COMPARATIVE ANALYSIS OF THE POSIBILITIES OF DECREASING COKES CONSUMPTION IN FURNACES BY PARTIALLY REPLACING IT WITH AUXILIARY FUELS

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For the sector of elaborating iron in the furnace, the metallurgical coke represents the raw material that is the most expensive and the most deficient. The purpose of this paper is to present the comparative analysis of the possibilities of decreasing the cost for manufacturing iron by partially replacing coke with another carbon carrying material, auxiliary fuel, which is more available and cheaper.

Keywords: siderurgy, iron, metallurgical coke, auxiliary fuels, coal powder

1. Introduction

It is unanimously accepted by all specialists in the siderurgy industry that steel cannot be only obtained from recycled scrap iron [2][3][4], due to the fact that in the recycling process residual elements, harmful to steel, represented by sulfur, phosphorus are being accumulated and they result in a downgrade of steel. In the load, there will be always quantities of fresh steel required, iron that resulted from liquid iron, solid iron or sponge iron, materials obtained from iron ore and coke at the reduction from the first fusion. For the industry of elaborating first fusion iron in the furnace the metallurgical coke is the material that is the most expensive and the most deficient. Iron cannot be obtained in the furnace without coke; in the cost price of obtaining iron, the coke represents 50%. Regarding the role of bringing carbon inside the furnace, coke can be partially replenished by other auxiliary fuels (coal dust, methane gas, tar, heavy fuel oil) [7][8].

2. Research methodology

The comparative analysis of the technological options of decreasing the specific coke consumption by replacing it with various auxiliary fuels is presented in the technological schemes and the mass balance for the various options of replacing coke through auxiliary fuels are represented graphically in the drawings 1-8 with their own interpretations [1].

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The technological and commercial effects of each option of replacing coke by other auxiliary fuels are highlighted by the result from calculating the total energy consumption (physical coke and replaced coke) presented in the tables 1-8 [1]. These values have been set by technological calculation, considering the standard technical coke specific consumption option:

$$K_t = 600\, kg/t\, iron$$

$$C_{fix} = 85\%$$

$$C_{kt} = \frac{85}{100} \cdot 600 = 510\, kgC/t\, iron$$

From the 510 kg /t carbon brought by coke, 68% will be gasified at the tuyeres:

$$510 \times \frac{68}{100} = 346{,}8\, kgC_{k\,agv}/t\, iron$$

$C_{k\ agv}$/t iron represents the ratio carbon from gasified coke at the tuyeres per 1 tonne of iron.

For a non-dimensional interpretation of the results, without being limited to a certain volume or a specific productivity of the furnace, all the data in the Figs. 1-8 are reported at 1 kg C from the gasified coke at the tuyeres.

Standard option:

$$Coal: 1.528\, kg/kgC_{k\,agv}$$

$$1.528 \times 346.8 = 529.91\, kg/t\, iron$$

$$\Delta_{coke} = 1{,}1376 - 0{,}645 = 0{,}4926\, kgCC$$

$$0{,}4926 \times 346{,}8 = 170{,}83\, kg\, coke$$

$$\Delta_{coke} = 1{,}1376 - 0{,}645 = 0{,}4926\, kgC_{k\,agv}$$

$$replaced\, coke: 170.83\, kg/t\, iron$$

$$used\, coke: 429.17\, kg/t\, iron$$

$$The\, 170.83\, kg/t\, iron\, are\, replaced\, by\, 0.340 \times 346.8 = 117.98\, kg/t\, coal\, and$$

$$obtaining\, CO_2\; 0.317 \times 346.8 = 109.93\, CO_2\, Nm^3/t\, iron$$

3. Results

The results of the comparative analysis are represented by the technological schemes of the mass balances and the calculation of the energy consumption for the various options of replacing coke with the auxiliary fuels.

