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REHEATING FURNACES IN THE STEEL INDUSTRY: UTILIZATION OF COMBUSTION GASES FOR LOAD PREHEATING AND COMBUSTION AIR PREHEATING USING COG, LDG AND BFG AS PROCESS GASES

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Abstract. *In the steel industry, reheating furnaces are the main energy consumers and it is estimated that furnaces use 67% of the total energy. The reheating furnace of the steel industry was studied, which uses the gas mixture from coke oven (COG), steelmaking process "Linz-Donawitz" (LDG) and blast furnace (BFG); with the production of steel laminates being its main activity. In this work to deal with energy consumption, a methodology was developed to recover the heat from the combustion gases and its use in load preheating and combustion air preheating. This evaluation was intended to obtain an economy in fuel consumption, and to improve technical energy indicators of production and heat generation, as well as to improve the efficiency of the furnace and the combustion process. When developing the present study in the reheating furnace it was evidenced an economy in the fuel consumption of the COG/LDG mixture of 6606 m^3/h and 4627 m^3/h for the load preheating and the air preheating, respectively. In addition, efficiency of the furnace was increased by 23.3% and 15.2%, with the technical energy indicators improved by 18.9% and 13.2% in each case. For the COG/BFG mixture, the results obtained were similar.*

Keywords: *combustion air preheating, heat recovery, load preheating, reheating furnace, steel industry.*

1. INTRODUCTION

In the steel industry the reheat furnace is used to heat slabs, parts, forging tasks and for the heat treatment of rolled steel, as iron is subjected to several thermal, mechanical or thermomechanical processes suitable for industrial applications (Casal *et al.*, 2015; Morgado *et al.*, 2015).

The energy consumption of reheating furnaces depends to a large extent on several factors such as production speed, furnace size, steel quality, and reheating temperature. However, there is a great contradiction between the depletion of traditional energy and the high use of energy. In other words, while non-renewable energy sources are depleted, the steel industry is not affected and continues to consume a large amount of energy (Hu *et al.*, 2017).

The consumption of energy of reheat furnace is important for several reasons: first because has an influence on combustion gas emissions; secondly, it is an important cost engine, which is subject to strict modifications; thirdly, it can indirectly influence in the quality of the product; and fourthly, it can influence furnace system wear (Chen *et al.*, 2005). Like the refrigeration industry, they are large consumers of energy. In the steel industry, control strategies must be established that lead them to a framework of competitiveness and efficient production (Mariños *et al.*, 2019).

Increased emissions of pollutants into the environment and the cost of industry are some of the consequences due to the great consumption of energy by the reheating furnaces (Rasul *et al.*, 2007). The steel industry is known as one of the world's leading CO_2 emissions sectors, accounting for approximately 7% of the total, emitting an average of 1.8 tons of CO_2 for every ton of steel produced. China is the country that emits the most CO_2 in the world with about 10 Gt of CO_2 per year, USA is the second with 5 Gt of CO_2 per year and India is the third CO_2 emitter that produces approximately 2

Gt of CO_2 per year. Brazil is in the eleventh position with about 530 million tons of CO_2 per year. Other pollutant gases in this industry include NO_x and SO_2 (An *et al.*, 2018).

Many works have been developed to reduce energy consumption in industrial furnaces. The development for optimal energy savings included mainly works that determine energy consumption and losses in the reheating furnace, and the use of several heat recovery techniques for the load preheating, and air preheating. Among the studies that used the several heat recovery techniques, such as the load preheating, was the work presented by Oh et al. (2015); and in the combustion air preheating, the work of Nishimura et al. (1997); Tu et al. (2017); Bu et al. (2019).

The purpose of this research is to reduce energy consumption, considering the recovery of heat from combustion gases for the preheating of the load and the preheating of the combustion air, with the purpose of comparing both results and obtaining energetic improvements such as the recovered heat, saving fuel, efficiency and energetic indicators of the reheating furnace. The utilization of the remaining heat in the combustion gases is a current research theme for its versatility with respect to fuel economy.

2. MATERIAL AND METHOD

2.1 System components for the production of steel plates

The hot strip rolling of the steel industry located in the state of Espiritu Santo/SP - Brazil has 2 reheating furnaces of mobile beam steel plates with a capacity of 490 tons per hour of nominal production, each supplied with mixed gas. The furnace and the system components for the production of steel plates will be analyzed, as well as the burning time of the burners, the features of heat recovery and combustion air. In addition, the mixture and process gases from the coke oven (COG), steelmaking process known as Linz-Donawitz (LDG) and blast furnace (BFG) used in the reheating furnaces of the steel industry are presented (Mariños *et al.*,2020a, 2020c).

