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To cite this article: V P Tsymbal *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **377** 012057

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Melting gasifier for nonwaste processing technology of dust fractions of coal and mine refuse

V P Tsymbal¹, I A Rybenko¹, V I Kozhemyachenko¹, P A Sechenov¹,
A A Rybushkin¹ and A A Olennikov²

¹Siberian State Industrial University, 42 Kirova str., Novokuznetsk, 654007, Russia

²Tyumen State University, 6 Volodarskogo str., Tyumen, 625003, Russia

E-mail: rybenkoi@mail.ru

Abstract. The paper presents the technology of processing waste coal and the unit for its implementation, which is a melting gasifier developed on the basis of the jet emulsion unit SER. The results of mathematical and physical modeling are given, the technological modes and structural parameters of the unit are determined.

1. Introduction

Previously, our research team developed a new continuous metallurgical process and a jet-emulsion reactor for processing iron-containing waste [1], which has a significant advantage over the world-known direct reduction processes: low specific volume (10-15 times less than the existing ones) and low energy intensity (1.5 times), as well as three times lower capital intensity.

2. Nonwaste gasifier based on the SER unit

The subsequent studies showed [2] that with a certain change in technology, this unit can be used for nonwaste gasification of dust fractions of waste coal with the production of three liquid products [3]: synthesis gas or electricity when it is combusted, aluminosilicate microspheres [4] and metal. The best option is the processing of dust fractions of waste coal with the addition of metal-containing waste. This facilitates the task of forming foamy slag, in which the dust coal fractions are efficiently combusted. The scheme of this unit is shown in figure 1.

In the spherical reactor-oscillator 2, by spraying the mixture with countercurrent jets of oxygen 3, a rather perfect gas suspension is created, which is fed through the gas-dynamic lockable channel 4 to the column reactor 5. Due to the bottom supply of the working mixture, in this reactor a high layer of foamed slag is maintained, inside of which the dust coal is burned to carbon monoxide by supplying oxygen and steam. And due to the creation of high turbulence in the column reactor, connecting channel 11 and slag tank 12, the gas-saturated slag foam breaks up into small aluminosilicate granules and microspheres [4], which are very liquid on the market and cost more than metal (from 35 to 50 thousand rubles for a tonne).

The resulting gas is combusted in a piston mini-power plant. Such power plants are mass-produced [5]. If necessary, this gas can be converted into motor fuel [6]. In addition, a certain amount of metal (5 ÷ 6% from ash weight) is accumulated in the forehearth 7. Thus, the polluting waste turns into three valuable liquid products, the input flow is just dust charge, the rest products are formed inside the technological scheme. When burning gas in a piston power plant, a completely energy independent scheme of the technology is created, including the production of its own oxygen and nitrogen [7].



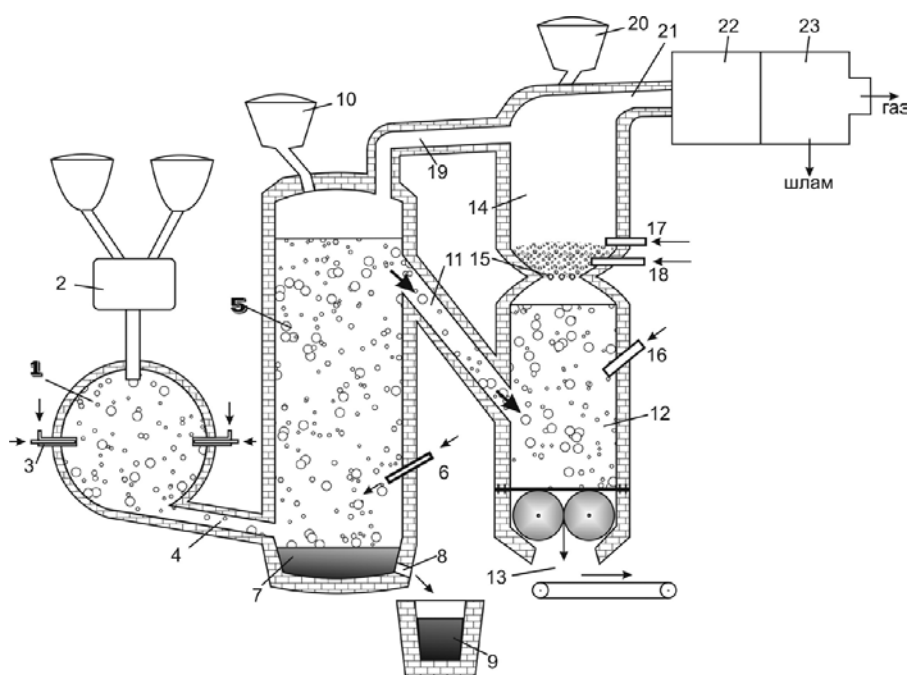


Figure 1. Scheme of nonwaste SER gasifier.

