



Smelting in cupola furnace for recarburization of direct reduction iron (DRI)

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Submitted: 28 November 2014; Accepted: 9 September 2015; Available On-line: 30 November 2015

ABSTRACT: Herein the synthesis of iron-carbon saturated alloys (foundries) melting in cupola furnaces from direct reduction iron is described. The fundamentals are reviewed and combinations undertaken are discussed along with their results, including conclusions and recommendations for follow up.

KEYWORDS: Cupola furnace; Direct reduction; Recarburization; Silicon; Slag

Citation / Cómo citar este artículo: Enríquez, J.L., Tremps, E., Ruiz-Bustanza, I., Morón, C., García-García, A., Robla, J.I., González-Gasca, C. (2015) "Smelting in cupola furnace for recarburization of direct reduction iron (DRI)". *Rev. Metal.* 51(4): e052. doi: <http://dx.doi.org/10.3989/revmetalm.052>.

RESUMEN: *Fusión en hornos de cubilote para recarburación de hierro de reducción directa.* Se describe la síntesis de aleaciones saturadas hierro-carbono (fundiciones) en hornos de cubilote a partir de hierro de reducción directa. Se revisan sus fundamentos, operaciones realizadas, resultados y conclusiones. Finalmente se ofrecen recomendaciones para su implantación industrial.

PALABRAS CLAVE: Escoria; Horno de cubilote; Recarburación; Reducción directa; Silicio

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1. INTRODUCTION

The cupola (American Foundrymen's Society, 1965) is a shaft furnace whose primary characteristic is its height. (Fig. 1). Thermically it is a counter current heat exchanger. During combustion, air enters through tuyeres and burns the coke inside, releasing heat (Enríquez and García, 1993). The iron introduced in the charging door is heated and melted by rising combustion gases. The melted metal

drips through the coke bed and falls to the hearth, draining out through the tap hole. The high level of thermal efficiency of this type of furnace allows the melting of any material.

Chemically, cupola is a continuous reactor. The iron mixes with CO from gases given off by the burning coke, melts, and carburizes. The melted iron drips through the burning coke bed, absorbing more carbon along the way. The third role played by coke is mechanical. It supports the weight of the

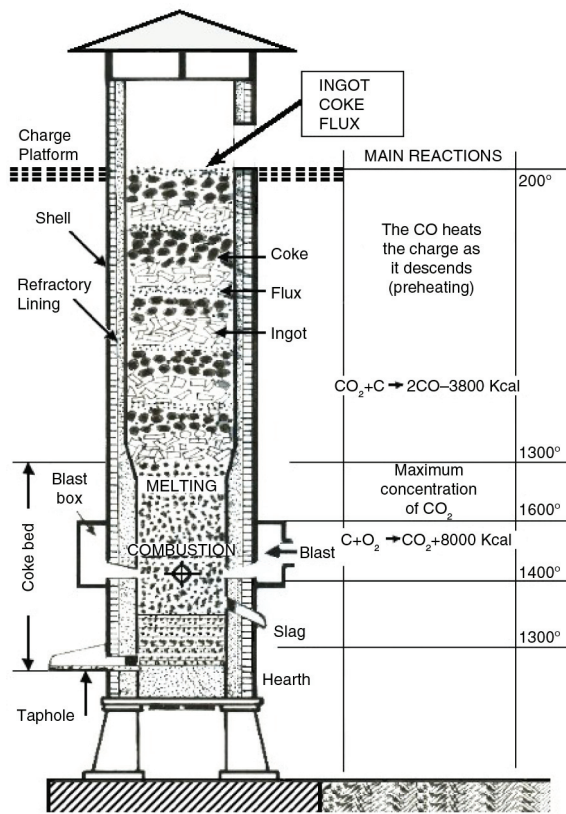


FIGURE 1. Zones and phenomena in the cupola furnace.

melting bed because it is the only component introduced into the furnace which remains solid at the inner temperatures of operation.

