
STEAM BOILERS, POWER-GENERATING FUEL, BURNERS, AND BOILER AUXILIARY EQUIPMENT

Development of Low-Temperature Thermochemical Conversion Reactors for Coal Power Engineering

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Abstract—The main principles applied in developing a technology for low-temperature thermochemical conversion of brown coals to obtain fuel gas and semicoke intended for being fired in two-fuel power installations are considered on the basis of a set of experimental and calculated investigations. The obtained results are compared with the experimental data obtained using other methods and with the results of previous industrial tests.

Keywords: built-in and external pyrolyzers, kinetic investigations, muffle cyclone-vortex reactor, oxydizing pyrolysis, thermogravimetric analysis, thermochemical conversion, partial gasification, calculations in ANSYS CFX and Thermoflow software systems

DOI: 10.1134/S0040601513120100

Thermochemical processing technologies for converting solid fuels into artificial gas suitable for producing electricity and synthetic liquid fuels at integrated coal gasification combined cycle (IGCC) plants, coal- and biochemical (gas-to-liquids) plants, and cogeneration stations equipped with internal-combustion engines constitute one of the trends in the coal power engineering and polygeneration around the world. Two main lines of activities on development of gas generator technologies have been emerged around the world.

Construction of high-temperature high-capacity (0.5–1.0 GW) dual-purpose (for power-generating and technological applications) installations is the dominating line [1]. Such installations operate, as a rule, with oxygen blasting, at high pressure (4.5–8.0 MPa), high-temperatures (1800–2200°C), and with slag-tap removal (STR).

Development of low-temperature (1200–1300°C) installations for a moderate power capacity (100–150 MW) is an alternative line of works in this field. Such installations operate with air or enriched blasting at atmospheric pressure and with dry slag removal. The state of ash in the active zone depends, as in the furnaces of power-generating boilers [2], on the aerodynamic circuit of the thermochemical conversion reactor. Partial melting of ash may occur in flow-type and fixed-bed reactors; fluidized-bed reactors operate without melting of ash.

The technology allows any carbon-containing raw material to be processed, including coal, petroleum

coke, furnace fuel oil, biomass, prepared solid domestic wastes, etc. The developments are currently at the level of pilot and demonstration projects. The fact that the use low-temperature gasification of solid fuel is more preferable is due to the following reasons:

(i) The active zone operates at lower temperatures (1200–1300°C).

(ii) Less stringent requirements are imposed on the fuel quality

(iii) A smaller-capacity gas generator is required, and the system is better suited for use in small-scale and regional power-generating facilities.

(iv) It is easier to organize steam–air blasting than steam–oxygen blasting.

(v) Low-temperature gasification systems are less capital intensive, simpler, and are highly reliable in operation.

The above-mentioned advantages prompt specialists to search for satisfactory technological solutions. However, for installations equipped with low-temperature thermochemical conversion (LTTC) reactors to be successfully promoted in the market of innovative technologies, they must have indicators commensurable with those for large-capacity high-temperature gasifiers.

The main problems encountered during operation of LTTC reactors are stemming from a low rate of thermal conversions and from the fact that thermochemical conversions are considerably incomplete and selective at these temperatures. As a result, with a reactor operating at air excess factor $\alpha < 1$, the yield from

Table 1. Characteristics of coals

Indicator	Low-ash (VBC ₋)	Initial (VBC)	High-ash (VBC ₊)
Total moisture W^r , %	11.32	8.67	4.72
Ash (dry basis) A^d , %	12.11/15	35.19/48.1	66.57/79
Volatile matter (dry ash-free basis) V^{daf} , %	39.33/8.3	32.17/8.9	23.01/1.6
LHV Q_i^r , MJ/kg	28.9	22.2	15.4
Apparent density, kg/m ³	1348/700	1477/900	1739/1250
Porosity, %	14.99/n.a.	18.97/n.a.	22.74/n.a.
Specific surface area, m ² /g	7.78/n.a.	11.74/n.a.	15.29/n.a.

The number in the numerator is for the initial particle; the number in the denominator is for the coke–ash residue after pyrolysis at 900°C; n.a.—data are not available.

it is as a rule a mixture of combustible gases and semi-coke. The use of such processes is advisable if one or two kinds of products are of great demand. In power engineering, LTTC reactors can be used in installations operating on two kinds of fuel.

For an LTTC reactor to be successfully developed, it is necessary to carry out kinetic and dynamic investigations of fuel conversion in a low-temperature range, to estimate the thermal engineering properties of obtained fuels, and to perform a set of pilot industrial tests of reactor systems.

INVESTIGATION OF THE SOLID FUEL CONVERSION KINETICS IN A LOW-TEMPERATURE RANGE

Solid fuel was subjected to a thermogravimetric analysis (TGA) with a view to model two stages of processing: conversion of initial coal in an LTTC reactor and conversion of its coke residue in an afterburning system.

Volchansk brown coal (VBC), the technical characteristics of which are close to those of coals available in the promising Severo-Sos'vinsk brown coal basin, was selected as fuel. In view of the fact that the technical composition of this coal is characterized by essential statistical nonuniformity, we also studied the products from cleaning this coal (Table 1). The burnout of coke–ash residue was monitored in the course of subjecting the samples of low-ash Donetsk anthracite culm (AC₋) and activated charcoal (ACC) to conversion¹.

