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STUDIES ON THE USE OF ELECTRICITY TO REDUCE THE CONSUMPTION OF COKE IN THE DEVELOPMENT OF CAST IRON IN THE FURNACE

Marian-Iulian NEACȘU
"Dunarea de Jos" University of Galati, Romania
e-mail: mneacsu@ugal.ro

ABSTRACT

The paper presents the studies carried out in order to reduce the consumption of the volume of coke required for the production of pig iron in the furnace. Reducing coke consumption is necessary because it is an increasingly expensive material that increases the production cost of pig iron. Internationally, for the partial replacement of coke, auxiliary fuels were generally used in the form of gas or in liquid form, and the most used turned out to be methane. This process is limited by the fact that the temperature in the furnace is difficult to ensure.

The studies carried out have demonstrated that, under the given conditions, it is possible to directly introduce electricity into the crucible, the charge of the crucible presenting properties of electrical resistance that allow the application of additional electrical heating.

KEYWORDS: cast iron, furnace, coke, electrical current, methane gas

1. Introduction

In recent years, numerous improvements have been made to the technology of producing pig iron in smokestacks in order to reduce the specific consumption of coke.

Very good results in industrial practice have been obtained by using auxiliary fuels blown through the wind mouths mixed with hot air, the temperature of which has increased in a controlled and purposeful way in order to compensate for the thermal deficit caused by the combustion of carbon monoxide, carbon and H_2, in the conditions in the furnace crucible, of these fuels.

Worldwide, the use of auxiliary fuels made of gaseous hydrocarbons has become widespread: methane, coke oven gas; of diluted hydrocarbons: fuel oil, tar; of coal in the form of dust or mixture with liquid hydrocarbons. The type of replacement fuel used is dependent on local economic conditions. Of these, the most used is methane [1].

In the present state of the art, the amount of coke that can be replaced in the aforementioned manner with other fuels more economically advantageous than coke is limited primarily because of the temperature to which the air in the furnace can be heated [2, 3].

Starting from the finding that the replacement of coke with other fuels blown through the vents is limited by the impossibility of ensuring by known means the surplus heat necessary to maintain the thermal level in the furnace crucible, the problem of using electrical energy for this purpose was raised.

The use of electric energy in the manner shown, aims to maintain the furnace in its operating parameters and is thus fundamentally different from the other electrothermal aggregates known for the elaboration of cast iron, such as electric furnaces or electric furnaces with a short vat [1, 3].

Although the main source of energy for carrying out the processes in the furnace remains coke, the use of electrical energy in the chimneys as addressed in the present work, has the role of replacing more coke with methane blown in at the vents. The electricity input is a maximum of 100 kWh/t cast iron [1].

Several technological options can be considered for the introduction of heat of electrical origin into the flue:

- the introduction of electricity into the furnace by means of wall electrodes, in the area of the wind mouths or at the base of the display;
- additional heating by electrical induction of the crucible;
- electrical superheating of the air blown into the vents, which can be carried out with the help of the

high-voltage electric arc, jet plasma or high-frequency plasma, the use of resistors, electrical induction with intermediate heat transmitters etc. [4].

2. Theoretical considerations

If it is provided that the thermal regime in the crucible of the furnace does not change when an additional quantity of methane is introduced, by compensating by electricity for the thermal deficit caused by the combustion of methane at CO and H_2 in the presence of coke, the theoretical amount of methane can be determined using the relationship [1, 4]:

$$m = \frac{860}{q_2 - q_1}, Nm^3\, CH_4/kWh \qquad (1)$$

in which:

m - quantity of methane (CH_4);
860 is the caloric equivalent of kWh in kcal;
q_1 - the caloric content of methane combustion products under the given conditions, without taking into account the additional heat input, kcal/Nm^3 CH_4;
q_2 - the caloric content of the methane combustion products considered at the theoretical temperature corresponding to the normal operation of the furnace, kcal/Nm^3 CH4.

The combustion reaction of methane in the presence of carbon from coke is [2, 5]:

$$CH_4 + 1/2O_2 = CO + 2H_2$$

In the case of air with 1% moisture that has the composition: O_2 = 20.79%; N_2 = 78.21%; $H_2O(v)$ = 1.00%, by burning 1 Nm^3CH_4 results: CO = 1.000 Nm^3; H_2 = 2.0234 Nm^3; N_2 = 1.8368 Nm^3, that is, a total volume of combustion products V_g = 4.8602 Nm^3 [4].