2.1.1 Walking beam reheating furnaces

The furnace basically contains four regions (preheating, heating 1, heating 2, and soaking) divided into 9 burner zones, as shown in Fig. 1. In addition, it has a chimney stove to take advantage of the combustion gas heat.

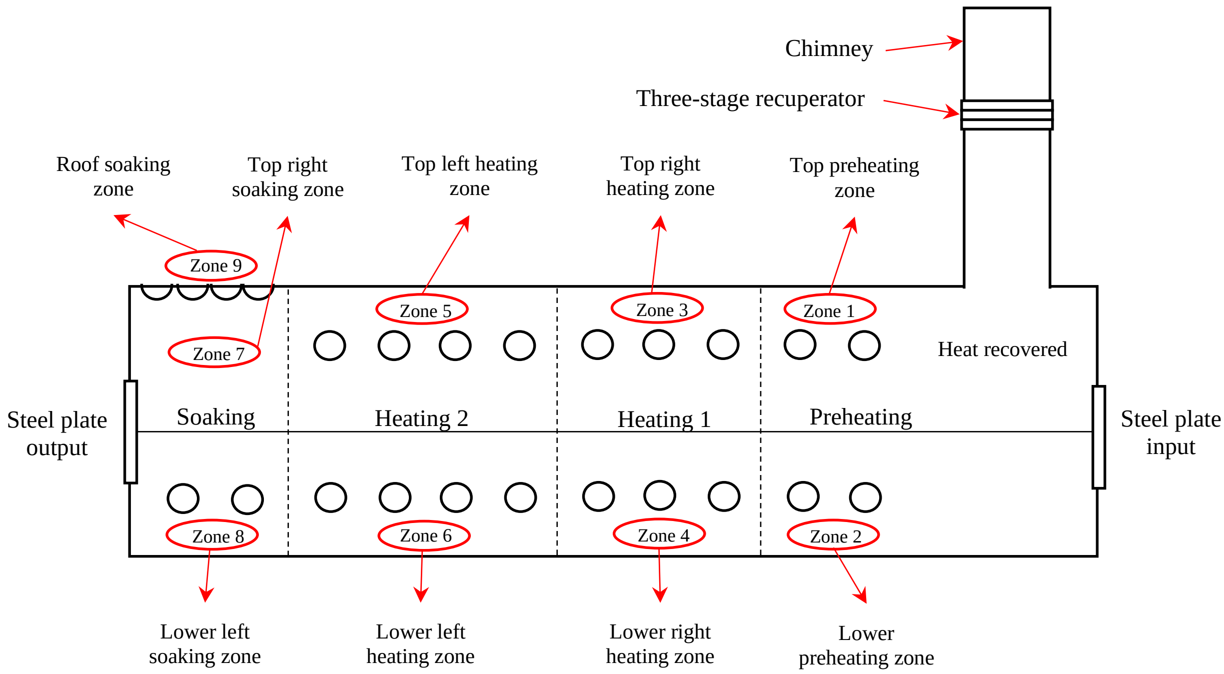

Figure 1. Distribution of regions and zones in the walking beam reheating furnace.

Fuel is a mixture of process gases from coke oven (COG), steelmaking process (LDG), and blast furnace (BFG). The mixture among them is as follows: COG/BFG and COG/LDG, which is distributed over the 20 pairs of burners. Combustion gases flow countercurrent with respect to plate displacement. A heat exchanger promotes heat exchange between combustion gases and air, so that the latter is supplied heated for fuel combustion. The air inlet shown in the smoke duct serves to promote where necessary a temperature decrease of the combustion products to values compatible with the heat exchanger materials.

The furnace studied is characterized by having mobile beams and flat roof with upper and lower burners. The upper and lower zones are equipped with side burners, some of them of modular flow. Some zones are equipped with "process" burners that make it possible to optimize the heating quality according to production.

2.1.2 Burner Characteristics

The furnace consists of 20 pairs of burners distributed between zones 1, 2, 3, 4, 5, 6 and 8, as shown in Fig. 2.

