DIRECT FROM MIDREX

1st Quarter 1999

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Principles & Use of Oxygen in a MIDREX™ Direct Reduction Plant

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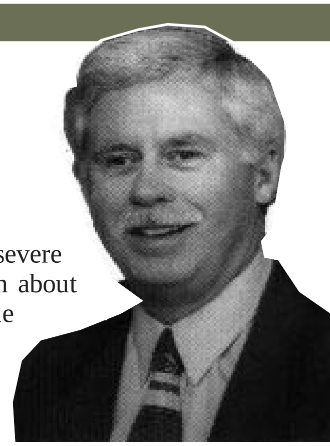
All tons referred to are metric tons (t) or million metric tons (Mt)

Commentary

The Long-Term View



Winston L. Tennies
President

All of us in the steel industry are dealing with the severe market downturn, and since so much is being written about it, I will not belabor the point. Our view is that the worst of the situation will probably last another one to two years. For those of us who plan to be long-term players in the industry, this sort of downturn must be seen in context. Over a 15-20 year planning horizon, it is not a major concern, and the correct strategy is to position yourself for the recovery. At Midrex, we continue to believe there are tremendous opportunities in steel.

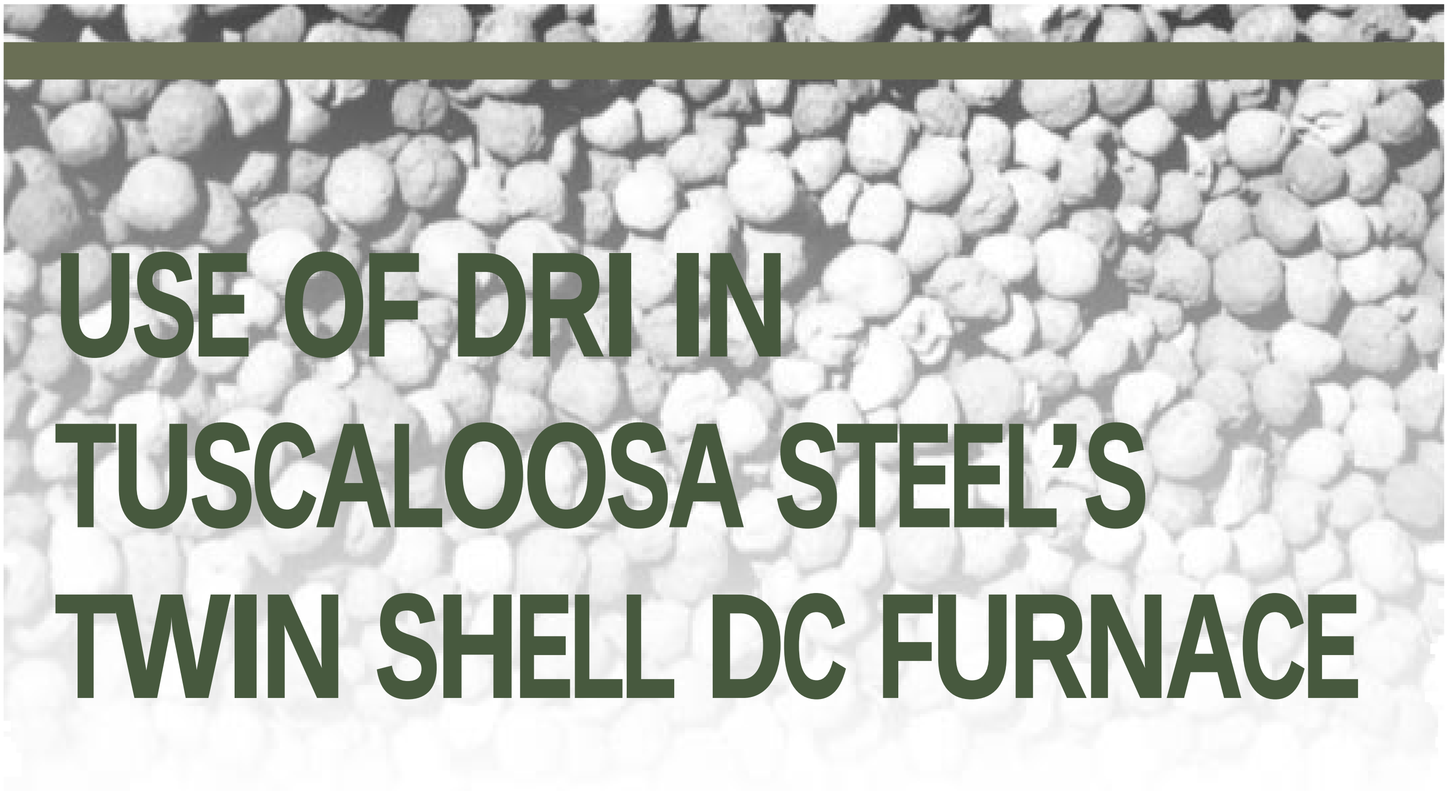
This down period provides an excellent time to evaluate the industry's needs for the future. We will continue to assess these needs, but already a number of trends are evident. First, mini-mills will continue their expansion into higher-quality products, which will necessitate the use of substantial amounts of virgin iron feed materials. The "integrated mini-mill" concept, which includes a direct reduction plant feeding a high-productivity meltshop to produce long or flat products, is the wave of the future. This has been a major part of the success of Ispat International. Second, steelmakers will accelerate their search for low-cost sources of high-quality hot metal. Most of the major gains in productivity and cost reduction in the finishing end of steelmaking have been realized. The game now is to reduce liquid steel cost, of which the cost of the iron used is the major component. Third, more steelmakers in industrialized countries will purchase semifinished steel from low-cost producers in other regions. There is no inherent need for any steel company to make its own steel; the decision becomes a matter of cost and strategic considerations.

