the correction factors ΔA^d and $\Delta(CO_2)^d_M$ taking into consideration these fluctuations were also given. Investigations of TED TTU showed that -2.0 and +2.0 are recommendable limits for the correction factors. Use of correction factors is very important at estimating the productivity of ash and gas handling devices.

2.3.   Calculation of Main Constituents of Fuel

Calculation of main constituents of fuel is started from the calculation of ash and carbonate CO_2 content of the dry fuel. Previously the average moisture of the fuel with given heating value is calculated using the formula in Fig. 3. Based on the latter the lower heating value of the dry fuel is calculated. So as steep and spasmodic changes in the composition and properties of Estonian oil shale due to changes in heating value do not occur [1], the computation model presented below is usable, at least in the first approximation, even in the case when data should be extrapolated.

The ash content of the dry fuel (A^d_{calcul}) is found using the formula in Fig. 1 and the content of carbonate CO_2 ($(CO_2)^d_{M\ calcul}$) using the formula in Fig. 2. Thereafter the calculated values are corrected using given correction factors:

$$A^d = A^d_{calcul} + \Delta A^d,$$

$$(CO_2)^d_M = (CO_2)^d_{M\ calcul} + \Delta(CO_2)^d_M.$$

The content of main components of oil shale may be calculated by formulas:

1.   Organic part:

$$R^d = 100 - A^d_{correc} - (CO_2)^d_M - S^d_p,$$

where A^d_{correc} – corrected ash content and S^d_p – content of pyrite (markasite) sulfur of oil shale.

2.   Carbonate part:

$$K^d = 100\ (CO_2)^d_M/45.1,$$

where 45.1 – average CO_2 content in carbonate part given in Table 1.

3.   Sandy-clay part:

$$L^d = 100 - R^d - K^d.$$

The given formulas show mutual relationship between the contents of some components. The calculation is made in two steps. The above-mentioned values of the main components are calculated first, followed by the calculation, after correction of S^d_p value (basing on the content of the sandy-clay part in the fuel and

average FeS_2 content in sandy-clay part), of the corrected values of the mentioned components.

The calculation of oil shale composition is started from finding the organic part content in oil shale. For finding of the corrected ash content A^d_{correc} present in the formula the additional factor should be subtracted from previously found ash content A^d. The additional factor accounts the increase in ash mass during incineration considering the masses of oil shale components to be burnt to ashes. For preliminary calculations for Estonian oil shale, 2 may be recommended for the additional factor value [4]:

$$A^d_{correc} = A^d - 2.$$

The content of pyrite (markasite) sulfur in the oil shale mineral part included in the formula for calculating the content of organic part may be found in the first approximation using the empirical formula:

$$(S^d_p)_{prev\ calcul} = 0.047(A^d - 1.257(CO_2)^d_M).$$

As it was mentioned before, the final calculation is made using the S^d_p value previously found on the basis of the content of sandy-clay part. (FeS_2 content of the sandy-clay part is given in Table 1. Accordingly, $S^d_p = 0.5359\ FeS_2\ L^d/100$. The corrected S^d_p value is sufficiently exact and does not need additional correction.)

2.4   Content of Combustible Components in Dry Fuel

Content of combustible oil shale components needed for finding the composition of flue gases is calculated using the average composition of the organic part given in the oil shale data-table (Table 1) and the content of fuel organic part. From FeS_2 belonging to the combustible matter only sulfur is taken into account. Combustion of iron was not observed because there were no components going over into flue gases. Content of combustible matter is calculated by the formula:

$$G^d_{comb} = G_o \cdot R^d/100,\ \%,$$

where G^d_{comb} – content of the given component of combustible matter in fuel and G_o – content of the given component in organic part given in Table 1. Sulfur content of combustible matter is found as a sum of organic and markasite sulfur.

2.5.   Calculation of Flue Gas Amounts and Needed Sulfur Binding Rate

Calculation of the sulfur-binding rate is made considering the coefficient of excess air given by the corresponding normative for dry gas. Flue gas amount is calculated using the methodology of the normative materials [4]. The requisite minimal sulfur-binding rate (k_S) for achieving given SO_2 content (to meet the acceptable limit) in flue gases is calculated by the formula:

$$k_S = (20\ S^d_{o+p} - SO_{2\ forgiven} \cdot V_{gk}/1000)/(20\ S^d_{o+p}).$$

In FB boilers sulfur-binding rate is usually high, it is recommendable to give ~10 mg/m^3 (3.45 ppm) as the accepted sulfur content for calculating k_S. (In the case of oil shale with a very high Ca/S molar ratio, ≤5 ppm sulfur content in flue gases is probable, as tests showed.)

Calculation of the flue gas amounts for fuel as received is made on the basis of the factor for excess air in the given boiler. Calculation is made according to the methodology [4].

