BEHAVIOR OF IRON ORE SELF-REDUCING MIXTURES IN ROTARY KILN AT 1673 AND 1773K[1]

Alberto Eloy Anduze Nogueira[2]
Adolfo Pillihuaman Zambrano[2]
Cyro Takano[3]
Marcelo Breda Mourão[3]

Abstract

This work try to understand the behavior of self-reducing mixtures of iron ore when charged into a experimental rotary kiln, at temperatures between 1673 K (1400 °C) and 1773 K (1500°C). It was attempted to observe the possible technological obstacles and to study briefly the heat and mass transport involved. The kiln was fed with two types of charge, one at the form of pellets and one as mixture of fines. In all cases, including the mixtures with sawing dust, it was obtained iron carbon nuggets, of variable sizes. There was a tendency to form a kiln ring, but it was minimized by low wetability of the slag on the graphite tube and by the subsequent reduction reaction. The self-reducing mixture, with or without pelletizing, showed to be adequate to this type of particular furnace.

Key words: Self-reducing; Rotary kilns; Iron-carbon nuggets.

1 *Technical contribution to the 7th Japan-Brazil Symposium on Dust Processin-Energy-Environment in Metallurgical Industries and 1st International Seminar on Self-reducing and Cold Bold Agglomeration, September 8-10 2008, São Paulo City – São Paulo State – Brazil*

2 *Post-Graduate Student Escola Politécnica da Universidade de São Paulo, Metallurgical and Materials Engineering Department.*

3 *Associate Professor - Escola Politécnica da Universidade de São Paulo, Metallurgical and Materials Engineering Department.*

Objective:
This work try to understand the behavior of self-reducing mixtures of iron ore when charged into a experimental rotary kiln, at temperatures between 1673 K (1400 °C) and 1773 K (1500 °C).

1 INTRODUTION

Presently, the iron ore is reduced basically by two main processes, with relation to reductant types: i) carbon based processes, where the blast furnace is the most important one; and ii) based in natural gas for producing DRI (Direct Reduced Iron) or HBI (Hot Briquette Iron).(1) The dependence in coking coals requires alternative routes for the Blast Furnace. The self-reducing processes are one of these alternatives, due to fast reaction rate, flexibility of reductants and ores.(2) Particularly the Rotary kiln presents some favorable characteristics(3) for processing self-reducing mixtures or agglomerates like: a good thermal efficiency; controllable thermal profile; intimate contact between reductacnt and ore particles; no needs for high strength of agglomerates; and allows to work with self-reducing mixture. As disadvantages are: tendency of kiln ring formation; tends to drag fines by the off gases; high mechanical and thermal spalling of refractory and others.

2 MATERIALS AND METHODOLOGY

2.1 Chemical Analysis of the Materials

Table 1: Proximate analysis of reductants.

Reductants	C fix	Ash	Volatile matter	Sulfur
Petroleum coke	88,8	0,4	10,8	0,8
Sawing dust	15,37	1,37	83,26	-

Table 2: composition of the of iron ore, sawing dust ash and HIS cement.

Components(%)	Iron ore	Ash from sawing dust	High initial Strength HIS cement
CaO	3,01	20,40	64,3
Al_2O_3	7,41	3,88	4,92
SiO_2	3,27	10,06	19,05
MgO	0,31	27,07	0,55
MnO	2,34	2,50	-
Fe_2O_3	83,66	28,98	2,78

Table 3: Composition of self-reducing mixtures.

Raw material	Pellets(wt%)	Without agglomeration (%)
Fe ore	80	43,5
Petr. coke	20	-
Cement	(+10)	-
Sawing dust	-	56,5

2.2 Residence Time

The residence time was controlled by adjusting the slope of the kiln, for pellets and for mixture.

2.3. The Kiln Characteristics

Electrically heated, length of 1500 mm, 2 concentric tubes (outer of alumina and inserted in it the high density graphite tube with internal diameter of 48 mm; rotation of 5 RPM and the thermal profile shown Figure 1.