To satisfy the market's needs, Midrex has embarked on a number of new initiatives, many of which have been discussed in recent issues of *Direct From Midrex* or will be highlighted in the future. First are the FASTMET® and FASTMELT™ Processes, the focus of the 4th quarter 1998 issue. These technologies provide for the production of DRI and hot metal from fine iron ore or steel mill wastes using solid carbon as the reductant. Next is the HOTLINK™ System, which was discussed in the 3rd quarter 1998 issue of *Direct From Midrex*. This concept allows an integrated mini-mill to directly feed hot DRI by gravity to an electric furnace, thus saving energy and increasing steelmaking productivity. Another development is the SUPER MEGAMOD™, a single shaft furnace capable of producing 2.5 million tons per year or more. This unit provides tremendous economy-of-scale, and would enable an integrated steelmaker to shut down a blast furnace. Finally, Midrex has established a new group to pursue DRI melting technologies. We are excited about this effort, because it will provide steelmakers more options to effectively melt the larger amounts of virgin iron materials required in the future.

Although MIDREX® Direct Reduction Plants continue to demonstrate remarkable performance (67 percent of world DRI production in 1998), we are not resting on our laurels. The pace of change in the steel industry is accelerating, and we plan to remain a major player in that effort. Midrex is committed to the business for the long-term, and we hope to have several new technologies in place when the rebound occurs. As always, we welcome your comments.

MISSION STATEMENT

Midrex Direct Reduction Corporation will lead in the ironmaking technology industry by supplying superior quality services that provide good value for our clients. We will meet or exceed performance expectations, execute projects on time, enhance existing product lines, and develop or acquire new technologies. Our employees are the key to our success, and we are committed to encouraging them to grow professionally and personally.



USE OF DRI IN TUSCALOOSA STEEL'S TWIN SHELL DC FURNACE

By Christopher S. Farmer
Tuscaloosa Steel Corporation

The following paper was originally presented at the Iron & Steel Society's 56th Electric Furnace Conference held in New Orleans, LA, Nov. 15-18, 1998. We would like to thank the author and Tuscaloosa Steel Company for their permission to reprint it here.

Tuscaloosa Steel Company (TSC) is a wholly owned subsidiary of British Steel plc. TSC was created in 1984 as a joint venture between Tippins, British Steel, O'Neil Steel, and American Cast Iron Pipe Company. TSC initially consisted of a steckel mill producing plate and coils from purchased slabs, the bulk of which were from British Steel plants in the UK. In 1991, British Steel bought out its partners and subsequently expanded the TSC business. This entailed the installation of an electric arc furnace, ladle furnace and a caster at the Tuscaloosa plant. The expansion also included upgrades to the rolling mill, which increased its capacity from 0.5M tons to 0.8M tons per year. This project was completed in October 1996.

In the early 1970s British Steel ordered two MIDREX™ Series 400 Modules to be installed at Hunterston in Scotland. However, with the dramatic rise in gas and oil prices in 1973, the project became uneconomical and was mothballed. Then, the expansion of the steelmaking capacity at Tuscaloosa and the demand for good quality low residual feedstock in the US led to a decision to relocate the modules to Mobile, Alabama. From this location, DRI could be supplied to Tuscaloosa and the market in general. Construction started in June 1996 and in December 1997 the first direct reduced iron was produced. The plant currently operates both modules that together are capable of producing 1,000,000 tons of DRI per year. The three iron ore feedstocks were selected to optimize process costs while maximizing product quality. A typical analysis of the finished DRI is shown in Table I.

Delivery and Inspection

DRI is delivered to TSC's dock from Mobile by barge via the Black Warrior River waterway by a fleet of covered barges. Each barge contains 1,500 tons of DRI and is unloaded by clamshell into dumptrucks and transported to a covered storage building. These barges are equipped with removable fiberglass panels that allow access for loading and unloading while protecting the DRI from the weather. All trucks delivering DRI are covered by waterproof tarps and unload under a roof directly into the storage area. Delivery by rail car will begin in December 1998. Future plans also call for a conveyor to be installed at the point of unloading that will carry the DRI to the storage area.

	Average
Total Fe	93.0%
Metallization	93.0%
Carbon	1.8%
CaO + MgO	1.3%
$SiO_2 + Al_2O_3$	2.0%
Sulfur	0.003%

Table I Typical DRI analysis

Delivery to the EAF

From the storage area, the DRI is dumped onto a covered conveyor by a front-end loader at ground level. The conveyor carries the DRI 454 feet up to one of two holding silos. The same conveyor can feed both silos. Each silo holds 300,000 lbs. of DRI and is nitrogen purged. Even though the DRI is passivated before being shipped, the silo is still purged with nitrogen to reduce the risk of re-oxidizing in the silo and the potential explosion hazard that exists with any dust producing process.

The DRI silos sit next to two more silos containing lime. The DRI silos have a load cell weigh system that delivers the material in pounds per minute to the delivery conveyor belt. The lime silos use rotary air locks to feed lime onto the same belt. The EAF operator through the level 2 computer controls the amount of DRI and lime fed onto the conveyor. The operator can set the total amount of DRI and lime and the feed rate of each. The level 2 computer has the ability to automatically control the feed rate of DRI according to power input, but this feature is not utilized at this time.

The lime and DRI are then transferred to a steep pocket conveyor that carries the mixture to the furnace transfer belt that sits atop the transformer vault 60 feet above ground level. This belt transfers the DRI onto the conveyor belt that feeds each furnace shell. This last belt extends out from the top of the vault into the receiving cone attached to the roof of the furnace shell. The roof feed belt is automatically retracted during roof opening and furnace tapping.

There are two disadvantages to the current DRI feed system. The first is the ability to only feed DRI to one shell at a time. If both shells could be fed DRI at the same time, the waiting shell could be loaded with DRI and then charged with scrap. Since the shells cannot be fed simultaneously, any additional DRI has to go into the charge bucket. Using DRI in the charge bucket increases the loading time and may slow production. The second disadvantage is the 4000 lb/min feed rate maximum. The average feed rate needed during maximum power input is 4000 lb/min. There is no leeway in the system for surge or beyond average feed rates. Fortunately, these disadvantages are small when running the normal charge and DRI feed practice.

