RELEVANT ASPECTS RELATED TO PRODUCTION OF IRON NICKEL ALLOYS (PIG IRON CONTAINING NICKEL) IN MINI BLAST FURNACES

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ABSTRACT

The production of nickel alloys in blast furnaces and reverberatory furnaces has been used in the past. However nowadays efficient production of low cost ferronickel alloys is normally carried out in submerged arc furnaces. Recently, production of iron nickel alloys in blast furnace has been started in China, because of high demand at that time, combined with inability to meet the same by the existing installations in that country. This work aims to identify factors, conditions, limitations and the economic feasibility of production of iron nickel alloys in blast furnaces. In order to assess the feasibility a "technology of reference" for the manufacture of those alloys in blast furnaces has been developed and it is reported in this work. Additionally, raw material and operating conditions are. Typical conditions prevailing in Brazil for the production of nickel containing pig iron with the technology based on Brazilian mini blast furnaces for pig iron production as well as the possibility of using nickel containing mining rejects and low grade nickel ores in the burden material are considered. Taking all this into account a cost comparison should be possible between electric furnace and blast furnace routes. The particular conditions under which iron nickel alloys production in a mini blast furnace is economically feasible have been discussed.

1 INTRODUCTION

Ferronickel with 1.5 to 8% Ni can be produced in blast furnaces and this grade is commonly known as nickel pig iron. Above that level the process is carried out in electric furnaces [1]. Conventional ferronickel grades have 20% or above nickel content. In this contribution the technological aspects of nickel pig iron with Nickel contents up to 7-8% with minor amounts of Si, P, Cr and C will be considered

Nickel bearing pig iron smelting in blast furnaces is not a novelty. In fact, together with reverberatory furnace, it was a chief process of smelting nickeliferous ores in the blast furnace. First blast furnaces for the production of nickel pig iron were built in the end of the 19th century [2]. Later, with the advent of electric furnaces, ferronickel with higher nickel contents were more efficiently produced in these with more flexibility and hence this was preferred to the blast furnace.

Recently, in 2006, nickel pig iron production in blast furnace was resumed in China, the reason being the nickel glut and neither China could purchase enough of nickel rich mineral for production of Fe-Ni in their electric furnaces nor the ferronickel suppliers around the world could supply the needed amount to cater to their booming stainless steel and alloy steel production. Their solution was to process low grade nickel ore in small blast furnaces (~300 m^3). From the above, it can be seen that nickel pig iron smelting in blast furnace has been revived due to those special market conditions and nickel bearing iron ores with low % of nickel is being utilized for the of alloy and stainless steels of different grades [3]

This contribution intends to analyze the conditions that must be satisfied to turn this practice feasible in other regions of the world.

2 CONSIDERATION OF RELEVANT PROCESS PARAMETERS

In order to evaluate the technical and economical conditions in nickel pig iron production, several parameters influencing the process should be taken into consideration, such as availability of raw material, reducing agent, energy source and other economic considerations like capital and operational costs and the market size and value etc.

2.1 Process Highlights

Ferronickel production both in blast furnace and electric furnace .have been analyzed taking into consideration the above aspects. For the electric furnace route for ferronickel production, shielded arc smelting instead of submerged arc operation has been considered.(Figure 1)

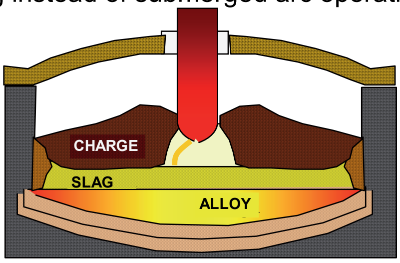

Figure 1: Electric furnace – Shielded arc

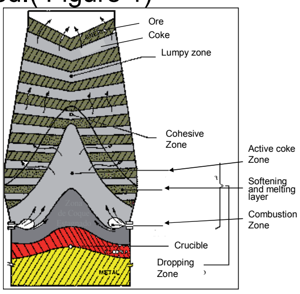

Figure 2: Blast furnace scheme

In shielded arc practice, as the electrodes are above the slag level, and hence the carbon from electrodes does not take part in the reduction reactions, which consume only the reducing agent (coke, charcoal). In such process some selectivity of the reduction of nickel relative to iron can be achieved [4, 5]