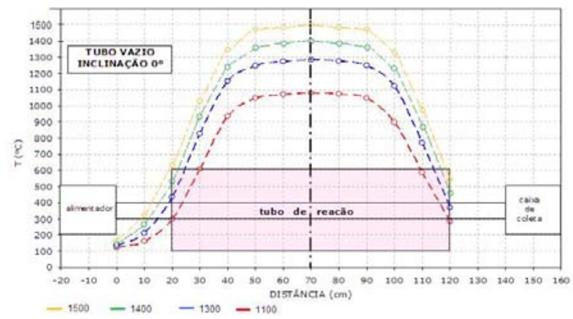
	
The experimental rotary kiln.	The thermal profile of the kiln.

Figure 1: photography of the kiln used in this work and its thermal profile.

2.4 Material Processing

Argon flow of 1NL/min, was used; residence times at hot zone of 1673 K (1400°C) and 1773 K (1500°C) were 20 minutes and 15 minutes respectively for pellets and mixture. This range of temperature was chose based on previous work.(5)

2.5 Reduction Fraction

Traditional weight loss was not used for determining the reduction fraction since some fine particles was carried by off gases and some material was lost during feeding by vibratory feeder. Alternatively this reduction fraction was determined using the thermogravimetric balance system, at 1623 K., described elsewhere.(5)

3 RESULTS AND DISCUSSIONS

The results obtained in this work are show in the figure and tables below.

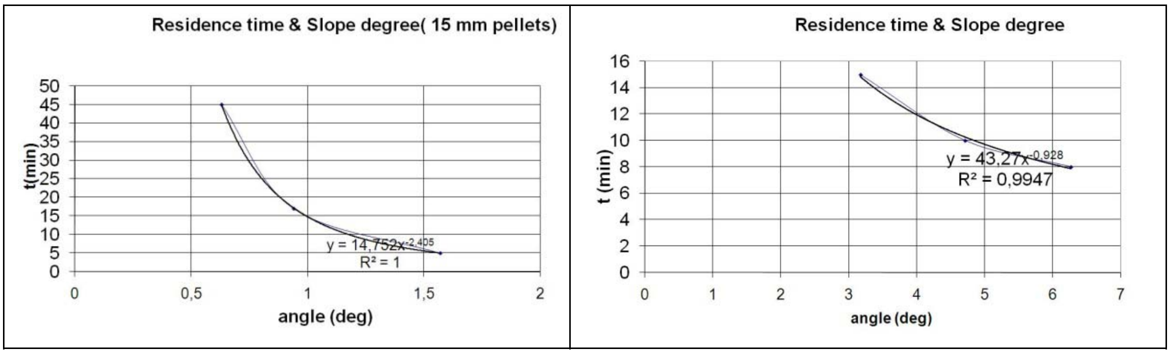


Figure 2: (a) Residence time of the pellets and (b) of the self-reducing pellets as a function of the slope degree

In the Figure 2 (a) it's possible to see the sensitivity of the residence time for the case of self-reducing pellets, that is, a small variation of the slope of the kiln results in large effect to residence time due to its spherical shape. For self-reducing pellets, the minimum slope for beginning to roll by gravity effect, without rotation of the kiln is α =10°. The self-reducing mixture is less sensitive of the slope degree, as can be observed in the Figure 2 (b).

		
Twin pellets linked by iron carbon nuggets.	Individual pellets.	Pellet covered by various iron carbon nuggets.

Figure 3: Self-reducing pellets, 80% hematite of low content, 20% petroleum coke, 10% HIS cement, T= 1673 K (1400°C).