EAF Design

Construction on Tuscaloosa Steel Corporation's melt shop was started in 1995 and the first heat of steel was melted in October 1996. The electric furnace consists of a twin shell (32 feet diameter each) DC furnace built by MAN GHH. A single 28-inch diameter electrode swings between each shell and arcs to a 216-pin bottom anode. The transformers and rectifiers, built by ABB, consist of two 58 MVA transformers in parallel that provide 775 V DC secondary max, 130,000 amp max and 91 MW max power to the furnace. There are six oxy-fuel burners per shell built by More along with a water cooled oxygen lance injecting 2,800 cubic feet per minute and a water cooled carbon lance injecting up to 66 pounds per minute. MAN GHH designed the furnaces to tap 150 ton heats in 54 minutes.

DRI Charging Practice

The furnace shells and DRI feed system were designed by MAN GHH to operate with a one-bucket scrap charge and DRI roof feed. The normal charge practice consists of 110 tons (66.6%) scrap charged to the furnace in one bucket. This charge is followed by 55 tons (33.3%) of DRI fed continuously through the roof starting at the 25 kW mark (about 10 minutes into the melt). This standard practice produces 148 tons of liquid steel every 60 minutes (52 power on minutes) and consumes 377 kWh of electricity per ton of liquid steel.

Even though the operation was designed to run 33% DRI through the roof, trials were run to determine the impact of various DRI usage levels on the operation. Individual trials varied from all scrap to 50% DRI heats. Once DRI usage was increased to above 35% the trials were further sub-grouped into all roof feed and combination roof and bucket charge. Table II shows how the kWh per ton of liquid steel (kWh/ton) and tap to tap times in minutes varied for DRI usage ranging from 0 to 50%.

Surprisingly, the all scrap heats had the highest kWh/ton and longest tap to tap times. It should take more energy to melt heats with DRI than 100% scrap. The high numbers are thought to be caused by the time and energy lost when the roof is swung off the shell to charge the second scrap bucket. Conversely, as DRI increased, so did the kWh and the tap to tap times. The DRI feed rate starts at 25% because this is the lowest roof feed possible without going to a second charge bucket.

The results shown in Table II comprise approximately 1200 heats melted from June '98 to September '98. In order to eliminate distortion in the data, only heats that met the operational parameters listed in Table III were used. Approximately 80% of the heats melted from June to September fell within the nominal operational parameters. The last aspect of DRI usage is the placement of the material. Should all the DRI be fed through the roof? A trial was conducted on DRI roof feed versus bucket loading. The results of these trial are shown in Table IV. The all roof feed trials were found to have slightly higher energy consumption and significantly higher operational times compared to the heats where only 33% of the charge was fed through the roof. Although better results were found at 33% roof feed, not enough data has been collected to determine if this is the optimum. More trials are scheduled for the future. However, based on the

DRI Used	kWh / ton	Tap to Tap (min)
0%	430	85
25%	375	62
30%	377	62
35%	380	64
40%	393	65
45%	399	67
50%	408	69

Table II Impact of % DRI Usage in EAF

Charge Weight	165 tons	+/-10
Lime Usage	8000 lbs.	+/-300
Gas Usage	550 ft^3/t	+/-15
O_2 Usage	850 ft^3/t	+/-100

Table III Operational Parameters
Note: The ranges are normally distributed

	kWh / ton	Tap to Tap (min)
33% DRI All Roof	380	64
43% DRI 33% / 10%	390	65
43% DRI All Roof	392	68

Table IV Charge Practices

results of these limited trials, the standard practice is to limit the roof feed to no more than 35% and charge the balance of the DRI to the charge bucket.

The results from the trials showed that the most efficient DRI charging practice for the Twin Shell DC EAF at Tuscaloosa Steel was a one bucket charge with 33% DRI roof fed. Two bucket, all scrap charges decreased productivity. Their biggest delay time was the extra 8 to 10 minutes needed to charge the second bucket of scrap. Also, while the roof is off to charge the second bucket, heat is being lost. This may explain the increased kWh usage for the all scrap heat. Another problem is that the workload on the scrap crane and charge crane doubles. The increased workload leads to more frequent repairs and more down time. At TSC, DRI roof feeding is required to achieve the lowest operational costs.

Power Profile

The original power profile for the EAF was designed to deliver the maximum power as soon as possible. The maximum settings, voltage to 700 V and amperage to 120 kA, were achieved as soon as possible. This power profile was developed before the Mobile plant came on line or any outside DRI was purchased for use as a roof feedstock. When DRI was first fed into the furnace through the roof, little attention was given to the impact of the power profile. In hindsight, this first power profile caused a lot of problems.

By increasing the voltage and amperage to the maximum setting, the arc was also increased to the maximum length. This long arc produced a deep, narrow melt area below the electrode. A small pool of molten metal was produced and the scrap melted down into this pool. In the meantime, DRI was being fed onto the scrap pile in the furnace. The cold DRI caused the top of the pile to fuse together. Now, the rest of the DRI coming into the furnace just rolled down the scrap pile and became trapped on the side walls. The entrapped DRI (and occasional piece of scrap) caused longer tap times and delays from lancing tapholes. After several months of experiments, a new power profile was developed. The new profile started at 300 V and 50 kA. This setting ran until the movement of the electrode arm stabilized. Then, the amperage was increased by 10 kA and maintained until the electrode arm had stabilized again. This sequence was repeated until the maximum amperage of 120 kA was reached. Then the voltage was increased 100 V per minute to the maximum 700 V. The total ramp time to maximum power was approximately 10 minutes.

By starting the voltage out at a low setting the arc length is relatively short. This short arc produced a wide, shallow melt area. A larger molten pool is produced and the scrap caves into this pool. Now, when the DRI is fed through the roof, it falls into a molten pool of metal. This controlled meltdown keeps the cold DRI away from the side walls and eliminates any delays from furnace skulling. The improved power profile has also reduced the energy needed to melt the charge by directing the DRI to the hottest part of the furnace as soon as possible. Table V compares operating parameters for the two power profiles.

Even though the power input starts lower in the second profile, by producing a large molten pool as quickly as possible, the DRI is melted faster. The new profile reduced power input by about 15 kWh per liquid steel ton and lowered the tap to tap time by 4 minutes. In addition to these operational improvements, DRI and scrap are no longer hanging or skulling along the side walls. The new power profile keeps the furnace cleaner and has reduced operational costs.