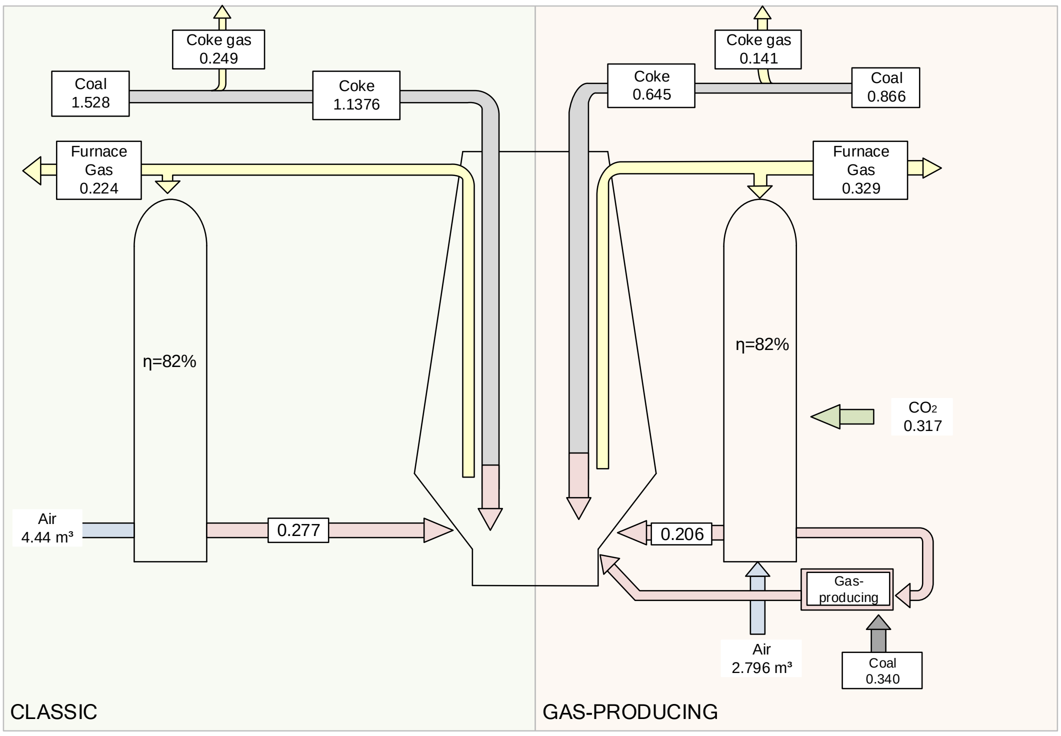

Fig. 1. Energy consumption in the case of injecting in the furnace, at the tuyeres, the reducing gasses from coal and CO_2 [1]

Table 1

The results of the energy consumption calculation in the case of injecting in the furnace, at the tuyeres, of the reducing gasses from coal and CO_2 [1]

Kg c.c.	Coke consumption standard option	Coke consumption at the partial replacement option		
		GAS-PRODUCING	FURNACE	TOTAL
Input				
Coal	1.528	-	0.886	0.866
Energetic coal	-	0.340	-	0.340
Milling	-	0.010	-	0.010
CO_2 m.c.	-	0.331	-	-
TOTAL	**1.528**			**1.216**
Output				
Coke gas	0.249	-	0.141	0.141
Furnace gas	0.224		0.329	0.329
TOTAL	**0.473**	**-**	**-**	**0.470**
Difference	**1.055**	**-**	**-**	**0.746**

The effect of the proposed option:

