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RESULTS OF EAF OPERATION WITH PTI, INC. PROLIME™ INJECTION SYSTEM[1]

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Abstract

Process Technology International Inc. (PTI) has commissioned several pneumatic, sidewall lime injection systems for use in Electric Arc Furnaces (EAF). The PTI lime injection systems convey hi-cal lime and dolo-lime through PTI's injection burners mounted in a PTI JetBOx™ on the side wall of the EAF. The PTI method of injecting hi-cal lime and dolo-lime through the EAF sidewall is superior to other methods of adding lime to the EAF. The major advantage of the PTI system is that lime is directly injected to the slag metal interface during furnace power on time. Other methods of adding lime to the EAF result in loss of material to the operation floor, the de-dusting system and pose a safety hazard to the operators. This paper summarizes the results achieved at four EAF steel mills after the installation of the PTI lime injection system. The reduction in operation cost, greater control of the process and increase to operator safety are highlighted.

Key words: Lime; Injection; Steelmaking.

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1 INTRODUCTION

PTI, Inc. is a developer of new processes and tools to improve production and efficiencies within the steel making industry. One of the biggest safety and housekeeping issues in most melt shops is the handling of lime. The methods used to transfer lime from the storage areas to the furnace results in lime spillage and loss of material to the dust evacuation system. PTI seeks to eliminate this material spillage, while improving housekeeping and safety in the melt shop. The preferred solution is direct addition of the lime from the storage areas into the EAF. PTI accomplishes the injection of lime through its ProLime™ Injection System, JetBOx™, and Quad™ burner which are specifically designed to optimize lime usage in the furnace.
Both lime and dolo-lime are typically delivered to the steel mill by truck or railcar and then transferred to a bulk storage area. The usual delivery method is to then feed the material by gravity on top of the scrap in the scrap bucket. Some shops may transfer the material several times, loading the material into silos, then transferring the material into hoppers then dumping the lime on top of the scrap. At each transfer point, material is lost to the ground and to the air.[1] Since the lime and dolo-lime are reactive, the lime poses a health and safety risk to the people and equipment that come in contact with the spilled material.[2,3]
Bulk additions of lime to the scrap bucket or to the EAF cause significant process issues.[4] A portion of the lime agglomerates in the furnace as a mass instead of going into solution in the slag. It is not unusual for lumps of lime to be seen floating in the slag at the end of melting. This lime is wasted as only material that has dissolved into the liquid slag contributes to the steel making process. A large addition of lime in the first scrap bucket results in a dramatically unbalanced slag early in the melting process.[5] The slag is oversaturated with lime, is mostly solid and does not contribute to phosphorous or sulfur removal. The process then requires additional power on time to allow this bulk addition of lime to dissolve into the slag and become useful. Adding lime in bulk to the EAF results in excessive lime consumption and added power consumption.
A simple, leaner process of adding lime to the EAF is needed that results in a safer melt shop and less expensive to operate steel making process. The new lime handling system must reduce the number of steps needed to get lime to the EAF and also contain the lime to reduce fugitive lime dust emissions to the melt shop and general mill environment. In addition, the new system must better equip the EAF operators to dynamically control slag chemistry and thereby improve slag conditions in the EAF. In addition, automating the lime feed rate insures that the lime addition matches the melting process. Possible methods used to move the lime to the EAF and then add lime to the furnace are discussed in the following sections.

2 MATERIAL AND METHODS

2.1 Methods of Conveying from Storage to Process

There are many methods available for moving lime from a storage area to the EAF. Both belt and pneumatic conveyors can be used to move lime from storage to the EAF. Belt and pneumatic conveyors each have characteristics that make them the preferred method for transfer of material. The pros and cons of each type of conveyor were considered.[6]

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Belt conveyors can easily move different size material at different flow rates over long distances. However, the capital cost of installing belt conveyors can be very expensive. Furthermore, since the lime sits on top of the belt, this type of conveyor does not readily contain the lime. Fine lime dust can be blown off the conveyor and material can spill at each drop point in the conveyor line thus adding to the housekeeping and environmental issues. In addition, the exposure of the material to the atmosphere increases the reaction of the lime with the moisture in the air thus decreasing the quality of the material and its usefulness in the process. Belt conveyors can move a variety of material sizes but the inability to contain the material and the cost of installation pose a large capital and installation cost on the melt shop.
Pneumatic transport lines move material within a closed pipe. The pneumatic transport lines easily contain the lime thereby eliminating the lime spillage and dust emissions to the melt shop. Pneumatic conveying systems are limited by the type and size of material that can be easily moved through the pipes. The material needed for this project, powdered lime, is easily fluidized and is an ideal candidate for pneumatic conveyance.