@ 30-35% DRI	PP1	PP2
Tap to Tap (min)	54	50
kWh / LS ton	390	377
Lbs. Lime / ton	55	55
Tap Temp	2960 F	2960 F

Table V Power Profile Comparison

1998	Lime	MgO	Inj Carbon
Feb	110	0	20
Mar	85	15	24
Apr	82	30	28
May	80	30	28
Jun	55	30	26
Jul	55	30	26
Aug	55	30	30
Sep	55	30	33

Table VI Pounds per Ton Lime, MgO and C

Slag Practice

One of the problems with using DRI in the EAF is the highly acidic slag generated directly from the gangue. The acidic slag (FeO and SiO_2) increases furnace refractory wear. Furthermore, as DRI consumption is increased, yield decreases. TSC experienced all of these operational problems when it started using Scaw Metal's (South African) DRI in October 1997 and continued through the first shipment of DRI received in February 1998 from the Mobile plant.

Yield and MgO Practice

The yield problems were thought to be caused by the sheer volume of slag being produced each heat. Estimates of slag pot weights showed that 60,000 to 70,000 pounds of slag were generated each heat. Since most of the slag was ending up in the slag pots, there was little time for the injection carbon to reduce the FeO being added by the DRI and produced from oxygen injection. A decrease in slag volume was needed in order to concentrate and reduce more FeO from the slag. The expected result was an improved metallic yield. As the lime addition was decreased, MgO was added to maintain consistent slag basicity. Table VI shows the lime and MgO additions made from February to September 1998.

The material added to the slag was "dead burned" (or sintered) MgO. This type of material was chosen over calcined MgO for two reasons. First, calcined MgO has a loss on ignition (LOI) of 18-30% while dead burned MgO has a loss of only 0.5-0.75%. The lower LOI of the dead burned material means that more MgO goes into solution with the slag and possibly at a faster rate. Second, calcined MgO is highly endothermic when brought to steelmaking temperatures and requires more energy to dissolve in the slag than

1998	V-ratio	MgO%
Feb	2.84	10.0
Mar	2.75	10.7
Apr	2.56	9.0
May	2.52	11.3
Jun	1.54	12.4
Jul	1.70	9.5
Aug	1.68	10
Sep	1.73	10

Table VII Slag Chemistry

1998	Gunning	Bank Repair	Yield
Feb	12.0	2.0	84.2
Mar	11.0	1.5	85.8
Apr	8.0	0.0	86.7
May	5.0	0.0	86.8
Jun	0.2	0.0	88.8
Jul	0.5	0.0	89.4
Aug	0.5	0.0	88.9
Sep	0.6	0.0	88.5

Table VIII Refractory Repair Material and Yield

the dead burned material. The lower LOI and energy requirements of dead burned MgO make it a better slag addition in TSC's operation. After the start of the MgO practice, the yield slowly rose from 84% in February to 86% in May. The increase in yield was believed to be caused by the drop in V-ratio during the same time. As the V-ratio decreased, FeO activity in the slag increased as illustrated in Figure 1. Now, more FeO was available for reduction to the steel bath. Furthermore, according to Figure 1, a further reduction in V-ratio would result in an even higher FeO activity. This higher FeO activity would presumably lead to a higher yield. As Table VI shows, in June the lime addition was decreased to 55 pounds/ton. The decrease in lime resulted in a drop of the V-ratio, seen in Table VII, to approximately 1.54. As expected, there was an increase in the yield to 89% as seen in Table VIII. The control of the slag volume and V-ratio helped increase the yield by 4%.

Gunning Consumption

This paper will not attempt to explain slag systems since there is already a large volume of literature on this subject. Instead, conclusions will be drawn based on observations collected from the process. After the dead burned MgO was added to the EAF, the reduction in gunning consumption was unintended, but in hindsight should not have been surprising. Table VII shows that even though 30 pounds/ton of MgO was added to the charge, the MgO in the slag did not change significantly. After the additions started in mid-March, the percent MgO in the slag was expected to increase. However, the percent MgO remained the same and instead, the gunning consumption decreased. From these observations, the EAF slag was now getting MgO from the charge addition instead of the furnace refractory. The conclusion was that the added material satisfied the MgO solubility of the slag. The slag stopped dissolving the gunning material from the furnace banks and gunning levels were reduced.

Summary

DRI has become an integral part of the steelmaking practices at Tuscaloosa Steel. Through improvements in the power profile and the slag practice, the cost of the liquid steel has decreased while the efficiency of melting has increased. The following list summarizes what TSC has learned in the past year:

(1) Develop a power profile that forms the largest molten pool as quickly as possible. Direct DRI into this molten pool for fast melting.

(2) Lower V-ratio to increase FeO activity and increase the amount of Fe reduced from the slag for higher yields.

(3) Add MgO to balance low V-ratio slag and decrease refractory repair (gunning).

Further improvements in yield and energy consumption are expected as new projects such as improved carbon injection and DRI feed rate control are implemented. While this paper has dealt with the use of DRI in the EAF and not the impact on steel quality, the effects of DRI on residual control and scrap cost are significant. These topics are left for future discussion.

Author's Acknowledgement

I would like to thank Dennis Acker for letting me document the furnace and slag practices that he has worked so hard to perfect. His insight and knowledge of the operations at TSC were invaluable in preparing this paper.