1.1. Carbon content

It is a function of the composition and temperature of the slag, coke-liquid interfaces, and coke characteristics (Tartera *et al.*, 1987; Alvarez *et al.*, 2002). In practice the maximum theoretical value is not reached. By recarburizing iron, quality cast irons are made from unsaturated inexpensive materials. The solubility of carbon in iron is given by Neumann's formula (1) (Neumann, 1968):

$$\log N_{C_{MAX}} = -\frac{12.7276}{T(K)} + 0.7266 \log T(K) - 3.0486 \quad (1)$$

where, N_C is the mole fraction of carbon. In addition:

$$C_{MAX} = 1.3 + 2.57 \cdot 10^{-3} T (^\circ C) \quad (2)$$

The influence of diverse elements on the solubility of carbon in the liquid iron is expressed in the following way:

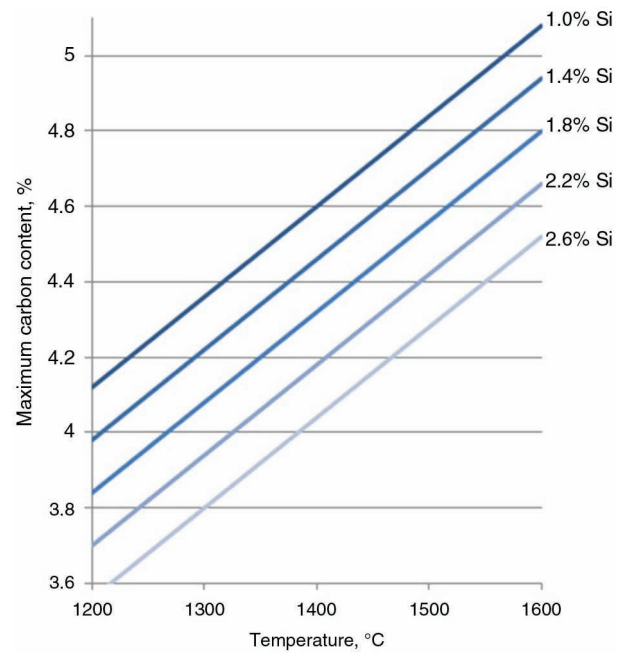


FIGURE 2. Influence of temperature and silicon content of melt.

$$C_{MAX} = 1.3 + 2.57 \cdot 10^{-3} T + 0.027 Mn - 0.31 Si - 0.33 P - 0.40 S \quad (3)$$

Experience shows that some elements (V, Cr, Mn, Mo) favour the solubility of carbon in iron, while others, especially Si, P and Al, strongly diminish it (Neumann, 1968). Figure 2 shows the effect that silicon content and iron temperature have on carbon solubility. We can see that the solubility of carbon in iron grows with the iron temperature, and decreases with an increase in silicon content.

Another way to express carbon solubility in iron is with the formula (4) (Shibaev and Grigorovich, 2008):

$$C = 0.64 + 2.54 \cdot 10^{-3} T + 0.034 Mn - 0.34 (Si + P + S) \quad (4)$$

More recently Janerka (2010) calculated recarburization in the following way:

$$E = M_M \frac{C_F - C_R}{M_R \cdot C_R} 100 \quad (5)$$

where E is the recarburization efficiency (%); M_M the metal mass (kg); C_F the carbon content at the end of the process (%); C_I the carbon content at the beginning of the process (%); M_R the mass of the recarburizer (kg) and C_R the carbon content in the recarburizer (%).

Figure 3 shows a nomogram which predicts the amount of carbon in iron at the tap hole, derived

from a survey taken from among North American Foundrymen (American Foundrymen’s Society, 1965).

The “carbon equivalent,” or CE, is the sum of the metallurgical effects of total carbon and of the most frequent elements (Karsay, 1980; Creese and Healy, 1985; Heine, 1986):

$$CE=C+0.32Si+0.33P\approx C+\frac{(Si+P)}{3} \tag{6}$$

Empirically (Enríquez and Hernáez, 1982; Coon, 1983), we know that the absorption of carbon in the cupola furnace depends on the composition of the base iron; the characteristics and operation of the furnace and the coke quality.