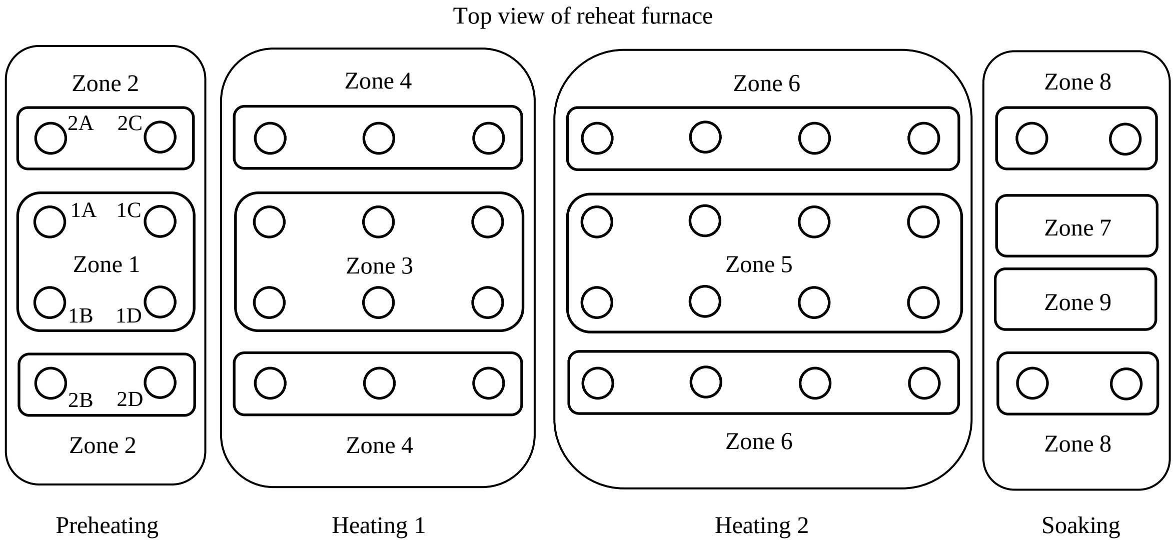

Figure 2. Burner distribution by zone in the steel plate reheating furnace.

Burners in all areas use air heated by the stove and mixed gas. Zones 6 and 8 have burners that can have long or short flame. This selection is made by the air inlet, which can be primary or secondary. The other burners only have primary air intake (Heurtey, 2000). Table 1 describes the models, quantity and maximum capacity of the burners in each furnace zone.

Table 1. Distribution and maximum capacity of burners by zone in the reheat furnace.

Zone	Series	Type	Quantity	Total capacity (kW)	Capacity per burner (kW)
1	SH WFB.G3	wide flame burners	4	7420	1855
2	SH WFB.G4	wide flame burners	4	9870	2468
3	SH WFB.G7	wide flame burners	6	27190	4532
4	SH WFB.G7	wide flame burners	6	25780	4297
5	SH WFB.G7	wide flame burners	8	32160	4020
6	SH WFMB.G10	wide flame modulating burners	8	40740	5093
7	SH BFP.G5	flat flame burners	11	2954	231
8	SH WFMB.G9	wide flame modulating burners	4	10360	2590
9	SH BPB.G5	flat flame burners	10	2686	231

The number of open burners and the opening time depends on demand. The burners are fired (or not) in 60 second cycles, in other words, every 60 seconds the control system sends a command to fire a pair of burners and for how many seconds it must remain fired. This means that within 60 seconds the 20 pairs of burners must receive a command from the control system, so every 3 seconds a pair of burners receives an instruction from the controller to start (or remain off) according to furnace heat demand. The operating time of each pair of burners depends on the energy they need to deliver to the furnace. For safety purposes, burners that do not have a pilot flame can only operate when the temperature inside the furnace is higher than 580 °C, to avoid the injection of unburned fuel that could cause an explosion.

2.1.3 Production of steel plates

The plates enter the furnace at different temperatures, ranging from environmental temperature to 800 °C and are transported inside by a mobile beams system (Mariños *et al.*, 2020c). The characteristics of the steel plates are presented in Tab. 2.

Table 2. Characteristics of the products to be heated in the reheating furnace.

Parameters	Loaded carbon steel slabs	Loaded stainless steel slabs (AISI 304, 304L)	Units
Temperatures	27 – 800	27 – 800	°C
Length in two lines	4500 – 5500	-	mm
Length in one line	5500 – 11500	10500 – 11500	mm
Width	750 – 1955	1040 – 1320	mm
Thickness	200 – 250	200	mm
Reference Slab	250 x 1250 x 11500	200 x 1250 x 11500	mm^3
Slab weight	40	24	t

2.1.4 Features of heat recuperator

The heat recuperator is a device that allows the recovery of part of the energy inside the combustion gases, through the mechanical ventilation system. This is done by means of an exchanger that puts into contact the internal gases that are extracted with the outside air that is introduced, without mixing the fluids of the two circuits (Mariños *et al.*, 2020c). Its characteristics of the heat recuperator are shown in Tab. 3.

