Efficiency of Peat Combustion in a Low Capacity Boiler: Analysis of Peat Reserves in the Arkhangelsk Region and Efficiency of Its Energy Use

Victor Lyubov, Anatoly Popov, Evgeniya Popova, and Alexander Chernov

1 Introduction

One of the prospective directions of power engineering development is the use of renewable energy sources. Russia has almost all types of renewable energy sources. Their economical proved potential which is intended for priority exploration has 275 million tons of equivalent fuel in total which is equal to 25% of energy sources annual consumption in the country including the energy of biomass (35 million tons of equivalent fuel).

The Arkhangelsk region has the largest peat reserves among the regions located in the European part of Russia. The explored and previously estimated reserves of peat are about 4 billion tons, the predicted resources are determined at about 8 billion tons. Peat deposits are unevenly distributed across the districts of the region [1, 2] (Table 1), while the 17 largest deposits account for 28% of all peat reserves.

Peat is a geologically young, poorly decomposed fuel with a high content of volatile substances (Table 2), which simplifies its combustion. However, high and widely varying peat moisture creates significant difficulties in the combustion. Peat reserves in the Arkhangelsk region are terrestrial, mixed, transitional, and lowland types of deposits, and two thirds of them are concentrated in high bogs [1, 2].

The ash content of peat varies over wide limits for individual bogs and sometimes reaches significant values: the Bludnoe bog (Table 2) and the Charus bog of the

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V. Lyubov · A. Popov (✉) · E. Popova
Higher School of Power Engineering, Oil and Gas, Northern (Arctic), Federal University named after M.V. Lomonosov, Northern Dvina Embankment, 17, 163002 Arkhangelsk, Russia
e-mail: a.n.popov@narfu.ru

A. Chernov
Arkhangelsk Plywood Factory, Frontovih Brigad 14, 164900 Arkhangelsk, Russia

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Table 1 Peat reserves in the fields of the Arkhangelsk region

Districts	Number of fields	The area in the border of the industrial depth of peat deposits, ha	Peat reserve at 40% moisture, thousand tons
Velsky	92	19.581	58.314
Verhnetoemsky	45	55.448	175.325
Vilegodsky	32	10.281	27.056
Vinogradovsky	68	47.806	172.927
Kargopolsky	151	139.878	533.340
Konoshsky	119	35.995	161.073
Kotlasky	55	18.174	56.750
Krasnoborsky	79	19.323	47.871
Lensky	11	10.164	27.193
Leshukonsky	66	32.807	63.413
Mezensky	121	211.469	500.333
Nyandomsky	22	33.428	152.651
Onezhsky	94	86.998	353.528
Pinezhsky	87	50.328	173.018
Plesecky	109	97.295	349.391
Primorsky	112	117.838	420.604
Ustyansky	124	10.811	30.711
Kholmogorsky	464	70.276	239.944
Shenkursky	57	47.406	189.590
Nenets Autonomous	18	2.974	6.851
Total	1.926	1.118.280	3.739.883

Table 2 Thermotechnical characteristics of peat from the Shenkursky deposit

Sample number	Moisture as received basis, W^{r} (%)	Ash content on dry weight basis/as received basis, A^{d}/A^{r} (%)	Volatiles on dry ash free basis, V^{daf} (%)	Lower calorific value as received/dry ash free basis, Q_i^{r}/Q_i^{daf} (MJ/kg)
Waimagan bog				
1	85	6.1/0.92	69.99	0.96/22.02
2	85	5.8/0.87	70.05	0.97/22.00
3	85	6.7/1.01	70.79	0.93/21.93
4	84	4.1/0.66	71.64	1.25/21.90
5	82	6.9/1.24	69.87	1.62/21.98

(continued)

Table 2 (continued)