Sulphur and coke ashes work against recarburization. We know that operating temperature, height of the hearth, coke size, and coke bed height favour it. The fluxes, metallic oxides and lining oxides make up slag which combines with coke ashes improving the reactivity of the coke. Experience shows that factors

such as blast enrichment with oxygen, hot blast, balanced blast, or the addition of fluxes increase the value of carbon capture by iron; Si and P decrease it (Levi, 1947; Leyshon and Shelby, 1972; Katz and Landefeld, 1985).

1.2. Silicon content

Silicon in the iron decreases by oxidation and increases as a result of the reduction of silica from the refractory, coke ashes, slag or gangue of DRI by the carbon present in the coke and iron. The reactions are:



Slag, which is basic, tends to combine with acid oxides of some elements (silica SiO₂, alumina Al₂O₃) taking them out of the equation and changing the equilibrium. As a consequence, the first reversible reaction (oxidation of silicon) will be forced towards the right, while the second goes towards the left. In this way silicon, which as we have seen works against recarburization, is removed, with a higher degree of carbon content in the molten iron. Figure 4 shows the effect of the percentage of coke between charges (weight of coke in every charge divided for the respective weight of metal) and the blast temperature, on silicon capture.

Considering the above, it can be concluded that the absence of silicon in the cold charge materials is

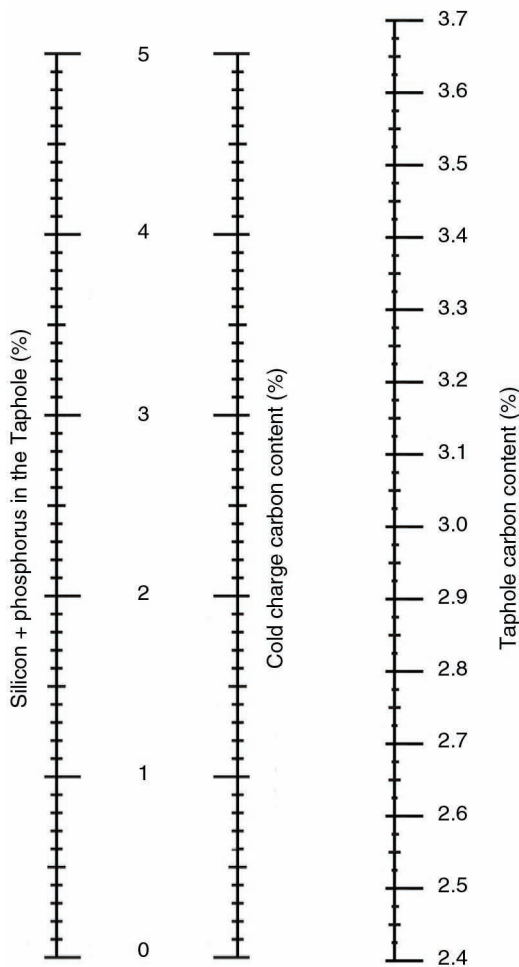


FIGURE 3. Nomogram of recarburization in the cupola furnace.

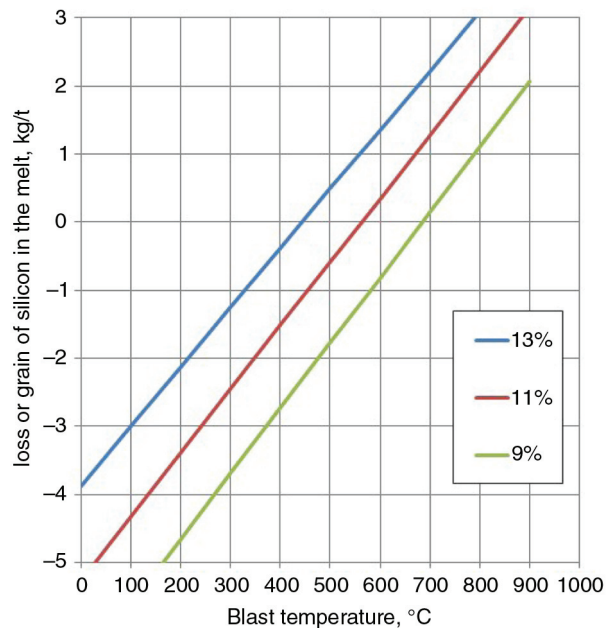


FIGURE 4. Influence of blast temperature and coke percentage in the cold charge on the silicon loss or gain.

key to recarburization, due to its negative effect and its abundance (if it is present) in the melt.

