

DEVELOPMENT OF A HIGH REDUCIBILITY ACID PELLETT AT IMEXSA

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ABSTRACT

Imexa is an integrated steel slab producer located on the west coast of Mexico, in the town of Lazaro Cardenas, Michoacan. Because of increasing slab production, demand for pellets to use in the direct reduction plants prompted Imexa to reactivate its partially completed pelletizing plant project in 1994. Pilot tests were carried out in 1995, at Peña Colorada, Colima, one of the four then-existing Mexican pelletizing plants. Various hematite minerals from Brazil were used as feed. These were mixed with limestone, dolomite, coke, and pellet fines in order to obtain fluxed pellets which would be used to feed two direct reduction processes. At the end of 1996, Imexa's pelletizing plant began to operate with the aim of producing 3.5 million metric tons of pellets per year. The percentage of metallization (PM) reached on reducing these oxide pellets during initial use in direct reduced iron (DRI) production was 84.9%, a low value. Further research with several mineral mixtures resulted in a binary basicity (B_2) of ~ 0.35 and PM of $\sim 94.0\%$.

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Key Words: Agglomeration process; Binary basicity; Coke; Direct reduction process; Dolomite; Electric arc furnace; Grinding; Iron minerals; Pellet; Percent of metallization; Raw materials; Slab; Sponge iron; Steel; Steel making.

1.0 INTRODUCTION

For the iron and steelmaking industry, one of the most important raw materials is the iron ore. The most commonly used ores for this industry are hematite (Fe_2O_3); limonite [$\text{FeO}(\text{OOH})$]; magnetite (Fe_3O_4); and siderite (FeCO_3). To improve its chemical and/or physical characteristics, the ores are often beneficiated. Because of differences in structure and mineral content of ores from different deposits, the methods of beneficiation can vary considerably. Once the iron minerals have been concentrated, they are agglomerated in order to improve gas–solid reaction contact for the downstream conversion to metallic iron; for example, in the direct reduction process.

There are at least four main types of agglomeration: nodulizing, briquetting, sintering, and pelletizing. All of these processes, as well as the type and nature of ore, concentrate, additives and treatment, have been studied and reviewed by several researchers (e.g., references 1–8). The main objective of this work is to report the experiences acquired during the startup of the Imexsa pelletizing plant. Its scope is to produce pellets that will be used to feed two direct reduction processes, HyL III and Midrex. The resulting sponge iron is directly fed into electric arc furnaces of 260 ton capacity, in order to produce a wide range of steel (i.e., API 5L X-70 and ultra low carbon steel) slabs.

2.0 PELLET PLANT FLOW SHEET

The new pelletizing plant of Imexsa has a design capacity of 3.5 million metric tons per year at an operating availability of 85%. The pellet components iron ore, coke, dolomite, limestone, and pellet fines are charged to bins which feed two wet grinding ball mills at 320 ton hr^{-1} and 75% solids by weight. Water is added to the ball mill discharge to achieve 68% of solids. The mixture is then pumped to a primary collection box, which feeds three slurry storage tanks (2789 m^3) or alternately to one thickener tank (2189 m^3) for processing of dilute slurry. The mixture of raw material and water is filtered to 8–10% moisture by means of seven vacuum disk filters ($70\text{--}130 \text{ ton hr}^{-1}$) and sent to one of two filter cake storage bins. After discharge, the filter cake is mixed with bentonite (as a binder) and sent to three mixers (320 ton hr^{-1}) and 5 balling disks (7.5 m in diameter, $42\text{--}51^\circ$ angle, and 4.0–8.1 rpm) in order to make the green pellets. The resulting green pellets are sized and sent to an indurating furnace to cook. In this furnace, the moisture in the bed is eliminated in the drying zones, followed by controlled heating from 450°C to a final temperature of 1320°C . The pellets are then cooled and sent to a reduction process.