Sample number	Moisture as received basis, W^r (%)	Ash content on dry weight basis/as received basis, A^d/A^r (%)	Volatiles on dry ash free basis, V^{daf} (%)	Lower calorific value as received/dry ash free basis, Q_i^r/Q_i^{daf} (MJ/kg)
6	86	8.8/1.23	70.17	0.63/21.89
7	82	11.4/2.05	68.32	1.45/21.99
8	78	8.2/1.80	69.56	2.48/21.97
9	86	5.7/0.80	70.22	0.75/22.03
Bludnoe bog				
1	82	20.7/3.73	68.59	0.94/21.05
2	82	26.8/4.82	71.25	0.73/21.20
3	84	18.7/2.99	70.90	0.63/21.06
4	85	17.4/2.61	69.33	0.49/21.23
Chistoe bog				
1	86	9.2/1.29	70.11	0.78/23.10
2	86	2.6/0.36	71.19	0.98/23.06
3	86	2.2/0.31	69.46	1.01/23.16
Zabegalka bog				
1	87	8.2/1.07	71.82	0.18/19.82
2	89	6.0/0.66	72.36	0.1/19.97
3	86	5.4/0.76	68.57	0.50/20.12
4	83	4.9/0.83	69.89	1.20/20.35
5	88	10.6/1.27	71.55	0.1/20.54

Kholmogorsky district. The not-go limit of ash content on dry weight is considered to be equal to 23% [3].

An extremely important characteristic of peat as a fuel is the degree of its decomposition. The entry of poorly decomposed peat into the boiler-house causes not only a sharp change in the combustion process, but also significantly complicates the operation of the transporting devices and feeders. This property, along with moisture and ash, characterizes sod and milled peat as fuel. The quality of peat is also largely dependent on its origin and nature of formation.

2 A Brief Overview of the Experimental Approaches

The number of production and operational testing of the boiler was determined by the necessity of obtaining the following basic dependences on heat output: flue gas heat loss, incomplete combustion heat loss and carbon loss, external heat loss, and sensible heat of slag. Testing was performed to draw the air and gas balances, to determine boiler's actual efficiency, gaseous and particulate emissions of harmful substances, air inleakage, aerodynamic resistance of air and gas paths, gas and air temperatures in controlled section areas of paths, etc.

Basic boiler's indicator measurements were carried out using regular measuring-and-recording apparatus including electronic sensors data received in the automated control system with the integrated BioControl 3000 microprocessor, and portable measuring instruments and research plants of the Research Center of Power Engineering Innovations of the Northern (Arctic) Federal University and the Shared Use of Equipment Center "Arktika".

Methods of production and operational testing of the boiler-furnace and auxiliary equipment are electrochemical method applied to flue gas analyzers, pressure and optical methods for determination of the volume of gas and airflow, ultrasonic fluid flow method, aspiration gas sampling method, thermal, pyrometric and contact methods for determination of the temperatures, combined relative and calorimetric methods supplemented by thermal imaging, weight and chemical methods for determination of the elemental composition of fuel, combustion residues, etc. [1, 3, 4].

Moisture, ash content, volatiles, low calorific value as received were determined in each of the main experiments for the sampled fuel. Experimental data analysis was performed using multiblock program-methodological complex [1, 5].

The analysis of fuels was carried out with the equipment of thermal analysis laboratory and IKA C2000 basic Version 2 calorimeter with LOIP FT-216-25 liquid cryothermostat. A study of the grain-size distribution of fuel composition and combustion residues was carried out with AS200 and Microtrac S3500 sieve shakers. The determination of velocity fields and flue gas flows was performed with a Pitot tube and a micromanometer of Testo-435 precision instrument. The results of the velocity fields study were used to determine the particulate matter concentrations at the flue gas after the boiler. In order to achieve that, an external filtration method was used, which is applied via an OP-442 TC impactor, a dust sampling probe, a filter holder, etc. [6]. A Testo 350XL gas analyzer was used to determine the content of combustion products. Fuel consumption was determined by the equation of the indirect heating balance.

Numerical modeling using ANSYS FLUENT Software is accomplished to elaborate the proved measures of further comprehensive increase of boiler operational performance.

