

EDUCATED USE OF DRI/HBI IMPROVES EAF ENERGY EFFICIENCY AND YIELD AND DOWNSTREAM OPERATING RESULTS

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KEYWORDS: DRI/HBI, EAF, Optimization, Energy, Efficiency, Yield, Productivity, Carbon, Hot charging, Cost savings

ABSTRACT

Electric Arc Furnace (EAF) operations have improved significantly over the past 30 years. Future significant improvements will require either new melting technologies or faster power input capabilities. In the meantime, steelmills can benefit significantly from optimizing practices and logistics, increasing chemical energy use further and correctly using DRI/HBI¹.

Historically, EAF DRI use was predicated for production of high quality, low residual steels, with the anticipated expense of kWh/Tonne, tap to tap time (T-T) and yield loss. Current educated use has produced practices indicating DRI use can improve energy, yield, productivity and operating costs.

Further, new DRI plant technology can increase DRI productivity and carbon content, allowing the EAF shop to reap substantial financial and technical benefits. Improved operating capabilities, coupled with the need for cost effective productivity, has renewed interest in capitalizing on high carbon, hot DRI use.

Worldwide industrial data presented herein will demonstrate how 50% DRI can increase productivity and efficiency over 100% scrap melting and how high carbon, hot DRI can increase productivity by 34% and reduce operating costs by \$9.72/Tonne_{liquid steel}. Benefits of DRI use regarding downstream yield and productivity benefits will also be discussed.

¹ Unless otherwise indicated, DRI is used to refer to DRI and HBI

INTRODUCTION¹

EAF operations have improved significantly over the last 30 years, leading to 30 min. T-T times, less than 300 kWh/Tonne electrical energy usage and electrode consumption of 1.5 kg/Tonne. Future significant improvements will require faster “power input” capabilities or new melting technologies. In the meantime, steelmills can benefit significantly by analyzing available in-house data, which will allow optimization of practices, logistics and bag-house operation, and make more efficient and increased use of chemical energy and oxygen (O₂), as well as more educated use of alternative iron sources (AISs) such as DRI, pig iron (PI) and hot metal (HM).

Historically, DRI use in the EAF, predicated by production of high quality, low residuals steels, carried with it steelmaking penalties of increased operating costs from higher kWh/Tonne_{liquid steel} (kWh/T_{ls}), T-T times, fluxes, FeO_{slag}, refractories and electrode wear, yield losses... This is true if the EAF operators initiate AIS use without appreciating the need to identify and understand the inherent and unique AIS properties and modifying practices accordingly. Educated EAF operators have established practices that not only negate the preconceived disadvantages, but actually improve operations and, hence, operating costs.

The need for cost effective steel production has renewed interest in chemical energy sources, such as high C and hot DRI (HDRI), which reduce electrical energy costs due to improved contained C efficiency (up to 95%) (1). This C efficiency, coupled with DRI's inherent low residual properties, will imbue the meltshop with benefits such as: economic residual control; lower nitrogen in the steel ([N]); improved, and often earlier, foamy slag; reduced energy use and electrode wear and increased yield. These meltshop benefits, especially tighter chemistry control, translate into downstream benefits due to tighter process control and optimization, ultimately leading to improved yield and quality.

This educated DRI use begs re-visitation of the historical \$8 to \$30 premium DRI Value in Use (VIU) (1). Yes, the VIU will be site-specific, dependent upon the local infrastructure and availability and the cost of many process variables. However, mills need to truly understand and quantify their current operating efficiencies, optimize their practices by charge mix and truly define yield. They must also take into account other meaningful variables such as ability to continuously charge, safety and ease of handling (shipping, transfer, sorting, storage, charging..) and other often un-quantifiable benefits ([N] removal capacity for example..), as well as the potential cost of practice changes required to accommodate DRI use. Only then will the truly quantified VIU of DRI be revealed. For example, most mills are unaware their specific in-house C efficiency (% of theoretical C combustion energy realized) is between 25% and 75%, and often around the 43% level, for charged or injected C versus the 95% efficiency for contained DRI C. The cost effectiveness of this, even in the light of the minimal cost incurred by the DRI plants to install new technologies to increase DRI productivity and C (2), is substantial in financial and technical terms, as will be seen.