2.2 Methods of Material Addition at Process Point

Once the lime is brought from the silo to the EAF, there must be a method of adding the lime to the furnace. Two methods of adding lime into the EAF were considered: roof addition and side wall addition. The first method considered was lime addition through the roof above the scrap. Since the lime is falling on top of the scrap, this method allows the lime to be fed to the furnace as soon as the roof is closed and an arc is struck. The possibility that a scull will form at the injection port is minimal since the scrap and lime melt away from the point of addition. However, adding lime on top of the scrap presents several problems. First, some of the lime is lost to the dedusting system due to proximity of the lime to the fourth hole[7] and second, there is some lag time between when the lime is added to the EAF and when the lime goes into solution. The lime added on top of the scrap must travel down with the scrap into the molten slag and steel and then dissolve to become part of the slag. The loss of material to the bag house and the lag time of getting lime to the molten bath were the main reasons that roof addition was not selected.
The second method considered was injection of lime through the side wall of the EAF. Installing the lime port in this location puts the injected lime as close to the newly formed liquid bath as possible. Any lime injected should go directly into solution as it contacts the liquid pool of molten steel.[8] However, there can be several problems associated with this addition method. First, there is the tendency of scull formation when the lime is injected into the EAF with cold scrap present. After several heats, the lime port can be completely blocked by lime, scrap and slag. Fortunately, with the addition of a burner at the lime injection point, this problem is solved. Second, lime injection cannot be started until the burner has created a “pocket” into which the lime can be injected which may be several minutes after an arc is struck. While sidewall lime injection cannot be started as soon as an arc is struck, it is reasonable to expect that lime injection can be started after several minutes of burner firing. This allows the sidewall injection of lime to start adding lime to the EAF at approximately the same time as a roof feed system. The additional advantage of sidewall injection is that now the lime is being added under – not on top of – the scrap. Adding lime under the scrap allows for the lime to go into solution sooner, form

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a foamy slag earlier and reduce the lime lost to the bag house. These reasons make side wall lime injection an ideal method for adding lime and dolo-lime to the EAF.

2.3 Design Used for Injection

Process Technology International, Inc. (PTI) has developed a solution to the current limitations of existing sidewall injection technology called the JetBOx^{TM}. PTI's patented solution increases the efficiency of material introduction in the EAF by moving the injection point closer to the bath and away from the refractory and sidewall. The JetBOx is a cast copper, water-cooled box, designed to withstand the harsh EAF environment. The JetBOx mounts through the sidewall and locates the tip of the material injection point inside the EAF away from the sidewall about 200 mm (8 inches) above the refractory step.