All the burning processes (aerodynamics, ignition, burning out, heat and mass transfer, chemical reactions) are analyzed tied together. The gaseous medium consists of carbon dioxide, molecular nitrogen, moisture vapor, oxygen volatiles. Calculation of the biofuel particles trajectories was carried out using the Lagrangian approach. Heat and mass transfer are described for disperse phase. A two-parameter Realizable $k - \varepsilon$ model has been chosen to take turbulence of stream on particles movement into account.

3 Numerical Modeling of Burning Processes

3.1 Geometry

The boiler has a fuel storage with a screw system feeding biofuel into a holding bin and reverse ignition protection device. Fuel is fed by a screw feeder from a holding bin in the lower part of a stoker burner. The burner has an advanced contour, in the lower part of which a grate is mounted and it consists of two parts. It is possible to clean the grate by turning it down on 90°. Fuel is fed at a "cycle-pause" regime. An automated ignition of fuel occurs by an electrical hot-air gun. Primary and secondary air enters a furnace due to an exhaust fan vacuum. The main part of secondary air is fed through eight tangential nozzles and provides burning out of combustible components of fuel.

The operating pressure of a heat carrier on the output of the boiler does not exceed 0.3 MPa and the temperature does not exceed 95 °C. The boiler has two circulation contours. In the first one, equipped with a buffer tank, chemically pretreated and degassed water circulates. The estimated temperature regime for the processing medium of the first contour is 95/60 °C. Warming of heating system water of the second contour proceeds into a plate heat exchanger.

Combustion products from a stoker burner enter an afterburner where they give a part of the heat and go out it through the furnace throat placed at the back wall. Flue gas provides warming of the first contour boiler water flowing in two paths of fire tubes, then it is steered to the chimney by an exhaust fan. The turbolizer-cleaners are mounted into fire tubes to increase heat-exchange efficiency. After the first path in fire tubes, combustion products reverse, wherein larger fractions of soot are separated into an ash pit and collected in a bin. Ash and slag are removed from the combustion chamber by an individual screw into a collection bin too.

An exhaust fan motor has frequency control to provide smooth shift boiler performance. The boiler has required protection devices [7, 8]. An automated control system with an integrated BioControl 3000 microprocessor equipped with exhaust gas oxygen sensor, afterburner outlet temperature sensor, and outlet boiler temperature sensor as well as inlet and outlet water temperature sensor, etc. It provides ambient temperature-dependent control of heating contours and operates other significant boiler performances.

3.2 Mesh

A 3D model of boiler combustion chamber using builtin module ANSYS ICEM CFD [9] was developed on the preliminary stage of numerical modeling. Taking into account the unique geometry of a stoker burner and combustion chamber, it was decided to build an unstructured tetrahedral mesh with 1670 cells. Analysis of developed mesh has shown that it is acceptable for the objectives of this level of complexity. Actual design and primary airflow rate through 16 gaps of grates were considered in numerical modeling. It was decided not to simulate undergrate part of the burner to simplify the computation.

3.3 Boundary Conditions

Calculation of the biofuel particles trajectories was carried out with the Discrete Phase Model and grain-size distribution of fuel was accounted using the Rosin–Rammler equation. Defined coefficients for this equation were determined by the sieve method [1]. It was resolved that fuel particles are spherical and consisted of coke and ash residue. There are the following stages of thermal treatment and burning of fuel particles calculation: warming, evaporation, ignition, burning of volatiles, coke residue burning out. Fuel particles in the furnace are thermally treated by radiative-convective heat transfer.

Heat transfer by radiation in the furnace was calculated using the P1-approximation. Primary and secondary air flow rates are given in boundary conditions [10].

The problem was solved by the method of successive approximations. At the initial stage, a coarser unstructured tetrahedral mesh with 672 thousand cells was used for the calculation. Then an increase in the number of calculated elements was made in order to eliminate the influence of the number of cells on the results of the solution. As a result, it was found that an increase in the number of design elements over 1.670 thousand does not have a significant impact on the outcome of the solution.

