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Full Length Article

Plasma coal conversion including mineral mass utilization

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HIGHLIGHTS

- Investigation of comprehensive plasma processing of low-rank brown coal is fulfilled.
- At comprehensive plasma processing of solid fuel its mineral mass converts to valuable components.
- The numerical and experimental results comparison showed their satisfied agreement.

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ABSTRACT

The article presents a plasma chemical technology for processing of solid fuels by the example of low-rank brown coal. Thermodynamic computation and experimental investigation of the technology was fulfilled. The technology allows producing synthesis gas from the coal organic mass and valuable components (technical silicon, ferrosilicon, aluminum, and carbon silicon) from the mineral mass. The thusly produced high-calorific synthesis gas can be used for synthesis of methanol, as a high-potential reducing agent instead of blast-furnace coke as well as power gas for thermal power plants.

1. Introduction

Currently and in the foreseeable future the global economy is oriented to use organic fuel, mostly, solid fuel [1]. The share of solid fuel constitutes 40.6% in the generation of heat and electric power [2]. Therefore, the development of technologies for their effective and environmentally friendly application represents a priority problem nowadays [3–9]. This work presents the results of long-term investigations of plasma resource- and power-saving technology for comprehensive processing of solid fuel (gasification of solid fuel with simultaneous mineral mass processing) [10–13]. The use of this technology for producing target products (synthesis gas, hydrogen, technical carbon, and valuable components of mineral mass of coal) meets the modern environmental and economic requirements applied to basic industrial sectors. In environmental terms, the comprehensive plasma technology of coal processing for the production of synthesis gas from the coal organic mass (COM) and valuable components from coal mineral mass (CMM) is highly promising. The essence of this technology is heating the coal dust by oxidizing electric arc plasma to the temperature of its complete gasification, turning COM into environmentally friendly fuel, a synthesis gas, free from particles of ash, oxides of nitrogen and sulfur. At the same time, CMM oxides are reduced by the carbon residue, generating valuable components, such as technical silicon, ferrosilicon, aluminum, and carbon silicon [13]. Free of carbon CMM can be used for the production of refractory and abrasion-resistant materials, mineral fibers, stone casting, and siliceous bricks.

2. Thermodynamic analysis

Thermodynamic analysis was fulfilled using a versatile computational program TERRA [9]. It was created for high-temperature

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processes computations and in contrast to traditional thermochemical methods of equilibrium computation that use the Gibbs energy, equilibrium constants and Guldberg and Vaage law of acting mass, TERRA is based on the principle of maximizing entropy for isolated thermodynamic systems in equilibrium. TERRA has its own database of thermochemical properties for more than 3000 chemical agents over a temperature range of 300 to 6000 K. The database contains thermochemical properties of ionized components and electronic gas, which are accounted at carrying out thermodynamic calculations.

Before discussing the results note, despite of the fact that in principle plasma reactor is opened, not isolated system and there is an exchange of energy and substance with external medium, thermodynamic modeling of solid fuel gasification inside the reactor is possible. First, at preparation of heat and material balance of the reactor actual heat losses are taken into account, and in this case mass-averaged temperature in the plasma reactor is determined as for thermodynamically isolated system. Second, time of the reagents stay in zone of reactions is about 1 s which is multiply longer than thermodynamic equilibration time in the system at high temperature of the process [10]. Third, the plasma reactor is flow reactor and quasistationary process of gasification is provided.

Figs. 1–3 show a typical equilibrium composition of gaseous and condensed phases in comprehensive plasma processing of Turgai brown coal (Table 1) of 27% ash content and 18,140 kJ/kg heating value. The mixture composition is: 100 kg of coal +41 kg of steam. The gaseous phase (Fig. 1) of comprehensive coal processing products includes, basically, a synthesis gas with a concentration of up to 99 vol% at 1500 K. The total concentration of atomic and molecular hydrogen, varying from 40% to 59.9%, exceeds the CO concentration in the entire temperature range. With increasing temperature, the concentration of carbon monoxide increases from 45.8% at 1500 K to 48% at 1800 K and then decreases to 34.9% at 4000 K. A great share of CMM components converts from the condensed phase (Fig. 3) to the gaseous and condensed phase (Fig. 2) at a temperature above 1500 K, turning completely into the gaseous phase at a temperature above 2600 K (Fig. 3). At temperatures above 3000 K, the gaseous phase includes, basically, Si, Al, Ca, Fe, Na, and compounds of SiO, SiH, AlH, and SiS. The latter compounds dissociate into relevant elements with increasing temperature.