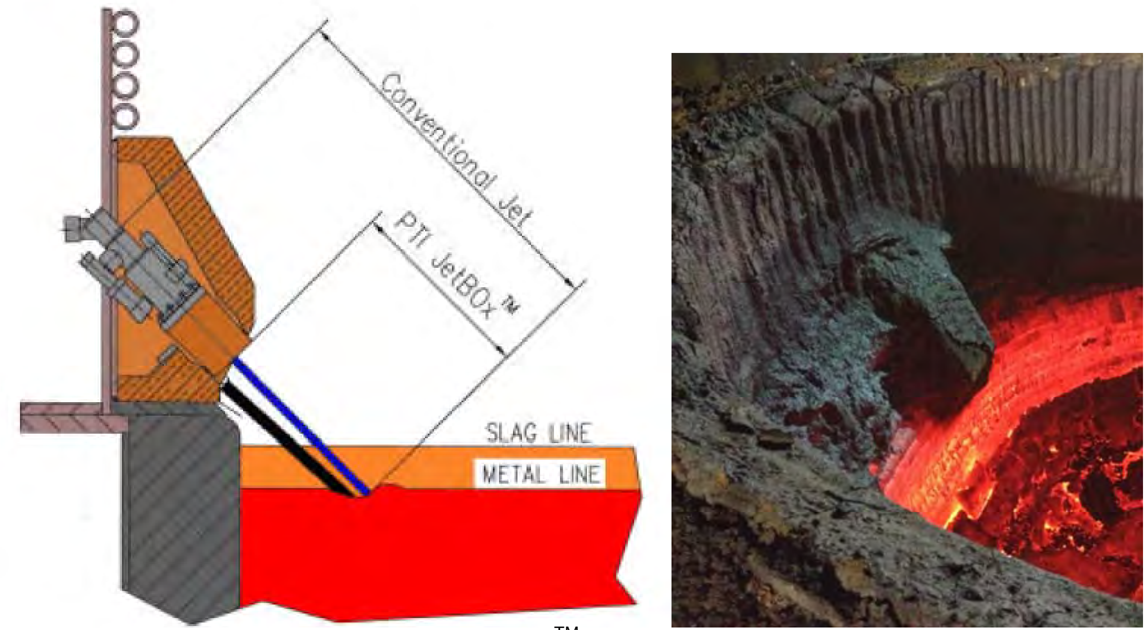

Figure 1. PTI JetBOx^{TM} Installed in sidewall of EAF.

PTI has designed and manufactured several types of devices to inject material into the sidewall of the EAF. These devices are designed to mount inside of the PTI JetBOX^{TM}. By mounting the device inside the JetBOxTM, the material injection point is as close to the liquid steel bath as possible. This allows the material to enter the process as fast as possible. In addition, the device that PTI designed for injecting material has chemical energy capability. The device is a burner capable of adding up to 5 MW of chemical energy to the cold scrap in the EAF. The burner also is designed to deliver supersonic oxygen to the process. The supersonic oxygen is delivered through a annulus Lava Nozzle that surrounds the material port. By surrounding the material, the oxygen stream keeps the material from spreading and ensures that the injected material reaches the liquid steel bath.

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Figure 2. PTI QuadJet^{TM} Material Injection Burner.

3 RESULTS

The following sections summarize the results from four Steel Mills located in North America into which PTI has installed its lime injection systems. The results highlight the operator safety improvements and the operational savings that each Steel Mill received after the installation of the PTI lime injection system.

3.1 Steel Mill A

The original method for adding lime and dolo lime to the EAF at Steel Mill A was to add lime to a hopper and then dump the material from the hopper into the scrap bucket. The scrap bucket with the lime was then added to the EAF. Both operations, adding lime to the hopper and adding scrap to the EAF resulted in a loss of lime to the shop floor and atmosphere. The original addition schedule for the 110 metric tonne furnace was as follows.

Table 1. Original Lime addition schedule

Charge	Time (min)	HI-Cal Lime (lbs)	Dolo Lime (lbs)	Total
First Charge	With Scrap	3.300 lbs (1.269 kg)	1.500 lbs (545 kg)	4.800 lbs (2.177 kg)
Second charge	With Scrap	3.000 lbs (794 kg)	1.200 lbs (340 kg)	4.200 lbs (1.905 kg)
Refine	-	0 lbs (2041 kg)	0 lbs (0 kg)	0 lbs
Total	18 minutes	6300 lbs (2.857 kg)	2.700 lbs (1.225 kg)	9.000 lbs (4.082 kg)

Steel Mill A started injecting 100% of the lime and dolo lime into the EAF on August 31, 2008. The lime injection addition schedule for the EAF is 5,000 lbs (2.268 kg) of hi-cal and 2,800 lbs (1,270 kg) of dolo-lime for each heat of steel produced. The hi-cal lime is injected at 450 lbs/min (204 kg/min) and the dolo-lime is injected at

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300 lbs/min (136 kg/min). The new injection schedule that was developed over several weeks of trials is as follows.