3.4 Model Validation

Also, to increase the accuracy of the solution results, the discretization scheme of convective terms of the basic equations was changed. At the first stage, a first-order discretization scheme (First Order Upwind) was chosen, which ensured fast convergence of the iterative process, but insufficient accuracy. At the second stage, a second-order discretization scheme (Second Order Upwind) was chosen using the algorithm for linking the speed and pressure fields SIMPLE [11–16].

Another factor affecting the accuracy of the solution is the convergence criterion. To ensure sufficient accuracy in solving this problem, an absolute criterion was established for all equations with a value of 0.001 (except for the energy and radiative heat-exchange equations 10^{-6}). The solution was launched on 1000 iterations. After reaching the value of the residuals for each equation, the program was reported "solution is converged (853 iteration)". It means that the program has reached the required level of convergence.

3.5 Results of Numerical Modeling

Modeling results have shown that the working medium ensures reliable cooling of afterburner walls, where the temperature is 30–40 °C higher than the temperature of the boiler water (Fig. 1). Gas temperature in the furnace throat of the afterburner is 750–760 °C (Fig. 1), which is valid and much in line with the experimental data obtained from efficiency tests of the boiler. The main burn out area of peat combustibles is in the boiler's afterburner where outlet gas and fuel flow velocity decrease quickly. The temperature range in this area has maximum value (~1.200 °C). The area of maximum carbon oxide and hydrogen concentrations is located slightly below (Fig. 2). A less bright area of active burning appears in the burner under secondary air tangential nozzles where the maximum temperature is about 1.080 °C. In this area, volatiles that are released during the thermal decomposition of small and large peat particles are burned out.

A huge concentration of fine particles in the sod peat makes a large part of them burn out in the gas flow. Uneven fuel distribution along the grate leads to the formation of craterlike combustion areas. However, gas flow swirling in the burner space formed by tangential secondary air nozzles allows to balance the concentrations of the gaseous components. Flow swirling intensity reduces, and its diameter increases when combustion products go to the afterburner. Gaseous combustible components are burnt out, providing minimum values of incomplete combustion heat loss, which is proved with experimental studies (Table 4) and numerical modeling. A huge concentration of fuel particles with the dimension of 125 µm and larger, which is not completely burnt out at the space of the combustion chamber and the after-

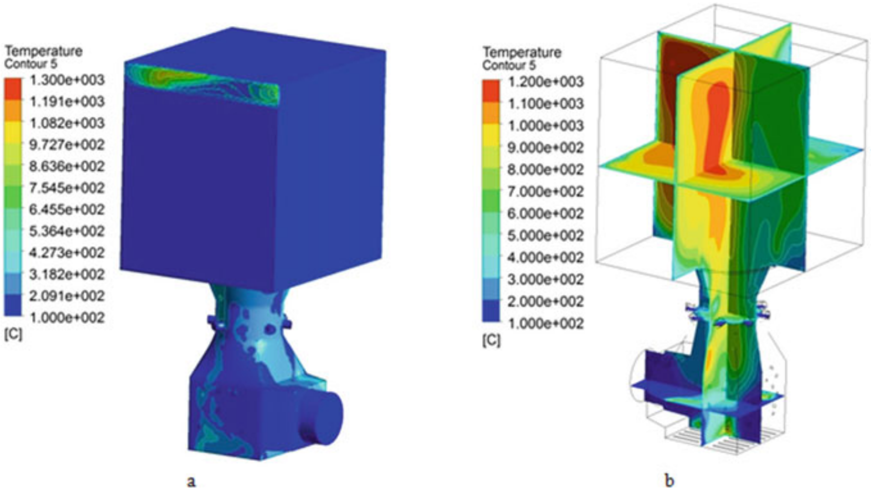

Fig. 1 Temperature distribution: **a** on the surface of the burner, the afterburner, and its furnace throat; **b** in the cross section of the burner and the afterburner