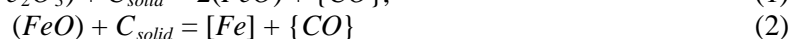
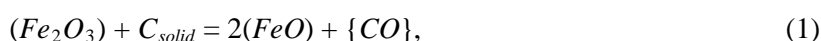
3. Melting gasifier for coal waste

Having underlined once again that the gasifier discussed above is effective when metal dust-containing waste is also processed along with the coal waste, we suggest considering a modified version of the gasifier intended to process coal waste only, that is, when there is no available metallurgical waste.

When processing only coal enrichment wastes, the problem of maintaining the stationary oscillatory mode of the reactor-oscillator 3 (figure 1) arises, since the content of the condensed phase sharply decreases in a gas suspension ejected through the gas-dynamic lockable channel 4. In this regard, it was decided to simplify the unit and abandon the use of a reactor-oscillator. But at the same time, naturally, the question arises how to ensure the basic condition for implementing the principle of self-organization [8, 9] – a large deviation from thermodynamic equilibrium, and how to ensure stable maintenance of slag foam in a column reactor without a sufficient amount of iron oxides in the slag.

It is advisable to show ways to solve this problem directly when describing the operation scheme of the modified version of the correct gasifier shown in figure 2.

The technology in the unit is implemented in the following way. A certain amount of metal is pre-melted in the induction heated forehearth 1. Further, during the operation of the unit, the surface of this metal is blown with hard oxygen jets, as a result of which a zone of highly oxidized slag 2 is created over the metal, as reactions of direct oxidation of iron occur intensively with formation of FeO and Fe_2O_3 . Particles of coal fall on this layer from above, as a result zone 3 is formed above, where the reduction reactions of these oxides intensively proceed:



and there is an intense release of carbon monoxide. As a result, a flow of carbon monoxide bubbles is created, which generates intensive mixing and turbulization of the slag emulsion layer. To improve the process of mixing the falling coal particles into the emulsion, an additional turbulization zone is created 4.

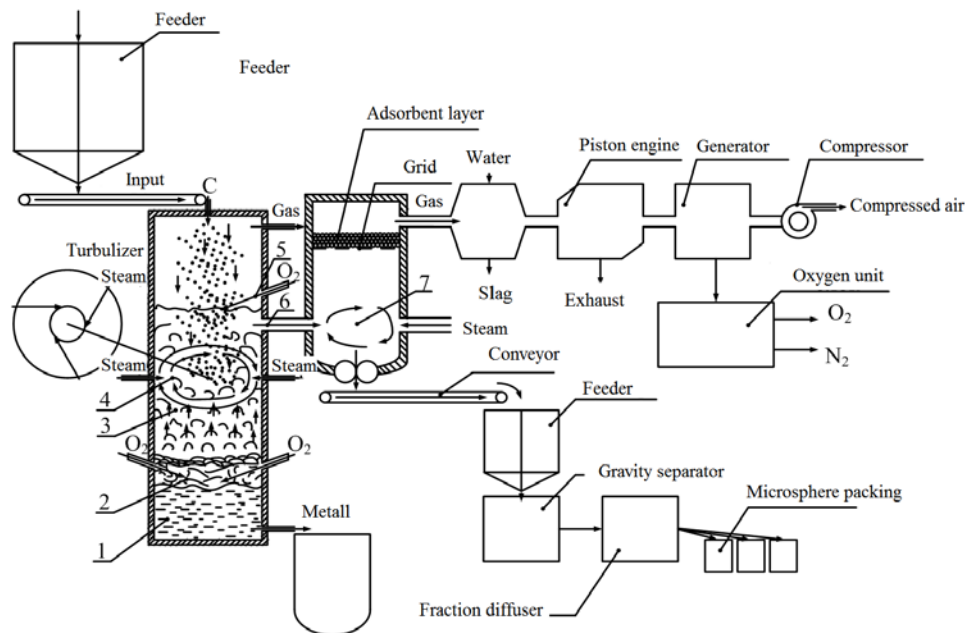


Figure 2. Melting gasifier for processing coal waste.

This is achieved due to the coaxial arrangement of the steam nozzles, while at the same time the vapor-oxygen conversion of the gas by the reaction is also carried out



which makes it possible to use the physical heat of the system for the increase of the caloric content of the exhaust gas, as well as to bring the volume ratio of CO/H_2 to unity, which makes it possible to apply it as synthesis gas to produce environmentally friendly motor fuel.