Table 3. Characteristics of the heat recuperator in operating condition.

Parameter	Specification	Units
Time	24	h/day
Number of steps	3	-
Exhaust gas temperature at the furnace outlet	865	°C
Exhaust gas temperature at the inlet of the recuperator	815 – 865	°C
Exhaust gas temperature at the outlet of the recuperator	461 – 510	°C
Exhaust gas volume at the inlet of the recuperator	169845	Nm^3/h
Combustion air temperature at the inlet of the recuperator	27	°C
Volume of combustion air at the inlet of the recuperator	131891	Nm^3/h
Combustion air temperature at the outlet of the recuperator	555 – 560	°C
Charging surface by 3 units	2473	m^2
Total weight for the 3 units	72000	kg

2.1.5 Characteristics of process gases

In the steel industry the following mixtures are employed: process gases coke oven (COG), steelmaking process (LDG), and blast furnace (BFG). Mixtures among these gases are also used: COG/BFG or COG/LDG. Sometimes NG is added in low proportion to increase the LHV of the mixture, thus obtaining COG/BFG/NG or COG/LDG/NG mixtures (Mariños *et al.*, 2020b).

Table 4 shows the above-mentioned gases compositions corrected to 100% e the characteristics of COG/LDG and COG/BFG mixed gases used in the steel industry.

2.2 Method to recover heat from combustion gases for the load preheating and the combustion air preheating

Reheat furnaces are used to heat billets prior to the rolling process. The plates to be heated enter the furnace at 200 °C and leave at 1200 °C. The furnace consists of blended gas fired burners with a flow rate of 35000 Nm^3/h and a LHV of 11769 kJ/Nm^3 for the COG/LDG mixture and 9986 kJ/Nm^3 for the COG/BFG mixture.

Recovering heat from combustion gases substantially improves furnace efficiency, and can be used for the load preheating and the combustion air preheating.

2.2.1 Load preheating

Load preheating is an ideal method for heat recovery. It reduces the sensitive heat of the load, lowers the combustion gas temperature on its way to the environment, transforms an intermittent process to continuous process with a better throughput, and substantially reduces fuel consumption.

Table 4. Volumetric compositions of each of the 100% corrected gases used in the reheating furnaces of the steel industry.

Compositions	COG	BFG	LDG	NG	42% COG and 58% LDG	42% COG and 58% BFG
H_2 (%)	51.72	4.50	1.31	0.00	22.49	27.41
CO_2 (%)	3.52	23.50	15.93	1.00	10.72	13.88
C_2H_4 (%)	1.44	0.00	0.00	0.01	0.60	0.77
C_2H_6 (%)	0.43	0.00	0.00	0.00	0.18	0.23
C_2H_2 (%)	0.12	0.00	0.00	4.94	0.05	0.04
H_2S (%)	0.20	0.00	0.00	0.04	0.08	0.06
C_3H_8 (%)	0.42	0.00	0.00	2.16	0.18	0.04
C_4H_{10} (%)	0.02	0.00	0.00	0.01	0.01	0.01
C_5H_{12} (%)	0.01	0.00	0.00	0.93	0.00	0.00
C_6H_6 (%)	0.76	0.00	0.00	0.00	0.32	0.34
C_7H_8 (%)	0.07	0.00	0.00	0.00	0.03	0.03
O_2 (%)	0.42	0.00	0.12	0.01	0.25	0.00
N_2 (%)	14.68	48.00	16.71	1.91	15.85	30.50
CH_4 (%)	19.74	0.00	0.00	88.99	8.29	10.50
CO (%)	6.47	24.00	65.93	0.00	40.96	16.20
LHV (kJ/Nm^3)	16309	8473	9979	38000	11769	9986
HHV (kJ/Nm^3)	18221	8498	10987	41865	12590	10995

2.2.1.1 Determination of load heating temperature

The goal is to make an energy balance between the heat absorbed by the load that is heated from the environmental temperature and the heat produced by the combustion gases from 860 °C. The heat of the load is shown in Eq. (1).

