TECHNO ECONOMICS OF RECOVERING FERRO ALLOYS FROM DUST AND SLAG

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1. Introduction

Slags, ladle skulls and casting bay residues from ferro alloy furnaces contain entrained metal. This metal can be recovered from slags by physical separation processes.

Electric arc furnace (EAF) dusts from steel and alloy production often contain valuable elements in the form of metal oxides. These metals can be recovered by hydrometallurgical or pyrometallurgical processes.

In both cases the minimum techno economic criteria that apply to the recovery of these metals are:-

- The metal recovered must be saleable in the market
- The unit cost of the recovered metal must not exceed the marginal unit cost of its production from the original raw materials

This paper presents the State of the Art of metal recovery from slags and EAF dusts from a techno-economic perspective.

2. Technology

2.1 Metal Recovery from Slags

2.1.1 Metal Separation

Various physical processes have been used to separate metal from slags. They include magnetic separation, dense media separation (DMS), spirals, shaking tables, jigs and classifiers.[1]

Magnetic separation (figure 1) only applies to alloys with suitable magnetic susceptibility. Even then, the grade/ recovery curve is such that high recovery usually implies low metal grade and vice-versa.

Figure 1 : ***Magnetic Separation***

DMS (figure 2) can only be applied to relatively fine feeds and requires a high recovery of the expensive FeSi medium.

Figure 2 : ***DMS***

Spirals (figure 3) also only apply to fine feeds and are difficult to control to achieve high grade and recovery.

Figure 3 : ***Spirals***

The best technology for metal recovery from slags involves a combination of ***pneumatic*** * coarse (<40mm) and fine jigs (±10mm) with ultrafine (<1mm) classifiers.[1, 2]

(* ***Mechanical jigs suffer from throughput recovery and grade constraints, particularly for larger size fractions.).***

This process results in an optimum metal size, grade and recovery. The slag residues are also suitably washed and sized to be used as construction materials. Table 1 shows recovery and grade results for a few plants operated by Atoll.

Table 1

ALLOY	SIZE FRACTION	SLAG IN METAL	RECOVERY
Charge Chrome	6 – 32 mm	2.1%	98.5%
	1 – 6 mm	3.4%	99.9%
	<1mm	9.3%	~90%
HCFeMn	10 – 25 mm	1.85%	98.43%
	4 – 10 mm	1.23%	98.60%
	<4 mm	<10%	~90%
SiMn	10 – 25	1.7%	97.5%
	3 – 10	1.4%	98.5%
	<3 mm	<10%	~90%

The jigging/ classifier technology can also be applied to "cleaning" metals contaminated with slags. On specification metal can be produced from metal slag mixtures of any composition.

All the metal from slag recovery processes are preceded by a comminution circuit which involves crushing, screening and sometimes milling of the slag prior to metal recovery.

Figure 4 shows a flowsheet of a typical metal from slag recovery plant while figure 5 is a photograph of the 5 million tpa FeMn/SiMn from slag recovery plant at Metalloys, Meyerton.