Using this process sequence, several mixtures of raw materials were tested in the pilot plant design stage to investigate the pellet chemical and physical properties. The objective was to produce an oxide pellet that, when processed to direct reduced iron (DRI), gave a reduced pellet with minimal degradation and a high percentage of metallization (PM), while containing CaO and MgO for use in slag chemistry control in the electric furnaces.

3.0 RESULTS AND DISCUSSION

During the start-up operation of the pelletizing plant, the first pellets were made according to the specification, for use in the direct reduction HYL III plant as shown in Table 1 (the Midrex plant was not constructed at the time). They had a total iron content of 66.6%_{min} and a binary basicity (B_2 , or ratio of CaO/SiO₂) target of 0.91.

After the pellets were fed into the direct reduction process, which employed a gas mixture of H₂ (50.07%), CO (24.33%), CO₂ (16.40%), CH₄ (5.80%), N₂ (1.40%), and H₂O (2%), and a reduction temperature of 915°C, the pellets showed very low PM values, reaching only 84.9%. Before startup of the pelletizing plant, the process purchased pellets at a rate of more than 7500 tons day⁻¹ and had a PM of 89.8%. The pellet formulation and design test work in 1995 had been for 88–89% metallization to feed a DRI plant with a design capacity of 6060 tons day⁻¹ of total product from four reactors. An oxide pellet with improved metallurgical properties from the original specification was required. As a result of this low value of metallization, a statistical analysis of data was carried out to identify the main variables affecting the reduction of pellets in terms of PM. Basicity appeared to be a major factor; consequently, several samples of pellets were produced and tested with varying basicity from 0.41 to 1.13.

Figure 1 shows the outcome of these results in terms of PM versus B_2 . As can be observed, at higher values of B_2 (i.e., >1.0), the PM reaches its lowest value (i.e., 77.5%). As B_2 decreases, the PM increases; for instance, when B_2 0.45 some pellets showed PM values in the range between 93 and 95%.

Table 1. Raw Materials and Specifications Used for the Production of the First Pellets According to the Direct Reduction HYL III Plant

Fe _T (%)	Fe ⁺⁺ (%)	SiO ₂ (%)	CaO (%)	MgO (%)	S (%)	B ₂	+5/8 in. (%)
66.6 _{min}	0.70 _{max}	2.00 _{max}	1.70 _{max}	0.70 _{max}	0.006 _{max}	0.9 _{target}	6.00 _{max}
-1/4 in. (%)	CS kg in ⁻²	TI (%)	IA (%)	Porosity (%)	LTD +1/4 in. (%)	LTD -1/8 in. (%)	LTD pellet (%)
2.00 _{max}	250 _{min}	94.0 _{min}	5.00 _{max}	24.0 _{min}	88.0 _{min}	10.0 _{max}	75.0 _{min}

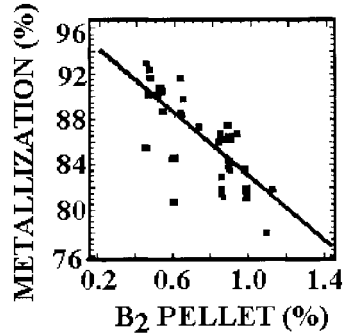


Figure 1. Percentage of metallization (PM) versus binary basicity (B_2) of test pellets produced at Imexsa.

It was then decided to carry out some reducibility tests on several pellets coming from different suppliers (names of the suppliers were omitted and samples were numbered from 1 to 7). These oxide pellets had B_2 values from 0.18 to 1.32. Figure 2 shows the results in terms of the PM versus B_2 of the pellets. The PM value varied once again as a function of B_2 . For instance, when B_2 was in the range between 0.76 and 1.32, the lowest values of metallization were obtained from 87.10 to 88.66%. When B_2 decreased, PM increased, reaching the highest value (94.80%) when B_2 was 0.32.

After those encouraging results, several mixtures of raw material were prepared for the production of pellets at Imexsa.