2. PREREDUCED PELLETS

The use of prerduced pellets (Direct Reduction Iron, DRI) has increased because they: a) resolve situations where blast furnace coke for pig iron is scarce and b) dilute contaminating elements which cannot be eliminated in conventional operation.

The classic charge of a foundry furnace is composed of pig iron, cast iron scrap, steel scrap, and ferroalloys. Recycling scrap causes contaminants to accumulate in produced cast irons. It would be better to use pig iron, but that would be significantly more expensive. DRI pellets, almost pure iron, transform in cast irons without any undesirable elements (Fernández and Mendiola, 1977; Lemus *et al.*, 1998). The present project looks at using this material as raw material in foundry shops (Dahlmann and Hussmann, 1976; Pietsch, 1976; Enríquez and Tremps, 1995). There are three stages in this project: chemical and physical characterization of the pellets; experimental melting in a pilot furnace and experimental melting in an industrial furnace.

2.1. Chemical composition

The main components of the DRI pellets are 88.24% total iron, 2.8% carbon and 6.1% gangue. This gangue is composed of 58.8% SiO₂, 20.6% Al₂O₃, 6.3% CaO and 14.3% MgO. It is an acidic gangue. The Carter Basicity Index (I_B) is the ratio of basic oxides and acidic oxides in a gangue or slag such that:

$$I_B = \frac{(CaO) + (MgO)}{(SiO_2) + (Al_2O_3)} \quad (9)$$

It can be said that:

- A low index (high SiO₂) means acid slag, reduction of silica and the passing of silicon to the melt and, consequently, poor recarburisation.
- This acid slag demands additional feeding of basic flux to neutralize it and, logically, more energy to melt that flux.
- For this reason the correct operation should be hot and basic, with tall coke beds and a high percentage of coke between charges, a very hot blast, and, if is possible, a basic or neutral refractory lining (magnesite, dolomite or graphite).

2.2. Physical analysis

In the sizing, 85% of the material has less than 15 mm mean diameter and shows a good homogeneity of size. However, this seems small if they are

TABLE 1. Mechanical characteristics of prerduced pellets

Physical Characteristics	Real density, kg dm ⁻³	6.72
	Bulk density, kg dm ⁻³	2.16
	Apparent density, kg dm ⁻³	3.52
	Porosity, %	47.60
	Mesh size (mm)	wt, %
Tumbler Test	>6.350	82.35
	6.350 to 0.595	14.44
	<0.595	3.21

falling among pieces of coke larger than 100 mm diameter. Physical measures are shown in Table 1, with resistance measurements also. These values lead to the conclusion that the material is quite durable, resistant to crushing and the weight of the successive charges it must support.

3. MELTING IN EXPERIMENTAL CUPOLA FURNACE

Melts have been made in two cupola furnaces, first on a small pilot experiment, and then on an industrial scale furnace (Enríquez, 1975; Geck and Maschlanka, 1976; Enríquez and Crespo, 1998). Runs in the pilot furnace were done in two consecutive stages: personnel training and furnace set up, auxiliary and control equipment, taking of samples and experimental melts, which are described below.

The main dimensional characteristics of the pilot cupola furnace are: useful inner diameter 385 mm, hearth height 450 mm and preheating zone height 2010 mm. It has two twin tuyeres through which a blast rate of 15 Nm³ min⁻¹ of air preheated to 200 °C is injected, against an inner back-pressure of 19.6 mbar (centrifugal blower, not compressor).