The kinetics of fuel particle conversion processes was studied out using a NETZSCH STA 449 F3 instrument intended for carrying out for a synchro-

nous thermal analysis with heating the furnace to 1100°C at a rate of 2.5–30 C per minute. A 60 ± 5 mg charge of pulverized VBC or ACC was placed in the instrument's holder 7 mm in diameter (blown from above air/argon mixture) in the form of a layer with height $h_1 = 3$ mm (with the diameter of particles $d_p \leq 0.2$ mm, the ratio $h_1/d_p > 10$). In the check experiments, a 10 ± 1 mg charge of pulverized AC₋ with an ash content of 10–12% and $d_p = 0.09$ –0.2 mm and 295 ± 5 mg ACC pellets were subjected to conversion. The reactivity of the coal organic mass was determined as the ratio of mass loss (dm) for the time ($d\tau$) to the current organic mass of the sample (m_c): $R = dm/(d\tau m_c)$, where R is the specific conversion rate, 1/s.

The results were compared with the data obtained from previous works on investigating the conversion of VBC with an average size of particles equal to 1–2 mm and high-ash AC₊ carried out on installations for studying coke reactivity (RSK) and on a Piroliz-M installation [3]. In Fig. 1, segments of TGA curves corresponding to certain conversion regime are separated. Volatiles burn out with the activation energy $E_a = 70$ kJ/mol irrespective of the heating rate (zone A); the high-reactive part of coke burns out in the segment b – c in an kinetic controlled regime with the activation energy $E_a' = 170$ –178 kJ/mol, which is a continuation of the similar VBC₊ regime revealed on the RSK installation. At higher temperature, a transition regime is formed in the segment c – d , which are stemming from a growth of reaction rate and buildup of ash layer thickness ($E_a'' = 67$ kJ/mol in the transition regime). The decelerating effect of ash layer on the combustion rate begins to be felt at point c after burnout of an insignificant (7%) part of coke mass, comprising 4% of the initial coal mass with an ash layer thickness equal to around 60 μm and grows to 100 μm at point d . To the left of point d ($t > 600^\circ\text{C}$), the reaction slows down almost completely due to the burnout of high-reaction carbon, which comprises the major (85%) part of the coke combustible mass (the segment d – e – f).

¹ The temperature schedule used for commercial-scale production of ACC (pyrolysis at $t = 600^\circ\text{C}$ and partial steam gasification at $t = 800$ –1000°C with outgassing the most reactive part of carbon) and the sequence in which the chemical reagents are admitted are close to the LTTC reactor operating mode, but owing to an essentially lower content of ash, a smaller level of systematic errors in processing the experimental data is achieved.

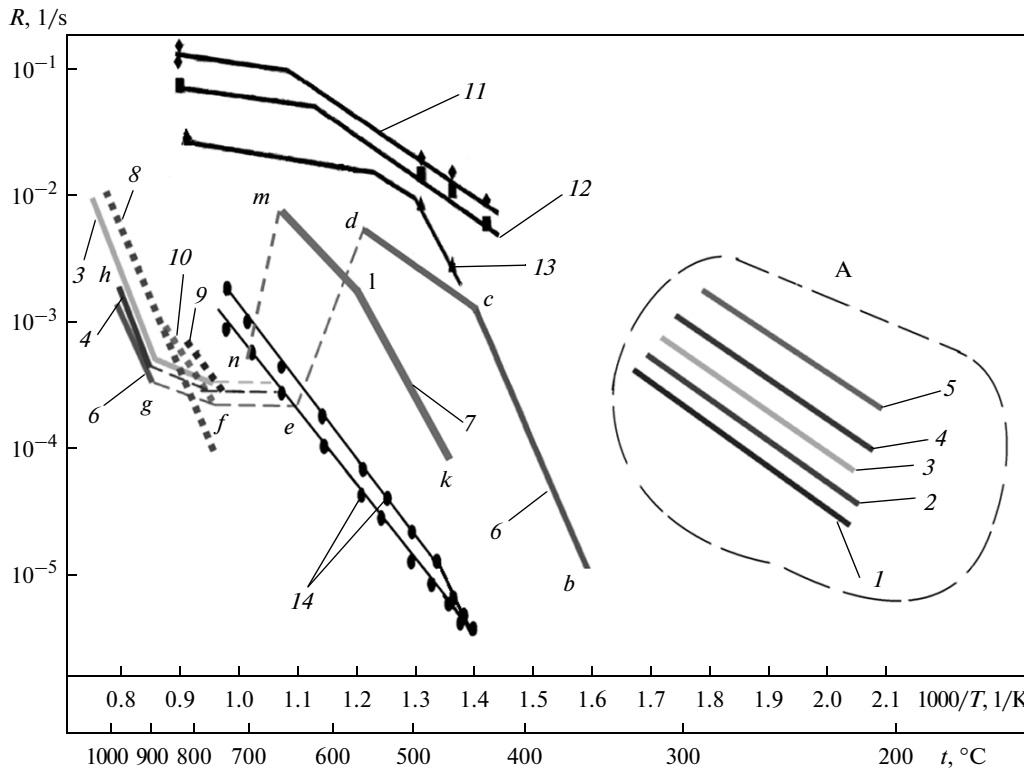


Fig. 1. Coals and cokes specific reaction rates with air as a function of temperature on different installations: STA: (1)–(5) VBC (2.5–30°C/min), (6) VBC coke, (7) coke from AC₋ (7.5°C/min), (8) ACC (steam), (9) ACC (steam/air), and (10) ACC (steam/CO₂). RSK and Piroiliz-M: (11) VBC₋, (12) VBC, (13) VBC₊, and (14) AC₊ ($A_C^d = 46.1\%$ and $d_p = 0.4$ – 0.6 and 1.0 – 1.6 mm). The dashed line encircles the volatile release region.