Afterburning of small carbon particles in the upper part of the column reactor is carried out with the help of oxygen tuyere 5. The gaseous suspension produced in the column reactor under pressure through channel 6 is ejected into the slag tank, where the slag particles are turbulized and cooled by means of coaxially arranged steam nozzles. The resulting closed and open microspheres, as well as heavily foamed, shapeless slag particles are discharged onto the conveyor, then their gravity separation and sieve screening are carried out.

Gas cooled in the receiver through a grid with a layer of adsorbent on it is fed into a wet or dry gas cleaning, and then to a piston engine that generates electricity used for the production of oxygen and nitrogen, and most of the energy is delivered to the network.

Thus, the above task of gasification of waste coal without the use of metal-containing waste is solved, but it should be emphasized once again that the possibility of using these waste products increases the efficiency of the technology considered above.

4. Results of mathematical and physical simulation

For this technological option using the “Engineering-Metallurgy” instrumentation system [10], mathematical modeling was performed to determine the optimal oxygen and water vapor flow rates for a given aggregate capacity of 1 kg/s of waste coal, the composition of which is given in table 1.

Table 1. The composition of waste coal.

C	A^d	V^{daf}	W^r	S^d
54.77	25.83	9.06	9.44	0.90

As a result of the optimization problem solution, the consumption of oxygen and water vapor was determined, ensuring the combustion of coal waste and heating of combustion products to a temperature of 1400 °C. Costs amounted to 0.721 and 0.098 kg/s or 0.504 and 0.124 m³/s for oxygen and water vapor, respectively.

The material balance of the process is given in table 2, thermal – in table 3. The calculated composition of gas and slag foam is presented in tables 4, 5.

Table 2. Material balance in the main unit.

Input, kg/s		Consumption, kg/s	
Waste coal	1.000	Condensed phase	0.298
Oxygen	0.721	Gas	1.521
Steam	0.098		
Total	1.819	Total	1.819

Table 3. Heat balance in the main unit.

Input	kg/s	MJ/s	Consumption	kg/s	MJ/s
1. Enthalpy of steam	0.098	0.032	1. Enthalpy of products		3.522
2. Exothermic reactions		4.763	condensed phase	0.298	0.522
$C+1/2O_2=CO$	0.440	4.218	gas	1.521	3.000
$CO+1/2O_2=CO_2$	0.000	0.000	2. Endothermic reactions		1.033
$H_4+1/2O_2=CO+2H_2$	0.059	0.546	moisture evaporation	0.094	0.212
$H_2+1/2O_2=H_2O$	0.000	0.000	$Fe_2O_3=2Fe+3/2O_2$	0.029	0.150
			$C+H_2O=CO+H_2$	0.059	0.670
			3. Heat losses		0.240
			Imbalance, %		0.000
Total:		4.795	Total:		4.795

Table 4. The composition of the gas phase in the main unit.

Composition	CO	CO ₂	N ₂	H ₂	H ₂ O	SO ₂	O ₂	Total
%	66.226	0.197	0.517	20.816	8.360	0.423	3.462	100.00
Nm ³ /h	1.025	0.003	0.008	0.322	0.129	0.007	0.054	1.548
m ³ /s	6.283	0.019	0.049	1.975	0.793	0.040	0.328	9.488

Table 5. The composition of the slag foam in the main unit.

Composition	SiO ₂	Al ₂ O ₃	FeO	CaO	MgO	MnO	P ₂ O ₅	Na ₂ O	K ₂ O	Total
%	61.909	26.749	1.413	2.570	2.570	0.000	0.000	2.219	2.570	100.0
kg/s	0.142	0.061	0.003	0.006	0.006	0.000	0.000	0.005	0.006	0.229

The amount of reduced iron in the main aggregate was 0.020 kg/s, unused carbon – 0.049 kg/s. The pressure in the main unit was 4.3 kg/s. At this pressure, for the removal of combustion products from the main unit into the slag receiver, the value of the diameter of the outlet channel should be 19.5 cm.

To confirm the gas-dynamic calculations, a physical simulation of blowing foamed water in a Plexiglas cylinder with an inner diameter of 10 cm and a height of 60 cm with interchangeable diameters of the output nozzle: 12, 9, 5 and 3 mm was performed.

By changing the flow rate of injected air, the pressure inside the vessel was maintained at 4.3 atm. The speed of the output stream from the nozzle in all four series of experiments turned out to be close to 300 m/s, which is explained by the presence of a relatively equal amount of condensed phase (water) in the outgoing two-phase flow.

When the diameter of the output nozzle is 3 mm, the consumption ratio at the exit of the reactor Q and the volume of the reactor V for the hot and cold aggregates coincided: $Q/V = 4.3$. This also means that the residence time and pressure in both reactors are the same.