Table 2. PTI Lime Injection schedule

Charge	Time (min)	HI-Cal Lime (lbs)	Dolo Lime (lbs)	Total
First Charge	Last 11 minutes	2500 lbs (1134 kg)	2000 lbs (907 kg)	4500 lbs (2041 kg)
Second charge	First 9 minutes	2500 lbs (1134 kg)	800 lbs (363 kg)	3300 lbs (1497 kg)
Refine	-	0 lbs (0 kg)	0 lbs (0 kg)	0 lbs
Total	20 minutes	5000 lbs (2268 kg)	2800 lbs (1270 kg)	7800 lbs (3538 kg)

While the total amount of lime added to the EAF was reduced, the slag volume processed by the mill service did not decline. In addition, the slag chemistry remained unchanged from before the start of 100% lime injection. The slag chemistry before and after this project was as follows in Table 3.

Table 3. Slag chemistry before and after PTI injection system remained the same

B3 ratio	CaO%	MgO%	FeO%	SiO_2%
1.3 – 1.4	30 - 34%	10 – 12%	25 – 28%	15 – 16%

All of the lime is injected while the burner is in burner mode. In addition, there is no disruption to the flow of lime with increasing burner power. Whether at 0.5 MW or 4.5 MW, the flow rate of lime remained stable. While not needed, trials were conducted to inject lime during supersonic oxygen injection. The flow rate of lime remained stable during supersonic oxygen injection as well. Conversely, the introduction of lime during supersonic injection did not affect the oxygen flow rate. Decarburization rates remained the same as the previous supersonic oxygen injectors with no material injection capability. Additional trials revealed that the system was capable of injecting lime up to 550 lbs/min (250 kgs/min) through the 2 ½ inch (63.5 mm) schedule 80 transport pipe.
The direct lime injection system resulted in lime usage reduction and improved operator safety. Since switching to pneumatic injection, the lime usage has dropped from 9,000 lbs or 75 lb/ton (4,082 kg or 37 kg/tonne) of total lime usage to a new lime usage amount of 7,800 lbs or 65 lb/ton (3538 kg 32 kg/tonne). This reduction in lime usage accounts for a 13% reduction in direct consumable material cost for each heat. Accompanying this lower specific EAF lime use is 1200 lbs (544 kg) less lime being lost to the bag house or shop floor. This reduction in fugitive lime dust emissions to the melt shop has resulted in a less housekeeping labor (and cost) and less dust sent to the bag house (and less bag house dust processing cost).

3.2 Steel Mill B

Before the installation of the PTI lime injection system, Steel Mill B used a screw conveyor to move material from a silo to a hopper. The hopper was then dumped directly into the EAF before the scrap charge. The problem encountered by Steel Mill B was that the bulk addition of material to the EAF often resulted in lime that would build up on the bottom of the EAF. This material on the bottom of the EAF would then melt in late causing slag eruptions and pieces of large un-melted lime to appear in

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the slag. These large un-melted lime "ice bergs" would cause electrode breaks and eventually end up in the slag pit. In addition to these large pieces of un-dissolved lime making no contribution to the process, energy was wasted in bringing them to steel making temperatures. After the startup of the PTI system, the lime addition to the EAF was reduced by 1.7 lb/ton (0.8 kg/ton) and the lime "ice bergs" were eliminated. The reduction in lime addition to the EAF had a direct impact on the energy consumption in the furnace. The kWh consumption was reduced by 17 kWh/ton and the power on time fell by 3 minutes per heat. The energy savings and productivity increase had a significant impact on total savings as seen in the following table.

Table 4. Summary of Results for Steel Mill B

	Pre Inj:	Post Inj:	$Savings$
Slag B-3	2.4 min	2.0	
Lime Delay	1.2 min/ht	0	
Carbon $/ton	$461	$305	$237,120.00
% Sulphur in Carbon	0.02	0.6	
Kwh/ton	417	401	$224,764.00
Lime #/ton	64.2	62.5	$27,505.00
Lime $/ton Cost	$163.20	$165.78	($15,575.00)
Power On	42	39	$232,192.00
FeO in Dust	38.8	31.6	
Hts/Reline	900	900	
EAF Refractory Cost $	$77,354	$71,129	$21,788.00
Electrode/ton	5.1	4.8	$198,593.00
Delta Life/ht	142	176	$32,332.00
Gun Mix lb/ton	0.9	0.3	$37,122.00
LMF Lime/ton	15.8	15	$25,017.00
		Total	$1,020,858.00

Upon startup of the PTI lime injection system, the lime consumption for the EAF was reduced by 1.7 lb/ton (0.8 kg/ton). Soon after the system start up, lime prices were increased by 2.58 $/ton. If the PTI lime injection system had not been installed, the cost of production would have increased by just over one million US dollars per year due to this material price increase. Instead, the PTI lime injection system reduced the increase to just over fifteen thousand dollars per year. The overall impact of the PTI lime injection system on Steel Mill B was a yearly savings of just over one million US dollars per year.