The AC₋ burnout rate curve has a similar shape but lies an order or two of magnitude lower. The conversion rate curve of AC₋ lies approximately an order of magnitude above that for high-ash AC₊ with $E_a' = 189$ kJ/mol, $E_a'' = 122$ kJ/mol (item 14) constructed in [3] according to the data obtained by A.Yu. Maistrenko. The conversion process in the segment k – l goes with the fuel carbon conversion ratio varying in the range $X_C = 0$ – 20% with $E_a' = 155$ – 160 kJ/mol, which is in good agreement with the data obtained by V.I. Babii on the high-temperature kinetics of low-ash Donetsk anthracites [4]. In the segment l – m $E_a'' = 84$ kJ/mol, and the conversion ratio X_C reaches 76%.

At temperatures above 900°C, a repeated growth of VBC coke conversion rate is observed with the value of $E_a' = 178$ kJ/mol in the segment g – h , which is typical for the kinetic controlled regime. This regime is almost identical with the conversion regime of low-reaction carbon of ACC in a steam–air mixture.

The low-reaction part contained in VBC coal (this part is observed at point f with the conversion ratio $X_C = 0.97$ – 0.98 in the form of crystallites and coal-mineral aggregates) does not allow full low-temperature conversion of fuel to be carried out in one stage.

Thus, a fraction of unburned carbon q_4 equal to 3% for VBC coal and more than 30% for VBC₊ was revealed in the course of previous studies carried out in a Piroiliz-M fluidized-bed reactor with an initial temperature equal to 820°C [3]. Qualitatively close results were obtained during an analysis of factors causing a growth in the fraction of unburned carbon in power-generating boilers firing Ekibastuz coal [4].

STUDYING THE LOW-TEMPERATURE THERMOCHEMICAL CONVERSION PROCESS

The pulverized coal conversion process was studied in the experimental installation schematically shown in Fig. 2. The installation consists of a segment for preliminary preparation of a fuel–air mixture operating as a muffle furnace extension of once-through reactor (1) made of a 2-m long tube with an inner diameter of 80 mm with heated part (2) of length $h_1 = 1$ m and nonheated parts with $h_2 = 0.2$ m and $h_3 = 0.9$ m (without heat insulation). In our studies we used Grade B2 coal from the Baganur coal field with low-fusible ash. The data from technical and fractional analysis of pulverized coal are given in [5].

In the fuel preparation segment, pulverized coal, supplied with a flowrate of 7.14 kg/h, is mixed with air

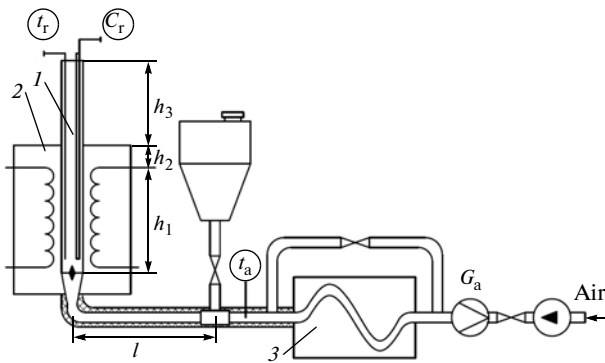


Fig. 2. Basic process circuit of the experimental setup.

heated in unit (3) to temperature t_a . For the time of their dwelling in the pulverized coal conduit ($l = 2.5$ m) $\tau_l = 0.4\text{--}0.45$ s, coal particles are heated to mixture temperature t_m . At $t_a = 200^\circ\text{C}$, the design temperature of pulverized coal–air mixture is $t_m \approx 160^\circ\text{C}$, which is sufficient for the coal to be dried in the main. At $t_a = 400^\circ\text{C}$ the mixture temperature $t_m \approx 290^\circ\text{C}$. According to the TGA data, coal may lose up to 30% of volatiles at this temperature, the oxidation of which begins directly in the pulverized coal conduit. As a consequence, the pulverized coal–air mixture ignites at the reactor inlet, and its temperature increases to 700°C . According to our assessments, the temperature growth rate in the reactor initial part is equal to $2 \times 10^4^\circ\text{C/s}$. After that, the mixture burns intensely throughout the oxygen zone, and its temperature increases to the maximal value $t_r' = 970^\circ\text{C}$. The average time for which particles dwell in the reactor heated zone is $0.4\text{--}0.6$ s, and their dwelling time in the reactor is $0.8\text{--}1.2$ s. The combustible gas mixture at the reactor outlet has a heating value of around 2 MJ/m³. The temperature of conversion products leaving the reactor is $t_r'' = 680^\circ\text{C}$.

An analysis of the data on pulverized coal conversion in the reactor allows us to gain some insight in the processes of incomplete combustion (IC) (Fig. 3a) and partial gasification (PG) (Fig. 3b).

DEVELOPMENT OF REACTORS FOR LOW-TEMPERATURE THERMOCHEMICAL CONVERSION

The method used for supplying heat to the pyrolysis zone is the key link in the thermochemical conversion process. The pyrolysis can be performed using one of the following versions: with predominance of (A) all-thermal or (B) autothermal conditions.