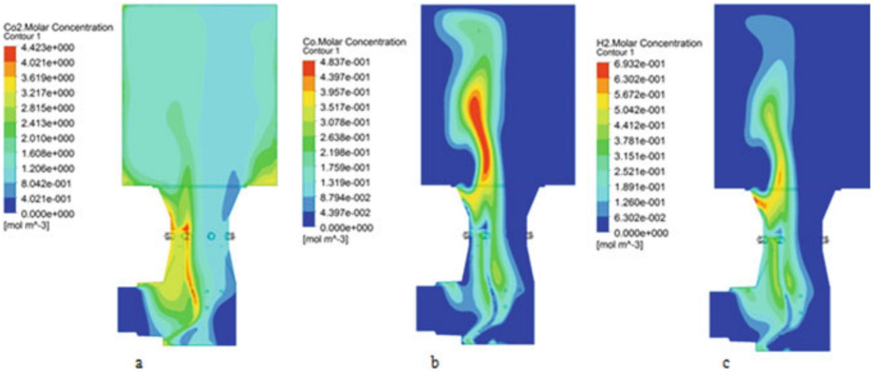

Fig. 2 The concentrations (Mol/m^3): **a** CO_2; **b** CO; **c** H_2

burner, leads to a sharp increase in carbon loss up to 13% (Table 4). The separation of unburned fuel particles after the first path in fire tubes creates a risk of their ignition in the ash pit and the collection bin.

4 Full-Scale Experiments

Peat is in the intermediate position between renewable and fossil fuels. It is slowly renewing fuel because the recovery period on the mining area excess 200 years. However, peat consumption in the Russian Federation is significantly lower than the annual natural increase that allows considering peat as a renewable energy source in this condition. Terrestrial, transitional, and lowland peat deposits can be used as a fuel. Gas appearing while burning this kind of fuel is the greenhouse gas. However, its quantity and degree of danger directly depend on the combustion technology and the field where this resource is extracted.

According to the "Concept for the Protection and Rational Use of Peat Bogs of Russia", the largest amount of peat reserves of categories A + B + C1—6.9 billion tons (36.2% of the reserves of the Russian Federation) was explored in the Northwest Federal District, with the current level of 5–10% peat formation. At the same time, the total number of deposits in this region is 18.912, and the projected peat resources are 16.2 billion tons [17, 18]. These data allow us to conclude about the potential use of reserves of this energy resource to ensure the generation of heat and electricity. It is important to note that not all deposits can be used at this stage of economic development. Therefore, the problem of choosing the best and most efficient peat resources is very serious. Evaluation is made in many ways, among which are thermal, grain size, morphological and other characteristics of fuels. The economic component of the issue is also of great importance, since some of the resources are located in hard-to-reach areas or in sparsely populated areas, where there is no need for large amounts of heat and electrical energy [1, 3, 4, 19]. Peat extraction and use are possible only with the implementation of subsidy policies and state support in such regions.

The adoption of modern and highly efficient technologies and equipment for mining, agglomeration, and burning peat will allow increasing their range level in fuel balance of peat mining regions from 1–2% to 8–10% by 2030, which will increase their energy independence.

The basis of peat is made up of plant residues of solid polymers of cellulose nature and their decomposition products, which are in balance with an aqueous solution of low and high molecular weight substances. The inorganic part is represented in peat by insoluble minerals of different nature, adsorption formations of minerals with humic substances, inorganic components of peat water, ion-exchange heteropolar organo-mineral complexes, and complex-heteropolar derivatives [19].

4.1 Analysis of Peat Reserves in the Arkhangelsk Region and Its Thermotechnical Characteristics

Analysis of thermotechnical characteristics of peat from the Shenkursky and Kholmogorsky deposits allowed us to draw the following conclusions:

- the investigated samples of the original peat have a high content of external moisture, which reduces its calorific value as received basis to $Q_i^{\mathrm{r}} = 0.1$–2.48 MJ/kg; therefore, the use of peat as an energy fuel without preliminary partial separation of external moisture is impractical. Partial separation of external moisture significantly increases its calorific value (Table 3);

Table 3 Thermotechnical characteristics of peat from the Rikasikha deposit of Primorsky district, the Charus deposit of Kholmogorsky district, and the Okulovo deposit of Mezensky district