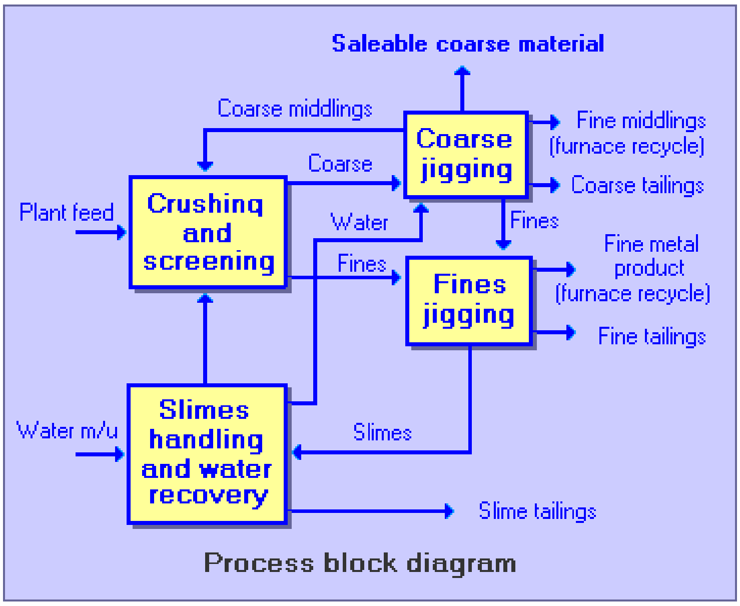


Figure 4 : ***Flowsheet***

Figure 5 : ***1,5 million tpa Metal From Slag Recovery Plant***

2.1.2 Metal Fines Remelting/ Refining

The market for ferro alloy fines has grown significantly over the past few years. Several ferro alloy users have developed technology to accommodate fines. However, the fines are usually purchased at a substantial discount to market prices for lumpy ferroalloys.

Metal ultra fines produced by metal from slag recovery plants sometimes contain too much slag and/ or off-specification metal compositions. Silicomanganese and ferromanganese ultrafines of this type have been successfully remelted/ refined in a DC furnace (figure 6a) to produce high value low carbon ferro manganese alloys using patented techniques developed by Mintek.[3]

Figure 6a : ***Mintek DC Furnace***

Induction furnaces have been used to melt/ refine briquetted FeCr, SiMn and FeMn fines. However, the furnace linings are vulnerable to attack by the slags/ unreduced oxides in the fines and several severe accidents have occurred. In some cases the metal fines do not "suscept" and induction furnaces cannot be used.

2.2 Metal Recovery from EAF Dust

2.2.1 Hydrometallurgical Processes

Several hydrometallurgical processes have been proposed to recover metal values from stainless steel EAF/AOD dusts (Ni, Cr, Fe, Mo) and carbon steel EAF dusts (Zn, Fe). Although pilot plants have been operated to our knowledge none of those processes is operating on commercial scale. [4]

2.2.2 Pyrometallurgical Processes

2.2.2.1 Carbon Steel Dusts

Zinc is the major element of value in carbon steel EAF dusts.

By far the largest volume of carbon steel dusts are processed to produce zinc oxide by the Waelz Kiln technology which is operated by the BUS Group (figure 7).[5,7]

Figure 7 : ***Rotary Kiln***

The Horsehead flame reactor also produces zinc oxide from carbon steel dusts and zinc bearing blast furnace slags. IMS attempted to produce zinc metal directly from carbon steel dusts by smelting the material in a DC furnace and fuming the zinc into a zinc splash condenser. However, the process was not technically viable.

Mintek has successfully produced zinc from EAF dust on a demonstration plant using a DC furnace attached to an ISP lead splash condenser (the Enviroplas process). The process has not yet been applied on a commercial scale.[6]

2.2.2.2 Stainless Steel Dusts

Stainless steel dusts have been successfully smelted by one of several processes:

- The Inmetco process (figure 8) which involves preheating/ prereduction in a rotary hearth furnace to produce a NiCr, Fe alloy from diluted wastes in the Pittsburgh area.[5]

Figure 8 : ***Rotary Hearth Furnace***

- The Scandust process (figure 9) which uses three “plasma” torches or electrodes to provide the energy for smelting the dusts to produce a Ni, Cr, Fe alloy from dusts/ waste from England, Sweden and Finland.[5]

Figure 9 : ***Scandust***

- The Heckett Multiserv “Tectronic” single electrode DC furnace that smelts the dust to produce the Ni, Cr, Fe alloy.
- The BUS Valera AC three electrode arc furnace smelting (figure 10) of briquetted dusts and wastes.

Figure 10 : ***AC 3 electrode furnace***

- The Mintek Enviroplas DC furnace (figure 6) technology that is being used to produce a Ni, Cr Fe alloy from Columbus dust/ wastes.[8]

Figure 6 : ***Palmiet DC furnace***

The Inmetco process has been operating at Ellwood City since 1978 and the Scandust process in Landskrona since 1984. The HM DC arc furnace has been operating at Terni, Italy since 1991, while Mintek’s Enviroplas process has operated since the early nineties.