In the blast furnace practice, carbon from coke/charcoal charged is not only reducing agent but also energy source. In this case, the amount of carbon charged in the furnace is much greater than that required only for nickel reduction. Due to this the iron oxide reduction reaction will be extended to its completeness, resulting in iron rich alloy. Figure 2 shows blast furnace scheme

Considering the Chinese approach [3], a charcoal blast furnace with useful volume of 200m^3 with glendons for heating up the blast is chosen for Ferronickel production .This type of plant is very common in Brazil for the production of Pig iron. It is a low cost and flexible facility. Nearly 7 million tons of pig iron are produced in such facilities in the Minas Gerais State of Brazil [6].

2.2 Raw Materials

Nickel containing lateritic ores have extensive occurrence all over the world. Figure 3 gives an idealized section through a lateritic nickel deposit, and the range of application of the available technologies. In the figure, the term “Pyrometallurgy” refers to conventional ferronickel smelting. Nickel pig iron smelting range is going to be analyzed.

The composition ranges and the respective extraction processes are given in the figure. As shown in the scheme, two main layers are identified – the saprolitic, deeper layer and the limonitic shallower layer. These layers differ from each other both from mineralogical and from chemical aspects and hence would necessitate different recovery processes. In between the above layers there are transition layers.

The technological routes as shown in the figure suggest that richer, magnesia bearing ores are more suitable for to ferronickel electric smelting process whereas the limonitic ones are more suitable for hydrometallurgical routes [7] [8].

Smelting of leaner ores for the production of Fe-Ni is possible technically but the energy consumption should increase considerably. This can be counteracted to some extent by an increase in the iron reduction (up to the limits of the ore iron content), but the nickel content will fall below that required for ferronickel normal grades. However in this case, one can resort to nickel pig iron smelting. The figure covers the whole range ore body profile and the suitability of a particular ore quality in respect of a recovery process.

Description	*Approximate assays on dry ore basis, %*					*Extractive procedure*
	Ni	Co	Fe	Cr_2O_3	MgO	
Hematitic overburden	<0.8	<0.1	>50	>1	<0.5	Removed to stockpile
Limonite	0.8 to 1.5	0.1 to 0.2	40 to 50	2 to 5	0.5 to 5	Hydrometallurgy
'Transition' material	1.5 to 1.8	0.02 to 0.1	25 to 40	1 to 2	5 to 15	Hydrometallurgy or Pyrometallurgy
Altered peridotite – 'silicate nickel ores /garnierite/saprolite / serpentine'	1.8 to 3		10 to 25		15 to 35	Pyrometallurgy
Unaltered peridotite 'silica bedrock'	0.25	0.01 to 0.02	5	0.2 to 1	35 to 45	Left in situ

Figure 3: Section through a lateritic deposit [2][7]

As such, it can be said that nickel pig iron production is more "free" in terms of ore quality in comparison with that of conventional ferronickel. If the ore is suitable (qualitatively and quantitatively), ferronickel smelting in electric furnace or hydrometallurgical processing would be preferred routes. On the other hand, if the ore quality is not adequate, nickel pig iron production in blast furnace could be an alternative. Naturally this would depend on demand for low nickel alloys which can be produced with nickel pig iron as starting material.

2.3 End Uses – Stainless Steel Products

Table 1 shows the chemical compositions of selected grades of stainless steels.
For comparison purposes, it was included a typical composition of one 300 Series steel.

Table 1: Chemical characteristics of selected stainless steels.[10]

Grades (AISI)	C (max)	Mn	Cr	Ni	N	Cu
201	0.15	5.50-6.50	16-18	3.5-5.5	0.25 max	-
203	0.15	7.5-10.0	17-19	4.0-6.0	0.25 max	-
204	0.15	6.5-9.0	15.5-17.5	1.5-3.5	0.05-0.25	2.0-4.0
205	0.12-0.25	14 – 15.5	16.5-18.0	1.0-1.75	0.32-0.40	-
304	0.08	2.0 max	18.0 -20.0	8.0-10.5	-	-

For the production of 300 series stainless steels, which contain 8% Nickel and above would require high grade Ferronickel normally produced in the electric furnace.