The aim was to determine the best formulation of pellets that would be fed to the direct reduction processes, with the goal of obtaining PM from 88.0% minimum to 92.0% desirable. Table 2 shows the raw material used for the production of pellets in the Imexsa plant. Materials A and B were the pelletizing plant-designed hematite concentrates. Concentrates C, D, and E were also hematite concentrates according to the availability of raw materials in the international market, and concentrate F was a magnetite concentrate. From those, 13 concentrate mixtures were prepared for pelletizing, as presented in Table 3.

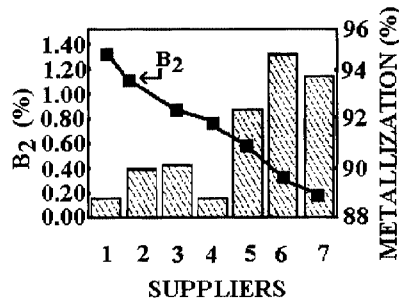


Figure 2. Purchased pellets: relationship of B_2 and metallization.

Table 2. Raw Material (RM) Used for the Production of the Imexsa Pellets

RM	Fe _T (%)	Fe ⁺⁺ (%)	S (%)	SiO ₂ (%)	CaO (%)	MgO (%)	Al ₂ O ₃ (%)	LOI (%)	°B	-325 Mesh (%)
A	68.4	0.17	0.003	1.03	0.06	0.03	0.27	0.54	248	44.5
B	67.9	0.40	0.003	1.51	0.06	0.03	0.35	0.75	241	45.2
C	66.8	0.87	0.002	1.23	0.06	0.04	0.37	2.85	1669	70.5
D	67.6	0.14	0.002	1.38	0.13	0.08	0.53	0.86	607	55.2
E	67.7	0.15	0.001	1.48	0.08	0.04	0.46	0.81	240	54.1
F	70.2	19.05	0.210	1.15	0.22	0.049	0.25	3.00	1131	66.3

B₂ binary basicity (ratio CaO/SiO₂); CS, breaking load; TI, tumble index; IA, index of abrasion; LTD, pellet firing temperature. LOI, loss on ignition; °B, blaine surface area.

Table 3. Mixtures of Concentrates Tested

1	2	3	4	5	6	7	8	9	10	11	12	13
67A 33B	60A 40C	45A 55C	65B 35C	100C	100B	100A	67A 33F	67B 33F	100D	67D 33F	67A 33F	80D 20C

Pellets from those mixtures were used to carry out bag tests. These tests consisted of placing metallic mesh boxes (bags) full of selected pellets (each test consisted of 30 bags of pellets) into the HYL III direct reduction reactor, under the same conditions of reduction as the normal production of sponge iron. The bags were recovered from the product conveyor after discharge from the reactor for analysis of the DRI.

After the bag tests, correlations were obtained. Figure 3a shows the behavior of PM versus B_2 ; note that most of the metallization values concentrated in the range between 87.5 and 92.0%, corresponding to B_2 values from 0.33 to 0.43.

It was also observed that higher PM values were obtained (93–95%) when the B_2 was between 0.37 and 0.39. Figure 3b shows a plot of PM versus pellet firing temperature (LTD) for pellet with sizes >0.25 in. The highest values of PM (between 87.5 and 92%) were obtained when the LTD of a pellet was $\sim 93\%$. Figure 3c shows the behavior of PM as a function of breaking load (CS) of a pellet.

The average PM values (87.5–92.0%) were reached when the CS values varied from 340 to 380 kg in.⁻¹. In addition, as can be observed in Figure 3c, higher PM values (93–95%) were reached when CS was between 330 and 349 kg in.⁻¹.

From the above results, it was identified that mixtures 2 (89.1% PM), 3 (90.9% PM), 4 (91.3% PM), 10 (91.5% PM), and 11 (91.1% PM) showed PM values higher than the minimum target value (88.0% PM), and mixtures 5 (92.9% PM), 12 (92.4% PM), and 13 (93.2% PM) showed PM values higher than the desired target value (92.0% PM).