3.3 Steel Mill C

The original lime handling system at Steel Mill C conveyed a powdered lime and dolo lime blend from a silo and injected this material through the EAF roof. A major problem with this roof feed system was that a large percentage of the material was lost to the de-dusting system. The lime percentage in the bag house dust was over 40%. Installation of PTI's JetBOx™ into the sidewall of the EAF allowed the material injection to be as close to the slag metal interface as possible. After installation of the PTI lime injection system, the lime percentage in the bag house was reduced to less than 20%.

The main feedstock for Steel Mill B is Direct Reduced Iron (DRI). Depending on the grade of steel being produced, the amount of DRI used can vary from 0% to 100% of

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the charge material. The average DRI usage is 50% per heat. Because DRI has significant levels of gangue (SiO_2, Al_2O_3, CaO and MgO), the amount of lime needed for each heat varies with the amount of DRI consumed. The following graph compares the original top feed lime system with the new PTI injection system. The amount of lime used in the EAF was reduced by an average of just over 1000 lbs per heat (454 kg per heat) after the sidewall lime injection system was installed.

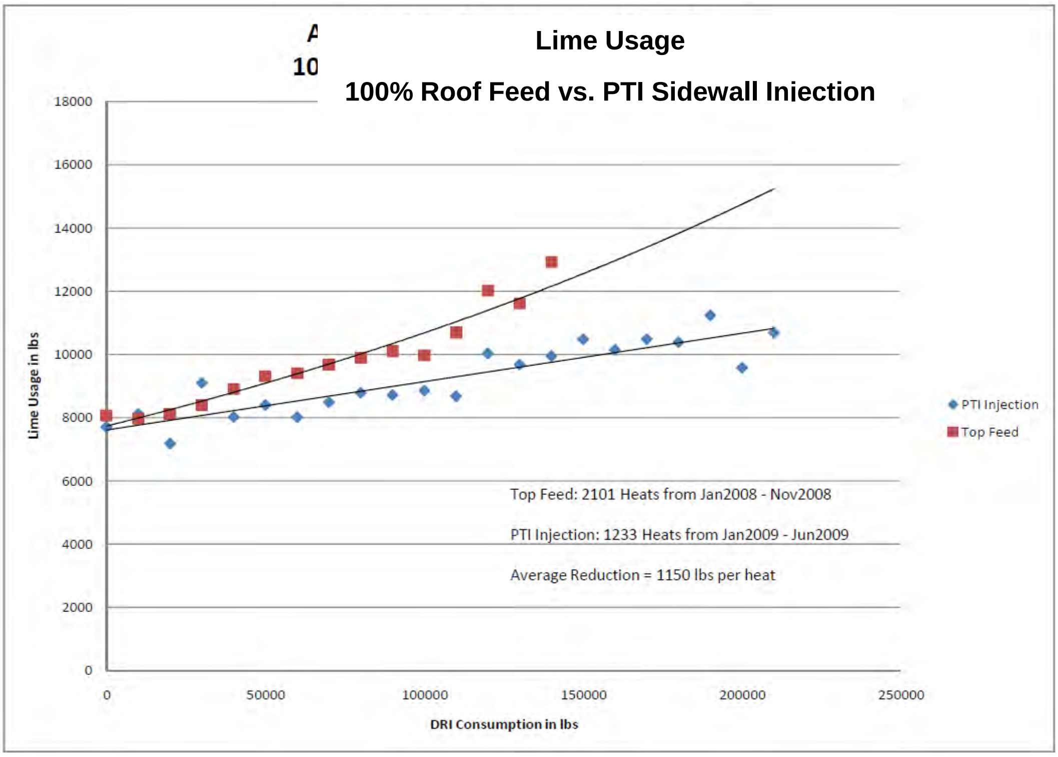

Figure 3. Roof Feed verses PTI Sidewall Injection.