The 200 Series is being produced since the 1930s and a lot of development work was done during 1940s and 1950s in USA, due to shortage of nickel at the time, This grade has became popular because of its lower price and suitability to some specific applications with even better results compared to 300 series steels.

The construction sector is the major consumer of 200 Series. 200 Series is already preferred in various applications [9] where it can be used. It constitutes over 60% of all stainless steels for this sector. In the last few years, 200 series market share is about 10% of the stainless steel market. Nickel content in the 200 Series steels is between 0 - 6%. As can be seen, these nickel contents are compatible with the nickel content range of nickel pig iron which could be the starting material for that purpose.

2.4 Reference prices

In order to check the feasibility of the blast furnace process, it is advisable to consider as a reference basis a stable scenario. Otherwise the evaluation could lead to false conclusions based on a particular condition. Hence it is assumed, that the conventional Ferronickel production would be in equilibrium with the demand, on a worldwide basis. Under these conditions, the price of nickel (contained in the alloy) is stable or within the normal market fluctuations. Figure 4 presents LME (London Metals Exchange) nickel prices variation in the last twelve months. From the graph, one can easily recognize the crisis period and the future recovery trend. As can be seen, there is lot of fluctuation and neither the lower region nor the peak of figure 4 are good reference points but there is a trend to stability in the near future . It is not easy to forecast precisely the future, but as a first approach, a hypothetical scenario has been adopted in this work, considering the mean value of the graph.

Figure 4: Nickel prices (cash buyer) – 12 months Source LME - September, 24th, 2009 [11]

3 PROCESS SIMULATION

In order to identify the conditions in which nickel pig iron produced in the blast furnace can compete with conventional ferronickel production in electric furnace , both processes were simulated, employing programs based on thermochemical models where mass and energy balances were made considering the typical operating conditions of each one.

The reference nickel ores are considered as coming from an ore body whose profile and characteristics are shown in figure 3. Naturally this ore body is not real, but its structure is typical of many of them, around the world. From this ore body, the ores for the two smelting simulation routes are chosen.
The first one to be simulated is the conventional ferronickel production in electric furnaces.

3.1 Conventional Ferronickel Production (Electric Furnace)

The process is based on RKEF technology (Rotary Kiln – Electric Furnace). In this simulation, ore composition is chosen for the required range of Nickel content. From figure 3 it is seen that the most suitable ore comes from the garnierite/saprolite/serpentine layer. The mean composition of this layer is given in table 2. It is also feasible to employ lower grade ores from the intermediate layer, and that the lower assumed limit of the composition is given in table 2.

Table 2: Selected layers ore composition – deeper layers

	Ni	Co	Fe	Cu	SiO_2	MgO	Cr_2O_3
Main layer	2.500	0.028	13.710	0.010	29.770	20.600	0.70
Limit layer	1.800	0.028	20.000	0.010	35.000	18.000	0.70

These compositions are referred to the ore after calcining.

The ferronickel smelting procedure is well known [2][4][12] and will not be described here.

The main features considered are as follows:
- Shielded arc procedure

- The amount of carbon charged corresponds to what is the stechiometrically necessary to generate CO for NiO reduction plus an additional amount to guarantee the aimed nickel recovery value.
- The SiO_2/MgO ratio is maintained within the 1.4 and 1.9 limits and the FeO content depends on the alloy requirement and energy consumption (This depends on the f charged carbon).

Many other factors have to be considered but the ones mentioned above are sufficient to characterize the process. The aimed nickel content in the alloy is 30%, with a lower limit of 20%. Reducing agent is a conventional metallurgical coke (C – 85%, Ash – 8%).

Process simulation was carried out employing a program based on a thermochemical model based on mass and energy balances, considering the typical conditions of a conventional ferronickel smelting operation and facility. In the simulation dry calcined ore is charged for the electric furnace [12].