Intrinsically, the simple DC arc furnace process should be the most technically effective for feed quantities less than 100 000 tpa. For throughputs greater than 100 000 tpa preheating and prereduction prior to smelting in the DC furnace may be technically justified.

3. Economics

3.1 Metal Recovery from Slags

3.1.1 Metal Separation

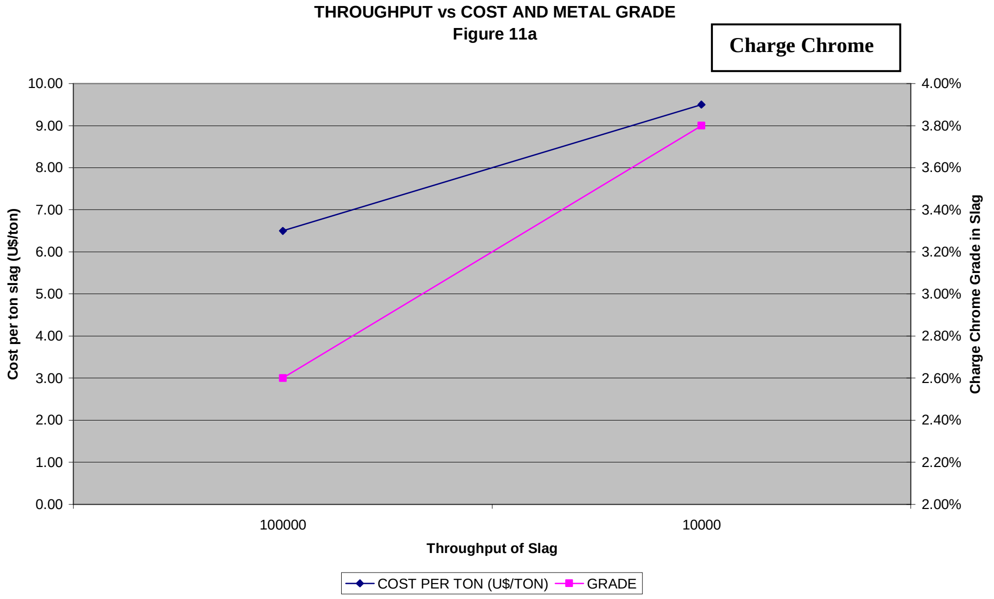
For metal grades up to 15%, the cost of metal recovery from slag by the jigging/ classifier process is a function of slag throughput. Unit cost decreases with increasing slag throughput. Above 15% metal grade throughput decreases and unit costs increase.

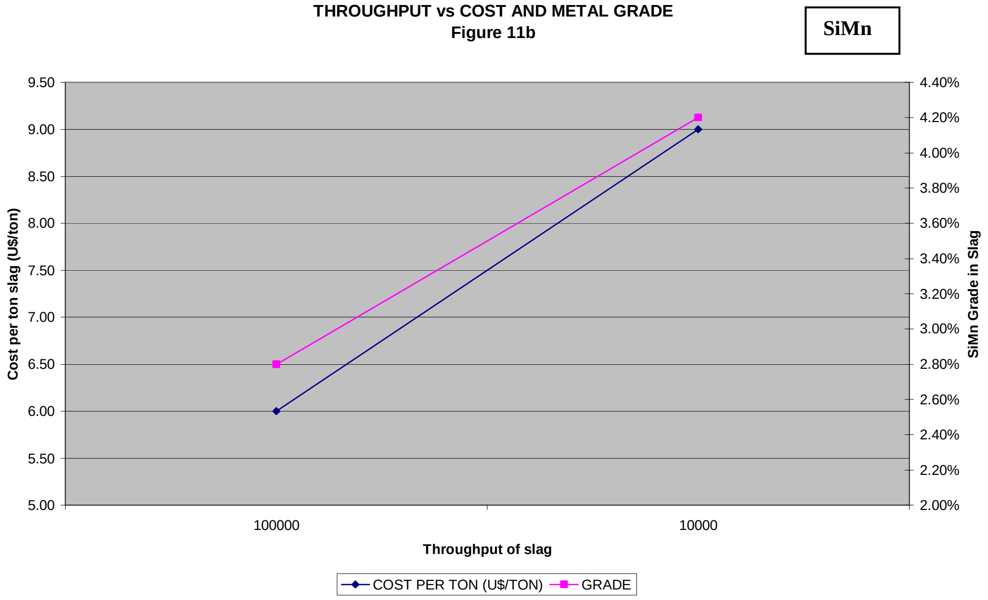
Figure 11 a, b & c shows the cost of metal recovery from slag as a function of throughput and the grade of recoverable metal required for the process to breakeven based on the criteria of marginal cost of production for charge chrome, SiMn and HCFeMn respectively.