$$\dot{Q}_{load} = \dot{m}_s \, Cp_b \, (T_{f\,s} - T_{i\,s}) \tag{1}$$

$$\dot{Q}_g = \dot{m}_g \, Cp_g \left(T_{i\,g} - T_{f\,g}\right) \tag{2}$$

In addition, we will ensure a temperature gradient between the hot fluid terminals of at least 20 °C:

$$T_{f\,g} = 20\,°C + T_{f\,s} \tag{3}$$

Substituting each of the factors of Eq. (3) into Eq. (2). The result is shown below:

$$\dot{m}_g \, Cp_g \left(T_{i\,g} - (20\,°C + T_{f\,s})\right) = \dot{m}_s \, Cp_b \, (T_{f\,s} - T_{i\,s}) \tag{4}$$

From Eq. (4), the subscripts i and f refer to the initial and final stages.

2.2.1.2 Inlet and outlet heat of the reheating furnace

Given the first law of thermodynamics for open systems without generating work, the process must take into account that the input heats are the same as the output heats.

Heat generated by fuel reaction ($\dot{Q}_1$)

Heat generated by fuel reaction is the heat supplied by the fuel when reacting with the combustion air and is due to its low heating value as defined in Eq. (5).

$$Q_f = LHV \, \dot{m}_f = LHV \, \dot{V}_f \, \rho_f \tag{5}$$

Sensitive heat by load preheating ($\dot{Q}_2$)

Sensitive heat by load preheating is the recovered heat that is transmitted to the load that enters the reheating furnace. The load is preheated to increase its chemical potential and improve combustion efficiency. It is evaluated according to Eq. (6).

$$\dot{Q}_2 = \dot{m}_s\, Cp_s\, (T_{fs} - T_{i\,s}) \tag{6}$$

Heat input to the furnace ($\dot{Q}_{in}$)

The heat contained in the billets is not considered in the equation because it enters at environmental temperature, therefore the heat input to the furnace is equal to Eq. (7).

$$\dot{Q}_{in} = \sum_{i=1}^{n} Q_i = \dot{Q}_1 + \dot{Q}_2 \tag{7}$$

In which sensible heat by preheating the load will replace part of the mixed gas consumption.

Sensitive heat of billets ($\dot{Q}_3$)

Sensitive heat of billets is rated based on the heat used to heat the billets from environmental temperature to the required temperature. It is defined according to Eq. (8).

$$\dot{Q}_3 = \dot{m}_b\, Cp_b\, (T_{fb} - T_{ib}) \tag{8}$$

In which, $\dot{m}_b$ is the billet mass flow.

Heat lost by combustion gases ($\dot{Q}_4$)

It is the heat lost by the combustion gases through the chimney and it is discharged into the atmosphere. The gases are temperature dependent and are evaluated according to Eq. (2).

Other heat losses ($\dot{Q}_5$)

These are losses added to the heat lost from combustion gases, such as heat leaks and the presence of unburned solids and gases. It is presented in Eq. (9).

$$\dot{Q}_5 = \dot{Q}_{in} - (\dot{Q}_3 + \dot{Q}_4) \tag{9}$$

Heat output of the furnace ($\dot{Q}_{ou}$)

The total heat output from the furnace is equal to the sum of the heats shown below in Eq. (10).

$$\dot{Q}_{ou} = \sum_{i=1}^{n} Q_i = \dot{Q}_3 + \dot{Q}_4 + \dot{Q}_5 \tag{10}$$

2.2.2 Combustion air preheating

Combustion air preheating systems take advantage of the temperature of the combustion gases to increase the temperature of the oxidizing air that normally enters at environmental temperature.

2.2.2.1 Determination of air heating temperature

The objective is to make an energy balance between the heat absorbed by heating the combustion air at environmental temperature and the heat produced by the combustion gases from 860 °C.

$$\dot{Q}_a = \dot{m}_a\, Cp_a\, (T_{f\,a} - T_{i\,a}) \tag{11}$$

The heat of the combustion gases is given in Eq. (2) and we equate with Eq. (11):

$$\dot{m}_g\, Cp_g\, \left(T_{i\,g} - T_{f\,g}\right) = \dot{m}_a\, Cp_a\, (T_{f\,a} - T_{i\,a}) \tag{12}$$

In addition, we will ensure a temperature gradient between the hot fluid terminals of at least 20 °C:

$$T_{f\,g} = 20\ °C + T_{f\,a} \tag{13}$$

Substituting each of the factors of Eq. (13) into Eq. (12). The result is shown below:

$$\dot{m}_g\, Cp_g\, \left(T_{i\,g} - (20\ °C + T_{f\,a})\right) = \dot{m}_a\, Cp_a\, (T_{f\,a} - T_{i\,a}) \tag{14}$$

From Eq. (14), $\dot{Q}_a$ is the heat absorbed by combustion air, $\dot{m}_a$ is the mass flow of combustion air. Subscripts i and f refer to the initial and final stages.