Since the new lime injection system utilized the PTI JetBOx^{TM} technology to allow the material injection point to be as close to the slag metal interface as possible, a larger percentage of lime used for the process went into the slag. The reduction in material loss to the de-dusting system allowed the amount of lime used per heat to be reduced by 5.6 kg/tonne, thus reducing the operation cost for Steel Mill C.

3.4 Steel Mill D

Steel Mill D currently uses conveyor belts to move lime from a storage silo to the roof of the furnace. The material moves over multiple conveyors with many drop points. In addition, the conveyors are not covered and the material is exposed to the atmosphere. he Hi-Cal and Dolo lime are delivered to the steel mill in lump form (see pictures below). The reason for this sizing is to minimize the dust lost during conveying and the dust lost to the bag house when the material is added through the roof of the furnace. However, both the Dolo and Hi-Cal lime are extremely friable and a large amount of dust is created during handling and transport from storage to the furnace. To reduce the amount of lime dust lost to the shop floor and atmosphere, Steel Mill D has installed an extensive dust evacuation system on the lime handling conveyors.

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Dolo

Calcium Carbonate ($CaCO_3$)	1.89
Calcium Hydroxide $Ca(OH)_3$	2.96
Calcium Oxide (CaO)	58.75
Magnesium Oxide (MgO)	36.00

Hi-Cal

Calcium Carbonate ($CaCO_3$)	1.30
Calcium Hydroxide $Ca(OH)_3$	10.89
Calcium Oxide (CaO)	86.63
Magnesium Oxide (MgO)	1.10

Figure 4. Roof fed Dolo and Hi-Cal lime produce large quantities of lime fines.

Approximately 4.0 tons of dust is captured each day by the lime dust collection system. The dust is then sent to a landfill for disposal. The value of the lime disposed each year in the fines is over $120,000.00 US dollars. The cost of disposal to the land fill each year is $110,000.00 per year. Thus the total losses incurred by Steel Mill D to convey lime to the furnace and feed through the roof are $230,000.00 per year.

Steel Mill D installed a PTI lime injection system to inject the lime fines back into the furnace. Instead of loading the fines into a hopper destined for a land fill, the fines are loaded into a special hopper designed to fit on top of the PTI lime injection system. The lime fines are injected through the PTI QuadJet^{TM} burner installed into a JetBOx^{TM} that is mounted onto the sidewall of the furnace. The injection system has proven to be very flexible. Steel Mill D has – in addition to lime fines - experimented with injection of DRI fines, crushed ladle brick and other waste materials from the melting process. The total direct savings for all materials injected through the PTI lime injection system have now exceeded $500,000.00 US dollars per year.

4 DISCUSSION

The direct lime injection system achieved the main project goals of lime usage reduction and improved operator safety. This reduction in fugitive lime dust emissions to the melt shop has resulted in a less housekeeping labor (and cost) and dust sent to the bag house. The impact of the new direct lime injection system is summarized as follows:

- improved operator safety - through elimination of fugitive lime dust emissions: reduction in eye and skin irritation;
- reduced maintenance: reduced fork truck damage; reduced crane maintenance;
- reduction in lime consumption: 3.0 lb/ton (1.4 kg/tonne) average reduction in lime consumption;

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- improved housekeeping: clean up on cranes and in melt shop virtually eliminated;
- increased control over slag chemistry: dynamically control the chemistry and physical properties of the slag during operation;
- improved phosphorous and sulfur removal at the furnace.

5 CONCLUSION

The PTI LimeJet™ and QuadJet™ system is a good choice for the direct injection of lime to the EAF. The PTI lime injection system reduces the loss of lime to the shop floor and atmosphere as well as loss of lime dust to the de-dusting system. The elimination of these material handling losses provide a direct return to the steel mills operation budget. In addition, removing the bulk lime additions from the scrap bucket eliminates the possibility of large lime “ice burgs” forming and causing electrode breaks and excess energy consumption. The direct injection of lime to the slag metal interface reduces lime consumption and as a direct consequence reduces the energy requirements of the EAF. Finally, the cost of installation of a pneumatic lime injection system is lower than conveyor systems and eliminates the problems associated with roof feeding of lime. Each steel mill that has installed the PTI lime injection system has realized substantial savings to the operation cost of their melt shop.

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