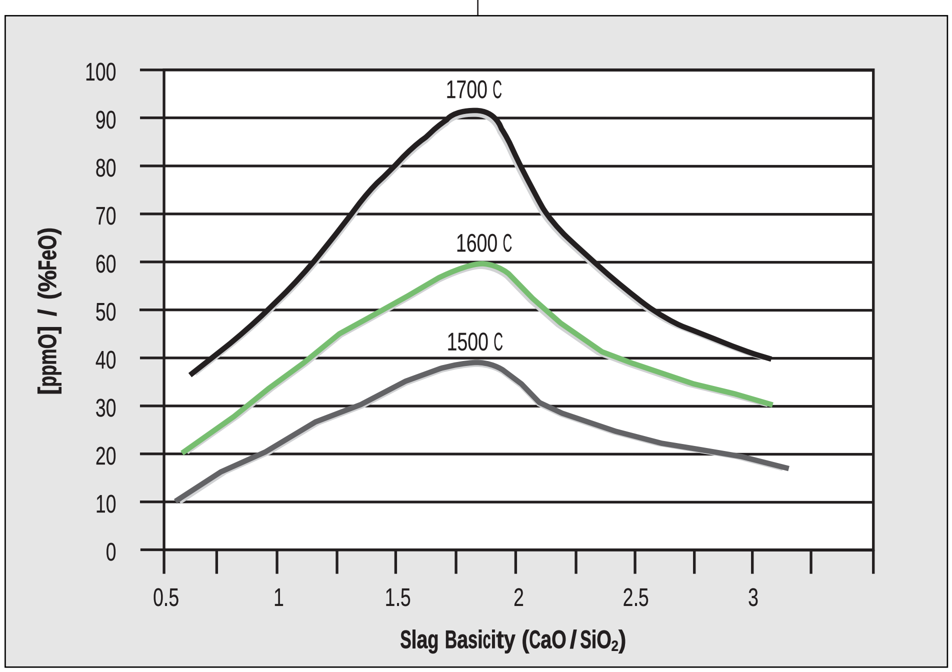


Figure 1 Equilibrium Ratio of FeO to Slag Basicity

PRINCIPLES & USE OF OXYGEN IN A MIDREX™ DIRECT REDUCTION PLANT

PART ONE

By Greg D. Hughes
Director – Technology
Midrex Direct Reduction Corporation

Introduction / Background

Over the past several years MIDREX™ Direct Reduction Plants have become quite interested and aggressive in the area of increasing plant capacity. Many options have been discussed regarding how best to increase plant production under a variety of different plant circumstances. Two of the most discussed methods of increasing plant production are:

- Various practices of in-situ reforming
- Oxygen injection into reformed gas or bustle gas

These methods are very popular because of their relatively low capital cost, ease of implementation, and substantial production increases for the investment. Following, we will discuss the theoretical basis of each of the oxygen and in-situ reforming practices and their various methods of implementation.

PRINCIPLES & USE OF IN-SITU REFORMING

One of the oldest methods of increasing plant production with little or no capital cost is the practice of in-situ reforming. Even though it has been used in various forms for many years (dating back to the 1970s), it is appropriate to discuss it here in light of the oxygen injection alternatives described below. The use of oxygen injection and oxide coating have enabled operators to run with much higher bustle temperatures to the shaft furnace than ever before. This increase in temperature or thermal energy can be used within the shaft furnace in one of two ways. It can either promote faster reduction kinetics, thereby reducing the required residence time to achieve a desired metallization, or it can promote more reforming of natural gas over the metallic iron catalyst within the transition zone and reduction zone of the furnace (in-situ reforming). Both of these effects lead to greater shaft furnace throughput. As the kinetic benefits will be discussed below, this section is devoted to the various implementations of in-situ reforming within a MIDREX™ Plant. In Figure 1, it can be seen that significant production gains can be realized as the amount of methane reacted within the shaft furnace is increased.

It should also be noted that as the shaft furnace operation approaches the region of 35 Nm^3 of CH_4 reformed per

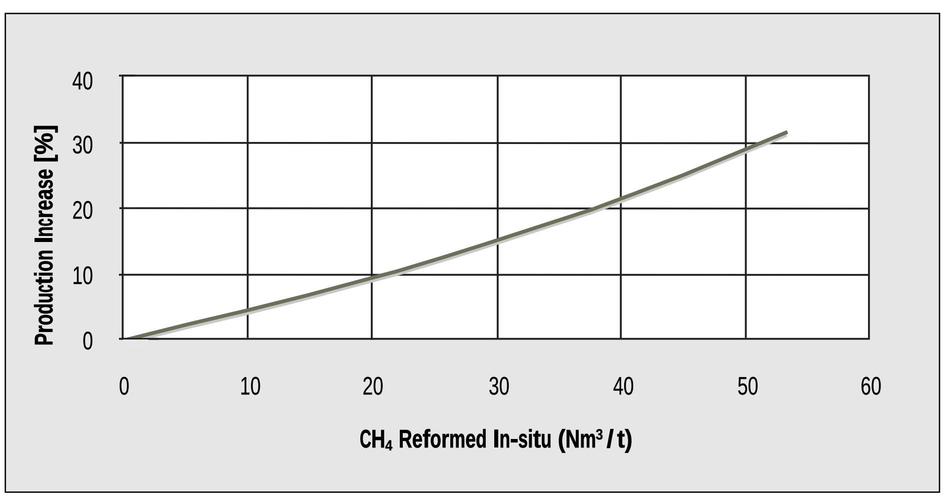


Figure 1 Production Increase with In-situ Reforming

ton of product or more, the need for high bustle temperature operation becomes imperative to supply the needed heat to accomplish this degree of reforming. For example, if no heat is added, reforming 1.0 Nm^3 of CH_4 per ton of product reduces the temperature within the shaft furnace by 3.25°C. This would mean that the reforming of 35 Nm^3 of CH_4 per ton product could reduce the shaft furnace temperature by close to 115°C.

In order to promote in-situ reforming in the shaft furnace, several components must exist. First, as indicated in the previous discussion, there must be sufficient heat available. Since all of the methane and higher hydrocarbon reforming reactions are endothermic, there must be a source of heat energy to keep the reaction going. The extra heat needed to promote the in-situ reforming reactions can be supplied via the hot reformed gas and, if available, through oxygen injection to the system. The inclusions of oxygen injection and oxide coating practices (to ensure the flowability of the burden at high temperatures) have greatly advanced the practice of in-situ reforming in today's direct reduction plants. Second, there must be oxidants available to combine with the hydrocarbons and reform into H_2 or CO. The balanced chemical reactions for reforming are shown below:

Reforming Reactions

$$CH_4 + H_2O \leftrightarrow CO + 3\ H_2$$
$$CH_4 + CO_2 \leftrightarrow 2\ CO + 2\ H_2$$

Last but definitely not least, there must be hydrocarbons available to be reformed. Various techniques have been used since the 1970s for introducing natural gas to the bustle gas (enrichment natural gas), transition zone and cooling zone of the MIDREX™ Shaft Furnace to achieve in-situ reforming and/or methane cracking.