The procedure for determining the inlet and outlet heats are the same as those given in section 2.2.2.2, with the difference of $\dot{Q}_2$, which for air preheating will be determined with Eq. (11). In addition, sensible heat by air preheating will replace part of the mixed gas consumption.

2.2.2.2 Indicators of heat recovery

Furnace Efficiency

The furnace efficiency relates the sensitive heat used by the billets and the heat supplied by the fuel. It is evaluated according to Eq. (15):

$$\eta = \left(\frac{\dot{Q}_3}{\dot{Q}_1}\right) 100\% \tag{15}$$

Fuel economy

Fuel economy was determined for each mixture and itis evaluated according to Eq. (16):

$$\text{Fuel economy} = \dot{m}_{\text{mixed gas}} - \left(\frac{Q_{ou} - Q_2}{LHV_{\text{mixed gas}}}\right) \tag{16}$$

The fuel economy percentage is obtained with Eq. (17):

$$\text{Fuel economy percentage} = \frac{\dot{m}_{\text{mixed gas}} - \left(\frac{Q_{ou} - Q_2)}{LHV_{\text{mixed gas}}}\right)}{\dot{m}_{\text{mixed gas}}} 100\% \tag{17}$$

Production Technical Energetic Indicator

The production technical indicator relates the mixed gas obtained by the preheating of the combustion load or air, and the productivity or mass flow of the steel plates.

Without taking advantage of the heat ($TEI_{p\ initial}$):

$$TEI_{p\,i} = \frac{\dot{m}_{\text{mixed gas}}}{\text{Productivity}} \tag{18}$$

Taking advantage of the heat to preheat the load and combustion air (TEI_p):

$$TEI_p = \frac{\left(\frac{Q_{ou} - Q_2}{LHV_{\text{mixed gas}}}\right)}{\text{productivity}} \tag{19}$$

Heat generation Technical Energetic Indicator

The heat generation technical indicator, also known as energy intensity, relates the energy supplied by the fuel per unit of production. It is obtained with the equation below.

Without taking advantage of the heat ($TEI_{h\ initial}$):

$$TEI_{h\,i} = \frac{\dot{m}_{\text{mixed gas}} * LHV}{\text{productivity}} \tag{20}$$

Taking advantage of the heat to preheat the load and combustion air (TEI_h):

$$TEI_h = \frac{Q_{ou} - Q_2}{\text{productivity}} \tag{21}$$

With the equations and methodology described, we had a general idea of what we intended to investigate. In that perspective, we support that this research has an established base which will be developed in the next section.

3. RESULTS AND DISCUSSIONS

The physical parameters shown in Tab. 5 were given by the hot strip rolling area of the steel industry located in the state of Espiritu Santo/SP – Brazil (Mariños *et al.*, 2020b). The equations developed in section 2 will be applied.

The application of the heat recovery method requires the parameters of mixed gas, combustion gases and air, which will be extracted from Tab. 2 of Mariños *et al.* (2020a, 2020c). For the development of techniques, it is complemented with some parameters of the billets shown in Tab. 5.

Table 5. Data for the application of the heat recovery method in the reheating furnace of the steel industry.

For billets		
Parameters	Specification	Units
Cp_b	0.843	kJ/kg K
Flow rate (productivity)	263300	kg/h
$T_{initial}/T_{final}$	27/1000	°C

3.1 Results of heat recovery for the load preheating and the combustion air preheating in the reheating furnace

For the development of heat recovery, the parameters of billets, mixed gas, combustion gases and air will be extracted from Tab. 5; as well as the equations presented in section 2.2. For development a fuel flow of 35000 Nm^3/h will be used. First, we get the input and output heats for the three cases analyzed: (a) without take advantage of the heat of the combustion gases, and taking advantage of the heat to: (b) preheat the load and (c) preheat the combustion air. Heat results will be presented in the Tabs. 6, 7 and 8 for the COG/LDG and COG/BFG fuel mixtures.

Table 6. Inlet and outlet heats without take advantage of the heat of the combustion gases.