What about PI, you ask? Yes, PI is the AIS of choice in many shops due to its high energy (C) content, ease of storage/handling and current, pre-conceived, VIU versus gas based DRI (+\$8 to +\$30/Tonne over DRI). However, limitations such as high sulphur and phosphorous, bag-house capacity (required for rapid blow down), continuous feeding preclusion (sizing and shape) and restricted O₂ equipment and/or supply, are reducing its favoured position and VIU.

Data hereunder shows how international mills, with knowledge of the “beast”, have evolved practices enabling them to charge 50% DRI more cost effectively than 100% scrap, to define “best cost for quality” charges, to realize substantially more benefits from high C and hot charged DRI than initially predicted and to quantify real downstream impacts, which have heretofore remained substantially un-quantified. This evidence points to a need for a

¹ Unless otherwise indicated, DRI is used to refer to both DRI and HBI

philosophical change in steelmill economics to one of a more global nature to ensure full realization of these global benefits.

EAF ENERGY REQUIREMENTS

The main parameters impacting EAF energy use are composition of raw materials (%gangue/chemistry, metallization, %C, %P, energy content), operating practices (power profiles, foamy slag and melting practices) and furnace design (heel, O₂ use and tools, OGS, charging system, AC/DC) (3). Without attention to these factors, DRI melting can be detrimental to the steelmill's bottom line, increasing the required melting power above that nominally required. Informed, intelligent, use can significantly benefit the operating results, as will be seen.

When comparing DRI with scrap, gangue is viewed as a major detriment to DRI use (i.e. increased oxide content/lower metallization, yield and productivity and higher melting energy requirements). However, one should not overlook the scrap "gangue" content, which can be as high as 10%, when considering low quality, open ground-stored, reclaimed (rebar) or obsolete scrap, which contains dirt and other non-metallics such as concrete, refractory, timber, plastic ... Table I shows an analysis Ispat Mexicana SA (IMEXSA) performed on their average grade scrap (3,4).

Table I. Comparison of Scrap and DRI Composition at IMEXSA

| | Total Fe | %FeO | %C | %Gangue |
|------------|----------|------|------|---------|
| IMEXSA DRI | 90.80 | 6.77 | 2.08 | 4.47 |
| Ave. Scrap | 93.85 | 1.80 | 0.47 | 4.25 |

Increasing the DRI acid (SiO₂ and Al₂O₃) gangue content by 1% will increase the basic fluxes (MgO and CaO) by 2.5% to satisfy the desired quaternary EAF "V" ratio and increase power requirements by 20 kWh/Tonne, as well as increase the slag volume. Table II shows the Asian cost penalties associated with various gangue components (5).

A certain amount of iron oxide is required in the system to help flux or dissolve the lime and/or dolomitic lime, thus promoting an early liquid slag. Also, as 67% of the iron oxide will be reduced by carbon, the CO gas evolved will promote an earlier better, foamy slag. A 1% increase in metallization would allow steelmills to realize savings of 10 to 25 kWh, 0.425 kg refractories and 0.0375 kg electrodes/Tonne_{liquid steel} with between 0.3% and 2% increase in yield. Figures 1 and 2 show the impact of changing metallization on energy consumption and yield, and Table III the cost savings realized at Acindar (3) in Argentina. The results, based on 100% DRI, 8% briquettes and 17 Nm³ O₂/Tonne, are better than the conservative numbers above; at -40 kWh/Tonne and 1.5% yield increase/1% increase in metallization from 91% to 95%.