The caloric content of the combustion products is [5]:

$$q_1 = 396 + Qv + Q_{CH_4} - Q_{H_2O},\ \text{kcal/Nm}^3\ CH_4 \qquad (2)$$

in which:

396 is the amount of heat resulting from the combustion of methane at CO and H_2, kcal/Nm^3 CH4;
Q_V - combustion air enthalpy;
Q_{CH_4} - enthalpy of methane, kcal/Nm^3 CH_4;
Q_{H_2O} - the heat of dissociation of water vapor from the combustion air.

The calculation shall be carried out for t_{air} = 1000 °C; 1100 °C; 1200 °C; 1300 °C and t_{CH_4} = 0 °C and 600 °C, with the results listed in Table 1 [1].

The table shows that methane combustion products have caloric content that increases with the temperature of preheat of air and methane.

By burning carbon from the coke in front of the air vents with a humidity of 1% results per 1 kg C: CO = 1.867 Nm^3; H_2 = 0.044 Nm^3; N_2 = 3.429 Nm^3, respectively a volume of combustion products V_g = 5.340 Nm^3.

Table 1. *Caloric content of methane-burning products* [1]

Temperature, °C		kcal/Nm^3 CH_4
Air	**Methane**	
1 000	0	1 127.44
1 100	0	1 213.75
1 200	0	1 301.09
1 300	0	1 389.09
1 000	600	1 454.24
1 100	600	1 538.55
1 200	600	1 637.79
1 300	600	1 713.89

Calculation of the theoretical carbon-burning temperature of the coke at the window holes is done with the relation [4]:

$$2340 + Q_v + Q_c - Q_{H2O} = C_0 \cdot V_g \cdot t \qquad (3)$$

in which:

2340 is the heat resulting from the combustion of carbon at CO, kcal/kg C;
Q_v - combustion air enthalpy, kcal/Nm^3 CH_4;
Q_c - carbon enthalpy that gets in front of the wind, kcal/kg C;
Q_{H2O} - the heat of dissociation of water vapor from the combustion air, kcal/kg C;
C_o - the average specific heat of diatomic gases, kcal/Nm^3 °C.

The normal combustion temperature, which results in the use of pre-heated air at 600 °C, without the insufflation of methane, is t = 1952 °C.

The enthalpy of CO and H_2 air methane combustion products, considered at temperature t = 1952 °C, is [4]:

$$q_2 = V_g \cdot C_o \cdot t,\ \text{kcal/Nm}^3\ CH_4$$
$$q_2 = 3336.6\ \text{kcal/Nm}^3\ CH_4$$

If the value of enthalpy q_2 is entered in relation (1), it follows [1, 4]:

$$m = \frac{860}{3336{,}6 - q_1} \text{Nm}^3\text{CH}_4/\text{kWh} \qquad (4)$$

By entering in the relation (4) the values in Table 1, the variation in the theoretical amount of methane possible to be introduced into the furnace due to electricity is obtained (Fig. 1).

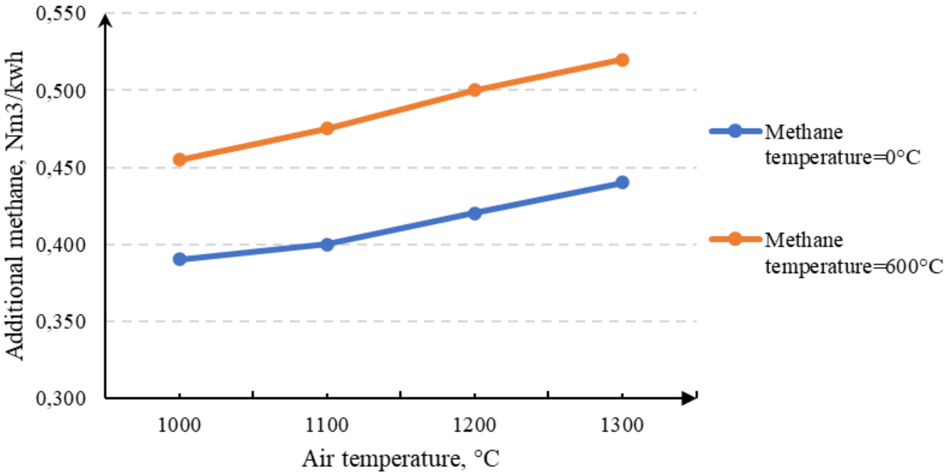

Fig. 1. *Variation in the theoretical amount of methane possible to insert into the furnace due to electricity* [1]

Figure 1 shows that the efficiency of the use of electricity in smoke increases with the temperature of air and methane. This is explained by the increased enthalpy of methane combustion products, which leads to a reduction in the need for electric heat for the introduction of an equal amount of extra methane into the furnace.