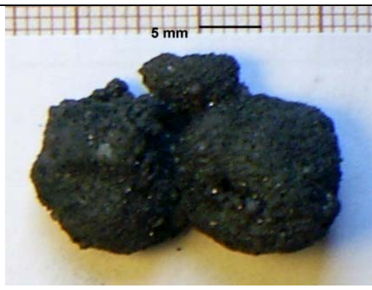
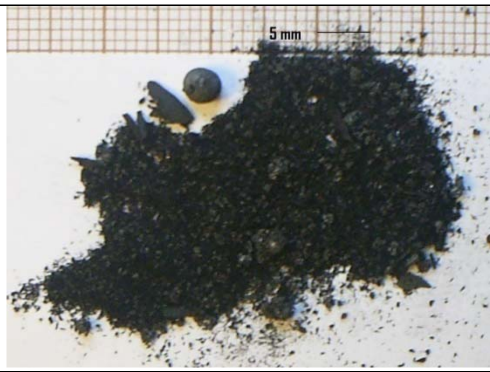
		
Pellet formed by diversity iron carbon nuggets and slag.	Twin pellets formed by iron carbon nuggets and slag.	Diversity of iron carbon nuggets.

Figure 4: Self reducing pellets, 80% low grade iron ore, 20% petroleum coke, 10% HIS cement, T= 1773 K (1500°C).

In the Figures 3 e 4 its possible to observe the products of the process of the self-reducing pellets with low grade iron ore, with 20% petroleum coke and 10% of total mass of cement type HIS, at 1673 K (1400°C) and 1773 K (1500 °C) respectively. In both cases, iron carbon nuggets were obtained of varied sizes at 1773 K coalescence of iron carbon nuggets was higher, as it is discussed subsequently. The nugget larger than approximately 0,1mm was around 80-90% of the total iron and 10-20% was retained in the slag after milling and classification. This fine portion can alternatively recycled by feeding the kiln.

(a) Self reducing mixture with 43,5% low grade iron ore and 56,5% sawing dust.



(b) General look of the obtained product.

Figure 5: self- reducing mixture prepared with low grade iron ore and sawing dust.

In the Figure 5 (a) can be seen the self-reducing mixture with 43,5% of low grade ore and 56,5% of sawing dust, and (b) the product after processing the mixture, where can be observed diverse iron carbon nuggets, charcoal particles and slag.
In the Tables 4 e 5 particle size distribution of the products obtained (metallic and not metallic), at 1673 and 1773K, from pellets, after milling, are presented. Pellet processed at 1673K shows around 77% larger than 0,1mm. At 1773K the coalescence was higher and reached 82% larger than 0,1mm. The effect of temperature can also be observed for particles larger than 0,3mm in comparison of results in the Tables 4 and 5.

Table 4: Particle size distribution of the product obtained from the self-reducing pellet of low grade iron ore, 20% petroleum coke, 10% cement HIS at 1673 K (1400°C) (ASTM B 214-76).

Mesh size (mm)	**Retained** (% in mass)	**Accumulated** (% in mass)
0,84	9,28	9,28
0,5	11,10	20,38
0,3	13,25	33,64
0,149	37,00	70,64
0,106	5,98	76,63
Bottom	23,38	100,00
total	100,00	

Table 5: Particle size distribution of the product obtained from the self-reducing pellet of low grade iron ore, 20% petroleum coke, 10% HIS cement at 1773 K (1500 °C) (ASTM B 214-76).

Mesh size (mm)	**Retained** (% in mass)	**Accumulated** (% in mass)
0,84	20,27	20,27
0,5	10,05	30,32
0,3	11,74	42,06
0,149	28,23	70,29
0,106	11,41	81,70
bottom	18,30	100,00
Total	100,00	

A surprising result was obtained with mixture of low grade iron ore with sawing dust without agglomeration as can be seen in the Figure 5 (b) and Table 6. A high coalescence of the metallic phase was observed. This result is credited to low quantity of the slag, since binder was not used and the sawing dust has low ash content.

Table 6: Particle size distribution of the product obtained from the self-reducing mixture of low grade iron ore, sawing dust at 1773 K (1500°C) (ASTM B 214-76).