Refractory lining was Silica/Alumina (85/15). The coke has MICUM indices M₄₀ and M₁₀ respectively equal to 82 and 14, which are values of a good quality coke. The flux is limestone sized to 30–50 mm. Each metal charge weighs 25 kg. Production is 800 kg h⁻¹.

3.1. Runs

Nine runs were done, each of 1000 kg (40 metallic charges), with variable proportions of DRI and ingot per charge. The process followed for melting the iron was the same as in previous industrial runs with conventional charges, starting with a preheating blast (10 Nm³ min⁻¹) and continuing with the total blast (15 Nm³ min⁻¹) before initial tapping. Each metal charge weighs 25 kg; the charge of coke, 5 kg and the charge of flux limestone, 1 kg. Optical pyrometer is employed for the measure of liquid iron temperature in tap-hole. The productivity is about 800 kg h⁻¹. The tilting forehearth was preheated to 1000 °C by means of a propane burner.

3.2. Results

3.2.1. Furnace behaviour

In contrast to conventional heats in the same furnace (Chastain, 2000), the following empirical observations can be made:

- Yellow oxidizing flames passing in front of the charging door.
- Smaller blast rate and greater back pressure.
- Great amount of a black oxidized slag (the normal one must be gray and vitreous).
- Low temperature of tapped iron.
- The wear on the refractory lining does not appear to vary.

3.2.2. Composition of the resulting slag

Table 2 gives the values of the slag for different percentages of pellets in the charges. The column at the right shows the basicity index (I_B).

3.2.3. Composition of obtained melts

Determined by emission spectrometry (Enríquez, 1981a; Enríquez and Echarri, 1988). The values of carbon and silicon for each melt sample can be seen in Table 3, as well as those for the Carbon Equivalent (CE). In the column to the right, average values are given. Carbon self-regulates in the furnace, unlike silicon which depends on charges of ferrosilicon.

3.3. Discussion on the pilot furnace

Increasing the percentage of pellets decreases the basicity index (I_B) of the slag from 0.31–0.46 for 25% pellets in the charges to 0.10–0.18 for 100%. As a result its desulphurating power diminishes. Higher acidity (silica content) in the slag, also, favours the reduction into free silicon and slows down, consequently, the carbon picks up.

TABLE 2. Values of slag for different percentages of pellets in the charges

Pellets (wt, %)	SiO ₂ (wt, %)	Al ₂ O ₃ (wt, %)	CaO+MgO (wt, %)	FeO (wt, %)	I_B
25	49.2	11.5	19.0	9.5	0.31
	44.6	13.0	26.6	1.4	0.46
33	49.8	8.9	18.2	2.0	0.31
	52.6	12.6	16.5	6.8	0.25
50	47.9	–	–	–	–
	51.2	–	–	–	–
100	46.4	8.3	5.4	36.2	0.10
	45.2	9.0	15.0	12.3	0.27
	52.8	13.3	12.3	12.0	0.18

It has a higher FeO content and oxidizing atmosphere that affects the fluidity and recarburization of the molten iron negatively. The iron oxide content increases from 1.4–9.5% for 25% pellets into 12.0–36.2% with 100% pellets.

In regards to the composition of obtained cast iron, the degree of recarburization was not satisfactory. The average values of carbon content are in the range of 1.85–2.90%. The goal was to reach values of 3.00–3.50% of carbon, range of composition for industrial cast irons.

Summarizing, the basic desired objective has been obtained, which is, the inexpensive synthetic production of saturated iron-carbon alloys in a cupola furnace. However, the results have been mediocre. It cannot be known with certainty whether the difficulties that were found were due to the small size, the consequent difficulty of operation of the cupola furnace, or the use of the product (DRI) which was slightly metallized with a lot of gangue and was small as basic component in the charge.

4. INDUSTRIAL FURNACE MELTINGS

The difficulties found using the experimental pilot furnace led to further work with an industrial sized furnace which was retired because it was substituted with better, more modern units (Hornung, *et al.*, 1975; Enríquez, 1981b; Enríquez, 1982; Enríquez and Alonso, 1996).