For the conditions of the calculation, it follows that for methane at a temperature of 0 °C, an additional 0.389 to 0.442 Nm^3 CH_4/kWh and for methane preheated at 600 °C, between 0.457 and 0.530 Nm^3 CH_4/kWh may be introduced.

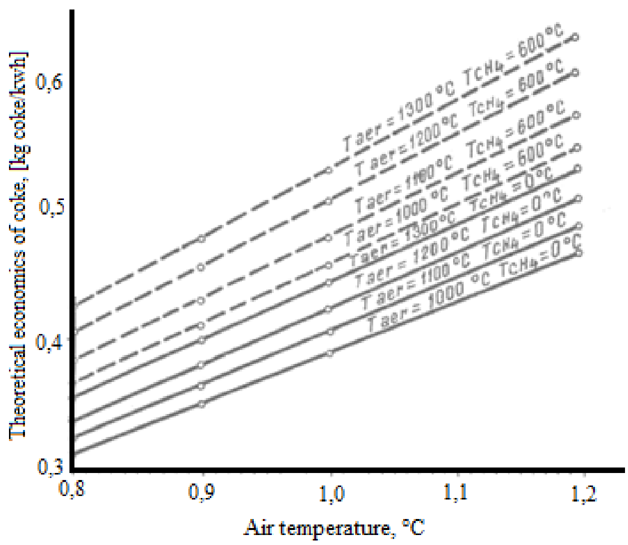

Fig. 2. *The variation in the theoretical coke economy, which can be obtained in kg/kWh, depending on the methane substitution index of coke, for different air and methane temperature values* [2]

The theoretical coke economy that can be obtained by using electricity in smoke is determined by the relation [5]:

$$k = i \cdot m, \text{ Kg/kWh} \quad (5)$$

in which:

i - is the acceptable replacement ratio of 0.8 to 1.2 kg/Nm^3 CH_4;

m - additional introduced methane, Nm^3/kWh;

k - quantity of coke, kg.

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When determining the actual electricity consumption (from the grid), account shall be taken of the electricity efficiency used.

Figure 2 shows the additional theoretical economic variation of coke that can be obtained, in kg/kWh, depending on the replacement index.

The additional methane consumption depends on the replacement index between 1.25 and 0.83 Nm^3 CH_4/kg of saved coke.

The additional heat that can be obtained by Joule effect in the wind-mouth area is thermally equivalent to overheating of the insufflation air. The equivalent temperature increase is determined with the relation [1, 4]:

$$t = \frac{860 \cdot E \cdot \eta}{C_i \cdot V} \quad (6)$$

in which:

η is the efficiency of the electrical installation (0.8 to 0.9);

E - specific electricity consumption in kWh/t cast iron, which is determined with the relation [2, 5]:

$$E = \frac{k}{\eta \cdot i \cdot m} \quad (7)$$

C_i - the average specific heat of the air at the insufflation temperature, kcal/Nm^3·°C;

V - the amount of air in cast iron Nm^3/t, which is calculated with the relation [2, 5]:

$$V = 4{,}300 \cdot \left(a \cdot \frac{K}{100} - C_{df}\right) + 2{,}348 \cdot M \quad (8)$$

in which:

K is the specific consumption of technical coke under the studied regimes, kg/t cast iron;

a - fixed carbon content in coke, %;

C_{df} - carbon from coke to be consumed for direct reduction and carburizing of cast iron, kg/t cast iron;

M - specific consumption of additional methane at the studied regime Nm^3/t cast iron.

It is preferable that before the application of the electric intensification of the operation of the furnaces, the classical ways of reducing the specific consumption of coke are practically exhausted, while raising the temperature of the hot air regime to the maximum value compatible with the construction of the capers and the normal operation of the furnace.