Mesh size (mm)	**Retained** (% in mass)	**Accumulated** (% in mass)
0,84	50,48	50,48
0,5	20,85	71,33
0,3	14,77	86,10
0,149	9,93	96,03
0,106	1,20	97,23
Bottom	2,78	100,00
Total	100,00	

Table 7: Reduction fraction for different compositions and temperatures.

Description	**Reduction fraction (%)** (m=0,396)
Self-reducing mixture, 80% hematite low content, 20% petroleum coke, 10% cement HIS, 1673 K.	95,87
Self-reducing mixture, 80% hematite low content, 20% petroleum coke, 10% cement HIS, 1773 K.	95,72
Self-reducing mixture, 43,48% hematite low grade, 56,52% sawing dust, 1773 K.	95,61

In the Table 7 reduction fractions obtained by the indirect method as above mentioned are presented. It's interesting to point out that the reduction fraction are all above 95% of maximum reduction fraction, where one can infer the reliability of the process.

In the Figures 6 and 7 can be observed one scheme of process representation, for the mixture and pellets .For the self reducing mixture, it is observed that at the pre-reduction zone, the material is in suspension as a "fluidized bed" .For self reducing pellets this fact was not observed. It's interesting to note that at the zone where normally have the kiln ring formation, at the beginning of the charge cohesive zone, the reduction reaction generates gas and also the product contraction is observed. These facts may be minimizing the ring formation. The internal coat of graphite has an important participation in this fact too. Fine particles are also carried out by off gases. It was observed that self-reducing pellets presented lesser tendency to dust generation and kiln ring formation than charging mixture without agglomeration.

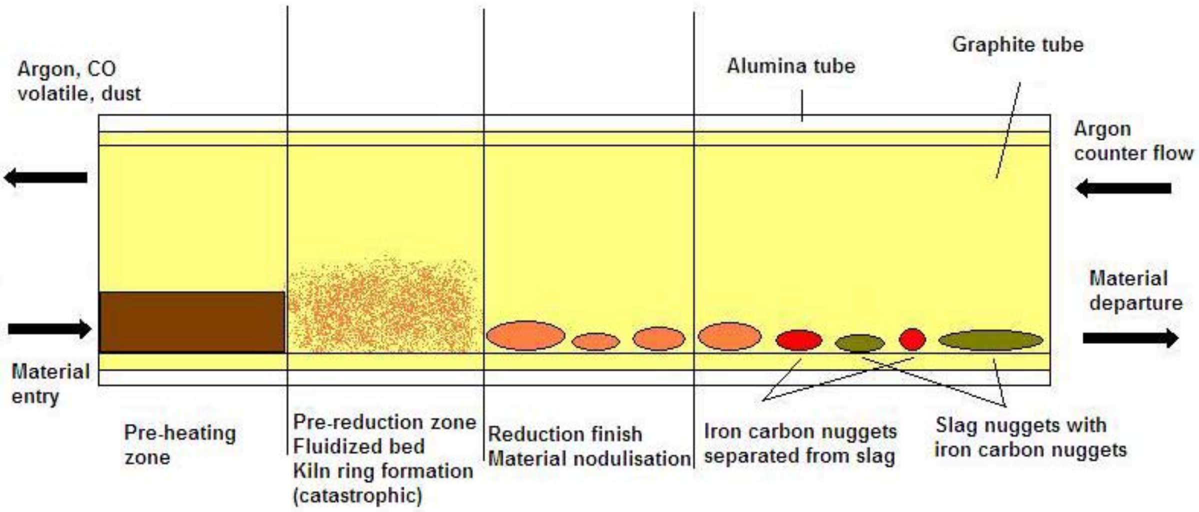


Figure 6: Scheme representation of the process for self-reducing mixture without agglomeration charged into kiln furnace.