Heats		COG/LDG		COG/BFG	
Heat input		GJ/h	%	GJ/h	%
Q_1	Heat provided by fuel	412	100	349	100
Q_2	Sensitive heat by load or air preheating	0	0	0	0
Q_e	Total heat of input	412	100	349	100
Heat output		GJ/h	%	GJ/h	%
Q_3	Sensitive heat of billets	216	52.4	216	61.8
Q_4	Heat lost by combustion gases	140	34.0	128	36.7
Q_5	Other heat losses	56	13.6	5	1.5
Q_s	Total heat output	412	100	349	100

From Tabs 7 and 8, heat Q_4, which is the heat lost by combustion gases, consists of two heats; the heat that will be used to heat the load and the combustion air (Q_{4r}) and the heat that is effectively lost in the atmosphere (Q_{4l}).

In the case of the load preheating, the heat is used from 860 °C to 397 °C for COG/LDG mixed gas and from 860 °C to 380 °C for COG/BFG mixed gas. And in the case for the combustion air preheating the heat is utilized from a temperature of 860 °C to 536 °C and from 860 °C to 538 °C for each mixture, respectively.

Table 7. Inlet and outlet heat by load preheating.

Heats		COG/LDG		COG/BFG	
Heat input		GJ/h	%	GJ/h	%
Q_1	Heat provided by fuel	334	81.1	276	78.9
$Q_2 = Q_{4r}$	Heat recovered - Transferred to load	78	18.9	73	21.1
Q_e	Total heat of input	412	100	349	100
Heat output		GJ/h	%	GJ/h	%
Q_3	Sensitive heat of billets	216	52.4	216	61.8
Q_4	Heat lost by combustion gases	140	34.0	128	36.7
Q_5	Other heat losses	56	13.6	5	1.5
Q_s	Total heat output	412	100	349	100

The results of load preheating and combustion air preheating are presented in Fig. 3. Figure 3 shows that with the preheating of the load, a fuel economy of 6606 m^3/h and 7402 m^3/h was obtained, as well as an improvement in the technical energetic indicators of production (ΔTEI_p) and heat generation (ΔTEI_h) of 18.9% and 21.1% for the COG/LDG and COG/BFG mixtures, respectively. Similarly, it is shown that furnace efficiency ($\Delta\eta$) was increased by 23.3% for the COG/LDG mixture and 26.8% for the COG/BFG mixture.

On the other hand, with the preheating of the air, fuel economy of 4627 m^3/h and 4959 m^3/h was obtained, as well as an improvement in the technical energetic indicators of production (ΔTEI_p) and heat generation (ΔTEI_h) of 13.2% and 14.2% for each mixture. Similarly, the furnace efficiency ($\Delta\eta$) was increased by 15.2% and 16.5% for the COG/LDG and COG/BFG mixtures respectively.

Table 8. Inlet and outlet heat by combustion air preheating.

Heats		COG/LDG		COG/BFG	
Heat input		GJ/h	%	GJ/h	%
Q_1	Heat provided by fuel	357	86.8	300	85.8
$Q_2 = Q_{4r}$	Heat recovered - Transferred to air	55	13.2	49	14.2
Q_e	Total heat of input	412	100	349	100
Heat output		GJ/h	%	GJ/h	%
Q_3	Sensitive heat of billets	216	52.4	216	61.8
Q_4	Heat lost by combustion gases	140	34.0	128	36.7
Q_5	Other heat losses	56	13.6	5	1.5
Q_s	Total heat output	412	100	349	100