Based on the alloy and slag aimed characteristics, the program calculates the mass inputs and outputs. In this program, both the operational requirements (calcination temperature, SiO_2/MgO ratio, alloy composition etc) and the thermodynamic ones (slag/alloy partitions, equilibrium conditions, interaction coefficients, etc), are processed and adjustments are made till the aimed results are achieved. These results are presented in table 3

Table 3: Main results - Ferronickel Smelting – Main ore layer

Main Parameters			**Alloy**		**Slag**	
	Kg/t ore	**Kg/t alloy**	Co	0.26%	CoO	0.02%
Inputs			Si	0.18%	SiO_2	47.68%
Calcined ore	1000	11686	Fe	69.64%	Cr_2O_3	1.09%
Coke	34	398	Cu	0.14%	NiO	0.51%
Electrode	6	70	Cr	0.17%	MgO	33.02%
Outputs			Ni	29.54%	FeO	17.34%
Alloy	86	1000	P	0.06%	Cu_2O	0.00%
Slag	701	8194	Selectivity	1.83%	SiO_2/MgO	1.44%

This slag has a high melting point, what is a normal feature in ferronickel smelting. This can be seen in figure 5. In this figure results of this work and those of main ferronickel facilities worldwide are plotted together. As can be seen, there is a very good fitting with actual results in similar plants, which confirms the validity of the procedure.

The energy balance resulted in an electrical energy consumption of 11294 kWh/t alloy. Using the same program and considering that the ore charge is from the limit layer, the results are presented in table 4.

Table 4: Main results - Ferronickel Smelting – Limit ore layer

Main Parameters			**Alloy**		**Slag**	
	Kg/t ore	**Kg/t alloy**	Co	0.24%	CoO	0.01%
Inputs			Si	0.20%	SiO_2	48.86%
Calcined ore	1000	10982	Fe	79.21%	Cr_2O_3	0.95%
Coke	43	476	Cu	0.14%	NiO	0.32%
Electrode	6	66	Cr	0.16%	MgO	25.15%
Outputs	2	22	Ni	19.99%	FeO	24.41%
Alloy	91	1000	P	0.06%	Cu_2O	0.00%
Slag	804	8834	Selectivity	220.58%	SiO_2/MgO	1.94%

This slag melting point is lower than in previous case because of the higher FeO content. This can be seen in figure 5.

The energy balance resulted in an electrical energy consumption of 13888 kWh/t alloy.

From the diagram, the melting point of the calculated slag (main layer) is around 1670ºC (which means an operational temperature of 1700ºC) and this is 1470ºC for limit layer (which means an operational temperature of 1500ºC).

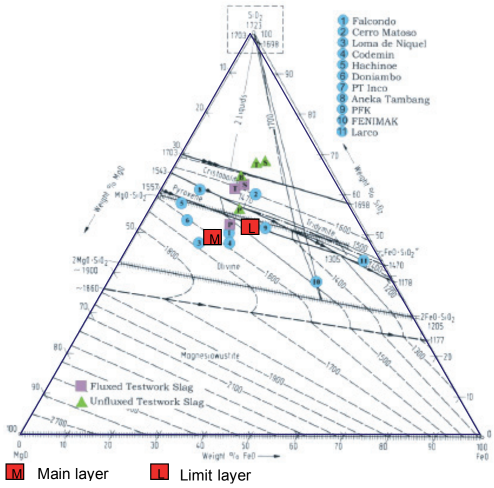

Figure 5: Phase diagram ferronickel slags [2]

3.2 Nickel Pig Iron Production In Blast Furnace

Charcoal blast furnaces of medium and small and medium sizes have been operating in Brazil since many decades (up to 200m^3 internal volume). In these the burden consists of iron ore or agglomerate, coke or charcoal and flux. The blast is heated in glendons up to 700ºC [7].