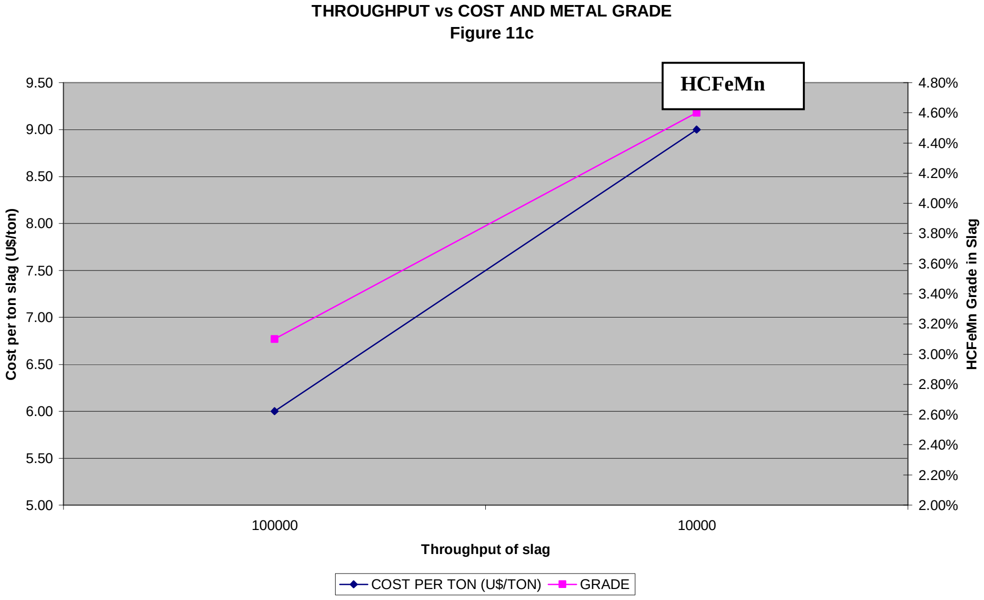
From the figures it is apparent that breakeven grade for the various alloys based on the marginal cost of production criteria is:-

FIGURE 11 a,b,c

METAL	MARGINAL PRODUCTION COST	THROUGHPUT TPM	COST PER TON (U$/TON)	GRADE
Charge Chrome	$250	100000	9.50	2.60%
Charge Chrome	$250	10000	6.50	3.80%
Si Mn	$215	100000	9.00	2.80%
Si Mn	$215	10000	6.00	4.20%
HCFeMn	$195	100000	9.00	3.10%
HCFeMn	$196	10000	6.00	4.60%







Marginal production cost is only a criterion when there is excess smelting capacity and slag can be dumped on site.