3. Experimental part

Due to the lack of experimental data on the introduction of electrical energy through wall electrodes into vertical-melting-vats furnaces, as well as the electrical characteristics of the charge in the crucible of the furnace, the experimental approach to the problem was made in this direction. The studies were done at a 250 m^3 furnace, where the possibility of introducing electricity through the body of the window holes and the mass of liquid cast iron from the crucible of the furnace was investigated.

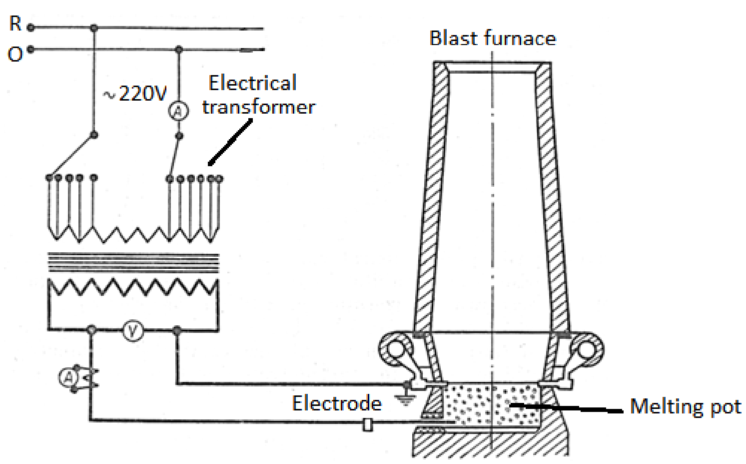

Fig. 3. *Experimental installation scheme*

Prior to the installation of the electrical energy installation, experiments were carried out that did not require any significant technological changes. It was investigated the possibility of passing electric current through the crucible material between the plane of the windpipe and the cast iron bath, respectively an electrode in contact with it, inserted through the cast iron outlet. The electrode was made up of a steel bar of 25 mm and 3 m long inserted through the plug of the cast iron outlet and located about 25 cm in length in contact with liquid cast iron.

The scheme of the installation is shown in Figure 3.

Electrical measurements have shown that the plug mass has sufficient electro-insulating characteristics so that short-circuit current losses between the metal electrode and the furnace mantle through the plug mass are very small.

After the discharge of the cast iron from the furnace, the metal electrode was knocked through the centre of the outlet plug of the cast iron, until it entered the cast iron bath. The transformer was then connected to the grid and by adjusting the voltage stages the current intensity and the power output in the system varied. The measurements tracked the current in the primary circuit of the transformer and the voltage and current in the transformer secondary.

The results are shown in Table 2, which refers to the phase of gradual voltage reduction.

According to the data in Table 2 recorded after the experiments, under the conditions given at the furnace it can be said that it is possible to directly introduce electricity into the crucible, the crucible load having electrical resistance properties that allow the application of an additional electric heating.

Table 2. *Experiments to introduce electrical energy into the crucible*

Voltage stage of transformer	Intensity (A)		Secondary voltage U_2 (V)	Electrical power (kW) I_2 U_2 (pt.cos φ=1)	Electrical resistance of the load in the crucible of the furnace
	Primary I_1	Secondary I_2			
8/8	190	1440	25	36.0	0.017
8/0	135	1120	21	23.5	0.018
7/0	70	850	17	14.6	0.020
6/0	50	720	14	10.5	0.019
5/0	10	580	11	6.4	0.019
4/0	-	500	10	5.0	0.020
3/0	-	448	9	4.1	0.020
1/0	-	408	8	3.3	0.020

4. Conclusions

The electric intensification of the operation of the furnace keeps unchanged the basic characteristic of this steel aggregate to use mainly heat energy obtained by burning coke.

The use of electricity is limited, up to consumption of the order of 100 kWh/t cast iron and aims only at a reduction in the specific consumption of coke on account of the increase in the amount of auxiliary fuel inked through the window wings.

The calculations show that when using methane as an auxiliary fuel it is possible to achieve a coke saving of the order of 0.3 to 0.6 kg/kWh, depending on the temperature of the air and the methane-inspired blast furnace and the methane-coke replacement ratio.

The experiments carried out indicated that at the furnace where the research was carried out, the crucible’s load has properties that allow the application of electric overheating by Joule effect.

Economically, large fluctuations in the price of coke on the world market, with price fluctuations sometimes reaching very high values, ensure a sufficient margin of profitability of the studied process and justify the research carried out in this direction.

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