Table II. Cost Associated with Various Gangue Components as Defined by BHP for Asian Mills

| | Cost in \$US/Tonne HBI Added to the EAF | | | | |
|---------------------------------------|---|--------|------------|-----------|-------|
| Gangue | +Fluxes | +Power | Yield Loss | Slag Cost | TOTAL |
| SiO ₂ / 0.1% | 0.156 | 0.062 | 0.135 | 0.015 | 0.368 |
| Al ₂ O ₃ / 0.1% | 0.114 | 0.062 | 0.135 | 0.015 | 0.326 |
| CaO / 0.1% | (0.075) | 0.030 | 0.135 | 0.001 | 0.091 |
| MgO /).1% | (0.071) | 0.028 | 0.135 | 0.001 | 0.093 |

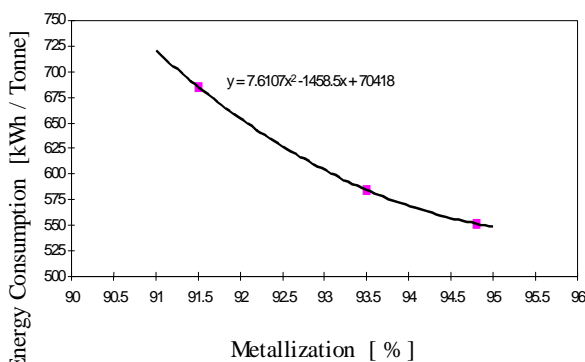


Figure 1 – Energy Consumption vs Metallization at Acindar

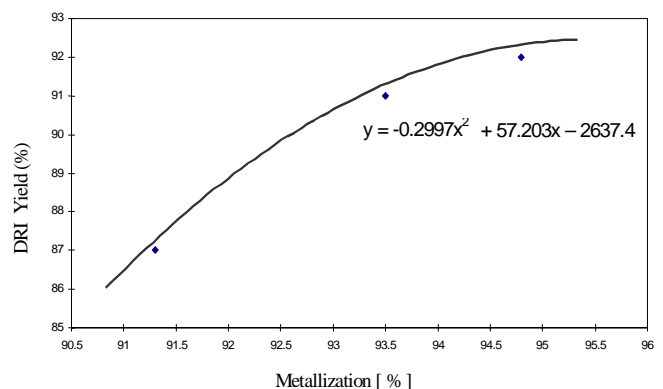


Figure 2 - DRI Yield versus Metallization at Acindar

Table III – Cost Benefits Realized by Acindar Increasing Metallization from 93.5% to 94.5% (3)

| | |
|-----------------------|---------------------------|
| Productivity | + ≤ 5% |
| Energy Consumption | - 25 kWh/Tonne |
| Electrode Consumption | - 0.15 kg/Tonne |
| Metallic Yield | + 1% |
| Refractories | - \$0.70/Tonne |
| Coke Charge | - 5.80 kg/Tonne |
| Total Cost Savings* | - \$6.00 to -\$8.09/Tonne |

*including productivity

The carbon “issue” remains a controversy in the minds of steelmakers primarily because they perceive they are “paying DRI prices for C”. However, whilst the benefits will remain site-specific, IMEXSA’s high C DRI results, and the economics thereto, prove the C efficiency benefits actually will save C costs. Further, today’s O₂ supply and technologies have over-turned the 1980’s “1.6% to 1.8% optimum C” mandate proffered by mills suffering from the lack of these tools.

A certain amount of the DRI’s carbon is required to reduce (neutralize) the FeO in the DRI:

$$\%C \text{ required for FeO neutralization} = (100\% - Fe_{\text{total}}) \times \frac{\% \text{ metallization}}{100} \times 100\% \quad (1)$$

1.4%C is required to neutralize the FeO in DRI with 93% metallization and 93% total iron. As the FeO melts and is reduced by the contained carbon, CO evolution creates an early foamy slag

reaction. Any excess C is available for $(\text{FeO})_{\text{slag}}$ reduction and combustion, whilst the combustible carbon varies dependent upon the $(\text{FeO})_{\text{slag}}$ (Table IV (6)).

Table IV – Impact of Excess and Combustible Carbon

| C_T | % (FeO) | 92.5% Met | 95% Met |
|-------|---------|-------------|-------------|
| 1.8% | | 0.30% C_E | 0.75% C_E |
| 2.4% | | 0.95% C_E | 1.45% C_E |
| 2.0% | 20% | 0.90% C_E | 1.45% C_E |
| 2.0% | 35% | 1.25% C_E | 1.75% C_E |

Where C_T is the total C and C_f the C to reduce the FeO_{DRI} or FeO_{DRI} and FeO_{slag}

Benefits of C contained in DRI are varied; i.e. reduction of (FeO) reduces refractory wear, O_2 combustion lowers the kWh/ T_{1s} and the increased CO production improves foamy slag practice and increases arc stability (especially important for the long arc DC operators). The DRI's inherent 95% combustion efficiency provides a 4.1 kWh/Tonne premium over the average efficiency from injected or charged C (inherently low due to early combustion without heat transfer, loss to the 4th hole or lack of slag penetration (1,4)).