These breakeven grades decrease significantly if other criteria are used to value the recovered metal:

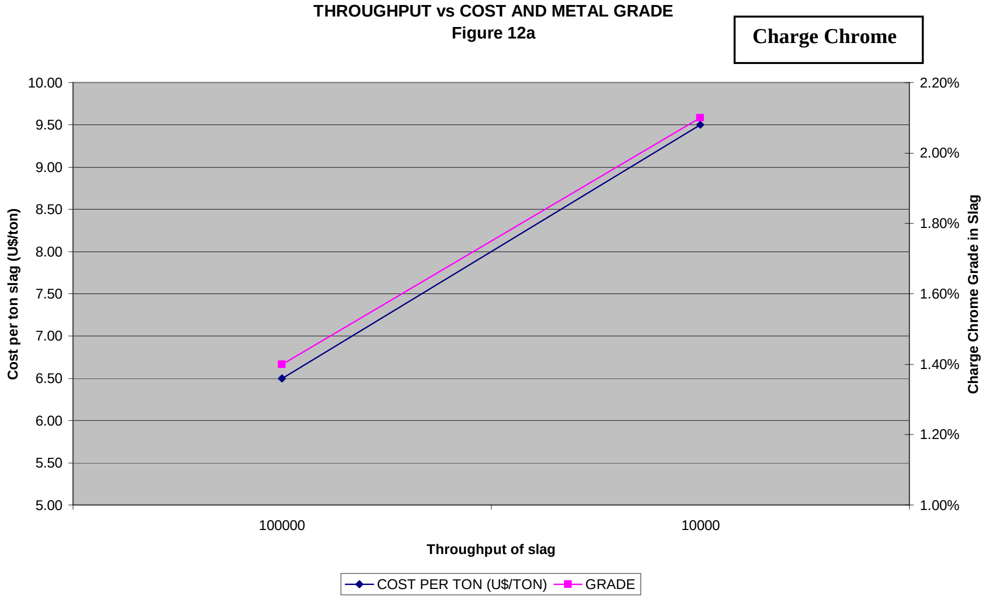
- When market demand exceeds production capacity or when sales are made from a dump, market price can be used for the metal. Allowing $100/t for distribution and marketing costs we obtain from figures 12 a, b, & c :

FIGURE 12 a,b,c

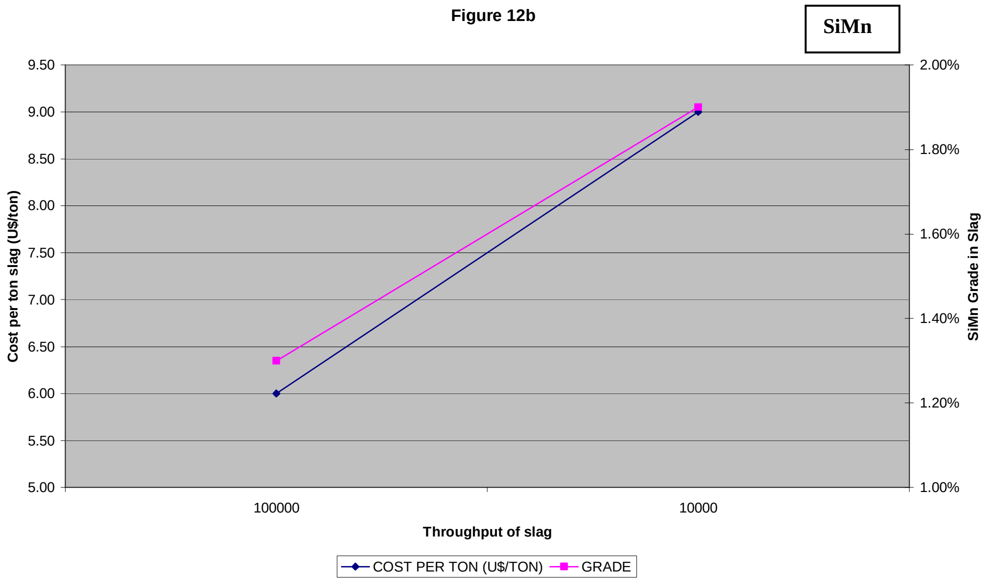
METAL	MARGINAL PRODUCTION COST	THROUGHPUT TPM	COST PER TON (U$/TON)	GRADE