Place of sampling	Wr (%)	$A^{\mathrm{d}}/A^{\mathrm{r}}$ (%)	V^{daf} (%)	S^{r} (%)	$Q_i^{\mathrm{r}}/Q_i^{\mathrm{daf}}$ (MJ/kg)	Note
Rikasikha, №1 site	34.42	3.92/2.57	76.39	0.14	13.87/23.39	Briquettes after drying in ambient conditions
Rikasikha, №2 site	61.53	5.67/2.18	79.34	0.08	6.96/2346	Briquettes
Rikasikha, №3 site	46.79	6.43/3.42	71.22	0.12	10.46/23.36	Briquettes after drying in ambient conditions
Charus bog	12.4	33.6/29.4	70.4	0.17	11.07/19.58	Briquettes after drying in storage shed
Okulovo	90.3	4.1/0.4	77.51	0.02	2.27/23.43	Peat deposit

- using of peat-briquetting equipment during peat extraction improves the conditions for its transportation and storage, and also allows to partially separate of external moisture (Table 3);
- the Bludnoe bog is characterized by high ash content ($A^{\mathrm{d}} = 17.4–26.8\%$) of peat, which will have even larger values in commercial production, therefore, it is not recommended to extract peat from this bog. This conclusion applies to the Charus bog of Kholmogorsky district ($A^{\mathrm{d}} \geq 25.6\%$);
- taking into account the vulnerability of the northern nature, as well as increasing the fire danger of forests during preparing peat bogs for industrial extraction of peat, its energy use is advisable only in those areas of the region where there is no forest cutting waste, sawmill and wood processing waste, overripe or shrinking stand of trees, as well as deposits of high calorific fossil fuels.

Such a district on the territory of the Arkhangelsk region is Mezensky. This area has very large reserves of peat and is slightly inferior only to the Kargopolsky district (Table 1). The greatest effect from the extraction and processing of peat can be obtained with its integrated use as a fuel, organic fertilizer, the raw material for the production of fodder yeast, sugar, molasses, and other products.

The analysis showed that the Mezensky district of the Arkhangelsk region has very large reserves of peat (more than 500 million tons), however, in its fuel and energy balance, nowadays, expensive imported coal, whose share is more than 96%, dominates. Energy use of local fuels (peat and wood) will allow: to produce cheaper energy, decrease environmental pollution, increase the energy independence of the region, ensure the creation of new jobs, etc. For the widespread introduction of local fuels into the energy sector of the region, it is necessary to carry out research of determining the efficiency of use of existing domestic and imported equipment, including low-scale power.

4.2 Heat-Generating Plant for the Study of the Efficiency of Burning Local Fuels

Experiments were carried out at the building of Research Center of Power Engineering Innovations of NArFU named after M. V. Lomonosov which is connected to the district heat supply system. The Reserve heat supply source is the Austrian “Firematic 60” boiler of Herz Energitechnik GmbH which is also used to provide laboratory sessions and research. The boiler is designed to operate on wood pellets and chips [7, 8]. According to the manufacturer, the boiler nominal capacity (60 KW) is achieved while burning biofuel with specific moisture of $W_t^{\mathrm{r}} < 25\%$.

4.3 Experimental Part

In the course of the boiler, efficiency tests were carried out while a combustion chamber was fed by peat pellets with a diameter of 10 mm and sufficient homogeneity composition (Table 4, tests No. 1, 2) and by sod peat (tests No. 3, 4). Sod peat had a high level of heterogeneity of grain-size distribution (an average coefficient of polydispersity was $n = 0.772$ and a coefficient characterized particle size was $b = 0.661 \times 10^{-3}$). The results of only two tests for each type of fuel are presented in accordance with requirements [20] and show the energy and environmental performance of the boiler.

After an automatic start-up of the boiler, the period it takes to reach the rated load does not exceed 20 min. After 33–38 min an automated control system provides inlet boiler water temperature close to the optimum value (60 °C).