The technology according to version A was elaborated in the built-in pyrolyzer, a commercial-grade device intended for subjecting pulverized coal to preliminary thermal treatment in a standard vortex pulverized coal–gas burner of a steam boiler [6] (Fig. 4). The considered device consists of a chamber for com-

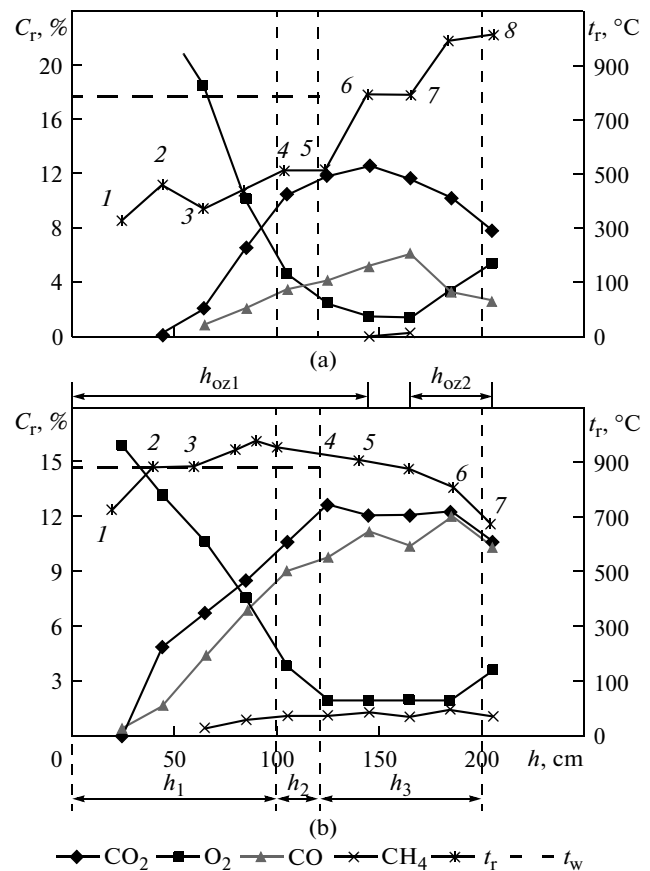


Fig. 3. Variation of temperature and volume concentration of gases over the reactor height. (a) Incomplete combustion mode ($\alpha = 0.7, t_a = 200^\circ\text{C}$, and reactor wall temperature $t_w = 777\text{--}795^\circ\text{C}$). (1)–(6) Processes in the main oxygen zone: (1) and (2) weak inflammation of volatiles, (3)–(5) heating of pulverized coal and release of volatiles (pyrolysis) due to heat transfer from the walls, and (5) and (6) afterburning of blast oxygen; (6) and (7) oxygen-free zone, and (7) and (8) combustion in the upper oxygen zone with flame breakthrough (to point 6) and afterburning of gases at the reactor outlet. (b) In the partial gasification mode ($\alpha = 0.5, t_a = 400^\circ\text{C}$, and $t_w = 870\text{--}885^\circ\text{C}$). (1)–(4) Combustion in the oxygen zone $h_{oz1} = h_1 + h_2$, specifically, (1) and (2) inflammation of volatiles outgoing from the pulverized-coal conduit, (3) induction time, and (3) and (4) combustion of pulverized coal–gas mixture to CO and CO_2 ; (4) and (5) weak gasification of coke in the oxygen-free zone, (5) and (6) cooling of pulverized coal–gas mixture, and (6) and (7) end effect (the flame is not pulled into the tube, and a typical diffusion gas flame saturated with incandescent coke particles flutters above the tube).

busting auxiliary fuel and a working channel, through which pulverized coal passed thermochemical treatment is admitted into the furnace. For subjecting pulverized coal to thermal treatment in oxygen-free medium, a system of coaxial flows enveloping the jet of highly concentrated air mixture is organized. With distance away from the central axis, this system takes up the annular flow of auxiliary fuel and products of its combustion, and the vortex air flow. With such struc-

ture of flows, the ingress of air into the fuel thermal treatment zone is limited, because this air is spent for firing auxiliary fuel before it comes in contact with pulverized coal. Owing to swirling of the air flow, it is gradually spent for mixing with auxiliary fuel, and the pyrolysis process temperature is maintained over the working channel length with a temperature profile similar to that obtained in the experimental installation (see Fig. 3). The working channel is cooled by the external annular flow of secondary air.

The study of the working process used for thermally processing pulverized Grade 1SS Kuznetsk coal in the built-in pyrolyzer showed the following.

(i) The average coal particle degassing ratio is 60–70%, and the content of volatiles per combustion mass in semicoke particles is 6–9% with the average value of this parameter in initial coal equal to 22%.

(ii) The content of excess oxygen in the pulverized coal–gas mixture at the working channel outlet is equal to 1.0–1.2%, which testifies that pulverized coal is subjected to thermal treatment in almost oxygen-free medium (the excess oxygen concentrates in the working channel wall zone).

(iii) The temperature in the channel outlet section varies in different modes from 700/500 to 850/730°C (at the flow axis/periphery).

(iv) According to the indications of surface thermocouples, the working channel wall temperature does not exceed 400°C at $t_a = 320\text{--}340^\circ\text{C}$, which testifies that the applied external air cooling system has good efficiency.