This will significantly impact site-specific carbon cost savings, provided mills can capitalize on the high energy. The substantial flat bath conditions are non-conductive to oxy fuel burner (OFB) use and favour high velocity oxygen lances. High C will require more rapid decarburization to prevent delays/penalties achieving final carbon, and OGS capacity must be sufficient (may require assessment of fan operation and alteration of the same (7,8)).

OPERATING PRACTICES

For effective DRI use in the EAF, steelmakers need to understand and optimize current practices first (7,8) and then, knowing the DRI chemistry, modify the standard operating procedures (SOPs) to ensure optimum performance. Adoption of modified SOPs has significantly improved productivity, power usage, yield, reproducibility of heat chemistry and, hence, production costs.

Experience shows (3,5), contrary to popular belief, that educated use of DRI (even in excess of 50%) can reduce kWh/ T_{charged} and T-T time to below that for 100% scrap. Table V shows savings for a DRI composition of 93% Fe_{total} , 93% metallization, 1.8%C, 1.5% (CaO + MgO), 1.9% ($\text{SiO}_2 + \text{Al}_2\text{O}_3$), 0.003%S at various %DRI charge levels.

Table VI shows the importance of power profile. The use of a multi tap profile (PP2) improves operations over a single tap profile (PP1) because it creates a better scrap bore-in and, hence, produces a better DRI feed area.

The ability to feed continuously significantly reduces the EAF energy requirement, as it offers a closed-door operation, which negates heat and time loss for roof swing(s) and charging, not to mention the potential [N] pick-up which can arise from the air ingress.

Table VII compares continuous versus batch feeding and indicates 33% continuously charged DRI is the best option, saving 46 kWh/charged short ton (46 kWh/ st_{charged}) and 4 minutes T-T time versus batch charging. Increasing to 43% DRI, with 10% batch charged, adds 10 kWh/ st_{charged} and 1 min. T-T time but still saves 36 kWh/ st_{charged} and 3 mins. T-T time versus batch charging. Table VIII shows the average current operation results at this mill.

Table V. DRI Impact on Energy and Time

| %DRI | kWh/ton | T-T (mins) |
|-----------|---------|------------|
| All Scrap | 421 | 61 |
| 25 | 375 | 52 |
| 30 | 377 | 53 |
| 35 | 380 | 54 |
| 40 | 393 | 55 |
| 45 | 399 | 57 |
| 50 | 408 | 59 |

Table VI. Power Profile Modification

| @30-35% DRI | PP1 | PP2 |
|--------------------------------|--------|--------|
| T-T (min.) | 54 | 50 |
| KWh/st _{charged} | 390 | 377 |
| Lbs lime/st _{charged} | 55 | 55 |
| Tap Temperature | 2960°F | 2960°F |

Table VII. Continuous vs. Batch Charging

| | KWh/st | T-T(mins) |
|--------------------------------|--------|-----------|
| 33%DRI – 2 bucket charge | 426 | 58 |
| 33% DRI – continuous charge | 380 | 54 |
| 43% DRI – 33% cont, 10% charge | 390 | 55 |
| 43% DRI - continuous | 392 | 58 |

Table VIII. Current Operation

| | |
|---------------|------------|
| Electricity | 396 kWh/st |
| Oxygen | 945 scf/st |
| Power on time | 45 mins |
| Tap to Tap | 56 mins |
| Flux | 83 lb/st |
| Refractory | 0.25 lb/st |
| Electrode | 2.8 lb/st |

