Conference Paper

Study of Combustion Properties for Cokes with Various Grain Size Composition

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Abstract

As of today, cupola-type units have rather wide range of use both for iron production or metal scrap remelting and for mineral melt production. The major fuel type for such units is solid fuel – cupola coke. Raw material market offers quite a wide range of such fuels to the factories. Their metallurgical properties based on certificate data may vary within a broad band. To determine the impact of coke grain size composition on its properties, 11 coke types from various manufacturers were selected. An actual property variation range of certain solid fuel types was identified to describe the nature of solid fuel impact on cupola shaft furnace performance. When studying the combustion properties of coal coke in conditions close to the cupola shaft furnace, operation data of total curve of differential scanning calorimetry (DSC) was used. Temperature ranges were specified for intensive heat evolution from the beginning of coke sample active oxidation to the completion of the burnup period, as well as apparent heat capacity and heat effect of coke combustion.

Keywords: foundry coke, combustion parameters, burnout interval, granulometric composition, thermal effect, thermogravimetry, apparent heat capacity

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1. Introduction

Currently the major type of fuel for solid component remelting in cupola-type units with a horizontal dimension constrained to 2.0 m, max., the charge material layer height of 18 m, maximum, and draft intensity of up to 100 $m^3/(m^2 \cdot min.)$ is cupola or blast furnace coke, which consumption varies from 80 to 400 kg/t of the melt depending on the unit condition and the used state of the art. At that, consumer properties of the used fuel significantly determine the technical capabilities to control performance of the melting furnace, unit energy consumption for the product manufacture and environmental measures of melting [1].

The raw material market offers quite a wide range of solid fuels to arrange the process of liquid melt production. This in the first instance concerns blast furnace and

cupola cokes, coals and solid carbonaceous materials, produced by oil industry and wastes with high carbon content. [2]. Their metallurgical properties based on certificate data may vary within a broad band.

Coke is the only charge material which at the gas and material counterflow in melting shaft furnaces [3] reaches the solid state tuyere zone. Here it creates conditions for the produced melt drain and collection in its formation zone and ensures conditions for gas distribution throughout the unit horizontal section. Thus coke strength properties and its grain size composition significantly determine the conditions of gas flow in the workspace and drain of charge material melted components. Thus the capabilities of heat and gas dynamic processes intensification in cupola shaft furnace operation depends on coke physical properties and first of all its fractional makeup.

2. Grain Size Analysis

To determine the nature of solid fuel type impact on cupola shaft furnace performance an actual variation range was stated for properties of specific solid fuel types with selection of representative coke samples of class +80 mm from various manufacturers.

In the course of coke sampling 10 spot (simultaneous) samples of 25–30 kg were taken from the warehouse. Then the coke was bolted with the round hole meshes of 40, 60 and 80 mm. Based on the fuel sieve analysis 2 samples of 50 kg were selected to determine the mechanical strength.

Grain size analysis results of the selected samples are shown in Table 1.

Requirements to coke lump size are determined by the layer unit thermal performance [4]. In case of peripheral air blast supply into the shaft furnace [5] fuel lump size increase contributes to airflow into the charge material deep layers, speed up their coke combustion process and reduce unit energy consumption for the end product manufacture while improving the unit performance.

When the gas flow is arranged primarily along the airflow and in the center of the workspace (central gas flow), use of fuel with finer lumps ensures the capability of heat generation processes closer to the unit periphery.

The average lump size of polydisperse charge material may be established by two methods. Weighted average size of coke lumps is determined by the expression

$$\text{dmid} = (a_1 d_1 + a_2 d_2 + a_3 d_3 + a_4 d_4)/100, \quad \text{mm}. \tag{1}$$

where a_i – mass fraction of certain fractions;

d_i – arithmetic mean size of corresponding fractions, mm.

Table 1: Grain size composition of selected coke samples.

Sample Number of Coke Producer	Mass Fraction, %, of Lumps with the Stated Size, mm				Average Lump Size d_l, mm	Equivalent Lump Size $d_{equiv.}$, mm	$D_l/d_{equiv.}$
	80	60–80	40–60	–40			
1	71.3	19.3	7.8	1.6	81.9	76.69	1.067
2	57.9	34.9	6.3	0.9	79.87	76.16	1.048
3	54.9	41.6	3	0.5	80.13	77.56	1.033
4	40.7	52.9	5.7	0.7	76.65	73.69	1.04
5	30.6	59.6	8.4	1.4	73.74	69.95	1.054
6	48.8	43.7	6	1.5	77.81	73.44	1.059
7	61.2	35.4	2.5	0.9	81.29	78.08	1.041
8	29.1	52.8	15.7	2.4	71.48	66.15	1.08
9	64	25.3	8.8	1.9	80.09	74.43	1.076
10	27.5	59.9	11	1.6	79.9	76.2	1.049
11	48.1	46.9	4.5	0.5	78.5	75.8	1.035

The lump size determined this way is used to consider body forces and evaluate the size impact on the heat exchange process development [6].