An important characteristic is the coal carbon gasification degree (X_C) and its dependence on the process temperature (Fig. 4). X_C is determined from the carbon content of the solid gasification products calculated in accordance with the Eq. (1).

$$X_C = (C_{in} - C_{fin})/C_{in} \cdot 100\% \quad (1)$$

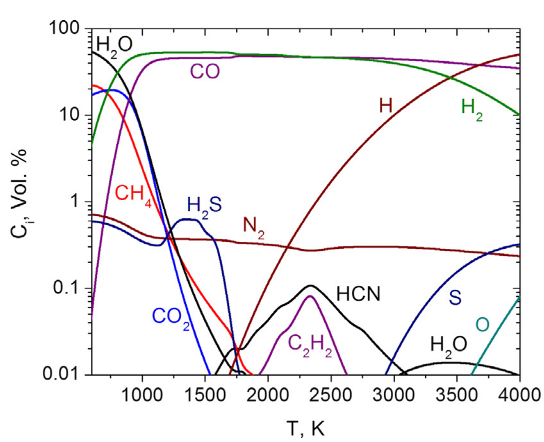

Fig. 1. Temperature dependence of the organic component concentration in the gaseous phase during comprehensive coal processing.

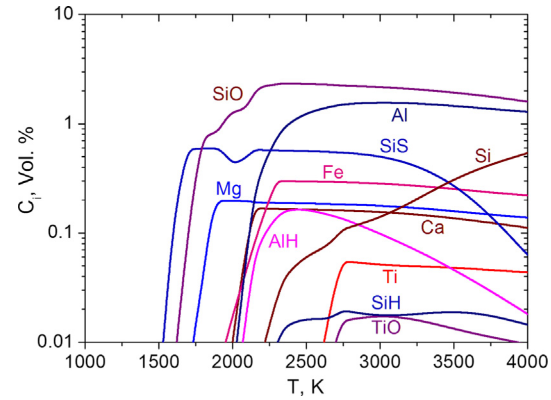

Fig. 2. Temperature dependence of the mineral component concentration in the gaseous phase during comprehensive coal processing.

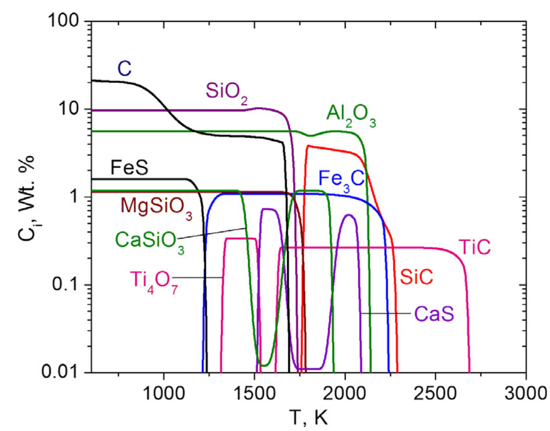

Fig. 3. Temperature dependence of the component concentrations in the condensed phase during comprehensive coal processing.

where C_{in} is the initial amount of carbon in the coal, and C_{fin} is the final (at current temperature of the process) amount of carbon in the solid residue. When determining the amount of carbon in the solid residue together with a fixed carbon, carbon of ferric and silicon carbides is taken into account.

It can be seen from Fig. 4 that the degree of gasification during comprehensive coal processing in the steam plasma reaches 100% at temperatures above 1750 K. In the temperature range of 1200–1700 K the gasification degree growth slows down. This is related to the fact that, actually, all steam introduced into the system is used up and no oxygen, required for gasification of the residual solid carbon, remains in the gaseous phase. With increasing temperature, the process of conversion of the mineral coal components begins. As a result, the gaseous phase includes oxygen the quantity of which is sufficient to complete the carbon gasification process.

Specific power consumption (Fig. 5) was defined as a difference between the total enthalpy of the final (current temperature of the process) and initial (T = 298 K) state of the system reduced to 1 kg of working substance (mixture of coal and plasma forming gas). Specific power consumption, having minor fluctuations in temperature range from 1600 to 1800 K in which reducing endothermic reactions with carbon run, monotonously increases with the temperature from 1 kWh/kg at 1000 K to 6.6 kWh/kg at 4000 K. At the temperatures of reaching 100% the coal gasification degree, which is 1750 K, specific power consumption for comprehensive plasma processing of coal is 2 kWh/kg.

The essence of the comprehensive coal processing is illustrated in Fig. 6. In comprehensive plasma coal processing, the endothermic effect of the carbon gasification reaction by water steam