$$\Delta_{coal} = 1.1376 - 0.645 = 0.4926\ kg\,c.c.$$

$$\Delta_{totalenergy} = 0.473 - 0.470 = 0.003\ kg\,c.c.$$

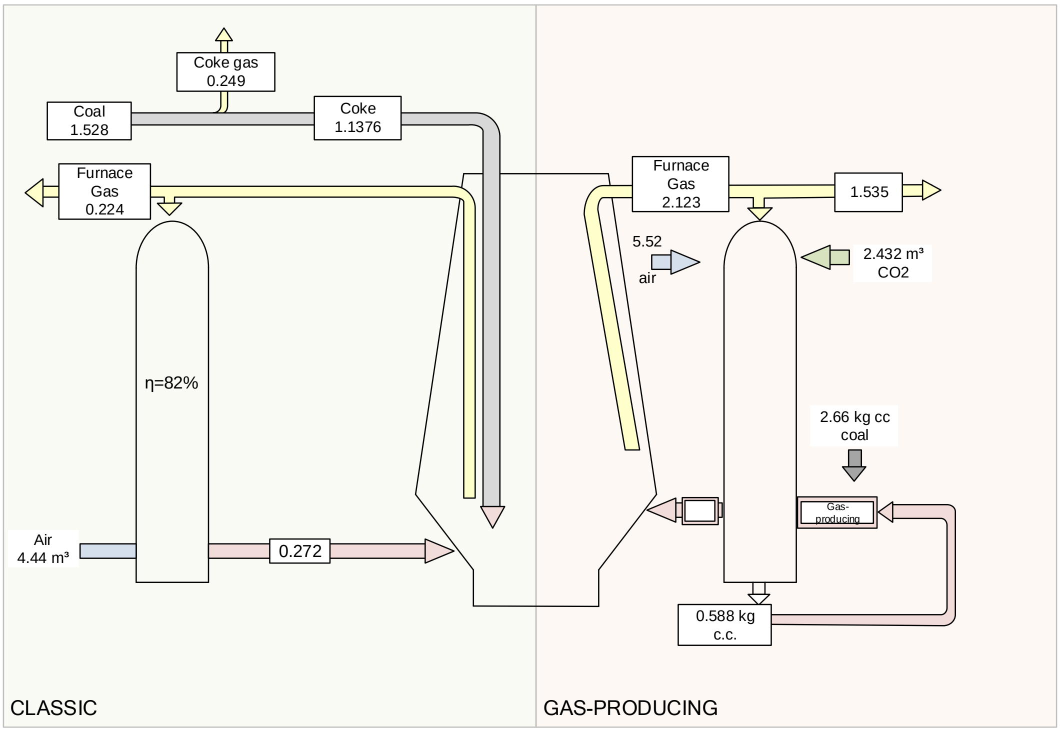

Fig. 2. Energy consumption in the case of injecting in the furnace, at the bottom of the shaft, the reducing gasses from coal and CO_2 [1]

Table 2

The results of the energy consumption calculation in the case of injecting in the furnace, at the bottom of the shaft, of the reducing gasses from coal and CO_2 [1]

Kg c.c.	Coke consumption standard option	Coke consumption at the partial replacement option		
		GAS-PRODUCING	FURNACE	TOTAL
Input				
Coal	1,528	-	-	-
Energetic coal	-	2,660	-	2,660
Milling	-	0,080	-	0,080
CO_2 m.c.	-	(2,430)	-	-
TOTAL	**1,528**			**2,740**
Output				
Coke gas	0,249		-	-
Furnace gas	0,224		1,535	1,536
TOTAL	**0,473**			**1,536**
Difference	**1,055**			**1,204**

The effect of the proposed option:

