LIME INJECTION TECHNOLOGY – A VIABLE TOOL FOR THE ELECTRIC ARC FURNACE

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Abstract

Pneumatic injection of lime in the electric arc furnace has gained interest in becoming a viable tool for the steelmaker and is a result of recent improvements in injection equipment, development of optimized lime products and refinement of electric arc furnace slag practices. Improvements in environmental aspects of the plant, operational cost benefits and flexibility in design of slag chemistry have been realized by steelmakers who have installed lime injection systems.

This paper will provide insight to the different lime injection systems, steel plant practices and evaluation of lime products required to meet the variety of equipment designs in this process. Operational parameters and results from steel plants utilizing lime injection technology in North America and Europe will be presented.

Introduction

The EAF process has evolved to a highly efficient scrap melter incorporating various technologies for energy and now flux additions to gain control of the process. Improvement in reducing electrical energy in the EAF via injection technology is well documented by the use of efficient designed modules for oxygen, gas and carbon injection.

The technological efforts concentrating on use of oxygen and carbon for injection has resulted in attention being shifted to optimizing the use of solid materials for further improving slag performance and recycling of by products in the EAF.

In recent years, injection of lime has been shown to be a viable technology for the electric arc furnace with benefits for the steelmaker. Optimum benefits are now being obtained by total injection of lime and dolomitic lime for the melting process rather than supplemental additions late in the heat.

Steelmakers would not consider limiting the application of their energy package for only a portion of the heat; likewise, lime injection technology provides an efficient delivery of lime at the proper time throughout the heat to gain the additional control of the slag and process benefits

The diagram below depicts the various injection systems used in the EAF with oxygen injection, deep carbon injection, foamy slag injection, lime injection and waste material injection. (Fig. 1)

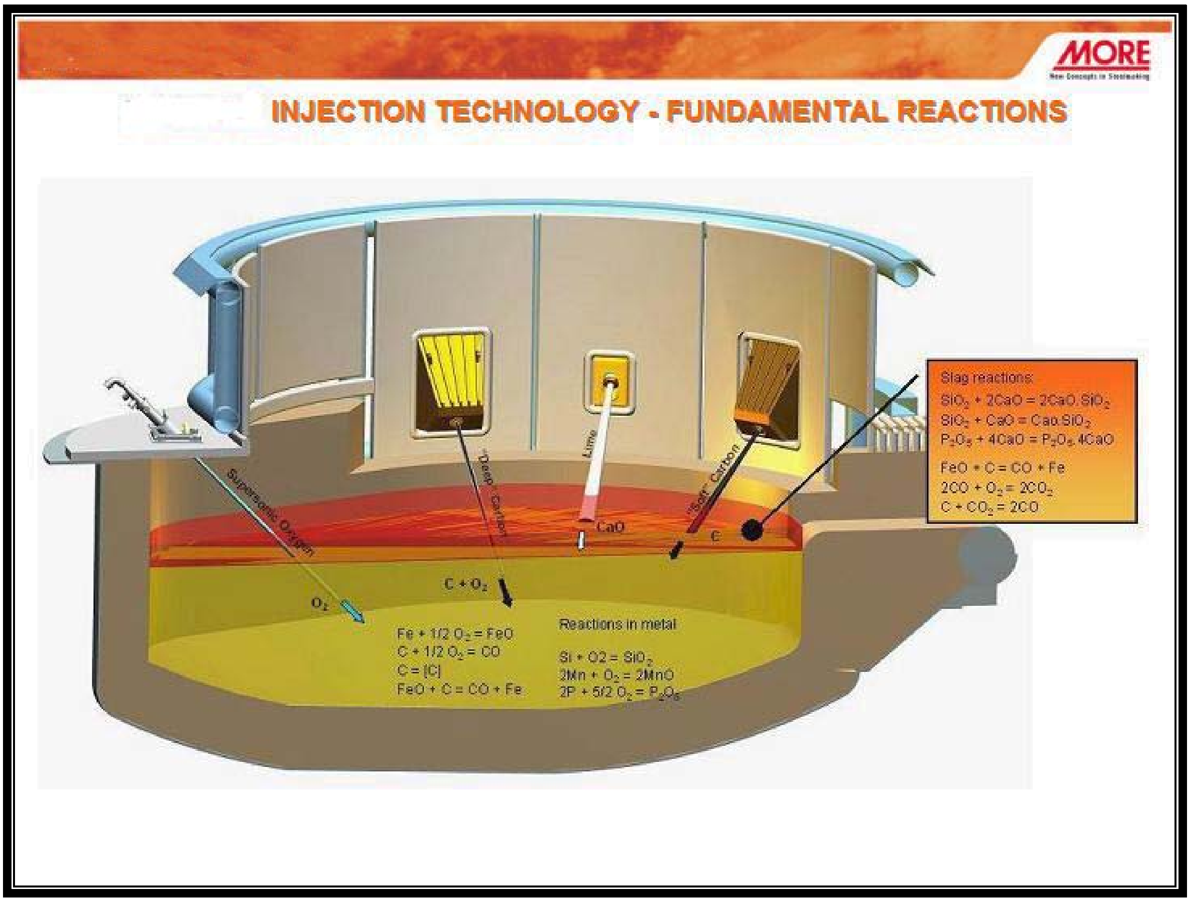

Figure 1. Various injection systems in electric arc furnace. Courtesy: More' srl.