In the period of January 1997 to December 1998, several changes were progressively made to the pellet chemistry and resulting pellet physical properties (Table 4). Those properties are directly influenced by the type and nature of the ore concentrate, additives, and their subsequent treatment to produce pellets (2). With regard to pellet chemistry, the total iron was kept to a value around 67%, B_2 was varied to lower values, the CaO content was varied, and the SiO₂ content was kept constant.

This resulted in a pellet with B_2 of 0.35 maximum, with a normal value between 0.28 and 0.34. With respect to physical properties, the percentage of porosity remained constant (24%) with slight variations in the tumble index, indices of abrasion, and low temperature degradation index. Breaking load increased from 250 to 310 min (kg in.⁻¹).

Also shown in Table 4 are some of the results obtained from reducibility

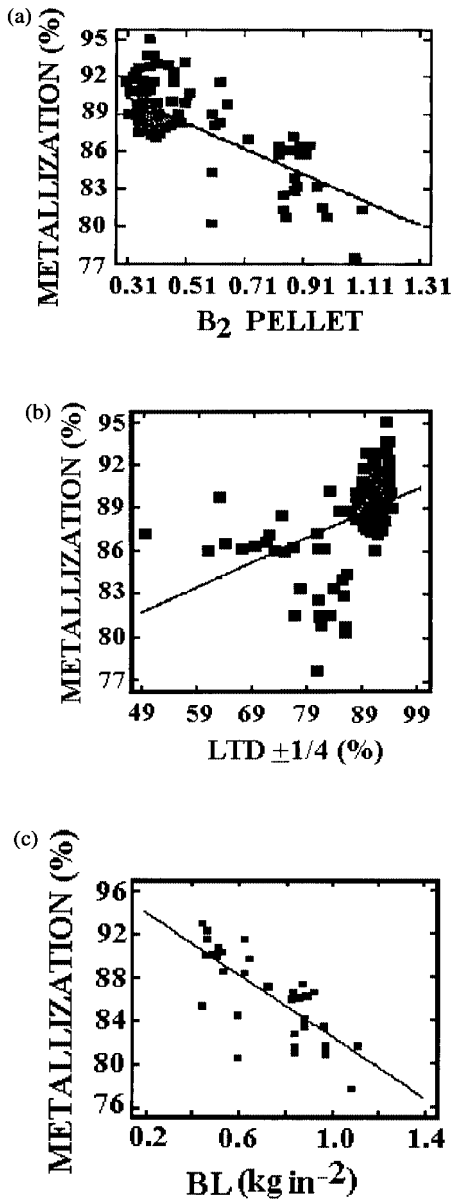


Figure 3. (a) Metallization versus B₂. (b) Metallization versus LTD of pellets with a size of ±0.25 in. (c) Metallization versus breaking load.