The furnace is in a foundry shop for automotive parts. It has an inner diameter of 600 mm, acidic refractory, cold blast, charge by means of tilting skip, and discontinuous tapping of iron and slag. The productivity is about 2200 kg h⁻¹. A monorail connects it with a 5 t channel induction furnace (Enríquez, 1980; Enríquez, 2000) that holds, homogenizes and overheats the liquid iron produced in the cupola. Although it was not the optimal solution for the process being studied, more positive results than those obtained with the small pilot furnace used in the former stage of the project are hoped for.

4.1. Melting

Two melting runs were done, using the same routine. In the first 5700 kg (19 charges) were melted, in the second 6600 kg (22 charges). In each run the five first charges contained 100% ingot, while after the sixth charge, with the furnace working in steady conditions, each charge contained 66% ingot and 33% of pellets. Then, each charge contained 50% of pellets until the heat was finished. The characteristics of coke are 4% humidity, 9% ashes, 1% volatiles and 0.85% sulphur. These figures are proper of a good quality coke. Furnace initial operation values are: 700 mm coke bed height and 600 kg coke bed weight. Mutual relation metal/coke/limestone per charge is 300 kg/ 45 kg/ 15 kg (that is to say, 15% coke ratio between charges).

TABLE 3. Composition of experimental furnace melts (carbon and silicon expressed at wt, %)

									Average value
25% of pellets Heat 1	Carbon	2.65	2.95	2.95	2.95	2.98	2.95		2.90
	Silicon	1.70	2.10	2.25	2.40	2.40	1.70		2.09
	CE	3.22	3.70	3.78	3.65	3.75	3.52		3.60
25% of pellets Heat 2	Carbon	2.58	2.40	2.36	2.36	2.32	2.50	2.66	2.45
	Silicon	1.50	1.65	1.35	1.40	1.40	1.60	1.40	1.47
	CE	3.08	2.95	2.81	2.83	2.79	3.03	3.13	2.95
33% of pellets Heat 3	Carbon	2.30	2.38	2.24	2.14	2.35			2.28
	Silicon	1.45	1.30	1.30	1.30	1.30			1.34
	CE	2.78	2.81	2.67	2.57	2.78			2.72
33% of pellets Heat 4	Carbon	1.62	1.66	1.80	2.00	2.00	2.00		1.85
	Silicon	2.90	2.40	6.00	6.00	6.50	5.50		4.88
	CE	2.59	2.46	3.80	4.00	4.17	3.83		3.47
50% of pellets Heat 5	Carbon	1.86	2.30	2.24	2.21	2.45	2.30		2.23
	Silicon	2.20	1.80	1.60	1.40	1.30	0.80		1.52
	CE	2.59	2.90	2.77	2.68	2.88	2.57		2.73
50% of pellets Heat 6	Carbon	1.80	1.82	1.68	1.98	1.94	2.00	1.95	1.88
	silicon	2.50	1.20	1.20	1.30	1.54	1.20	1.75	1.53
	CE	2.63	2.22	2.08	2.41	2.45	2.40	2.53	2.38
100% of pellets Heat 7	carbon	2.75	2.46	1.96	1.96	2.00	1.86		2.16
	silicon	3.60	3.50	3.40	1.35	0.80	0.14		2.13
	CE	3.95	3.63	3.09	2.41	2.27	1.91		2.88
100% of pellets Heat 8	carbon	2.50	2.90	2.65	2.60	2.00	2.30	2.56	2.50
	silicon	4.00	3.00	3.20	3.00	2.10	1.60	1.30	2.60
	CE	3.83	3.90	3.71	3.60	2.70	2.83	2.99	3.37
100% of pellets Heat 9	carbon	2.35	2.00	2.22	2.18	2.42	2.00	2.40	2.22
	silicon	2.90	2.40	2.65	2.40	1.80	2.10	1.85	2.30
	CE	3.32	3.10	2.98	3.02	2.70	3.02		2.99

The liquid metal obtained is transferred to the channel induction furnace, where additions (FeSi, FeMn, FeCr), if required, for a cast iron for automobile parts (260 MPa tensile strength) are done. Samples were taken from the tap hole for chemical analysis, mechanical tests, and metallography. Compositions of the metal charges are shown in Table 4.