The reactor yields fuel gas enriched with pyrolysis products and has a low content of nitrogen (the concentration of N_2 is less than 10%) and a relatively high heating value (approximately 11–12 MJ/m³), and semicoke with ash content $A_c^d \approx 24\%$ and $Q_i^d \approx 23$ MJ/kg. The working process temperature level creates favorable conditions for admitting sulfur binding additives into the pyrolyzer inner space.

The use of an external flow-type apparatus made according to the RF patent No. 2349623 (Fig. 5) is a further development of the built-in pyrolyzer design arrangement. The pyrolysis process is organized in this apparatus by using the main solutions adopted in the built-in pyrolyzer, but its design differs from the former in using an additional device serving for separating the pyrolysis products and for separately removing them from the apparatus. It is supposed to perform the process by separating tars from the conversion products and firing them in the reactor head part (which comprise approximately 10% of the supplied fuel).

The technology according to version B was tried out in a cyclone-vortex muffle-type prechamber device constructed on the basis of RF patent No. 2174649 intended for subjecting pulverized coal to preliminary thermal treatment without firing auxiliary fuel. Mechanically, the apparatus is made as a hor-

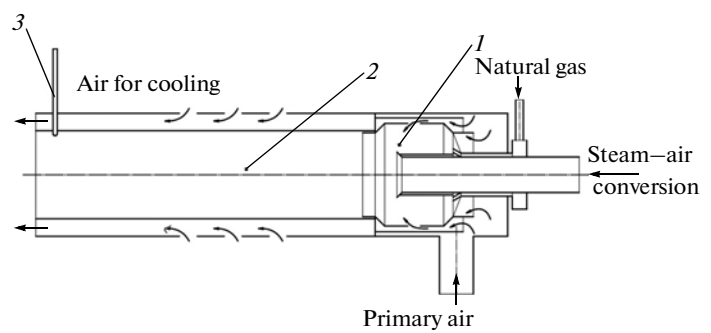


Fig. 4. Schematic design of the built-in pyrolyzer. (1) Chamber for firing auxiliary fuel, (2) working channel, and (3) thermocouple.

izontal cyclone into which pulverized coal is supplied along the central axis and hot air is admitted in the tangential direction. Commercial-grade tests of the apparatus carried out in one of its operating modes are described in [5]. The reactor operation was mathematically modeled in the ANSYS CFX 14.5 software package. When the reactor is used in the IC mode, its operation resembles that of the built-in pyrolyzer, during which the major part (60–70%) of pulverized coal flow passes through the reactor without changing its motion direction and is heated to a temperature of around 1000°C at the outlet, and volatiles release from the flow as it moves on. The remaining part, which performs the functions of auxiliary fuel, burns out at shortage of oxidizer in a ring-shaped vortex that heats the particles in the central flow. As a result, a cone-shaped reduction zone is formed in the central area at a distance equal to 2/3 of the reactor length (with a concentration of O_2 less than 1%) with the content of carbon oxide equal to 45% and carbon dioxide approximately 5%, which is enveloped by a high-temperature mixture of air and combustion products. As this mixture leaves the reactor, it comes in interaction with the gaseous products obtained from pyrolysis of the central flow (Fig. 6). The reactor has the following design indicators: $Q_i^d \approx 1.2$ MJ/m³ for gas, and the heat in gas to the heat in coke ratio is 1:4. The operating mode is selected so as to have the content of oxygen at the reactor outlet less than 1% and to have the nonuniformity of temperature profile in the outlet section within 100–150°C.

THERMAL ENGINEERING PARAMETERS OF THE PRODUCTS OBTAINED FROM LOW-TEMPERATURE THERMOCHEMICAL CONVERSION

For determining the application field of products obtained from low-temperature conversion, the combustion of four groups of gases was numerically investigated. The gases obtained from the fuels indicated in Table 2 were used as the basis.

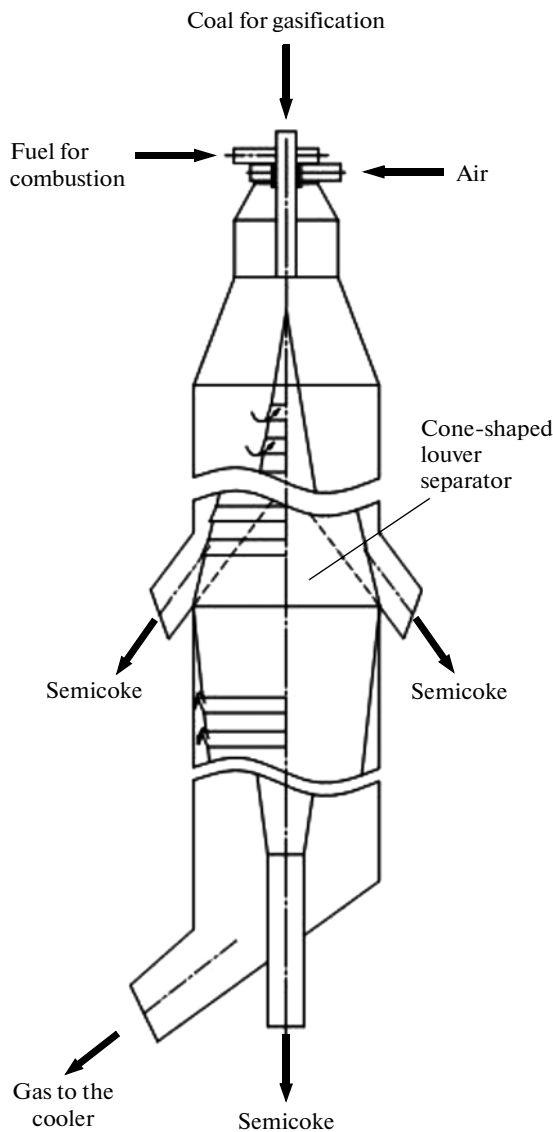


Fig. 5. Schematic design of the external flow-type pyrolyzer.