2.6. Calculation of Amounts of Formed Ash and Flue Gases per MJ

Calculation of these characteristics is necessary at the estimation of operation conditions of boiler single elements. In the given case it is suitable to take the LHV value of fuel as received as a basis for calculation. There exist two possibilities. Ash content and flue gas amount may be calculated from either the given heating value (Q^r_i) or the corrected one ($Q^r_{i\text{-correc}}$). The latter takes into account increase in the heating value due both the decomposition heat of carbonates not decomposed and the heat from sulfur binding. The first way is suitable in preliminary calculations for boiler operating at atmospheric pressure when the decomposition rate of carbonates (k_{CO2}) is high. The second way is recommended for more exact calculations and for pressurized FB boiler where k_{CO2} does not exceed 0.3-0.4 and $k_S \approx 1$.

The total ash content in boiler per fuel kg (kg/kg) is calculated by the formula:

$$A^r_{boiler} = (1.2177\,(CO_2)^d_M + 0.938\,L^d + (1 - k_{CO2})\,(CO_2)^d_M + 2.5\,S^d_{o+p}\,k_S + \\ + 0.005\,L^d)\,K_{recalcul}/100,$$

where $K_{recalcul}$ - recalculation coefficient from dry fuel to fuel as received, $(1-k_{CO2})$ $(CO_2)^d_M$ – takes into account the increase in ash amounts due to the decomposition heat of carbonates not decomposed, and $2.5\,S^d_{o+p}\,k_S$ - increase in ash amount due to the heat from sulfur binding.

Using the first calculation way, finding the ash amount (A^r_Q) and flue gas amount (V_{gQ}) per MJ for boilers operating at atmospheric pressure is easy:

$$A^r_Q = A^r_{boiler}/Q^r_i,$$
$$V_{gQ} = V_g/Q^r_i.$$

In the case of the second way some additional calculations should be done, as it was mentioned before. These are:

1. Finding the minimal k_{CO2}. In pressurized boilers CO_2 partial pressure is kept at least equal to the decomposition pressure of carbonates at the given temperature. So the carbonate decomposition rate cannot be taken for zero because, due to the binding of sulfur by ash, part of the carbonate CO_2 is channeled off from ash. In addition, the carbonate part of oil shale contains $MgCO_3$ that in boiler fully decomposes. Investigation of ash obtained from a pressurized test boiler showed that sulfur reacts mainly with calcium carbonate forming $CaSO_4$. MgO formed stays in this case in the ash in its free mode. The minimal decomposition rate of carbonates in the given case is found using the formula:

$$k_{CO2\text{-min}} = 1.375\,S^d_{o+p}\,k_S/(CO_2)^d_M + 0.16.$$

As the decomposition rate of carbonate k_{CO2} should not be less than $k_{CO2\,min}$, the given value of k_{CO2} should be corrected.

2. Increase in the heating value due to carbonates not decomposed may be calculated (considering that $CaCO_3$ is not decomposed):

$$\Delta Q^r_{i\text{-carbon}} = (1-k_{CO2})\,4.1232\,(CO_2)^d_M\,K_{recalcul}/100,\ \text{MJ/kg}.$$

3. Increase in the heating value due to the sulfur binding may be calculated using the formula (accounting the $CaSO_4$ formation heat 15.616 MJ/kg per bound sulfur. The binding factor of sulfur by ash ~0.4 is already accounted in the value of Q^r_i at its estimation in the calorimetric bomb. So only additional binding should be considered here):

$$\Delta Q^r_{i\text{-sulf}} = 15.616\ S^d_{o+p}\ K_{recalcul}\ (k_S - 0.4)/100,\ MJ/kg.$$

Correspondingly, the final corrected heating value can be found by the formula:

$$Q^r_{i\text{-correc}} = Q^r_i + \Delta Q^r_{i\text{-carbon}} + \Delta Q^r_{i\text{-sulf}},\ MJ/kg.$$

Using the corrected heating value, the ash amount converted can be calculated by the formula:

$$A^r_{Q\ correc} = (1.2177\ (CO_2)^d_M + 0.938\ L^d + (1 - k_{CO2})\ (CO_2)^d_M + 2.5\ S^d_{o+p}\ k_S +$$
$$+ 0.005\ L^d)\ K_{recalcul}/(100\ Q^r_{i\text{-correc}}),\ kg/MJ,$$

and flue gas amount by the formula:

$$V_{gQ\text{-correc}} = V_g/Q^r_{i\text{-correc}},\ nm^3/MJ.$$

2.7. Content of Mineral Part Components in Dry Fuel

Components of sandy-clay part

Calculations were based on the average composition of sandy-clay part and its content in the oil shale under investigation:

$$G^d_{M\text{-comp}} = G_L\ L^d/100,\ \%,$$

where $G^d_{M\text{-comp}}$ – content of the corresponding component of mineral matter in dry oil shale, and G_L – content of the component in the sandy-clay part (Table 1).