Historically, enrichment natural gas has been limited in its use as a primary source for in-situ reforming hydrocarbons. The sensible cooling of the bustle gas inherent in the addition of cool natural gas limited the amount of natural gas that could be added to the hot reformed gas and still be able to maintain the desired bustle gas temperature. Oxygen injection eliminates that limitation.

Principles & Use of Oxygen

The method that has attracted most attention in the last few years for increasing production in a MIDREX Plant is the use of oxygen. The oxygen can be supplied in various ways depending on the circumstances of the specific direct reduction facility. Some plants can supply the oxygen from the same system that supplies the steel shop, others can supply the oxygen in an "over-the-fence" arrangement with an outside oxygen supplier either for the entire steel/DR complex or simply dedicated to supplying the DR facility, etc. The circumstances and economics of the actual source of the oxygen vary greatly from location to location and an examination of these economics is not discussed here. The use of oxygen as a method of increasing plant production can be achieved by one of several methods and these methods can be placed into two major categories:

- Oxygen injection into reformed gas or bustle gas (which is discussed in this article)
- Partial oxidation to generate reducing gas (which will be covered in Part II in *DFM, 2nd Quarter 1999*)

Oxygen Injection into Reformed Gas or Bustle Gas

Increasing plant capacity without the addition of reformer capacity (catalyst, tubes, heat recovery, etc.) can be achieved by optimizing the operation of the shaft furnace. This has been done over the years by most of the MIDREX Plants through maximization of the bustle gas temperature and of the reduction furnace burden temperature by minimizing the cooling of the bustle gas. This has been carried out to the extent allowable by the raw materials used. More recently, the use of coatings applied to the feed oxide material has enabled most MIDREX Plants to eliminate the use of the reformed gas cooler altogether and utilize the full temperature of the reformed gas in the reduction furnace.

Increased Thermal Energy

In some operating plants, additional production increases are accomplished by further increasing the temperature of the reduction zone to improve reduction kinetics and increase productivity. To do this, bustle gas temperature is increased by the injection of a measured quantity of oxygen into the reformed gas line or the bustle gas line. This injected oxygen combines with the reductants in the reformed gas or bustle gas to liberate heat. The typical combustion reactions that occur within the reformed gas or bustle gas are shown below:

Combustion Reactions

$$CH_4 + 2\ O_2 \leftrightarrow CO_2 + 2\ H_2O$$
$$2\ H_2 + O_2 \leftrightarrow 2\ H_2O$$
$$2\ CO + O_2 \leftrightarrow 2\ CO_2$$

The increase in thermal energy in the bustle gas as a result of the oxygen injection can be used either to promote in-situ reforming (as described above) or to increase the temperature within the shaft furnace burden, thereby increasing the reduction kinetics. It should be noted that the reduction reactions that predominantly control the throughput of the shaft furnace are the FeO reduction reactions, as shown below:

FeO Reduction Reactions

$$H_2 + FeO \leftrightarrow Fe + H_2O \quad \text{Endothermic}$$
$$CO + FeO \leftrightarrow Fe + CO_2 \quad \text{Exothermic}$$

Approach to Equilibrium

One might draw the conclusion that since the CO-FeO reduction reaction is exothermic in nature, an increase in the bustle temperature might limit the equilibrium of this reaction and ultimately reduce the shaft furnace throughput. This is often presented as a reason why lower H_2/CO gases benefit much less from a boost in bustle temperature. In actual fact, the magnitude of the increase in the reduction kinetics of the CO-FeO reduction reaction is much greater than the inhibiting impact of the higher temperature on the chemical equilibrium of the same reaction. Also, since the basic shaft furnace design is a countercurrent gas-solid flow system, equilibrium is never achieved within the shaft itself. It is this "approach to equilibrium," promoted by the countercurrent flow system, which buffers or prevents the higher temperature from creating an equilibrium limitation to the reduction reactions. In other words, there is always a driving force for further reduction within the shaft furnace