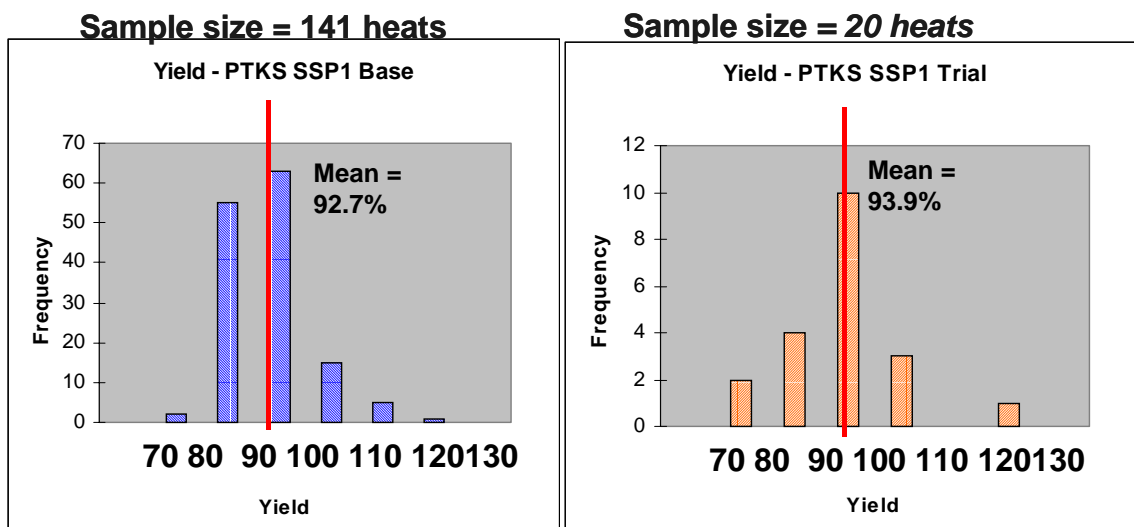
Table IX – Impact of Higher %C DRI at IMEXSA

| Parameter | Cost/Unit | Change/T | Savings (cost)/T _{Is} | Change/T | Savings (Cost)/T _{Is} |
|--------------|-------------------------|-----------|--------------------------------|-----------|--------------------------------|
| | | | for 2.6%C | | for 3.1%C |
| Lime | \$0.06/kg | +2.25 | (\$0.135) | | |
| Coke | \$0.18/kg | -4.13 | \$0.743 | -4.33 | \$0.779 |
| Oxygen | \$0.038/Nm ³ | +2.4 | (\$0.091) | +10.3 | (\$0.391) |
| KWh | \$0.035/kWh | -34.6 | \$1.211 | -58.9 | \$2.062 |
| Electrode | \$3.30/kg | -0.05 | \$0.165 | -0.07 | \$0.231 |
| Refractory | \$0.53/kg | -0.70 | \$0.340 | -3.7 | \$1.961 |
| POT | 66 min | -4 | | -9 | |
| Productivity | \$175/T | +9 | \$8.75 | +14 | \$14 |
| T/h/ EAF | | (0.05T/T) | | (0.08T/T) | |
| DRI “XS C” | | +5.2 | (\$0.110) | +10.2 | (\$0.150) |
| TOTAL | | | | | |
| \$0.035/kWh | Excluding productivity | | \$2.12 | | \$4.64 |
| \$0.050/kWh | | | \$2.49 | | \$5.53 |

Modification of SOPs was required when IMEXSA began melting high C (2.7% to 3.1%) DRI (3,4). Procedural changes included negation of charge/injected C, earlier O₂ use, faster DRI charge rate due to the improved, earlier foamy slag, better heat transfer and bath reactions achieved from in-situ C. Table IX shows the operational benefits realized by IMEXSA when increasing from 2.08%C to 3.1%C with 94.4% DRI charged heats. The economic data, assigned by the author, shows savings of \$4.64/T_{Is} at a power cost of \$0.035/kWh without accounting for the 14 T/hour productivity benefit.

PT Krakatau Steel (5), having only low quality, local, scrap available to them, decided to assess the impact of using higher quality HBI. As shown in Figure 3, a 14% replacement of the local scrap by HBI increased their mean yield 1.2%, from 92.7% to 93.9%.