Components of carbonate part

Calculations were based on the average composition of the carbonate part and its content in the oil shale under investigation:

$$G^d_{M\text{-comp}} = G_K\ K^d/100,\ \%,$$

where G_K – content of the given component in the carbonate part (Table 1).

2.8. Composition of Ash Formed in Boiler

Content of ash formed in a boiler is calculated for so called sulfate-free ash – for CO_2, S, SO_3 and Cl-free mass. In the case of components coming from the carbonate part into ash, oxidation of FeO into Fe_2O_3 at burning was accounted. The percentage of components coming from carbonate minerals into ash for dry fuel is as follows:

$$CaO = 1.0665\ (CO_2)^d_M,$$
$$MgO = 0.1463\ (CO_2)^d_M,$$
$$Fe_2O_3 = 0.0049\ (CO_2)^d_M.$$

Accordingly, the total percentage of components coming from the carbonate part into ash (calculated for dry fuel) is as follows:

$$K^d_{ash} = (1.0665 + 0.1463 + 0.0049)\ (CO_2)^d_M = 1.2177\ (CO_2)^d_M.$$

In the case of calculation of the components coming from the sandy-clay part into ash, it should be considered that during combustion the crystal water vaporizes and iron of FeS_2 oxidizes into Fe_2O_3. In the case of sulfate-free ash also SO_3 containing in the sandy-clay part is not accounted either.

The percentage of Fe_2O_3 formed from FeS_2 of the sandy-clay part (calculated for the sandy-clay part) is found by the formula:

$$Fe_2O_3 = 0.4655 \ FeS_2 \ 1.4297 = 0.6655 \ FeS_2.$$

Using the value 9.3% for the FeS_2 content in the sandy-clay part taken from oil shale data-table, the relative amount of Fe_2O_3 formed at burning equals 6.19%.

Consequently, the percentage of the sandy-clay to be burnt to ashes is as follows:

$$L_{ash} = 100 - FeS_2 + Fe_2O_3 - H_2O - SO_3 = 100 - 9.3 + 6.19 - 2.6 - 0.5 = 93.8\%$$

and the percentage of the total sulfate-free ash in the dry fuel is as follows:

$$A^d_{S\text{-free}} = K^d_{ash} + 0.938L^d = 1.2177 \ (CO_2)^d_M + 0.938 \ L^d.$$

On the basis of given above, the percentage of single ash components in sulfate-free ash may be calculated on the basis of the data from Table 1 using the formula:

$$G_{ash} = (G_K \ K^d + G_L \ L^d)/A^d_{S\text{-free}},$$

where in the case of components not present in the carbonate part, $G_K \ K^d = 0$. Fe_2O_3 content of the sandy-clay part (G_L) is the sum of primary Fe_2O_3 of sandy-clay part given in Table 1 and Fe_2O_3 arising at burning of markasite.

3.   Calculation Sample

A sample for calculation of the composition of oil shale and its combustion products and the product amounts is presented in Table 2. For circulating FB boiler, the following basic data were chosen: oil shale heating value – Q^r_i=8.200 MJ/kg, carbonate decomposition degree – 0.8, and coefficient of excess air – 1.25. The values for correction factors ΔA^d and $\Delta(CO_2)^d_M$ are: -2.0, 0.0 and +2.0, respectively.

Table 2. **Composition of Oil Shale and Ash Formed at Combustion and Amounts of Combustion Gases**

Initial data			
Heating value of fuel as received, Q^r_i, MJ/kg	8.200	8.200	8.200
Decomposition rate of carbonates, k_{CO2}	0.800	0.800	0.800
Permitted SO_2 content in flue gas, mg/nm³	10	10	10
calculated at coefficient of excess air α_t	1.40	1.40	1.40
Coefficient of excess air in boiler, α	1.25	1.25	1.25
Correction factor ΔA^d, %	-2.0	0.0	2.0
Correction factor $\Delta(CO_2)^d_M$, %	-2.0	0.0	2.0

Calculation of ash and carbonate CO_2 content of dry fuel			
Moisture of fuel as received, W^r_t, %	11.4	11.4	11.4
Calorific value of dry fuel, Q^d_i, MJ/kg	9.570	9.570	9.570
Calculated ash content, A^d_{calcul}, %	51.68	51.68	51.68
Calculated CO_2 content, $(CO_2)^d_{M\ calcul}$, %	20.29	20.29	20.29
$A^d = A^d_{calcul} + \Delta A^d$, %	49.68	51.68	53.68
$(CO_2)^d_M = (CO_2)^d_{M\ calcul} + \Delta(CO_2)^d_M$, %	18.29	20.29	22.29