In this case, the energy necessary to the process is supplied by carbon, which is also consumed in reduction reactions leading to almost complete reduction of iron and as such there is very little or no FeO in the slag. Two main restrictions can be recognized from this. The first one is the impossibility of improving the Ni/Fe ratio in alloy, in comparison to the ore, what explains the typically low nickel content in the alloy produced in blast furnace. The second is the low FeO content in slag , having mostly silica and magnesia, causing high slag melting temperatures (figure 5), that are not achievable in a small blast furnace with low blast temperatures, without oxygen enrichment of the blast . However fluxes like limestone can be added to lower the slag temperatures As such the slag practice adopted in the electric furnace smelting, does not apply to the blast furnace practice

Considering the discussions on ore body from figure 3, it is clear that ores from any level could be employed in blast furnace smelting. However as has been pointed out richer ores are normally processed in electric furnace or by hydrometallurgical route and the ores poor in nickel content can be processed in blast furnace.

There are many aspects to be considered in the evaluation of ore burden, mainly hematitic in the conventional blast furnace process of pig iron production. From that point of view the present ore material containing nickel really cannot be considered as ore It is rather a waste that is removed to allow the exploitation of the higher grade layers. The chemical analysis of this layer is given below (table 5). Adopting the same criteria considered earlier in the ferronickel simulation, the limit for the ore to be used for nickel pig iron production would be somewhere in the intermediate layer, reported in figure 3. The limit layer considered has ore characteristics given in table 5.

Table 5: Selected layers ore composition – shallower layers

	Ni	Co	Fe	Cu	SiO_2	MgO	Cr_2O_3
Overburden	0.8	0.064	35.0	0.010	44.0	3.0	0.70
Limit layer	1.6	0.064	35.0	0.010	38.0	10.0	0.70

The simulation was carried out employing a program developed for pig iron production in small blast furnaces with a thermochemical model involving heat and mass balances.

As the small blast furnaces for pig iron production mostly operate with charcoal as fuel in Brazil the present simulation is also done with the same reducing agent, whose characteristics are the same as employed in Brazilian small blast furnaces (C – 70%; Ash – 3%; VM – 21%).

As already mentioned, almost all iron and nickel are reduced to the metallic phase. In order to achieve a low melting point and free running slag, limestone should be introduced in the burden so that the CaO+MgO/SiO2 ratio is about 0.8. Inputs and outputs calculated by the program, as well as the resulting slag and alloy, are presented in table 6

Table 6: Main results - Nickel Pig Iron – Overburden layer

Main Parameters		Alloy		Slag	
	Kg/t alloy	Co	0.13%	CoO	0.00%
Inputs		Si	0.28%	SiO_2	49.31%
Ore	2760	Fe	93.71%	Cr_2O_3	1.03%
Charcoal	1016	Cu	0.00%	NiO	0.01%
Limestone	2086	Cr	0.19%	MgO	8.68%
Outputs		Ni	2.19%	FeO	1.30%
Alloy	1000	P	0.10%	Cu_2O	0.00%
Slag	2450	C	3.50%	CaO/SiO_2	0.8%

The slag, phase is of CaO-MgO-SiO2 system, in the region of pseudowolastonite, whose characteristics are compatible with the operation of small blast furnaces with relatively low blast temperatures. Figure 6 shows the slag composition of the system.

The simulation with the limit layer ore was carried out employing the same program and the operating conditions, reducing agent etc, as in the previous case. The main results, from this simulation are presented in table 8

Table 7: Main results - Nickel Pig Iron – Limit layer

Main Parameters		Alloy		Slag	
	Kg/t alloy	Co	0.18%	CaO	33.21%
Inputs		Si	0.38%	SiO_2	47.44%
Ore	2760	Fe	90.17%	Cr_2O_3	1.15%
Charcoal	1016	Cu	0.00%	NiO	0.03%
Limestone	2086	Cr	0.20%	MgO	16.99%
Outputs		Ni	6.01%	FeO	0.93%
Alloy	1000	P	0.15%	Cu_2O	0.00%
Slag	2450	C	3.00%	CaO/SiO_2	0.8%

The slag referred to the ore in the limit layer, also of the CaO-MgO-SiO_2 system, is in the region of akermanite, whose characteristics are compatible with the operation of small blast furnaces with relatively low blast temperatures. Figure 6 shows the position of the slags in that system.