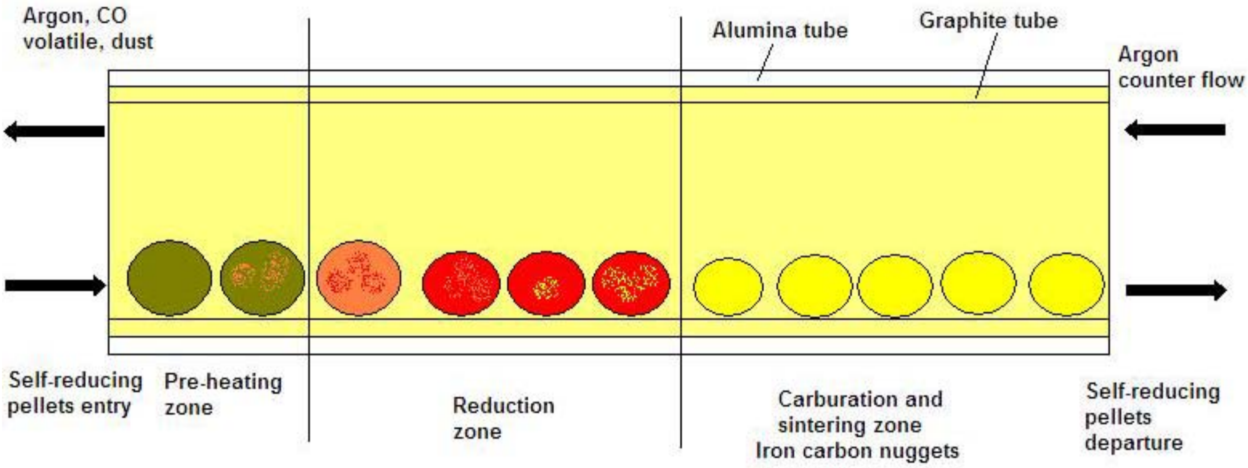


Figure 7: Scheme representation for the process for self-reducing pellets charged into kiln furnace.

4 CONCLUTIONS

The following conclusions are based on laboratory kiln furnace electrically heated, charged by self-reducing pellets and mixtures without agglomeration.

- The iron carbon nuggets of different particle size were obtained at 1673 and 1773K, with pellets and with mixture without agglomeration.
- Larger size nugget was obtained at higher temperature and with mixture without agglomeration.
- The residence time can be adjusted by varying the slope degree of the tube even for pellet.
- For the self-reducing mixture, a “fluidized bed” zone was formed at the beginning of the reduction reaction region.
- The self-reducing agglomerates generate less dust and kiln ring formation is lower with relation to mixture without agglomeration.

Acknowledgements

To FAPESP (Sao Paulo State Foundation for Research Support) project no. 03/02404-0 and to CNPq (Brazilian Council for Research and Technological Development) – project no.141980/2005-2

REFERENCES

1 Shimizu, M; Nishioka, K; Maeda, T; Rapid reduction and melting of carbon composite iron ore pellets on high temperature, Fourth Japan-Brazil symposium on dust processing-energy-environment in metallurgical industries, Proceeding, EPUSP, São Paulo, Brazil, 2002, 103-114.
2 Lu, W; Huang D; The evolution of Ironmaking process based on coal-containing iron ore agglomerates, ISIJ international, vol 41, n. 8, 2001, 807-812.
3 Janke, W; produção de ferro esponja pelo processo SL/RN, XX congresso da ABM, Rio de Janeiro, 1965, 101-106.
4 Virella, A; Formação e destruição de anéis nos fornos rotativos para cimento Portland, Instituto técnico de la construcción y del cemento. Numero 162, tipografía artística, Madrid, España, 7-20.
5 Nogueira, A. Mourão, M. Takano, C. Estudo do processo de redução e fusão de pelotas auto-redutoras no intervalo entre 1573 a 1673 K, 59° congresso anual da ABM-Internacional, 19 de julho de 2004, São Paulo-SP-Brasil, 114-124.