Table 4 The main performance of the boiler burning peat pellets and sod peat

Value	Symbol, dimension	No			
		No. 1	No. 2	No. 3	No. 4
Heat capacity	Q, KW	79.7	79.7	74.8	74.8
Outlet operating pressure of the water	$P_{o.p}$, MPa	0.15	0.20	0.27	0.27
Outlet water temperature	$t_{o.w}$, °C	74.0	75.0	78.0	78.0
Moisture of fuel	W_t^{r}, %	16.50	8.20		
Ash content of fuel	A^{r}, %	9.95	11.76		
Sulfur content	S_t^{r}, %	0.22	0.19		
Volatile yield	V^{daf}, %	74.56	67.88		
Lower calorific value	Q_i^{r}, MJ/kg	14.875	15.469		
Flue gas temperature	$\vartheta_{f.g}$, °C	137.2	137.5	135.2	133.0
Excess air in flue gas	$\alpha,_{f.g}$	1.38	1.41	1.27	1.24
Heat loss: Flue gas	q_2, %	5.77	5.88	5.29	5.07
Incomplete combustion	q_3, %	0.01	0.02	0.00	0.01
Carbon	q_4, %	2.17	2.17	13.00	13.00
External	q_5, %	0.38	0.38	0.40	0.40
Gross efficiency of the boiler	η_{gross}, %	91.37	91.24	81.01	81.22
Total fuel consumption	B, kg/h	21	21	21	21
Emission of NO_x	NO_x, mg/MJ	169	177	156	136
Emission of CO	CO, mg/MJ	7	23	4	11
Emission of SO_2	SO_2, mg/MJ	338	331	272	278
Particulate matter emission	PM, mg/MJ	12.6	12.8	32.4	32.5

4.4 Results of Production and Operational Testing

The analysis of thermal conditions has shown that heat loss with flue gas is $q_2 =$ 5.00–6.00%, but it rises when load and inlet boiler water temperature increases.

A stage fuel combustion scheme and efficient mixing of secondary air with combustible components of fuel while keeping the excess air coefficient in the furnace within the range 1.21–1.41 allows reaching low values of heat loss due to incomplete fuel combustion (Table 4). Values of carbon oxide concentrations corrected to excess air coefficient of 1.4 are 9–58 mg/Nm^3.

Carbon loss when the boiler operates on peat pellets is $q_4 = 2.17\%$ (content of combustibles in fly ash $C_c^{\text{ash}} = 19.50\%$). Conversion to burning the sod peat with high content of fine particles lead to a sharp increase of carbon loss to $q_4 =$ 13.00% (content of combustibles in slag $C_c^{\text{slag}} = 20.70\%$, $C_c^{\text{ash}} = 53.17\%$). The gross efficiency of the boiler decreases by about an order of 10% (Table 4). When the combustion products reverse after the first path in fire tubes particulate matter with predominant dimensions of 125 μm and larger are separated into ash pit from where removed in a collection bin. Fractional fly ash analysis has shown that the greatest amount of combustible components is contained in particles of 0.5 mm or larger (Fig. 3a). Analysis of the experimental data, taking into account the mass content of different fractions, has shown that removal of unburned peat particles with the size of $0.25 < \delta < 2$ mm (Fig. 3b) has a significant role in the carbon loss.

External heat loss is determined according to the reference curves [21] for Russian heating installations during the engineering calculation as well as standard tests. Validity of appliance of master curves for the foreign devices should be proved experimentally. The amended approach was elaborated for the determination of external heat loss. This approach is based on the combined use of the relative and calorimetric methods supplemented with thermal imaging [7].

Experimental studies have shown that external heat loss for the rated load (60 KW) of the boiler does not exceed 0.5% that is significantly lower in comparison with Russian standards [21]. Low values of this loss are explained by moderate