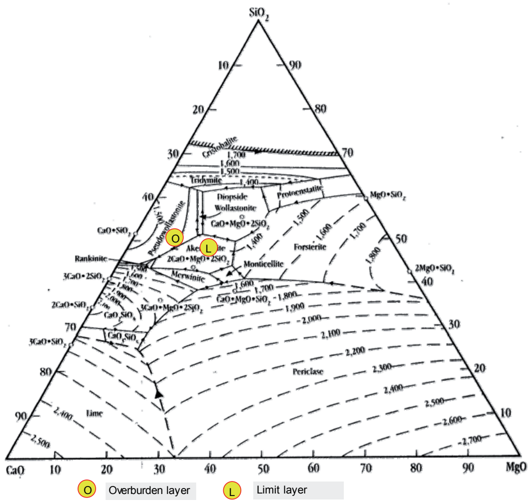

Figure 6: Phase diagram nickel pig iron slags [15]

4 EVALUATION OF SIMULATION RESULTS

The parameters values from the simulations enable the evaluation of feasibility of Nickel Pig Iron production small blast furnaces and the product competitivety in relation to the conventional ferronickel production

On facilities subject, a conventional ferronickel smelter includes, besides electric furnace, ore drier and a calcining rotary kiln. For alloy refining a ladle furnace facility (de-S) and an oxygen converter type vessel would be required (de-P and de-C).

Charcoal based small blast furnace facility is very simple and does not require drying and calcining facilities) Charcoal has little sulphur and hence ladle furnace is not necessary.
In the particular case of Brazil, there are many such small blast furnaces for the production of pig iron and these can be adapted to nickel pig iron smelting.

The main items of operating costs are given in table 9 and 10 corresponding, respectively to the electric furnace route (conventional ferronickel production) and blast furnace route (nickel pig iron)

Average price from figure 4 has been taken as a reasonable and acceptable reference point. The value arrived at for the price of nickel on this basis is around US$ 16000.00/ton. Another price that must be considered for market stability is that of the ore. Even though this may be smelters property, its value must be taken into consideration in the calculations. Ore price is normally fixed relative to the nickel content, considering a non speculative scenario, parameters are the LME price, the ore grade and the payable premium, and this price can be calculated according to following relation [12]:

Ore Price = LME Nickel Price x Nickel Grade x (Nickel Grade x Payable Premium)

Payable premium depends on market conditions, nickel grade, mine characteristics etc.

Table 8: Main cost items – Rotary Kiln / Electric Furnace Route

	Main layer: Ni_{ore}-2.5%; Ni_{alloy}-30.0%			**Limit layer: Ni_{ore}-1.8%; Ni_{alloy}-20.0%**		
	u/t alloy	US$/u	US$/t alloy	u/t alloy	US$/u	US$/t alloy
Ore (t)	11.686	100.00	1168.60	10.982	51.84	569.30
Energy(kWh)	11294	0.083	937.40	13888	0.083	1152.70
Electrode(t)	0.070	500	35.00	0.066	500.00	33.00
Coke(t)	398	250.00	99.50	476	250.00	119.00
Charcoal(t)	1260	266.70	336.00	1260	266.70	336.00
TOTAL			2576.50			2210.01

Table 9: Main cost items – Blast Furnace Route

	Ovb layer: Ni_{ore}-0,8%; Ni_{alloy}-2,2%			Limit layer: Ni_{ore}-1,6%; Ni_{alloy}-6,0%		
	u/t alloy	US$/u	US$/t alloy	u/t alloy	US$/u	US$/t alloy
Ore (t)	2.760	10.24	28.26	3.790	40.96	155.24
Charcoal (t)	1.016	266.70	270.93	1.641	266.70	437.60
Limestone(t)	2.086	150.00	312.10	2.052	150.00	307.80
TOTAL			612.10			900.64

Based on these figures and considering the Ni contents both in ores and alloys, the cost of the Ni units can be calculated and put together, for comparison purposes in figure 7.