Figure 3. 14% HBI Replacement of Local Scrap Increases Yield at PT Krakatau Steel



Hot charging DRI also has significant benefits (1,3,5). 600°C DRI use at Essar, whilst necessitating a slower DRI feed rate to prevent EAF C boils, resulted in savings of 124 to 145 kWh and 0.03 kg electrodes/Tonne_{ls}, 0.06 min. POT/T_{HDRI}. A reduction in DRI FeO content versus their normal HBI production was seen. Combining the Essar and IMEXSA data, Table X shows savings of 191 kWh and \$9.27/T can be projected for the use of 700°C, 3.1%C DRI at 94.4%DRI charge rate. The cost savings do not account for the 32.6% productivity increase (1.4 million Tonnes/year based on IMEXSA data).

Table X. Economic impact of 3.1% HDRI*

| | | | |
|---|-----------------------|-------------|----------------|
| Carbon in DRI | 2.08% | 3.10% | 3.10% |
| Charge %DRI/% scrap (T _{DRI} /T _{scrap}) | 94.4 / 5.6 (252 / 15) | | |
| DRI Temperature (°C) | 25 | 700 | |
| Scrap Temperature (°C) | 25 | | |
| % Metallization | 95 | | |
| % Yield | 90 | | |
| Power on Time (minutes) | 66 | 57 | 38.9 |
| Tap to Tap Time (minutes) | 80 | 71 | 53.9 |
| Total Energy (kWh/T _{ls}) | 585.9 | 527 (-58.9) | 419.1 (-191.1) |
| Productivity (T/h) | 163 | 177 (+14) | 222 (+59) |
| Savings @ \$0.035/kWh | | \$4.64 | \$9.27 |
| Savings @ \$0.050/kWh | | \$5.53 | \$12.14 |

*Economics assigned by this author

DOWNSTREAM IMPACT OF DRI/HBI

Some of the downstream issues addressed by the use of DRI are: hot shortness, seams, cracks, intergranular weaknesses, irregularity in mechanical properties, poor cold formability and heat affected zone embrittlement (9,10).

The main impact of DRI, downstream of the EAF shop, stems from the lower residual content. During hot and cold rolling and annealing, uncontrolled variation in residual elements causes inconsistency in the processing conditions. The variability is equally, if not more, important than the absolute residual level, preventing process optimization around one set of steel chemistry conditions. The main undesirable impurities are Copper (Cu), Tin (Sn), Nickel (Ni), Chrome (Cr) and Molybdenum (Mo) where Cu and Sn are the most potent. There are also the non-metallic residual elements such as Sulphur (S), Phosphorous (P), Nitrogen (N₂) and Hydrogen (H₂) which are removable.

The narrower chemistry band inherent in steel made with DRI allows optimization of the continuous caster and rolling mill settings which in turn improves yield, produces lower incidence of process problems (particularly avoidance of hot shortness cracking problems during thin slab casting) and allows manufacturing process specification to be achieved

The sensitivity (problematic) level depends upon the casting type and speed, secondary cooling and mold powder. For example, in high speed, thin slab, casting hot shortness issues result with Cu levels of 0.10% to 0.12% due to the relative high surface area to slab volume. Direct strip casting is not sensitive even at 0.5% Cu due to the near elimination of scale in strip casting (9).

Operating Results

A North American Steelmaker, using 15% DRI for low %C aluminum killed (AK) steel production found “length percent edge obvious slivers” in coils to be reduced by 45% and the cracks/meter in slabs by 45.6%.

Table XI shows the impact of DRI use on the drawability of an 1008 SiK steel. DRI increased the maximum reduction of area by 12% over the scrap charge based material due to the lower residuals levels (Cu and [N]).

Table XI. Impact of Charge Material on Drawability of 1008

| | Copper | Nitrogen | ≈ max ROA |
|--------------|--------|----------|-----------|
| Scrap Charge | 0.20% | 80 ppm | 83% |
| DRI Charge | 0.05% | 22 ppm | 95% |

At Casima (meltshop) and Sivensa (rolling mill) in Venezuela (11), 34% HBI was used for production of rebar steel to demonstrate accrued downstream value from lower, more consistent, residual levels. This resulted in an overall yield increase (meltshop to finished product) of 0.7% (Figure 4). At the continuous caster, HBI heats had a higher chemistry acceptance rate and billets had lower nitrogen and blowhole defects. In the rolling mill, HBI billets produced fewer “tails” and the incidence of cobbles was generally lower.