Considering that based on practical data of blast furnace performance the reasonable value of a weighted average lump size of coke is within 55–58 mm [7], the studied cokes are described by the oversize and ensure reduced heat exchange intensity in the cupola shaft.

Equivalent lump size of coke lumps is determined by expression

$$d_{eq} = 100/(a_1/d_1 + a_2/d_2 + a_3/d_3 + a_4/d_4), \text{mm}. \quad (2)$$

Its values are used to review the change rules of the bed porosity [8].

The most generalized feature of coke grain size uniformity is relation of weighted average lump size to the equivalent one, which determines the used fuel size uniformity. The more uniform is its grain size and the closer is this relation to 1.0, the higher is the quality of the used coke. Solid fuel grain size composition also forms density of its bulk weight which varies within 430–480 kg/m^3 [9] for the blast furnace coke.

Data shown in Table 1 demonstrate that coke types of class +80 mm produced and used in the industry significantly differ in grain size composition. At that the weighted average lump diameter varies within 71,48 to 82,0 mm, the equivalent diameter varies

Table 2: Coke sample oxidation parameters.

Parameter	Coke Type										
	1	2	3	4	5	6	7	8	9	10	11
Initial oxidation temperature, °C	573.4	490.9	449.8	537.9	575.9	504.6	503.1	577.5	479.8	512.7	589.8
Burnup range, deg.	414.7	438.5	463.5	364.3	418	532	481.7	309.2	408.1	465.6	429.1
Heat effect, kJ/kg	19487	18536	19493	19319	18888	19647	18737	20185	19664	18504	18286
Apparent heat capacity, kJ/(h·K)	1.403	1.327	1.654	1.705	1.865	2.025	1.467	1.516	1.3	1.911	1.176

within 66,15 to 78,4 mm and their relation varies within 1,033 to 1,089. These values are determined by coking conditions of coal pits in the coke furnaces and the carbonized coke cooling conditions. Thus their combustion regularities in layer units may significantly differ.

3. Thermo-Gravimetric Analysis

When studying the carbon oxidation process features of coal coke in conditions close to cupola-type shaft unit operation data of total differential scanning calorimetry (DSC) curve of selected coke types at heating rates of 5°C/min in air oxidizing atmosphere was used. As per [10] in the course of isostatic heating of carbon materials several significant periods of their heat treatment are defined: drying and reheating of initial samples to the ignition temperature, active oxidation of combustible components and diffusion process stage. Specific features of their development are described by the following:

1. temperature range of intensive heat emission from the beginning of the coke sample active oxidation to completion of the burnup period;
2. apparent heat capacity, including physical and chemical components [11];
3. combustion heat in the course of the process.

Evaluation results of these values are shown in Table 2.

4. Results and Discussion

Summary data on temperature range variation of coke carbon loam oxidation is shown in Figure 1. Its analysis demonstrated that at average weighted values of solid fuel lump diameter of about 76–77 mm (a) and their effective diameter of about 72 mm (b) the minimum level of initial oxidation temperature was observed for the evaluated coke samples. In the same conditions the maximum possible extension of their combustion range is observed. At that, the coke size uniformity decreases, what is described by higher relation of the weighted average diameter of coke lumps to the effective one. The evaluated relation of coke lump size practically has no impact on initial oxidation temperature of fuel carbon, and in case of this value of about 1.06 the oxidation range has the minimum value of about 415°C, what ensures its most rapid combustion. Such behavior of coke burnup process variation may be related only to development of heating conditions of its separate lumps.

No observed dependence of apparent heat capacity variation of selected coke samples from their weighted average and effective diameters or relation of these parameters were detected (R^2– 0,2, max.).

Cumulative heat effect, showing itself in total heat emission from a fuel weight unit and determined based on a thermogram as an area under the temperature variation curve of a sample within the exothermal process development period shall be regarded as integral feature of coke combustion. Observed dependences of evaluated values from the cumulative heat effect are shown in Figure 2.