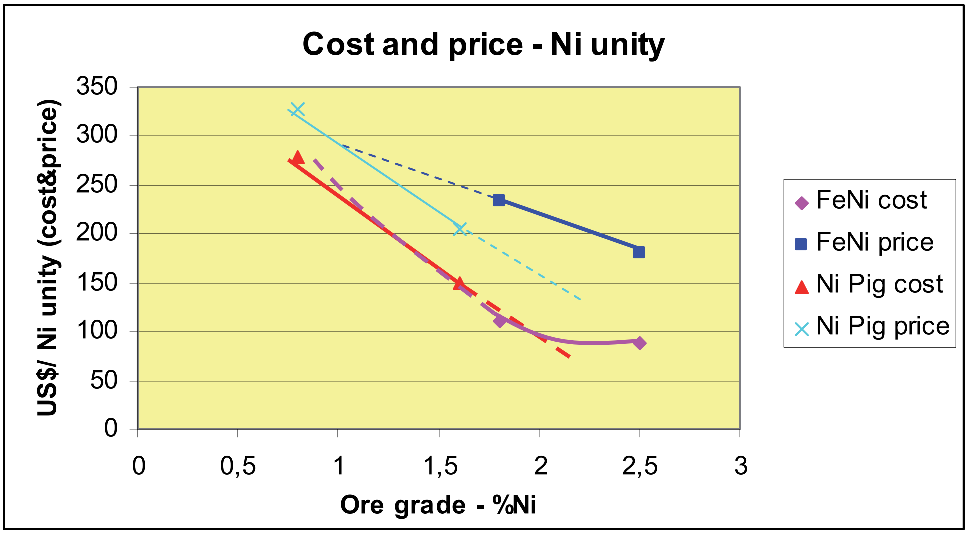

Figure 7: Variation of the cost of Ni in alloy with Ni ore content

The cost lines were calculated dividing the total cost values in each condition by the Ni content in alloy (FeNi and Ni Pig)
The commercial values were calculated considering both the Ni and the Fe content, according to the following formulas:
FeNi

(Alloy price/t) = (Ni price) x %Ni + (Pig Iron price)x (100 - %Ni)/%Ni [14]

Where: %Ni is the alloy Ni content.
As can be seen, this price considers the iron values, that weren't valuated in the past.
Ni Pig Iron

(Alloy price/t) = Ni price x %Ni + (Pig Iron price) x %Fe

Where: %Ni and %Fe are the Ni and Fe contents in alloy. In this case, the iron value calculations consider that this product is in fact a pig iron.

The LME price considered for nickel is US$16000.00/t and that for iron is the pig iron price, FOB Brazilian port, in August/2009 that was considered as US$ 350.00/t.

The Nickel values in the alloys were considered as 90% LME, for FeNi and 85%LME for Ni Pig Iron.

According to the graph, the range of each product seems clear and suggests a complementary condition between the two kinds of product.

As can be seen, the differences between cost and value are almost constant.

The difference of behavior between the two routes is due to the energy sources of each one and the kind of alloy produced. In ferronickel smelting, the increase of Ni content in alloy is achieved by an increase of FeO slagging and by lowering the amount of reductant. Besides that, the minimum nickel content in a conventional ferronickel is estimated around 20% which means that leaner the ore, greater is the slag volume and higher energy consumption per ton of alloy.

In the blast furnace route, it is not possible to reduce charged carbon as it is also the process energy source. In short, the energy source is maintained in an approximately constant level and the same occurs to nickel pig iron amount – only the Ni and Fe contents change with the respective contents in ore.

5 CONCLUDING REMARKS

According to the above considerations, it can be pointed out that there are situations in which Nickel Pig Iron can be a feasible option. Some of these conditions are listed below:

- To recover nickel values from poor and/or small ore bodies, which is not sufficient to turn feasible for a hydrometallurgical project;
- To recover nickel values from removed overburden and limonitic layers in parallel with the utilization of rich ore by ferronickel smelter in a complementary operation.
- From the above considerations it is clear that the production of nickel pig iron through blast furnace route can utilize many operating and non-operating nickel lateritic deposits to produce nickel containing alloys and this can become a routine operation and could be adopted in countries like Brazil. However deeper evaluation and experimentation would be required prior to commercial ventures.

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