TABLE 4. Composition of each metal charge

	Starting	Initial	Final
Midrex prereduced pellets	0%	33%	50%
High silicon ingot	50%	33%	25%
Automotive returns	50%	33%	25%
Ferrosilicon	8 briquet (8 kg Si total content)		
Ferromanganese	2 briquet (2 kg Mn total content)		
Ferrochromium	1/2 briquet (1/2 kg Cr total content)		

4.2. Results

4.2.1. Operation characteristics

- The operation of cupola was normal, with no anomalies worth mentioning. The first metal was able to be cast without any temperature problems.
- During the run, the temperature of liquid iron, measured with optical pyrometer, was 1390 °C. In the pilot cupola it was only 1370 °C. The molten iron showed a satisfactory fluidity.
- The volume of slag was greater than that usually produced with conventional charges but it did not interfere with the operation.
- Observation through the peep-holes of tuyeres showed the free fall of intact cold pellets between the coke pieces. This circumstance could be disadvantageous for the carburisation and temperature of the molten iron.

TABLE 5. Chemical composition of obtained slag

Percentage of pellets in the charge (wt, %)	SiO ₂ (wt, %)	Al ₂ O ₃ (wt, %)	CaO+MgO (wt, %)	FeO (wt, %)	I _B
0	41.6	9.2	13.9	2.5	0.27
	44.6	8.9	14.6	1.8	0.27
	44.1	8.9	14.6	1.7	0.27
33	48.0	12.3	10.5	11.0	0.17
	51.0	13.6	9.5	11.1	0.15
	51.0	11.7	9.7	11.0	0.15
50	46.0	16.0	9.7	11.0	0.16
	52.0	12.9	5.9	15.2	0.09

4.2.2. Observation of obtained slag

The slag has a good quality, with satisfactory fluidity. It shows a green colour and vitreous appearance that is characteristic of the slag from the cupola with acid lining. The composition is given in Table 5.

The basicity index falls from 0.27 to 0.09 when the amount of DRI increases from 0 to 50%. With the same proportion, the tenor of FeO increases from 1.7 to 15.2%. These values are approximately the same as those obtained in the pilot furnace.

4.2.3. Composition of obtained melts

Analysis values of samples taken along the run are given in Tables 6 and 7 for 33% and 50%, respectively, of DRI in the charges. The average values for carbon were 3.33 and 3.34. They can be considered satisfactory. The results for equivalent carbon CE were 3.940 and 3.907, which was clearly hypoeutectic.

5. DISCUSSION

- **Slag.** The observed Carter basicity index (I_B) of furnace slag when conventional charge is used is 0.27; the same with pellets is 0.09–0.16.

TABLE 6. Chemical composition (expressed at wt, %) of melts (33% pellets per charge)

C	Si	Mn	S	P	Cr	CE
3.340	2.17	0.750	0.100	0.060	0.280	4.083
3.596	1.57	0.769	0.074	0.116	0.059	4.158
3.145	2.17	0.586	0.123	0.093	0.159	3.961
3.318	1.91	0.684	0.097	0.071	0.222	3.978
2.960	1.00	0.234	0.102	0.075	0.060	3.318
3.250	1.73	0.610	0.100	0.080	0.180	3.853
3.676	1.55	0.649	0.105	0.103	0.141	4.227

Average carbon value = 3.326; Average CE value = 3.940.

The content of FeO increases drastically and the basicity index decreases. That means poor quality of the slag.