The gases obtained as a result of incomplete combustion and partial gasification, which have the lowest heating value ($Q_i^d = 1\text{--}2 \text{ MJ/m}^3$), are represented by the products from conversion of Baganur coal obtained in the experimental installation and cyclone-vortex apparatus.

The gases obtained from complete air and steam-air conversion (SAC) processes, which are related to the group of lean power-generating gases ($Q_i^d = 3.38\text{--}7.1 \text{ MJ/m}^3$) are represented by the products from conversion of wood and wood charcoal (items 2 and 3 in Table 2) that were obtained earlier in pilot commercial and experimental installations with a fixed bed [7]. The compositions of SAC gases (items 4–8) were also calculated using the licensed software package Ther-

moflow for the equilibrium conditions of the process carried out in a flow atmospheric-type dry-bottom reactor: the temperature in the active zone $t_r' = 1300^\circ\text{C}$, the outlet temperature $t_r'' = 800^\circ\text{C}$, and the fraction of unburned carbon $q_4 = 1\text{--}2\%$. The gas has almost zero content of hydrocarbons.

The group of rich artificial gases ($Q_i^d > 10 \text{ MJ/m}^3$) is represented by products from conversion of Grade 1SS Kuznetsk coal obtained in the built-in pyrolyzer. For comparison, data on a group of industrial gases are given (items 10–13 in Table 2), the composition of which was taken according to the data published in the literature [8, 9].

The version of calculating the theoretical combustion temperature shown in Fig. 7a corresponds to the maximal heating of blasting used in boiler engineering. In our investigation, such heating was used in the laboratory experiment. Similar air heating conditions were the case during operation of a cyclone-vortex apparatus (350°C), built-in pyrolyzer ($320\text{--}340^\circ\text{C}$) and fixed-bed apparatuses ($350\text{--}400^\circ\text{C}$). With such heating, the theoretical combustion temperature of cold gases from partial gasification ($t_g = 30^\circ\text{C}$) at $\alpha \approx 1$ will be $1200\text{--}1500^\circ\text{C}$ (see Fig. 7a), which is insufficient for setting up stable combustion. However, if the PG gases are heated to $t_g = 500^\circ\text{C}$, the theoretical combustion temperature t_t rises to $1770\text{--}2200^\circ\text{C}$ (see the dashed curves in Fig. 7a), and flame instability is no longer a problem. This statement is confirmed by positive experience gained from joint afterburning of hot coal conversion products in a flame in the laboratory experiment described previously and under field conditions in the course of kindling a boiler from its cold state [5].

The range of theoretical combustion temperatures of cold gases from air and steam-air conversion carried out according to version A is, as for lean industrial gases, $1550\text{--}2000^\circ\text{C}$, which is sufficient for firing them in a flame in thermal power installations. The well-known experience with firing cold blast-furnace gas (350°C) in hot air [5] corroborates this statement. The level of t_t for pyrolysis gases (2250°C) is almost identical with that for rich industrial gases. In firing lean mixtures according to version A ($\alpha = 3\text{--}5$), the combustion temperature drops drastically, the difference between the groups of gases becomes smaller, and the dependence on temperature t_g becomes weaker.

The version B corresponds to high-temperature heating of air used in flameless combustion systems, as well as in high-temperature regenerative and recuperative air heaters. Stoichiometric combustion of cold gases from LTTTC performed according to this version is little different from the previous one because t_g is exceeded by $100\text{--}200^\circ\text{C}$. The effect from increasing the blast temperature is more tangible in the case of using a depleted combustible mixture. During operation in this mode at $\alpha = 3\text{--}5$, the theoretical temperature is higher by the value Δt_t close to the additional