$$\Delta_{totalenergy} = 0.473 - 1.536 = -1.063\, kg c.c.$$

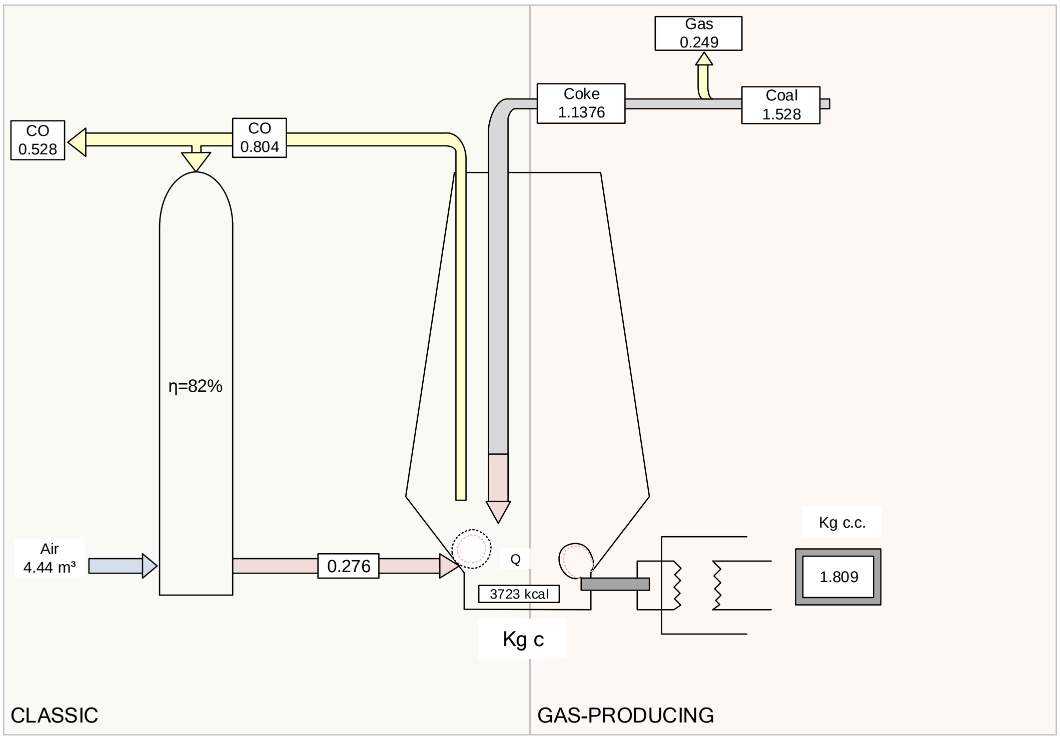

Fig. 3. Energy balance of replacing with electric energy [1]

Table 3

The result of the energy balance calculation of replacing coke with electric energy [1]

Kg c.c.	Coke utilized	Electric energy utilized
Input		
Coal	1,528	1.809
Output		
Coke gas	0.249	-
Furnace gas	0.528	-
Net Consumption	**0.751**	**1.809**

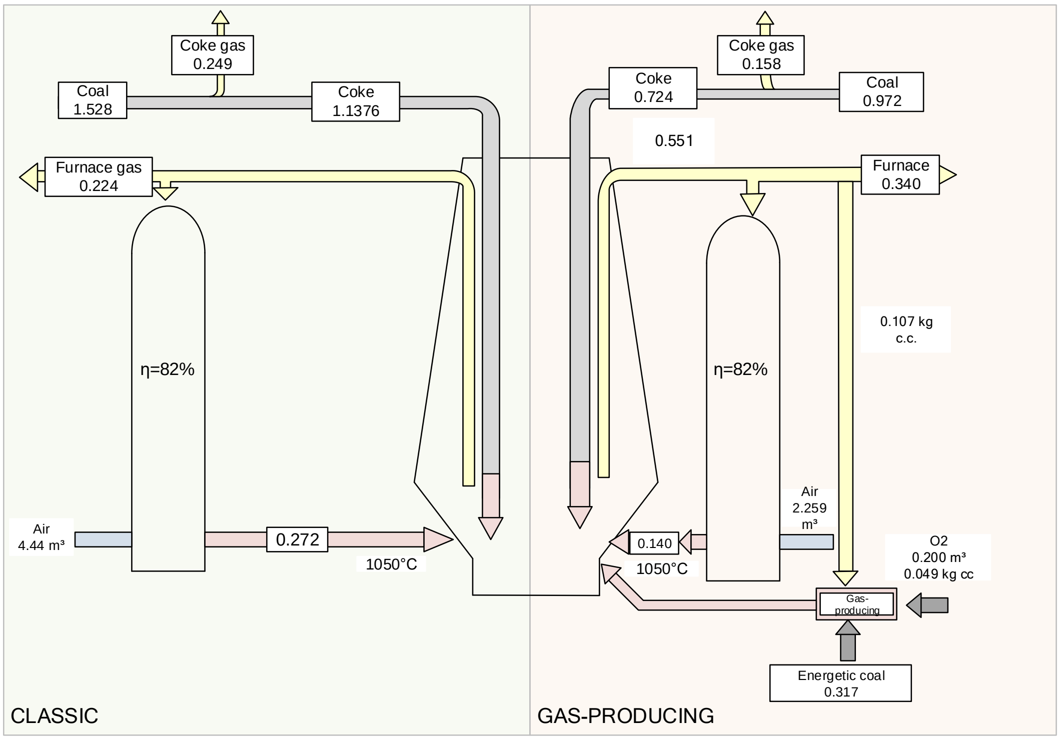

Fig. 4. Energy consumption (kg c.c.) at the injection of gasified coal with O_2 through the furnaces tuyeres [1]

Table 4

The results of the energy consumption calculation (kg c.c.) in the case of injecting gasified coal with O_2 through the furnaces tuyeres [1]