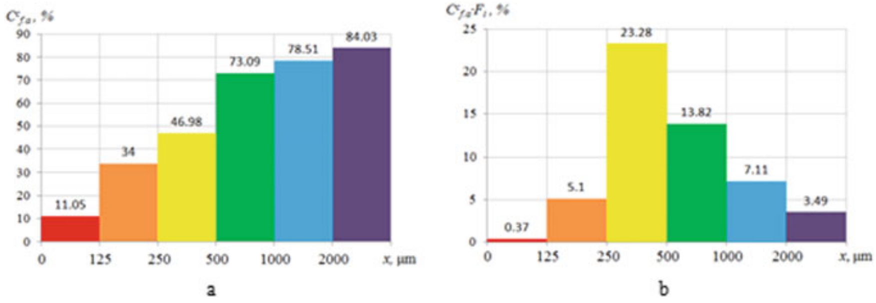

Fig. 3 Concentration of combustible substances in particles separated into collection bin while burning sod peat: **a** fractionating concentration of combustible substances; **b** concentration of combustibles taking into account weight percentage of different fractions

overall dimensions of the boiler and high quality of lining and thermo insulation materials. Losses due to the temperature of bottom ash while the boiler operates on peat are 0.30–0.31%.

Moderate emission of NO_x (Table 4) is explained by the low level of maximum temperatures and excess air in burner and afterburner as well as a two-stage combustion scheme. Sulfur dioxide concentration does not exceed 853 mg/Nm^3 (for $O_2 =$ 6%).

4.5 Results of Particulate Matter Investigation

The results of research of soot particles emission with the use of external filtration method under isokinetic conditions of gas extraction have shown that soot emission factor is 2.447 g/GJ, and emission factor PM2.5 is 0.347 g/GJ while burning peat pellets. When the boiler operates on sod peat the soot emission factor increases fast up to 17.254 g/GJ and emission factor PM2.5—up to 2.416 g/GJ accordingly.

The captured particles were studied by the electronic scanning Zeiss SIGMA VP (Carl Zeiss) microscope. Three main types of particles in selected samples have been identified: spherical shape and solid crystal particles and particles with an amorphous structure.

Elemental composition, dimension and shapes of carried away particles have been studied [8, 22]. The obtained results have shown that solid particles with dimension less than 13 μm are predominantly carried away to the atmosphere.

5 Conclusions

Results from calculations and comparison of numerical studies with experimental data have shown that chosen model of burning can be used to study the boiler's operational performance with grate firing of solid fuels which contain a significant number of fine particles burning in a suspension state.

Numerical modeling and the boiler's efficiency tests have shown that stage combustion scheme and intensive mixing of secondary air with combustible components of fuel allow providing highly efficient operation of the boiler in the condition of low oxygen concentration of 4.0–6.0%. As oxygen concentration increases by more than 6%, the emission of harmful substances to the atmosphere also rises. To that end, the threshold value of oxygen concentration should be reduced to 4% in the automated control system.

Obtained experimental and estimated studies have shown that higher ash content (in 20 times approximately) and high heterogeneity of sod peat grain-size distribution in comparison with biofuels projected for this boiler do not allow to recommend this boiler to operate on sod peat with no significant changes in the collection and removal of the combustion residues as well as protection system for spontaneous ignition.

In addition, the transition from burning peat pellets to sod peat caused an almost threefold increase in solid particles concentrations in the flue gases removed (Table 4) which indicates the feasibility of installing an ash collector.

An analysis of peat reserves in the fields of the Arkhangelsk region has been carried out and the thermotechnical performance of some of them has been investigated. The factors that determine the prospects for the use of peat in the regional economy are found. It is shown that the Mezensky district of the Arkhangelsk region has peat reserves in the amount of more than 500 million tons, but in the fuel and energy balance of which dominated expensive imported coal, which accounts for more than 96%. The absence of deposits of high calorific fossil fuels, as well as overripe or shrinking stand trees and waste of logging and wood processing, makes it possible to consider the Mezensky District as a priority site for wide integrated use of peat.

A comprehensive energy survey has shown that the Firematic 60 boiler provides high technical and economic performance and minimum emissions of harmful substances to the atmosphere while combusting biofuels and peat pellets. It should be used for low-rise buildings heat supply in weather conditions of the Arctic region especially.

Effective combustion of sod peat with high heterogeneity of grain-size distribution cannot be organized in the furnace of this boiler with no significant changes in the collection and removal of the combustion residues system as well as protection system for spontaneous ignition and mounting of the ash collector.

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