During the NG pricing crisis of 2000, Hylsa (1) had the opportunity to assess the impact of varying DRI levels on the failure rate of hot rolled coil (2.5mm gauge) for non-exposed, low carbon (0.05% to 0.07%C) automotive applications. They found a significant reduction in the number of coils failing the bending tests (deviations) at 50% DRI and further benefit in excess of 70% DRI (Figure 5). These bending test failures were due to high Copper induced hot short micro-cracks which in turn were directly related to the reduced use of DRI in steelmaking as shown in Table XII.

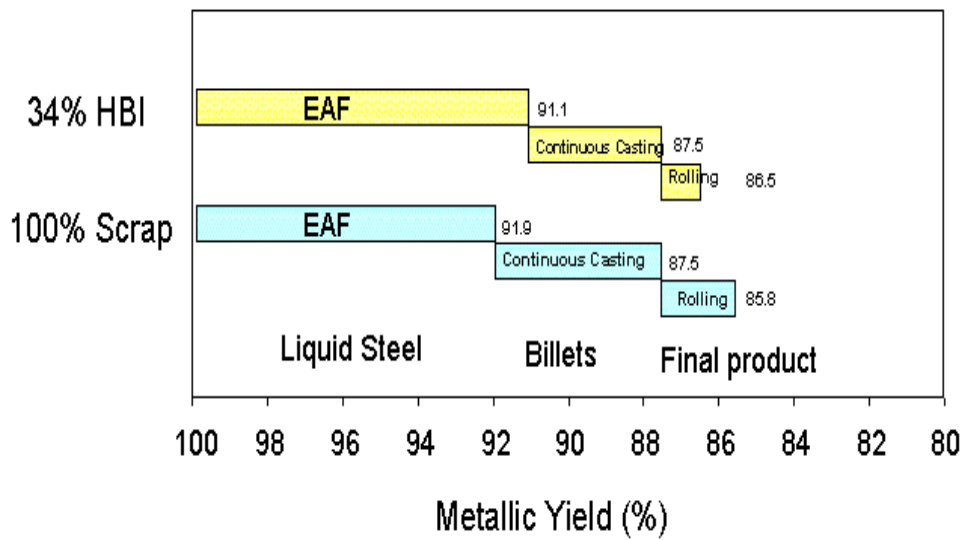


Figure 4. Substituting 34% of 92% Met HBI Improves Yield in Casima / Sivensa

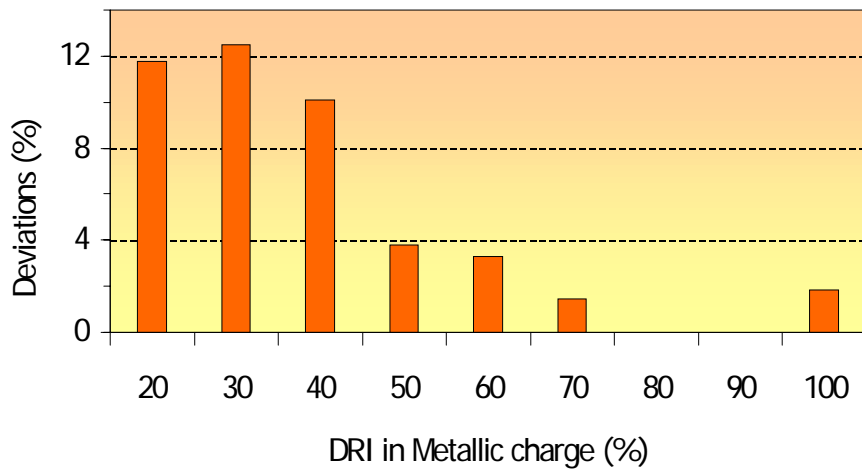
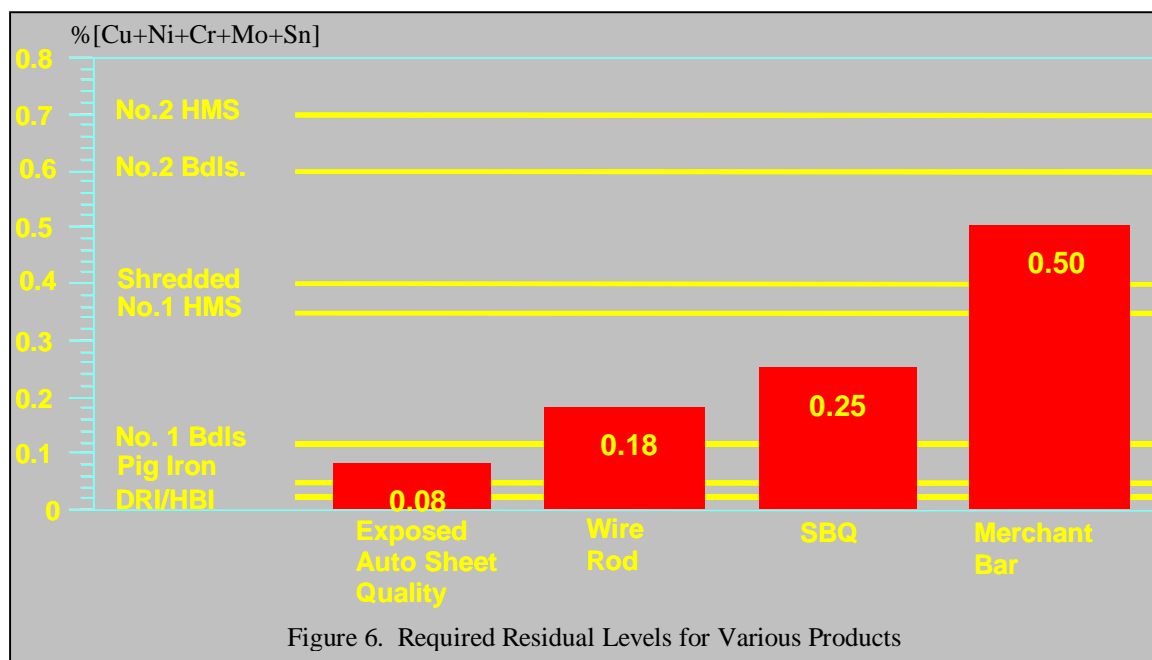


Figure 5. Impact of %DRI Charged on the % Coils Failing Bend Tests

Table XII. Impact of %DRI Charged on the residual level at HYLSA

| Element | Meltshop #1 | | Meltshop #2 |
|---------|-------------|----------|-------------|
| | 50% DRI | 100% DRI | 50% DRI |
| Cu | 0.061 | 0.004 | 0.064 |
| Ni | 0.031 | 0.008 | 0.030 |
| Mo | 0.005 | 0.002 | 0.006 |
| Cr | 0.016 | 0.006 | 0.014 |
| Sn | 0.003 | 0.001 | 0.007 |
| Totals | 0.116 | 0.021 | 0.121 |

Figure 6 shows the residual levels for various application and indicates why DRI, HBI and Pig Iron are predicated for auto and wire rod applications.



CONCLUSIONS

Effective use of DRI requires the steelmaker to know the composition of the DRI feedstock and modify the standard operating procedures to insure optimum performance is achieved. DRI should not be melted without recourse to new melting procedures which will afford the steelmaker benefits including: economic control of residuals, lower nitrogen levels, improved (often earlier) foamy slag practice, reduced electrode wear, increased yield, improved quality and downstream process optimization due to the tighter chemistry band.

Significant EAF savings are a reality. When used correctly, DRI improves EAF energy efficiency and yield, reduces tap to tap times and increase productivity compared to 100% scrap.

DRI contained C is a more efficient, cost effective, carbon source than charged or injected C. The VIU of C and DRI must be determined for local, site-specific, prevailing conditions.

Predictable, low residual, chemistry allows optimization of downstream process settings which affords the steelmaker increased yield, quality and productivity.

ACKNOWLEDGEMENTS

The author would like to thank the MIDREX Process Licensees and other steelmakers using DRI/HBI who have shared their operating data. The sharing of such data will assist the industry in achieving lower cost, more efficient production.

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