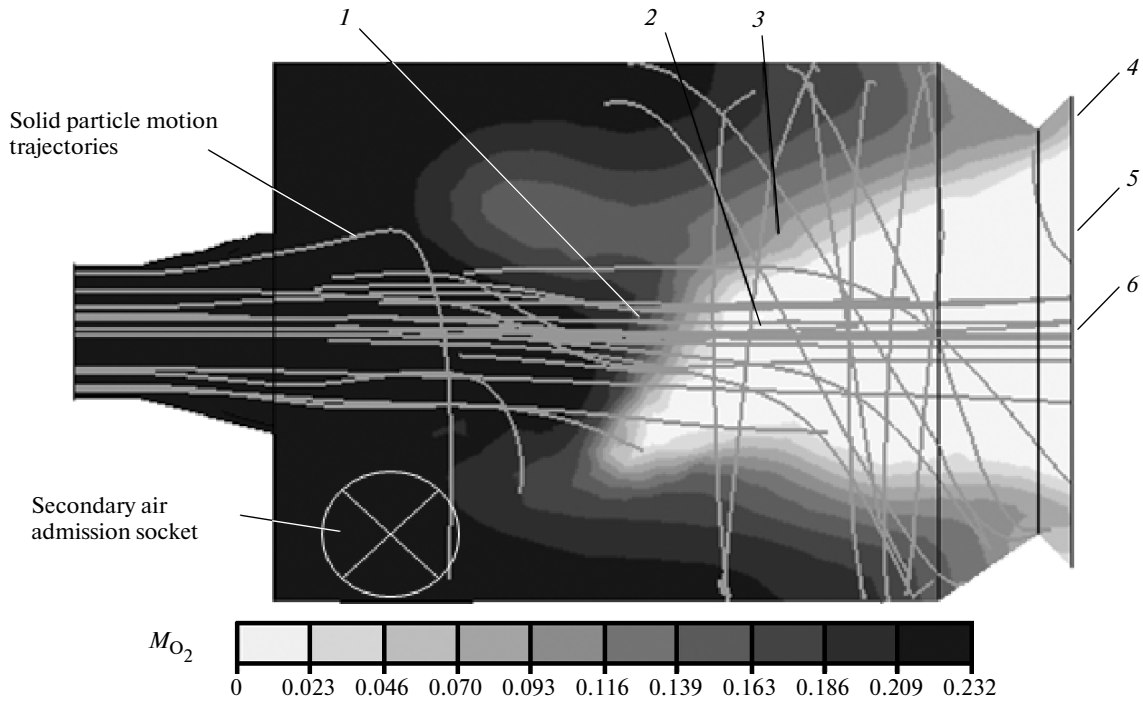


Fig. 6. Distribution of oxygen mass concentrations in the reactor longitudinal section and solid particle motion trajectories. Mass concentrations of CO and CO₂ at different points (M_{CO} and M_{CO_2}): (1) 0.02 and 0.0, (2) 0.35 and 0.09, (3) 0.0 and 0.11, (4) 0.0 and 0.2, (5) 0.27 and 0.12, and (6) 0.5 and 0.04.

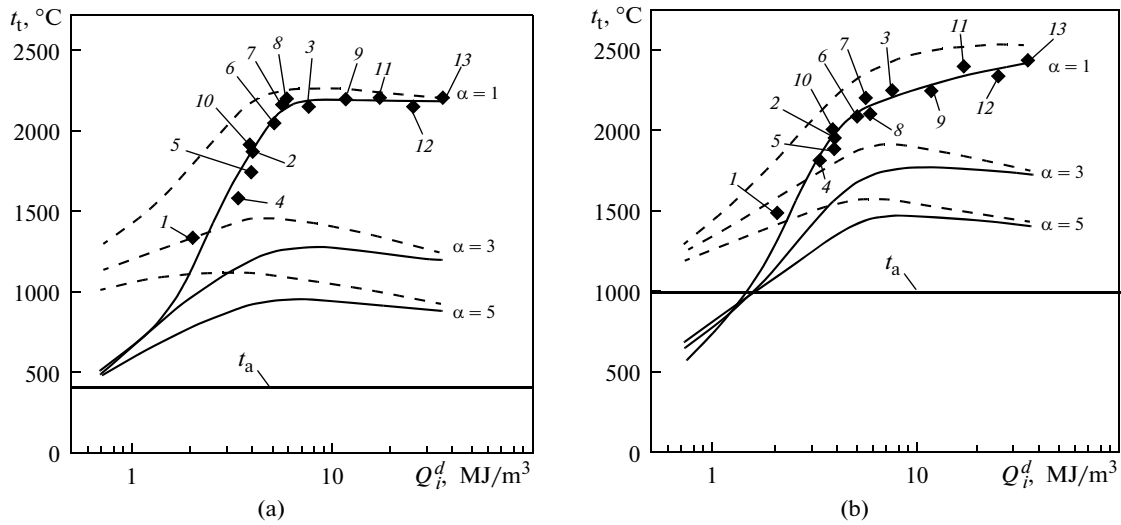


Fig. 7. Theoretical combustion temperature of artificial gases taking into account the dissociation of combustion products according to [8] (the numbers of points correspond to the numbers of items in Table 2) at different values of air excess factor α . (a) $t_a = 400^\circ\text{C}$ and (b) $t_a = 1000^\circ\text{C}$. Gas temperature $t_g, ^\circ\text{C}$: solid curves 30°C and dashed curves 500°C .

heating than at $t_a = 400^\circ\text{C}$. For cold gases from partial gasification, $\Delta t_t = 300\text{--}500^\circ\text{C}$, for gases from steam–air conversion $\Delta t_t = 500\text{--}700^\circ\text{C}$, and for pyrolysis gases $\Delta t_t = 600\text{--}700^\circ\text{C}$. Gases from steam–air conversion and pyrolysis exceed the boundary $t_t = 1500^\circ\text{C}$.

The version with $t_g = 500^\circ\text{C}$ is the most efficient one for firing lean gases from partial gasification and from air and steam–air conversion at $t_a = 1000^\circ\text{C}$. With this version, t_t in the range $1500\text{--}2000^\circ\text{C}$ is obtained for all of the studied gases at $\alpha = 3\text{--}5$.