- **Carbon.** The values indicate that recarburization occurred satisfactorily, according to the previous theoretical studies on the influence of low silicon content and good operation temperatures shown in the beginning of the present article. Those values are clearly better than those in the small pilot cupola but slightly poorer than those obtained during conventional runs with carburised materials in industrial cupolas. Going from 33 to 50% pellets per charge did not result in a substantial variation in average carbon or CE values and the furnace self-regulated spontaneously.
- **Silicon.** The furnace was part of an industrial factory and the materials obtained had to be suitable for the automotive parts produced there (iron - carbon - silicon alloys). Occasional variations in the content of silicon found from one tap to another may be the result of the little

TABLE 7. Chemical composition (expressed at wt, %) of melts (50% pellets per charge)

C	Si	Mn	S	P	Cr	CE
3.178	<1.00	0.421	–	0.078	0.096	3.537
3.029	<1.00	0.223	0.100	0.071	0.075	3.386
3.000	<0.50	0.102	0.068	0.055	0.021	3.185
3.528	<1.00	0.527	0.052	0.092	0.093	3.892
3.340	1.93	0.800	0.110	0.060	0.120	3.973
3.430	3.00	0.790	0.098	0.099	0.190	4.463
3.442	2.48	0.539	0.104	0.092	0.190	4.299
3.560	2.00	0.553	0.100	0.094	0.224	4.248
3.274	1.30	0.465	0.095	0.085	0.115	3.735
3.381	2.18	0.734	0.093	0.072	0.160	4.132
3.327	2.10	0.585	0.087	0.084	0.157	4.055

Average carbon value = 3.342; Average CE value = 3.907.

pellets falling across the hollow spaces between coke pieces. It must be borne in mind that taking samples from tap hole flow gives erratic composition values which are then homogenized in the holding furnace.

- **Sulphur and phosphorous.** They are not seen; notable variations, such as the sulphur present come only from the coke. Phosphorus is in the gangue and does not vary substantially either. A more basic slag should be favourable for attaining a better degree of desulphurisation. In any case, the amounts of both are well within permitted limits for quality casting for automotive castings owing to the scarce content of these elements in the DRI.
- **Alloy elements.** Variations in different samples can be seen which, as in the case of silicon, are due to the premature descent of the pellets. Analysis of successive samples from the holding furnace indicate the gradual disappearance of copper and molybdenum from the mixture contained in this furnace, after being diluted by melted iron falling from the cupola tap hole. This is important to consider when it is necessary to decrease the amount of trace elements which cannot be entirely eliminated in conventional operations.

6. CONCLUSIONS AND RECOMMENDATIONS

- Cupola furnace, in order for this unit to operate satisfactorily, it has to have a usable diameter at least 700 mm which has a productivity of $P=6 D^2 \approx 3000 \text{ kg h}^{-1}$. Smaller sizes cause manipulation difficulties in molten metal and loss of temperature.
- The dimensions of the small experimental pilot furnace are clearly below, which does not make the conclusions that are deduced from its use very reliable. The dimensions of the cupola furnace used in this work approach the minimal prescribed value.
- As for the metallic charge materials, the basic rules of operation of cupolas require that the size of the pieces must be equal to 1/3 of the internal diameter of the furnace in the melting zone. That is, 130 mm in pilot furnace and 200 mm in industrial furnace. The DRI pellet used (there were no others) have a diameter of 15 mm, well below the established standards, despite which it has been working with them and get acceptable products.
- There is a considerable increase in the quantity of acid slag, due in large part to the gangue of the pellets. It would be better to use pellets with less gangue and not exceed the 30% DRI in the furnace cold charge.
- The filtration and fall of pellets detected gave us snapshot glimpses with significant variation in

the composition and temperature of iron in the tap hole. This heterogeneity is greatest when the furnace cold charge consists of 50% of pellets DRI. This could be avoided if the pre-reduced iron was canned or briquetted.

- Various furnace characteristics employed (cold blast, tilting skip basket, intermittent casting) are not the best solutions with pellets.
- The use of a channel induction furnace as a holding furnace, resolve partially the problems of composition and temperature heterogeneity mentioned earlier.
- Acquired experience shows that it is inadvisable, under current operating conditions, to use more than 50% pre-reduced iron pellets in the cold charge. The maximum suggested would be 33%.
- More efficient operation could be achieved by using hot blast and basic lining in the cupola. Continuous and self slaged tap hole require an induction fore hearth to regulate melt temperature and composition (duplex cupola - induction).

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