Charge Chrome	$250	100000	9.50	1.40%
Charge Chrome	$250	10000	6.50	2.10%
Si Mn	$215	100000	9.00	1.30%
Si Mn	$215	10000	6.00	1.90%
HCFeMn	$195	100000	9.00	1.50%
HCFeMn	$196	10000	6.00	2.20%

THROUGHPUT vs COST AND METAL GRADE
Figure 12a

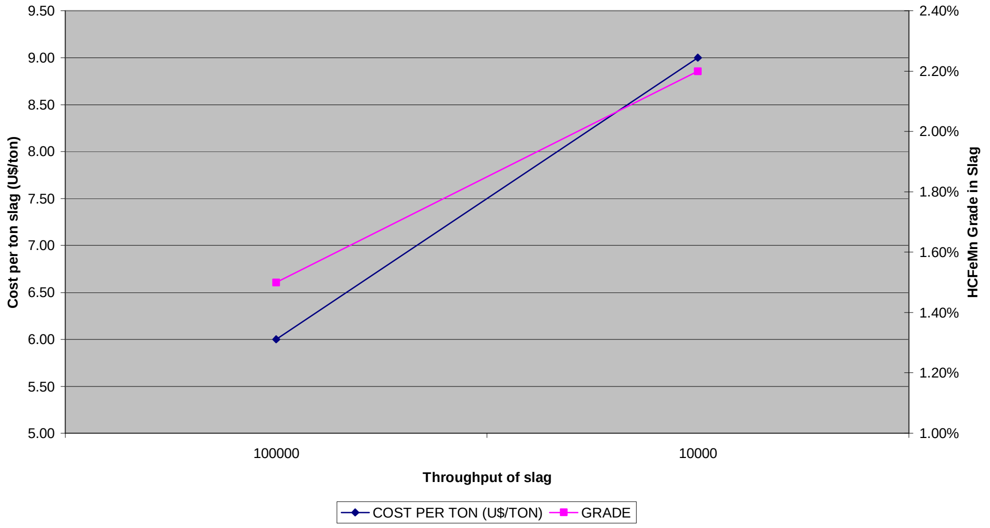


THROUGHPUT vs COST AND METAL GRADE
Figure 12b



THROUGHPUT vs COST AND METAL GRADE
Figure 12c

HCFeMn



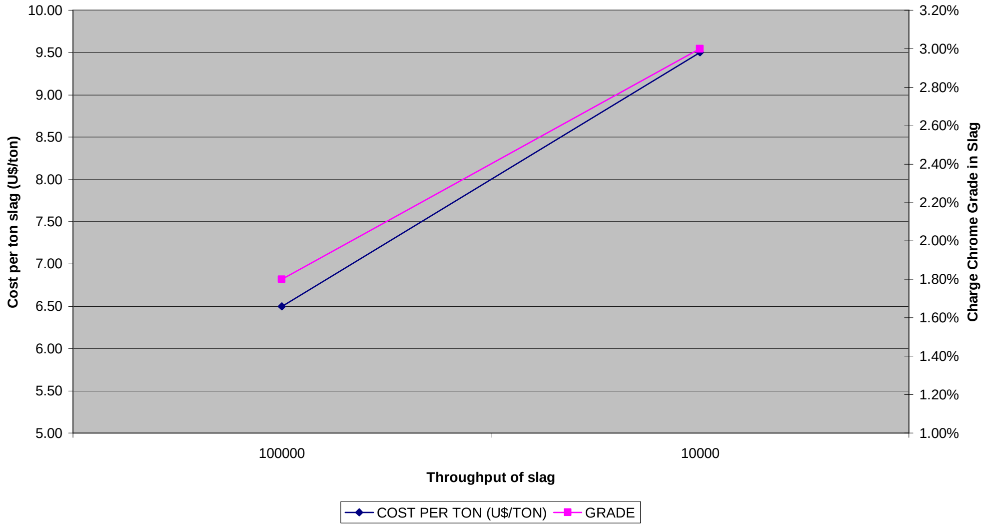
- When the crushed, washed and sized slag is sold as construction material for $2/t ex works we obtain from figures 13 a, b & c:

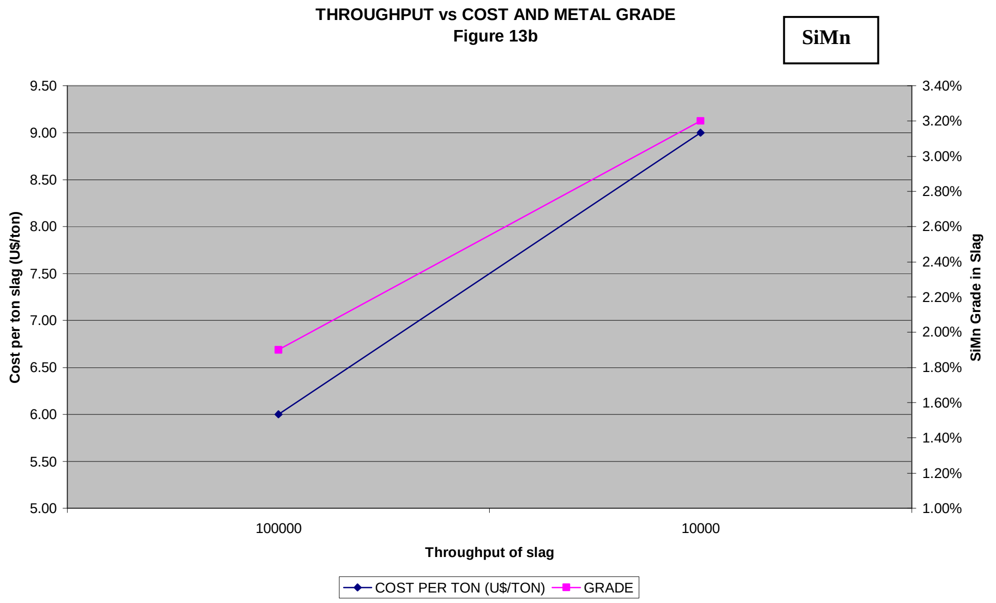
FIGURE 13 a,b,c

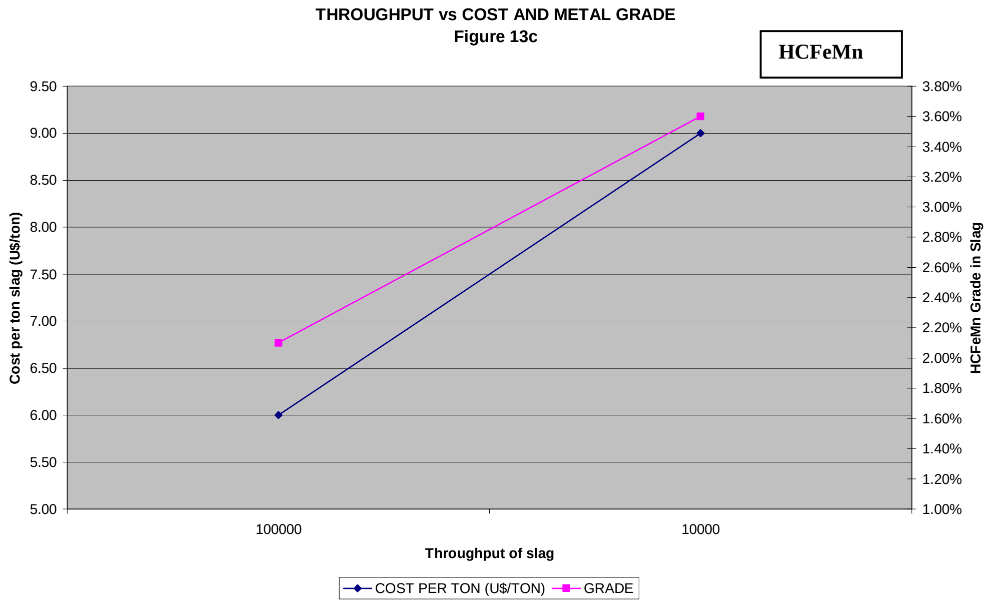
METAL	MARGINAL PRODUCTION COST	THROUGHPUT TPM	COST PER TON (U$/TON)	GRADE
Charge Chrome	$250	100000	9.50	1.80%
Charge Chrome	$250	10000	6.50	3.00%
Si Mn	$215	100000	9.00	1.90%
Si Mn	$215	10000	6.00	3.20%
HCFeMn	$195	100000	9.00	2.10%
HCFeMn	$196	10000	6.00	3.60%