Given this similarity, as well as the ratio of costs in the hot and cold reactors, for the hot reactor by recalculation from the cold one the obtained diameter of the output channel is 19.4 cm, which coincides with the results of mathematical modeling.

For the gasification process in the main unit, studies were conducted on the effect of water vapor consumption on the temperature and composition of combustion products (figure 3). Studies have shown that a change in steam consumption in the main unit from 0 to 0.25 kg/s leads to a decrease in the temperature of combustion products from 1520 to 1180 °C. The amount of CO in the gas phase decreases from 72 to 59%, and H_2O increases to 18%. Also the concentration of hydrogen is slightly reduced.

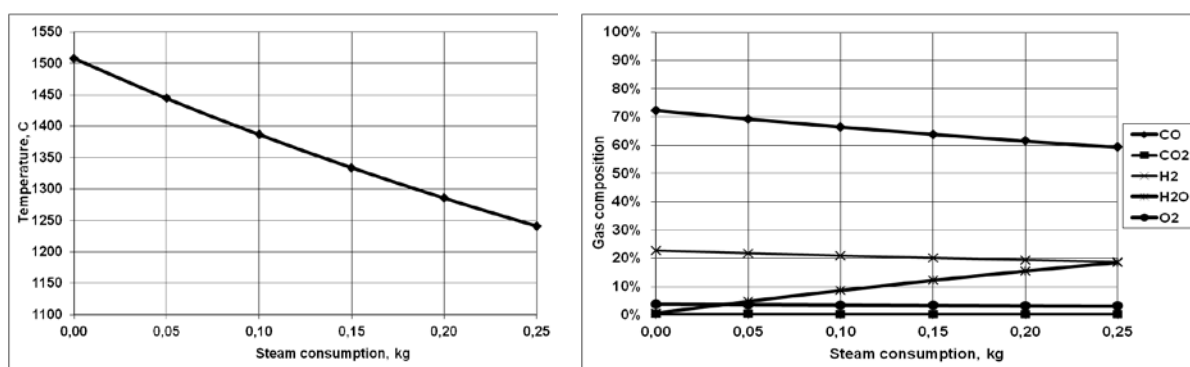


Figure 3. The dependencies of the process parameters of waste coal gasification on steam consumption in the main unit.

The gas-slag emulsion formed in the main unit enters the slag receiver, where it is cooled with water vapor to a temperature of 700 °C. Cooling occurs, during the implementation of the endothermic gasification reaction (3). The study of the possibility of this reaction was carried out by thermodynamic modeling using the Terra software package, which showed that the gasification process is carried out at temperatures above 800 °C (figure 4).

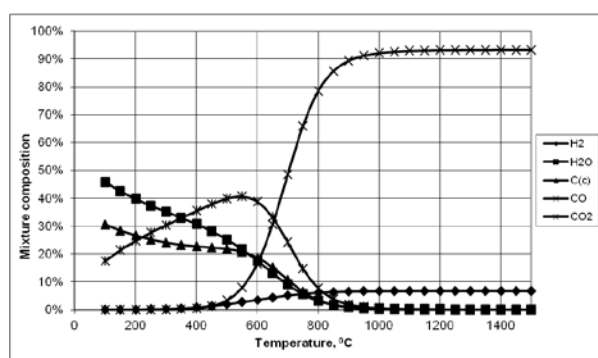


Figure 4. Dependencies of the process parameters of waste coal gasification on temperature.

As a result of the optimization problem solution, the consumptions of steam and waste coal were obtained, which are necessary for cooling the gas in the slag receiver up to 700 °C. The steam consumption was 0.135 kg/s or 0.169 m³/s, and the coal preparation waste was 0.211 kg/s. The composition of the gas in the slag tank after steam treatment is given in table 6. Its calorific value was 11435 kJ m³ or 2660 kcal/m³.

Table 6. The composition of the gas phase in the slag tank.

Composition	CO	CO_2	N_2	H_2	H_2O	SO_2	Total
%	61.884	2.629	0.395	32.154	2.938	0.323	100.00

Nm ³ /h	1.254	0.053	0.008	0.652	0.060	0.007	2.027
m ³ /s	4.470	0.190	0.029	2.323	0.212	0.000	7.224

Here we did not set the task of obtaining conditional synthesis gas, since we were focused on gas combustion in a piston power station.

5. Conclusion

A nonwaste melter gasifier was created on the basis of the jet-emulsion unit SER for processing waste coal to produce three liquid products: synthesis gas or electricity when it is burned, aluminosilicate microspheres and metal. The design of the unit and the technology for processing the dust fractions of waste coal with the addition of metal-containing waste, as well as without the addition of such waste, was developed. Mathematical and physical modeling of the process was carried out and optimal consumption of materials in the main unit and slag tank was determined, providing the specified process parameters: temperature and gas phase composition.

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