This data shows that cumulative heat effect of coke oxidation with increase of both weighted average and effective sizes of their lumps rises mainly due to total amount growth of material combustible mass. However higher degree of their size inhomogeneity, evaluated as relation of weighted average size to effective one is attended by decreased cumulative heat effect of coke oxidation.

5. Summary

Thus, the evaluations carried out for the oxidation process of commercial cokes of various grain size composition demonstrated the following:

1. Their burnup is determined by conditions of heat and mass exchange process development both on their surface with increased heat generation and on heat

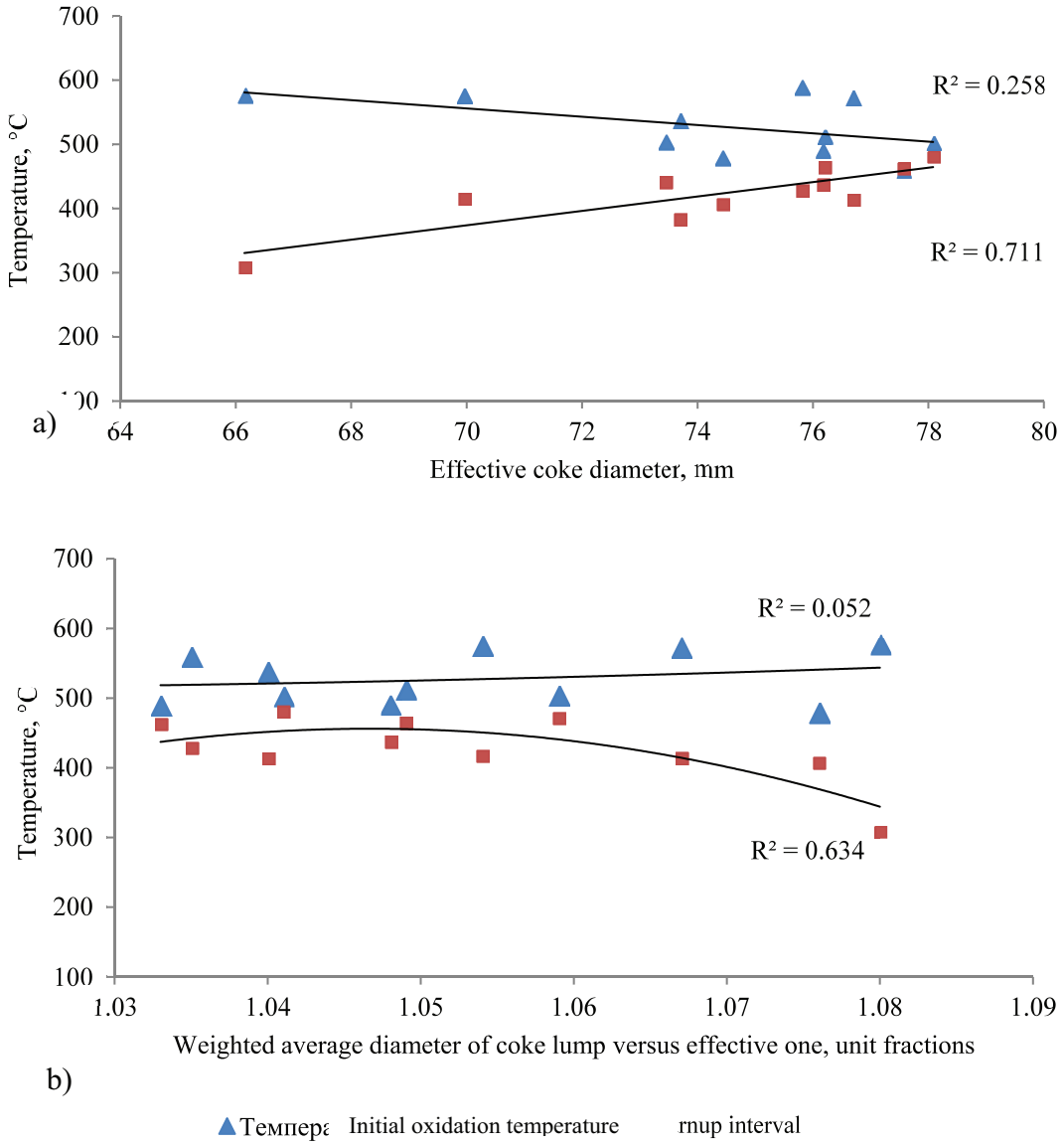

Figure 1: Variation of coke oxidation initial temperature and interval from weighted average (a), effective (b) and relation of weighted average and effective lump diameters.

penetration into the internal layers resulting in development of endothermic processes of structure oxidation.