Kg c.c.	Coke consumption standard option	Coke consumption at the partial replacement option		
		GAS-PRODUCING	FURNACE	TOTAL
Input				
Coal	1.528	-	0.972	0.972
Energetic coal	-	0.317+0.049(O_2)	-	0.366
Milling	-	0.009	-	0.009
TOTAL	**1.528**	**-**	**-**	**1.347**
Output				
Coke gas	0.249	-	0.158	0.158
Furnace gas	0.224	-	0.340	0.340
TOTAL	**0.473**	**-**	**-**	**0.498**
Difference	**1.055**	**-**	**-**	**0.849**

The effect of the proposed option:

$$\Delta_{coal} = 1.1376 - 0.724 = 0.4136\ kg\,c.c.$$

$$\Delta_{totalenergy} = 0.473 - 0.498 = 0.025\ kg\,c.c.$$

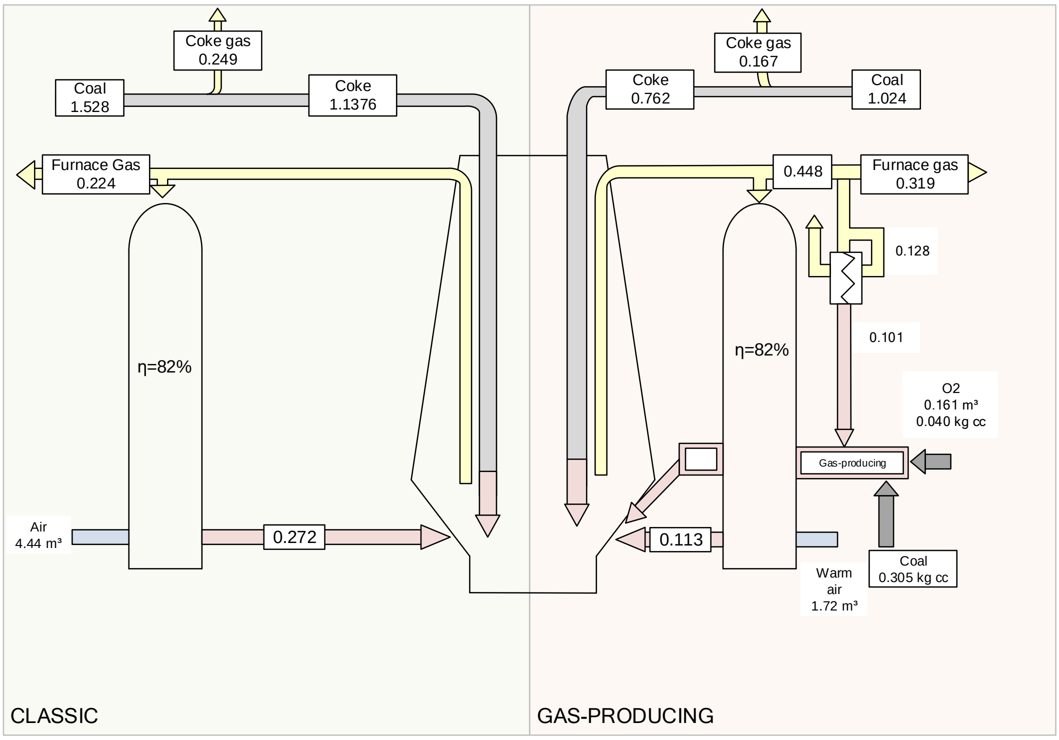

Fig. 5. Injecting at the tuyeres the gas-producing gasses obtained with O_2 and pre-heated furnace gas [1]

Table 5

The results of calculation of injecting at the tuyeres the gas-producing gasses with O_2 and pre-heated furnace gas [1]

Kg c.c.	Coke consumption standard option	Coke consumption at the partial replacement option		
		GAS-PRODUCING	FURNACE	TOTAL
Input				
Coal	1.528	-	0.975	0.975
Energetic coal	-	0.301+0.037	-	0.338
Milling	-	0.009	-	0.009
TOTAL	**1.528**	**-**	**-**	**1.322**
Output				
Coke gas	0.249	-	0.159	0.158
Furnace gas	0.224	-	0.382	0.382
TOTAL	**0.473**	**-**	**-**	**0.541**
Difference	**1.055**	**-**	**-**	**0.781**