THROUGHPUT vs COST AND METAL GRADE
Figure 13a

Charge Chrome




THROUGHPUT vs COST AND METAL GRADE
Figure 13b


THROUGHPUT vs COST AND METAL GRADE
Figure 13c

- When FeMn slag with metal removed (high Mn to Fe ratio) is used as a feed material for SiMn production.

3.1.2 Metal Fines Remelting/ Refining

The discount applied to metal fines is usually quoted as 15% of market price. However this may be regarded as a minimum discount.

Nevertheless, remelting/ refining metal fines costs about double the 15% discount on metal prices, so very little remelting is practiced even by the few producers that operate DC furnaces.

However, by combining off specification FeSi, SiMn, HCFeMn metal fines and high Mn : Fe ration baghouse dusts as a feed to a DC furnace it is possible to produce MCFeMn alloys that enjoy a price premium that makes the remelting/ refining process viable.

Similarly, FeCr fines remelting is not economically viable unless one can prepare “master alloys” by blending in high value metals such as Nli, Mo, V etc or by producing special “granulated” or “blobulated” metal shapes for use as coolants.

3.2 Metal Recovery from EAF Dusts

3.2.1 Pyrometallurgical Processes

3.2.1.1 Carbon Steel Dusts

At current zinc prices the BUS Waelz Kiln process for zinc beraing dusts and slags is only viable if disposal fees are charged. Its viability depends on high landfill costs or stringent hazardous waste classifications.

Mintek’s Enviroplas process that produces PW grade or distilled special high grade zinc is potentially more cost effective than the Waelz Kiln process. However, its implementation has been delayed by the depressed zinc prices over the last few years.

3.2.1.2 Stainless Steel Dusts

Costs of processing stainless steel dusts and wastes range from US$250 to US$350 per ton.

The viability of the Inmetco process depends to an extent on economies of scale. The Inmetco process appears to require at least 50 000 tpa feed, so on site or over-the-fence processing is not viable for stainless steel mills producing less than 1 million tpa. DC furnaces can be viable for mills producing more than 300 000 tpa of stainless steel. However the major cost drivers of all the alternative processes appear to be electrical power versus fossil fuel and labour.

The Ni, Cr Fe alloy produced is valued at LME prices for the metals less a discount for C content and “scrap” similarity. Ni and Cr content determine value.

Typical breakdown grades of Ni and Cr in the dusts/wastes are 12 – 14% Cr and 1,5 – 2% Ni. Since Cr content is relatively constant the Ni content determines the viability of the process.

Usually stainless steel dusts and wastes are classified as hazardous wastes, so the cost of disposal to a hazardous waste landfill is an added credit which means that the process can still be viable at Ni concentrations as low as 1%.

Recyclable dusts and wastes from stainless steel production constitute 2,5 to 3% of throughput. Some 70% of these wastes are recovered as Ni, Cr, Fe alloy by the smelting processes described – clearly not a major source of raw material. Nevertheless the recovery of the alloy alleviates a potential environmental problem in an economically viable manner.

4. Conclusion

Metal recovery from ferroalloy slags is a viable swing producer of metal, even at relatively low metal grades. It can be used to supplement metal production during periods of low demand when furnaces are temporarily shut down and during periods of high demand when furnaces are at full capacity.

It also allows greater operational flexibility in processing ladle skulls, casting boy residues and contamination metal.

Metal recovery from stainless steel EAF dusts and other oxidized wastes is economically viable as an on site or over-the-fence toll treatment process for most stainless steel producers.

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