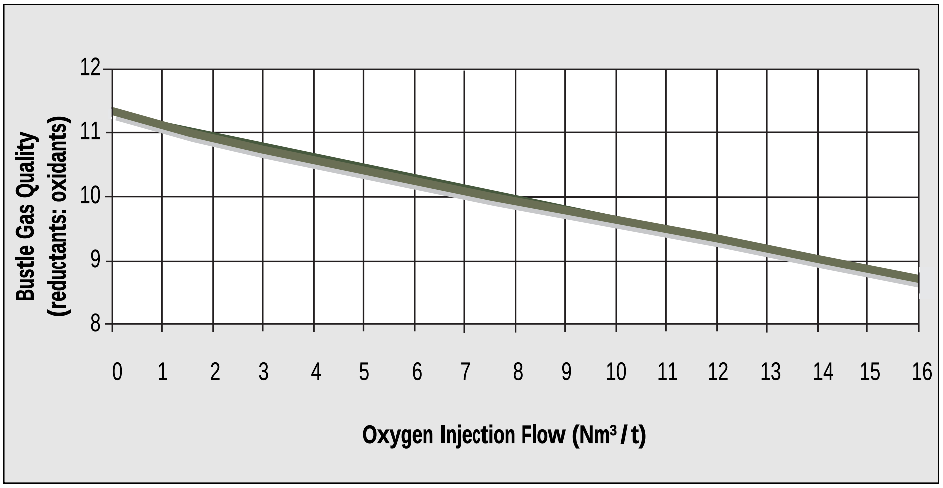


Figure 2 Bustle Gas Quality

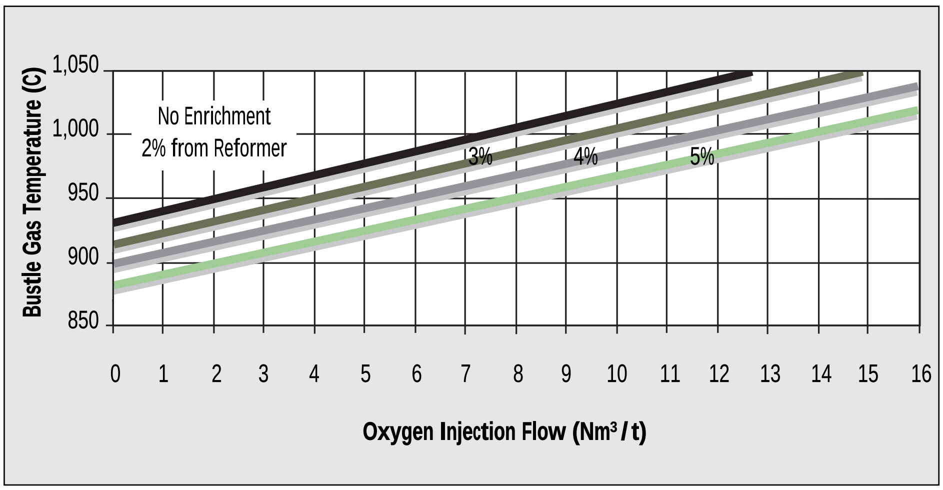


Figure 3 Temperature Rise with Oxygen at Various Bustle Gas Hydrocarbon Levels

since the gases are never allowed to come to equilibrium with the solids at any point within the shaft furnace. As the upflowing gas becomes less reducing, it is encountering less metallized (easier to reduce) solid material, thereby maintaining a good driving force for reduction.

Bustle Gas Quality vs. Bustle Gas Temperature

Another often-cited reason why oxygen injection can have only a limited benefit in providing an increase in plant capacity is that the heat liberated and used to increase the bustle temperature is achieved at the expense of the reductants created in the reformer. Put another way, the oxygen combines with the CO and H_2 to generate H_2O, CO_2, and heat. Therefore, the oxygen used to increase the bustle gas temperature correspondingly lowers the resulting bustle gas quality $(CO + H_2)/(CO_2 + H_2O)$. Figure 2 shows the change in bustle gas quality as a function of the oxygen injection rate.

This perceived penalty is not realized in actual operation since the corresponding increase in bustle gas temperature causes a much greater increase in the reduction kinetics than the quality loss does on reduction potential. Even though there is a loss in gas quality, the overall effect is in the direction of greater productivity due to the enhanced reduction kinetics.

To further assist in gauging the oxygen requirements, based on the operating parameters of a plant, the graph in Figure 3 displays the oxygen requirement as a function of enrichment natural gas addition. The graph shows the oxygen required to achieve a specified bustle temperature assuming an initial 930°C reformed gas temperature. As the enrichment natural gas addition is increased, the amount of oxygen required to achieve a specified bustle temperature also increases.

Conclusion

The actual implementation of the oxygen injection system can vary somewhat from plant to plant, but the overriding goals and principles remain the same. From the process point of view, all implementations accomplish the same objective, increased bustle gas temperature over that provided by the reformer alone.

Based on actual operating trials at a number of MIDREX Plants using a number of these different methods of oxygen injection, it has been shown that a direct reduction plant can realize a capacity increase in the range of 1–2 percent for every 10°C increase in bustle gas temperature that can be achieved. The actual capacity increase will vary depending on ore reducibility, ore resistance to sticking, furnace flow profile, etc.

It should be noted here that while the injection of oxygen into the reformed gas or bustle gas has proven to provide very significant increases in plant capacity, the actual implementation of this injection system should be done with extreme care for plant and personnel safety reasons. The incorporation of oxygen injection into a plant can be a low-cost, high-yield plant modification, but it must be done right.

The next section of this article will be published in the 2nd Quarter 1999 issue of Direct From Midrex. Part II will focus on two methods of using partial oxidation in order to generate reducing gas of sufficient temperatures and gas quality to be used directly as a bustle gas source for the MIDREX® Process: (1) reformer augmentation and (2) reformer replacement.

Reformer augmentation is based on boosting the plant capacity by supplementing the reformer gas generation with a parallel partial oxidation gas generator. Reformer replacement is more applicable to new plants and involves the removal of the reformer from the flowsheet.

MIDREX™ Direct Reduction Plants 1998 Operations Summary

Operators of MIDREX™ Direct Reduction Plants faced the same problems as the rest of the steel industry in 1998: reduced steel demand, dramatically lowered prices for all finished steel, the lowest scrap prices since the early 1980s, and plummeting merchant demand for DRI and HBI. Despite this difficult situation, total production via the MIDREX® Direct Reduction Process increased eight percent from 1997, reaching nearly 25 million tons. Seventeen MIDREX™ Modules set new annual production records, with 10 of the records coming from facilities that have been operating for several years. Twenty new monthly records were set, 13 of those from modules that started up prior to 1997. In addition, three MIDREX Plants established new records; QASCO became the first plant to produce over 700,000 tons in a 5.0 meter MIDREX™ Shaft Furnace, Acindar produced over one million tons in a 5.5 meter MIDREX Shaft Furnace, and IMEXSA produced 1.5 million tons in a 6.5 meter MIDREX Shaft Furnace.

MIDREX Plants continue to increase productivity, with bustle gas temperatures now approaching 1000°C. Metallization levels are routinely 93-95 percent, with some plants operating at up to 97 percent metallization. Moderate carbon levels, on the order of 1.7-2.2 percent, are the norm, although some plants have produced DRI with up to 2.5 percent carbon. The flexibility of MIDREX Plants to control metallization and carbon content independently provides a significant benefit during changes in the steel and DRI/HBI markets.

Three facilities began operations in 1998. American Iron Reduction (AIR), a 1.2 Mt/y MIDREX MEGAMOD™, was started up in January. The plant was built primarily to provide DRI for Georgetown Steel's meltshop in Georgetown, SC; GS Industries' mill in Kansas City, MO; and Birmingham Steel's Memphis, TN, minimill. The remaining portion of the plant's output will be sold on the merchant market. With the collapse of the US DRI market in 1998, it has been very difficult to sell product. Therefore, the AIR plant has been operating at reduced capacity.

The second 400,000 t/y module at Tuscaloosa Steel/Mobile DRI started up in February (the first module began operations in December 1997). The complex, originally built in Scotland, was refurbished and moved to Mobile, AL. Both modules are rated at 400,000 t/y. The plant has operated well, except for a problem with the alloy steel teeth on the shaft furnace burdenfeeder, which were replaced in both shaft furnaces during the summer of 1998. The plan is to use approximately one-third of the DRI at Tuscaloosa Steel's mill in Tuscaloosa, AL, one-third at Trico Steel in Decatur, AL, and the remainder will be sold on the merchant market. The plant has faced the same market problems as AIR and operated at reduced capacity during 1998.