Table 2. Characteristics of gases from LTTC

Sl. no.	Kind of fuel	Q_i^d , MJ/m ³	Content of, %							V_0 , m ³ /m ³
			CO ₂	O ₂	C _n H _m	CO	H ₂	CH ₄	N ₂	
<i>Gases from incomplete combustion and partial gasification</i>										
1	Baganur coal	2.07	12.3	1.6	0	12.1	0	1.5	72.5	0.35
<i>Gases from air and steam--air gasification (SAG)</i>										
2	Wood charcoal	4.0	3	Around 0	Around 0	25	8	Around 0	64	0.78
3	Wood	7.6	3	Around 0	Around 0	36	21	2.3	37.7	1.57
4	Wood*	3.4	17.6	0	0	10	19.8	0	51.9	0.71
5	Volchansk brown coal*	3.98	14	0	0	14.9	19.4	0	51.7	0.82
6	Grade 1SS Kuznetsk coal*	5.14	4.1	0	0	26.8	16.1	0	52.2	1.03
7	Wood charcoal*	5.68	1.3	0	0	33.5	13.1	0.1	51.3	1.12
8	VBC_*	5.98	4.7	0	0	30.6	19.4	0	54.7	1.19
<i>Pyrolysis gases</i>										
9	Grade 1SS Kuznetsk coal	11.9	15	1	3	30	9	15	27	2.74
<i>Industrial gases</i>										
10	Blast-furnace gas	3.94	10.5	0	0	28	2.7	0.3	58.5	0.76
11	Coke gas	18.02	3	1	2	7	58	25	4	4.16
12	Semicoke gas	25.56	13	0	7	9	9	54	8	6.57
13	Natural gas	35.50	0.14	0	0.86	0	0	98	1	9.42

* Calculated composition of gas.

To analyze the possibility of firing cokes from partial gasification, we estimated their ash content A_c^d and heating value Q_i^d (Fig. 8) depending on the composition of initial coal. The coke ash content was estimated assuming that volatiles are completely released from the coke residue (the amount of volatiles is found using the standard method).

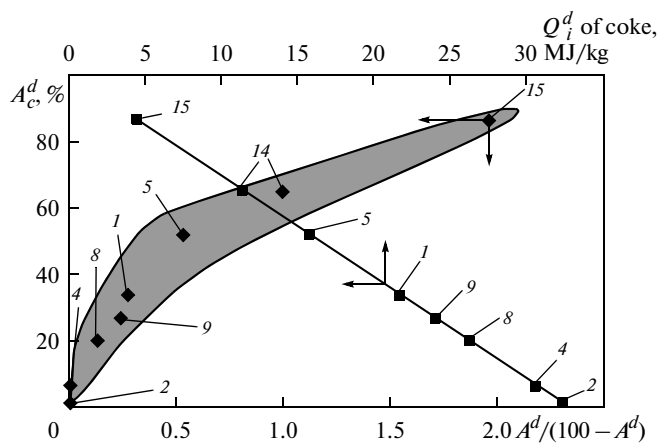


Fig. 8. Ash content and heating value of coke vs. the composition of initial coal (the numbers of points correspond to the items in Table 2; (14) sludge of Kizelov coal and (15) VBC₊).

The highlighted area (see Fig. 8) reflects the results from processing the data presented in [9]. If we assume that the maximal ash content in cokes fired in powdered form should be as that for anthracite (less than 25% according to GOST R 58186-2000), then cokes of low-ash fuels with a heating value of no less than 25 MJ/kg are suitable for the technology considered. However, since the cokes of brown coal have much higher reactivity than anthracite (see Fig. 1) it would be incorrect to speak about the possibility of applying this constraint, and the question about the limiting ash content in coke residue from high-reaction coals needs to be considered separately.

CONCLUSIONS

(1) High-reaction fuels like VBC are ideally suited for low-temperature air conversion into fuel gas for being used in power installations.

(2) After the release of volatiles from VBC coal, it is combusted in two stages: the main high-reaction part of coke residue burns out first, and at the final stage, low-reaction graphitized structures burn out in a kinetic controlled regime, which have an effect on the formation of unburned carbon in the furnace process.

(3) With pulverized brown coal dwelling in the experimental once-through reactor with a wall temperature of 870–885°C for 0.8–1.2 s, it becomes possible to convert powder preheated in primary air (with

a temperature of 400°C) into low-calorific gas with $Q_i^d \approx 2 \text{ MJ/m}^3$ and coke residue with an ash content of approximately 30%.

(4) In case of using a prechamber cyclone–vortex device for subjecting brown coal to air conversion with the dwelling time an order of magnitude shorter than in the experimental reactor, it becomes possible (according to calculations) to obtain a fuel mixture of gases with $Q_i^d \approx 1.2 \text{ MJ/m}^3$ and semicoke with a heat output ratio of 1 : 4, which after separation can be used in power installations.

(5) Positive results obtained from the conversion carried out in the pyrolysis mode, which has been elaborated on the design of a device for preliminary thermal treatment of pulverized coal (this device is built into the burner) with the products from combusting natural gas, allows us to recommend this design for use as a reactor serving to produce rich fuel gas with $Q_i^d \approx 11\text{--}12 \text{ MJ/m}^3$ and semicoke for power-generating purposes.

(6) Cold gases obtained from partial gasification and steam–air gasification can be fired in a rich mixture with highly heated air. However, the most stable mode of combusting these gases is their firing in heated state in a depleted mixture ($\alpha \approx 3\text{--}5$) with highly heated air.

(7) Pyrolysis gases can be fired in a rich mixture with air heated in a standard manner. However, more stable combustion will be achieved in case of firing a lean mixture ($\alpha \approx 3\text{--}5$) of pyrolysis gases in highly heated air.

ACKNOWLEDGMENTS

This work was supported by the Ministry of the Russian Federation for Education and Science and

was carried out within the framework of the Federal Target Program “Investigations and Developments in the Top-Priority Lines of Developing the Scientific and Technological Complex of Russia for 2007–2013” (State Contract no. 14.516.11.0043).

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Translated by V. Filatov