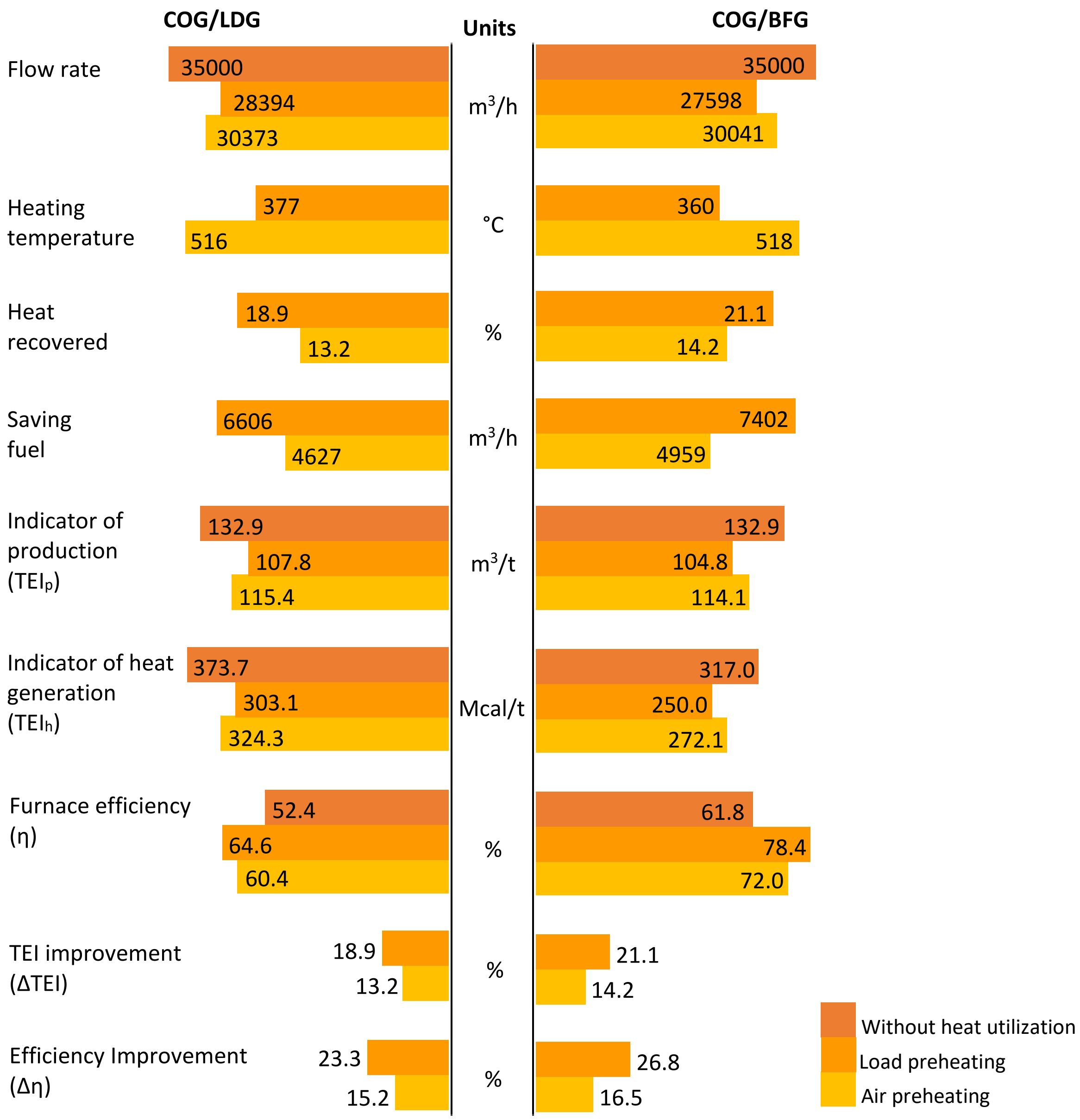

Figure 3. Energetic parameters of the analyzed cases: without heat utilization, with utilization for the load preheating and combustion air preheating.

With the energy parameters presented in Fig. 3, it is concluded that the best results are obtained with the preheating of the load, since we obtain greater savings in fuel consumption, of 28393.7/35000 for the COG/LDG mixture, and 27598.3/35000 for the COG/BFG mixture. This leads to an improvement in furnace efficiency of 64.6% and 78.4% for each mixture, respectively. It is also observed that the highest heating temperature is obtained with the preheating of the air at 516 °C and 518 °C, unlike the preheating of the load, the temperature was 377 °C and 360 °C for each mixture. In the first case, due to air properties, a greater use of heat is obtained, thus increasing its temperature.

4. CONCLUSIONS

The heat recovery method in the reheating furnace was analyzed for the combustion of the COG/BFG and COG/LDG mixed gases, obtaining many advantages. With the preheating of the load, a saving fuel of 6606 m^3/h and 7402 m^3/h was obtained, as well as an improvement in the technical indicators of production and heat generation of 18.9% and 21.1%. Similarly, the efficiency of the furnace was increased by 23.3% and 26.8% for each mixture, respectively.

With the preheating of the air, a saving fuel of 4627 m^3/h and 4959 m^3/h was obtained, an improvement in the technical indicators of production and heat generation of 13.2% and 14.2%, and the efficiency of the furnace was increased by 15.2% and 16.5% for the COG/BFG and COG/LDG mixtures.

5. ACKNOWLEDGEMENTS

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