The COMSIGUA Plant in Matanzas, Venezuela, produced its first HBI in August, and successfully completed its performance test on October 24. During the test, the 1.0 Mt/y facility operated at 112 percent of its guaranteed production rate. The plant is a joint venture involving Kobe Steel, CVG Ferrominera Orinoco, five Japanese trading companies, and TAMSA, a Mexican steel producer. The majority of the product will be exported to North America and a number of shipments have been made to date.

COMSIGUA HBI Plant

American Iron Reduction (AIR)

Tuscaloosa Steel/Mobile DRI

A number of new plants are either undergoing commissioning or are under construction. These include Saldanha Steel, an 804,000 t/y MIDREX Module that will be the world's first commercial direct reduction plant using coal gas as the reductant. The complex in Saldanha Bay, South Africa, includes a COREX® Plant, which will supply the reducing gas to the MIDREX Shaft Furnace. The DRI will be used with COREX Hot Metal in the steel meltshop. Start-up of the MIDREX Module is scheduled for March. With a rated capacity of 1.36 Mt/y, Ispat DR3 will be the world's highest capacity single unit direct reduction plant. DRI from this Trinidad site will be used at various Ispat meltshops and sold on the open market. The plant is now undergoing commissioning.

One MIDREX Plant is under construction, the third module at ANSDK in Egypt. This 800,000 t/y facility will provide DRI for ANSDK's new flat product minimill. Start-up is planned for late 1999.

Minnesota Iron & Steel Names Management Team and Partnership Agreements

Minnesota Iron & Steel Company (MIS) has made several major announcements regarding its efforts to build the first fully integrated sheet mini-mill in the US. John D. Lefler was named President and Chief Executive Officer of the Nashwauk-based company, reporting to Robert M. Greer, Chairman of the Board of Directors. Mr. Lefler was formerly President and CEO of Gulf States Steel of Gadsden, Alabama, and spent 20 years in various management positions at the US Steel unit of USX Corporation. MIS has also announced that Gordon E. Knudsvig has been named Chief Financial Officer of MIS.

MIS also announced that Danieli & C. of Buttrio, Italy, was named lead technology partner to MIS with respect to the mini-mill equipment, and a consortium led by ITOCHU Corporation of Japan, and including Kobe Steel of Japan, was named lead technology partner with respect to DRI modules to be supplied by Midrex Direct Reduction Corporation. ITOCHU will also purchase a substantial amount of the steel production from MIS. MIS further announced that on February 1, it entered into a long-term, take-or-pay agreement with a major automotive company. Mr. Greer commented, "With these recent events, we are confident that the MIS project is becoming a reality. John and Gordy bring great experience to the company, and our technology partners are the best in their fields. We are particularly pleased with our partnership with our automotive customer. This will be the first sheet mini-mill in the world targeting the highest quality automotive requirements, and this is the basis upon which we entered into our partnership agreements."

MIS will build a sheet mini-mill on the Mesabi Iron Range in northeastern Minnesota which will incorporate a taconite iron ore mine and pelletization plant with an annual production capability of 3.6 million metric tons of taconite iron pellets, two MIDREX MEGAMOD™ Plants with an aggregate capability of 2.4 million metric tons, and a thin-slab caster hot strip mill with a production capacity of 2.4 million net tons of hot rolled sheet steel. Mr. Lefler commented that "the combination of attractive iron ore characteristics, the elimination of transportation and third-party costs on iron and DRI, and recent advances in mini-mill casting and rolling technology make a most compelling case for ultra-low-cost, Tier I product. This is what our automotive customer was attracted to. Our goal is to produce the highest quality OEM sheet steel for a cash production cost of under $200 per net ton. This would be at least a $50 per ton advantage against even the lowest-cost high-quality producers today, and would keep us profitable in any steel environment you can think of."

SMI Steel – South Carolina Awards Contract for Ladle Metallurgical Station

SMI Steel – South Carolina has awarded a contract to EMC International, Inc. of Pittsburgh, Pennsylvania, for supply of a Ladle Metallurgical Station (LMS) to be installed at SMI–SC's plant in Cayce-West Columbia, South Carolina. Delivery of equipment is scheduled for June 1999.

The LMS will be capable of processing up to 90 ton heats of molten steel and will be designed for operation with an existing 20 MVA furnace transformer. The LMS equipment will include: a pivoting ladle carrier; a rotating turret type superstructure; 14-inch diameter electrodes; EMCI's "top hat" configuration water-cooled ladle roof; channelized type exhaust fume collection hood; induction stirring; back-up stirring lance; a Prefabricated Control Pulpit with a PLC based Level 1 control system; EMCI's "EMARC" solid state, impedance balancing electrode regulating system and a Prefabricated Metallurgical Laboratory.

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Nucor Steel – Hertford County Awards Contract for Flux Materials, Charge Carbon and Alloy Materials Handling Systems

Nucor Steel – Hertford County has awarded EMC International, Inc. of Pittsburgh, Pennsylvania, a contract for supply of Charge Carbon/Lime, Alloy/Flux and Injection Carbon Materials Handling Systems for Nucor's new plate mill presently being constructed in Hertford County, North Carolina. The materials handling systems will receive, stock, store, transfer, and deliver lime and coal to a Consteel conveyor or to charging buckets at the bucket loading station; lime, metallurgical carbon, and alloys into the ladles at the EAF tap position or to the LMF for alloy trimming operations; and injection carbon stocking and storing equipment for Nucor's EAF injection system. The material handling systems will employ an arrangement of receiving hoppers, stocking and delivery belt or drag chain conveyors, storage silos and bins, surge/weigh bins, and pneumatic conveying equipment for delivery of materials to designated locations while simultaneously preparing the next batch of materials. All this will be accomplished within the time constraints of the steelmaking operations and with accuracies required for Nucor's production and quality requirements. Raw materials can be delivered to the receiving areas in railcars, trucks, or front-end loaders. Delivery of the materials handling system equipment is scheduled for September 1999.

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