2. Increase of weighted average coke lump diameter, effective diameter and their relation do not contribute to variation of apparent heat capacity values.

3. To ensure the most efficient development of coke oxidation processes use of finer carbonaceous materials with the minimum variations of their grain size composition is expedient.

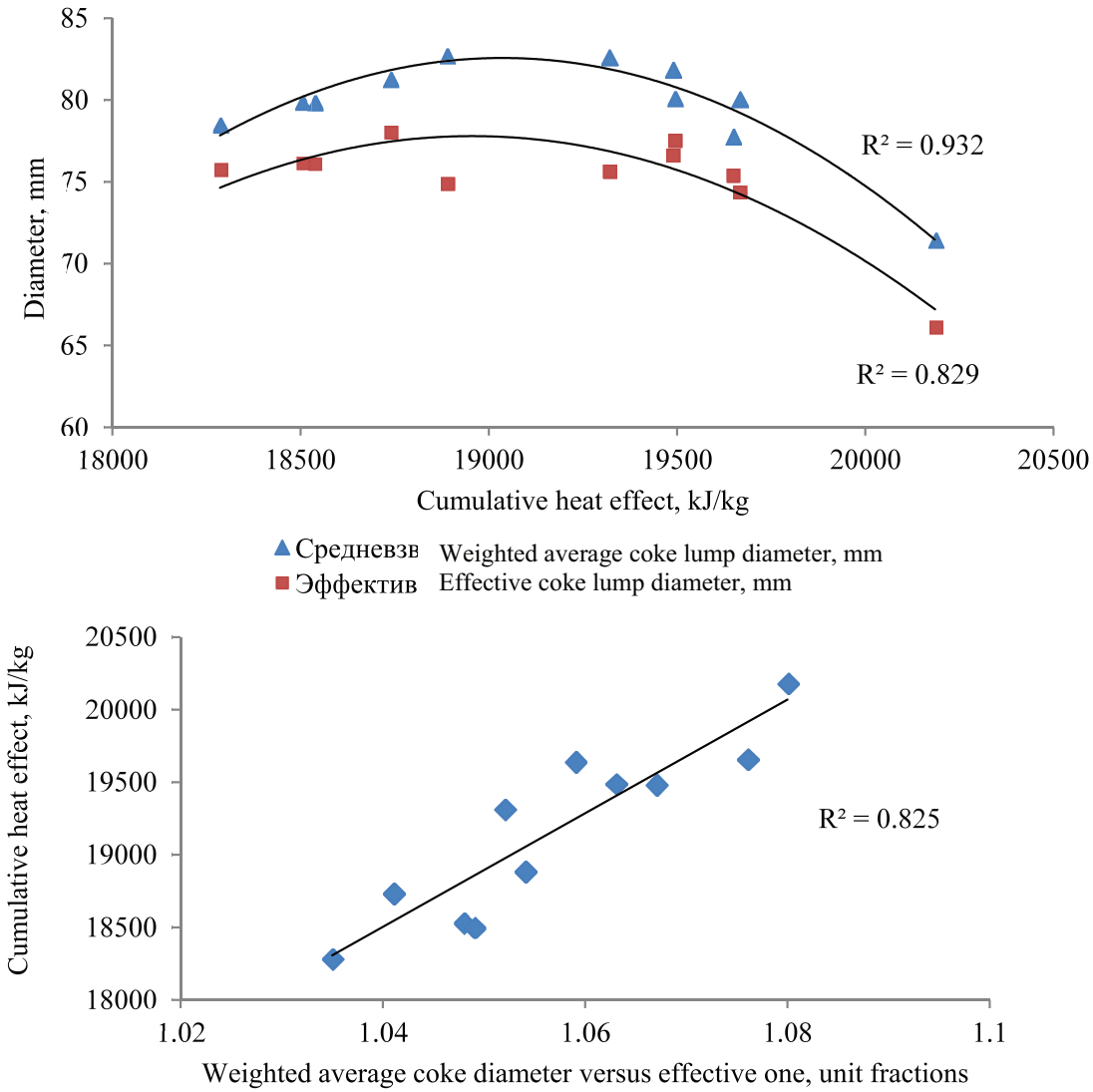

Figure 2: Variation of cumulative heat effect of coke oxidation from weighted average (a), effective (b) and relation of weighted average and effective diameters (c) of coke lumps.

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