Table 4. Production of Pellets from 1997 Through 1998

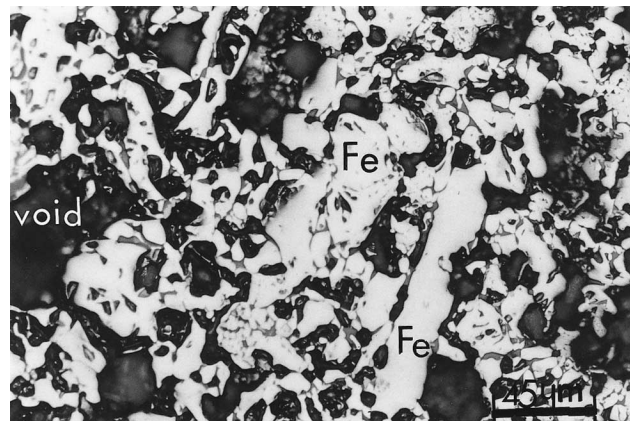
Date	Jan. 97		Feb. 97		Mar. 97		Oct. 97		Nov. 97		Dec. 97		98		IE		FE	
	Jan. 97	Feb. 97	Jan. 97	Feb. 97	Jan. 97	Feb. 97	Mar. 97	Oct. 97	Nov. 97	Dec. 97	98	IE	FE	IE	FE	IE	FE	
Fe _T	66.4	66.2	66.2	66.4	67.1	67.3	67.3	67.2	67.2	67.6	67.4	66.6	67.0	66.6	67.0	66.6	67.0	
Fe ⁺⁺	0.19	0.18	0.26	0.25	0.30	0.19	0.19	0.14	0.14	0.14	0.15	0.70	0.50	0.70	0.70	0.70	0.50	
SiO ₂	2.27	2.04	1.75	1.64	1.66	1.82	1.82	1.87	1.87	1.64	1.75	2.0	2.0	2.0	2.0	2.0	2.0	
CaO	1.43	1.83	1.88	1.43	0.82	0.67	0.64	0.64	0.64	0.49	0.49	1.70	0.70	1.70	1.70	1.70	0.70	
MgO	0.02	0.58	0.55	0.57	0.30	0.22	0.24	0.24	0.24	0.22	0.31	0.70	0.50	0.70	0.70	0.70	0.50	
S	2	3	4	4	4	4	3	3	3	2	1	6	5	6	6	6	5	
B ₂	0.63	0.90	1.08	0.87	0.49	0.37	0.34	0.34	0.34	0.30	0.26	0.91	0.35	0.91	0.91	0.91	0.35	
+5/8	5.92	5.06	4.75	5.50	5.43	6.70	4.40	4.40	4.40	6.30	6 ^{max}	5 ^{max}	5 ^{max}	5 ^{max}	5 ^{max}	5 ^{max}	5 ^{max}	
+1/4	5.92	5.06	4.75	5.50	5.43	8.25	6.70	6.70	6.70	4.40	6.30	6 ^{max}	5 ^{max}	6 ^{max}	6 ^{max}	6 ^{max}	5 ^{max}	
P	26.6	26.5	26.1	26.5	26.2	25.5	26.4	26.4	26.4	26.5	26.3	24 ^{min}	25 ^{min}	24 ^{min}	25 ^{min}	24 ^{min}	25 ^{min}	
TI	95.3	95.2	95.8	95.8	95.0	94.7	94.8	94.8	94.8	95.3	94.0	94 ^{min}	94 ^{min}	94 ^{min}	94 ^{min}	94 ^{min}	94 ^{min}	
IA	4.79	4.67	4.13	4.08	4.12	4.54	4.70	4.70	4.70	4.70	4.00	5 ^{max}	4.6 ^{max}	5 ^{max}	4.6 ^{max}	5 ^{max}	4.6 ^{max}	
CS	400	395	408	423	369	349	345	345	345	336	349	250 ^{min}	310 ^{min}	250 ^{min}	310 ^{min}	250 ^{min}	310 ^{min}	
L ₁	75.2	76.6	78.0	80.4	91.4	90.7	88.6	88.6	88.6	88.8	90.3	88 ^{min}	89 ^{min}	88 ^{min}	89 ^{min}	88 ^{min}	89 ^{min}	
L ₂	23.4	22.4	20.9	18.4	8.1	8.8	10.7	10.4	10.4	10.4	8.9	10 ^{max}	9 ^{max}	10 ^{max}	9 ^{max}	10 ^{max}	9 ^{max}	
L ₃	88.7	91.8	89.9	92.6	94.2	91.1	89.8	88.6	88.6	88.6	89.1	75 ^{min}	88 ^{min}	75 ^{min}	88 ^{min}	75 ^{min}	88 ^{min}	
M	88.1	85.5	80.1	82.4	89.4	89.5	94.5	94.4	94.4	94.4	94.7	88 ^{min}	92 ^{min}	88 ^{min}	92 ^{min}	88 ^{min}	92 ^{min}	
K ₁	—	3.74	3.80	4.60	3.50	3.50	—	—	—	—	3.37	3 ^{min}	4 ^{min}	3 ^{min}	4 ^{min}	3 ^{min}	4 ^{min}	
K ₂	—	—	3.60	2.30	4.40	5.10	4.65	4.32	4.32	4.29	4.29	4 ^{min}	4 ^{min}	4 ^{min}	4 ^{min}	4 ^{min}	4 ^{min}	

Values are in (%); S is in (%X10⁻³); B₂, binary basicity; P is the porosity; TI, tumbler index; IA, index of abrasion; CS, breaking load in kg in.⁻¹; L₁, LTD for pellets >0.25 in.; L₂, LTD for pellets <0.125 in.; L₃, LTD of pellet; K₁, reducibility at 800°C; and K₂, reducibility at 950°C.