The effect of the proposed option:

$$\Delta_{coke} = 1.1376 - 0.762 = 0.3756\ kg c.c.$$

$$\Delta_{totalenergy} = 0.473 - 0.541 = -0.068\ kg c.c.$$

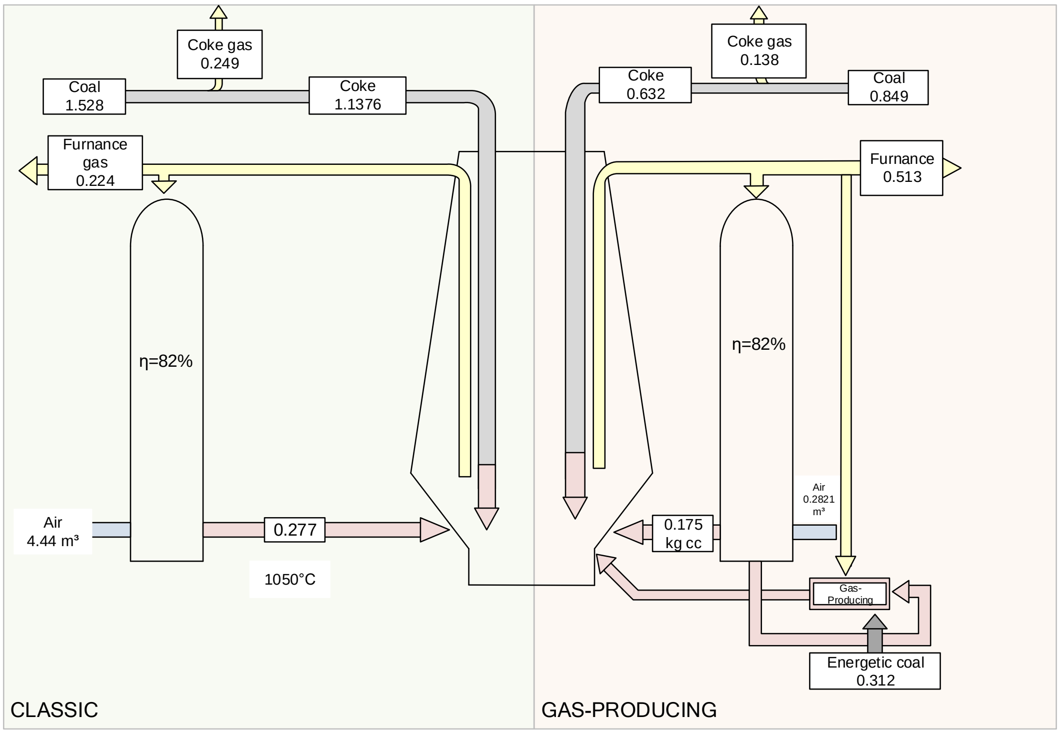

Fig. 6. Energy consumption (kg c.c.) at the injection of the gasified coal with air and cold furnace gas [1]

Table 6

The results of calculation of energy consumption (kg c.c.) at the injection of the gasified coal with air and cold furnace gas [1]

Kg c.c.	Coke consumption standard option	Coke consumption at the partial replacement option		
		GAS-PRODUCING	FURNACE	TOTAL
Input				
Coal	1.528	-	0.849	0.849
Energetic coal	-	0.312	-	0.312
Milling	-	0.011	-	0.011
TOTAL	**1.528**	**-**	**-**	**1.172**
Output				
Coke gas	0.249	-	0.138	0.138
Furnace gas	0.224	-	0.513	0.513
TOTAL	**0.473**	**-**	**-**	**0.651**
Difference	**1.055**	**-**	**-**	**0.521**

The effect of the proposed option:

$$\Delta_{coke} = 1.1376 - 0.632 = 0.5056\ kg c.c.$$

$$\Delta_{total energy} = 0.473 - 0.651 = -0.178\ kg c.c./kg coke$$

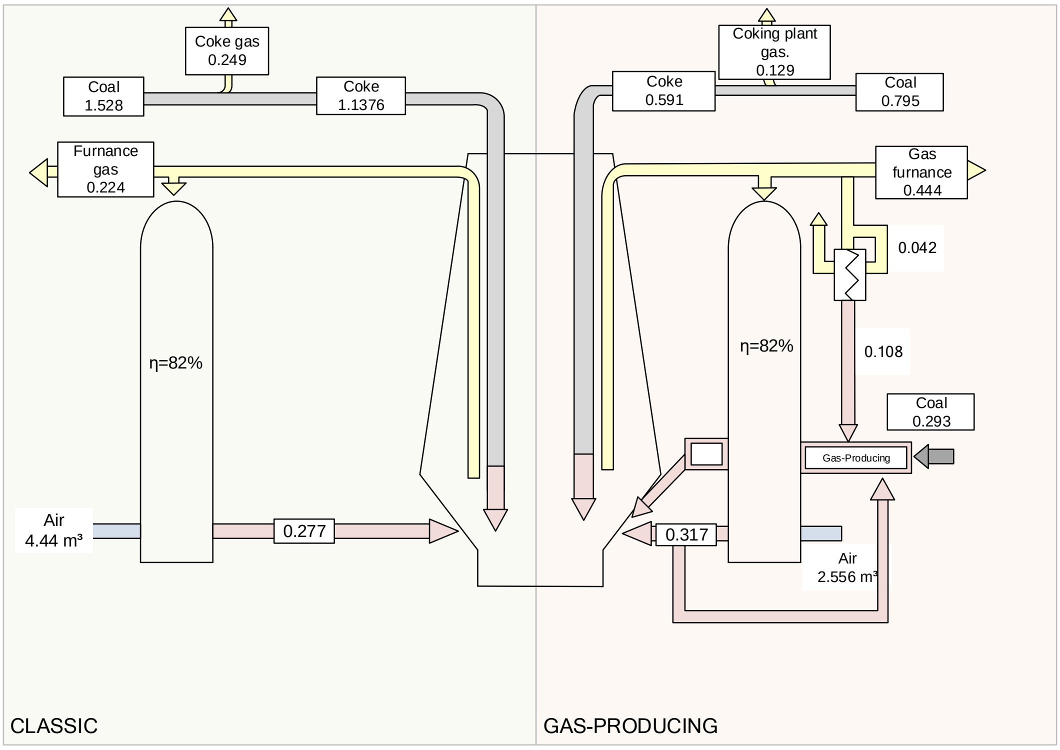

Fig. 7. Energy consumption (kg c.c.) at the injection of the gasified coal with air and pre-heated furnace gas [1]

Table 7

The results of calculation of energy consumption (kg c.c.) at the injection of the gasified coal with air and pre-heated furnace gas [1]

Kg c.c.	Coke consumption standard option	Coke consumption at the partial replacement option		
		GAS-PRODUCING	FURNACE	TOTAL
Input				
Coal	1.528	-	0.795	0.795
Energetic coal	-	0.293	-	0.293
Milling	-	0.009	-	0.009
TOTAL	**1.528**	**-**	**-**	**1.097**
Output				
Coke gas	0.249	-	0.129	0.129
Furnace gas	0.224	-	0.444	0.444
TOTAL	**0.473**	**-**	**-**	**0.573**
Difference	**1.055**	**-**	**-**	**0.524**

The effect of the proposed option:

$$\Delta_{coke} = 1.1376 - 0.591 = 0.5466\ kg\,c.c.$$

$$\Delta_{totalenergy} = 0.473 - 0.573 = -0.100\ kg\,c.c.$$

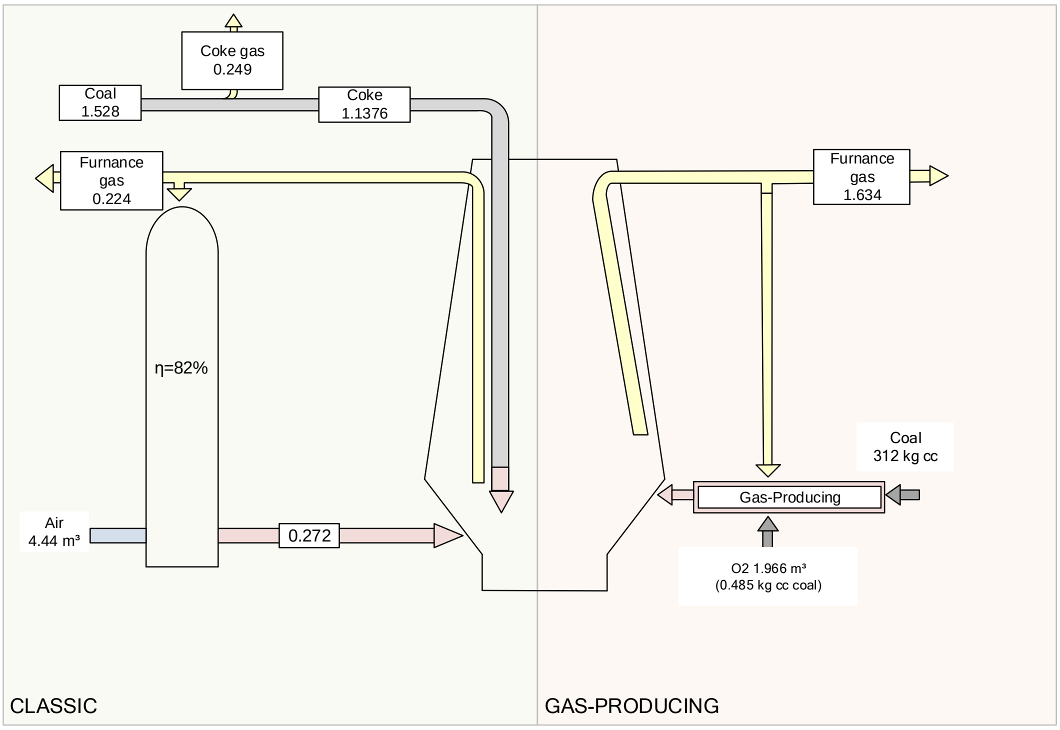

Fig. 8. Injecting at the shaft of the reducing gas obtained from coal and oxygen (cold furnace gas) [1]

Table 8

The results of injecting at the shaft of the reducing gas obtained from coal and oxygen (cold furnace gas) [1]

Kg c.c.	Coke consumption standard option	Coke consumption at the partial replacement option		
		GAS-PRODUCING	FURNACE	TOTAL
Input				
Coal	1.528	-	-	-
Energetic coal	-	3.120+0.485	-	3.605
Milling	-	0.071	-	0.071
TOTAL	**1.528**	**-**	**-**	**3.676**
Output				
Coke gas	0,249	-	-	-
Furnace gas	-	-	1,634	1,634
TOTAL	**0,249**	**-**	**-**	**1,634**
Difference	**1,279**	**-**	**-**	**2,024**

4. Conclusions

Analyzing the results of the calculation of the mass and energy balance presented in the Fig. 1-8 and Tables 1-8, can be observed the multitude of technological possibilities of partially replacing, in technological and technical limits, a quantity of coke with another auxiliary fuel. In all the analyzed options it is obvious that by replacing coke, expensive and deficient, with other sources of carbon available in bigger quantities, direct (methane gas, tar, steam, coal dust, pitch) or after a nonconventional technological process (warm or cold gas-producing gas obtained by gasifying coal, cold or pre-heated furnace gas, gas from coking plant etc.) the economic effects shall be beneficial. If the purpose is to decrease the quantities of physical technical coke with injected pulverized coal at the tuyeres with cold or warm carrier gas, the partial replacement of the coke with gas-producing gas obtained by gasifying the coal with oxygen or CO_2 introduced at the tuyeres, no matter what the quantity of the coal gasified is, but from an environment point of view the best option is the replacement from gasifying coal from coke with and equivalent quantity of thermic energy obtained from electric energy from ecological sources.

With regard to the role of carbon in the furnace, if coke can be partially supplied by other auxiliary fuels (coal dust, methane gas, tar, pitch), other roles of the coke in the furnace cannot be supplemented by other materials. For this reason, metallurgical coke is vital to obtaining "fresh iron" in the furnace, serving as a raw material for the production of steel, without which the development of human society is not possible [4].

Because the role of coke in the furnace is not only to bring the carbon necessary for the oxides reduction and carbonation reactions of the freshly obtained iron, coke plays an important role in supporting the load column, being the only material that goes through the furnace, from the tuyeres, the whole route in solid state. Another important role of the coke is to ensure the upward flow of the gaseous phase throughout the furnace height, the permeability of the coke to the circulation of the gaseous phase being given by the internal porosity of the coke pieces, as well as the voids between the coke pieces

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