Calculation of oil shale main constituents			
Corrected ash content, A^d_{correc}, %	47.68	49.68	51.68
Content of pyrite sulfur, $(S^d_p)_{prev.\ calcul}$, %	1.25	1.23	1.21
Organic part, $(R^d)_{prev\ calcul}$, %	32.77	28.79	24.82
Carbonate part, K^d, %	40.56	44.99	49.43
Sandy-clay part, $(L^d)_{prev\ calcul}$, %	26.67	26.21	25.75
Content of pyrite sulfur, S^d_p, %	1.33	1.31	1.28
Content of organic part, R^d, %	32.70	28.72	24.74
Content of sandy-clay part, L^d, %	26.74	26.29	25.83

Calculation of the content oil shale combustible matter			
Content of carbon, C^d, %	25.32	22.24	19.16
Content of hydrogen, H^d, %	3.17	2.79	2.40
Content of organic sulfur, S^d_o, %	0.58	0.51	0.44
Content of nitrogen, N^d, %	0.11	0.09	0.08
Content of chlorine, Cl^d, %	0.25	0.22	0.19
Content of oxygen, O^d, %	3.27	2.87	2.48
Content of organic + pyrite sulfur, S^d_{o+p}, %	1.90	1.81	1.72

Calculation of sulfur binding rate			
Theoretical amount of air, V^o, nm³/kg	3.05	2.68	2.31
$V_{CO2\ dry\ fuel}$, nm³/kg	0.55	0.50	0.45
$V_{N2\ dry\ fuel\ at\ \alpha 1}$, nm³/kg	3.37	2.97	2.56
$V_{O2\ dry\ fuel\ at\ \alpha 1}$, nm³/kg	0.26	0.23	0.19
Amount of dry gases, V_{gk}, nm³/kg	4.17	3.69	3.20
Sulfur binding rate, k_S	0.999	0.999	0.999

Calculation of flue gas amounts for fuel as received (using a given coefficient of excess air)			
Recalculation factor for fuel as received, $K_{recalcul}$	0.886	0.886	0.886
Amount of air for fuel as received, V^o, nm³/kg	2.70	2.37	2.05
V_{CO2}, nm³/kg	0.48	0.44	0.40
V_{SO2}, nm³/kg	0.00	0.00	0.00
V_{N2}, nm³/kg	2.67	2.35	2.03
V_{O2}, nm³/kg	0.14	0.12	0.11
V_{H2O}, nm³/kg	0.46	0.42	0.38
Total amount of flue gas, V_g, nm³/kg	3.75	3.33	2.91

Amounts of ash and flue gas per MJ			
On the basis of given heating value Q^r_i			
A^r_Q, kg/MJ	0.0604	0.0628	0.0651
V_{gQ}, nm³/MJ	0.457	0.406	0.355
On the basis of corrected heating value $Q^r_{i\,correc}$			
$k_{CO2\text{-}sulf}$ (minimal k_{CO2})	0.303	0.283	0.266
Corrected heating value			
$\Delta Q^r_{i\text{-}carb}$, MJ/kg	0.134	0.148	0.163
$\Delta Q^r_{i\text{-}sulf}$, MJ/kg	0.158	0.150	0.142
$Q^r_{i\text{-}correc}$, MJ/kg	8.491	8.498	8.505
Corrected ash and flue gas amounts			
$A^r_{Q\text{-}correc}$, kg/MJ	0.0583	0.0605	0.0628
$V_{gQ\text{-}correc}$, nm³/MJ	0.442	0.392	0.342
Composition of mineral part components in dry fuel, %			
Components of the sandy-clay part			
SiO_2	16.0	15.7	15.4
CaO	0.2	0.2	0.2
Al_2O_3	4.3	4.2	4.2
Fe_2O_3	0.7	0.7	0.7
TiO_2	0.2	0.2	0.2
MgO	0.1	0.1	0.1
Na_2O	0.2	0.2	0.2
K_2O	1.7	1.7	1.6
FeS_2	2.5	2.4	2.4
SO_3	0.1	0.1	0.1
H_2O	0.7	0.7	0.7
Components of the carbonate part			
CaO	19.5	21.6	23.8
MgO	2.7	3.0	3.3
FeO	0.1	0.1	0.1
CO_2	18.3	20.3	22.3
Composition of ash formed in boiler, %			
SiO_2	33.8	31.8	30.1
Al_2O_3	9.1	8.6	8.1
Fe_2O_3	5.3	5.0	4.7
CaO	41.6	44.2	46.6
MgO	5.9	6.2	6.5
K_2O	3.6	3.4	3.2
Na_2O	0.5	0.4	0.4
TiO_2	0.4	0.4	0.4
Total:	100.0	100.0	100.0

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