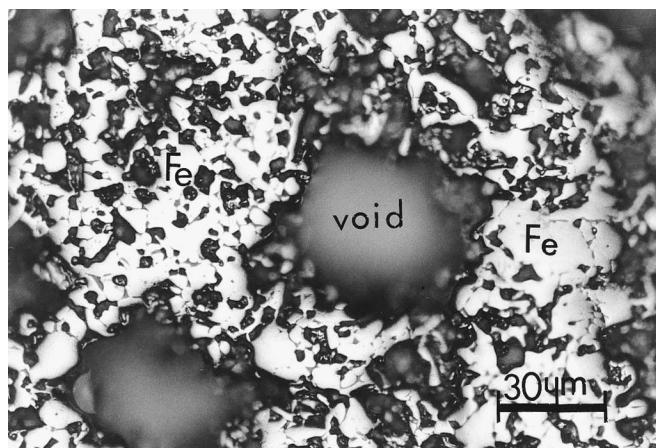
(*K*) testing. These tests were run at two temperatures: 800 and 950°C. During 1998, the *K* value at 800°C was 3.37 and the value at 950°C was 4.29.

Among other actions taken, some parameters were modified during pellet production and during direct reduction of the oxide pellets. For example, the pellet indurating temperature was increased from 1280 to 1320°C, along with an increase in the burn-through temperature in the wind box gases from 440 to 490°C.

With these modifications, the low temperature degradation properties of the pellets improved in the direct reduction reactors. This degradation can take place when the hematite pellets are transformed to magnetite and then wustite during processing. To keep and even increase the high percentages of metallization during normal HYL DRI production, the production rate was decreased from 1800 to



(a)



(b)

Figure 4. (a) Structure of reduced pellets in HYL III reduction process. (b) Structure of reduced pellets in Midrex process.

1600 ton day⁻¹ and the temperature of reducing gases was increased from 915 to 960°C by adding 1400–1600 m³ of O₂. Sticking of pellets in the direct reduction reactors was avoided by applying a coating of 70% CaO + 30% MgO in slurry (at 20–30% solids by weight). This solution was added to the pellets in a proportion of 1.7 kg solids/ton of pellet at the indurating machine discharge and during feeding of pellets to the direct reduction reactors.

Having made these modifications and using the proper selection of raw materials, Imexsa produced pellets with outstanding PM values during normal DRI plant production. In 1998, a 94.7% of metallization was reached and maintained to the present for both the Midrex and HYL III processes. Figure 4 shows the resulting reduced pellet after having been processed in the HYL III reduction process (Fig. 4a) and in the Midrex reduction reactor (Fig. 4b). The high degree of metallization is illustrated. Differences in grain shape and size are due to sourcing of the pellet feed.

4.0 CONCLUSIONS

The main actions taken in the pellet plant with the aim of obtaining an oxide pellet with high reducibility for the direct reduction plant were to

1. Decrease the B_2 of the pellet from 0.91 to 0.35% as maximum, increase the indurating temperature from an initial temperature of 1280 to 1320°C, increase the burn-through wind box gas temperature from 440 to 490°C, and increase the coke content from 0.6 to 0.9%.
2. Avoid sticking of pellets in the direct reduction reactors by applying a coating to the pellets in a proportion of 1.7 kg ton⁻¹ of pellet at the indurating machine discharge and during feeding of pellets to the direct reduction reactors.

These actions resulted in an increase in the PM from 84.9 to 94% in DRI from the reactors.

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