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The Art of Lime Addition

Historically, steelmakers used creativity for lime additions to the electric arc furnace instead of science. Various methods which are still in use at many plants are:

- scrap bucket additions
- blown in through the roof using large nozzles
- conveyor systems directly to a fifth hole in the roof
- super sacks dropped into the hot furnace.
- lime screening and briquetting of fines on site for use in the furnace

Many of these techniques create significant environmental issues with lime emissions in the shop. Even with some improvement in reducing lime emissions using the fifth hole through the roof, lime fines are still generated through the various drop points to the opening and are transferred to the baghouse through the furnace fourth hole evacuation system. The impact from these mechanical systems could be seen in lime yield being lost to the baghouse and in the shop environment.

The impetus from foamy slag practices to protect the furnace sidewalls and refractory created the need to efficiently introduce lime during melting. Lime injection now provides an opportunity for the steelmaker for foamy slag control, reduce cost related to safety, process improvements, waste disposal and maintenance of mechanical conveyor systems.

Previous attempts at injection of lime in the electric arc furnace provided little incentive for steelmakers to pursue this as part of their steelmaking practices. In part, design of equipment, slag practices and lime products used for injection were not conducive in making this a useful tool for steelmakers. The first attempt at sidewall injection of lime appears to have been with a two point injection system at Triest, Italy in 1990. Recent developments to be discussed here have considerably improved the value of lime injection.

The Science of Lime Additions

Comfort of steelmakers in accepting the science of lime injection through the sidewall lance systems can be related to the following points:

- Improved slag practices and desire to control them
- Injection technology improvements over the last few years
- Efforts for cleaner shop environment for workers
- Reduced cost of waste disposal and maintenance of material handling systems
- Flexibility in additions of dolomitic and high calcium lime in EAF
- Further improvements in process performance

Lime Injection System – Dense Phase or Dilute Phase

The pneumatic conveying of materials has created some confusion among steelmakers as to whether they should use Dense Phase or Dilute Phase for the type of materials to inject.

Dilute phase dates from 1866 and conveys materials requiring a large volume of low pressure air producing higher air velocities whereby all the particles in the pipe are suspended above what is called the ***saltation velocity***. This is the point at which particles will drop out of suspension in the flowing air stream and begin bouncing along the bottom of the pipe.

Dense phase started its development in the 1950's whereby materials conveyance requires a lower volume of high pressure air producing a velocity that is below the ***saltation velocity***. Thereby creating individual plugs which are moved by boosts of compressed air. An example of conveyance of material can be seen in figure 2:

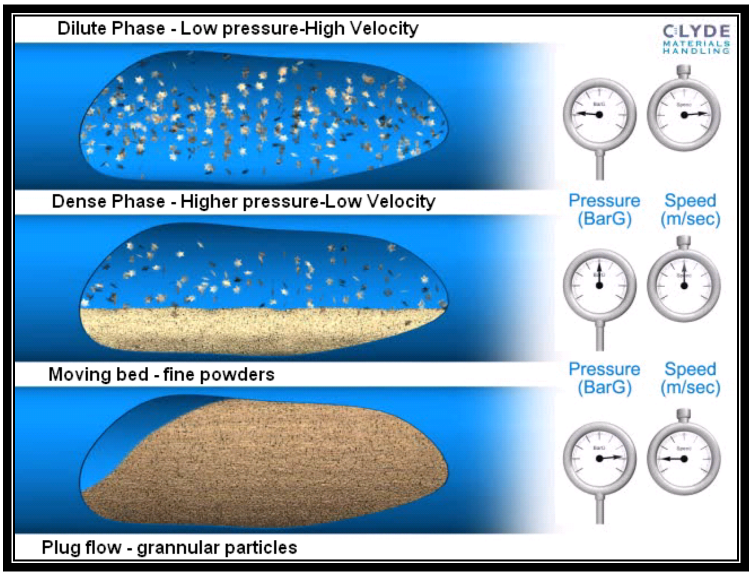

Figure 2. Dilute Phase vs Dense Phase flow characteristics Courtesy: Clyde Materials

The optimum method for lime injection is dense phase which allows fine particle lime to be injected into the EAF where the injection lance is located close to the slag for deeper penetration into the slag/metal interface.

The table below shows the comparison of Dilute Phase vs Dense Phase systems:

Overview	**Dense Phase**	**Dilute Phase**
Conveying velocity	Low	High
Air Pressure	High	Low
Pipe bore sizing	Small	Large
Abrasive materials	Low wear	High wear
Product size	small	large and small
Product degradation	Negligible	Greater

The concept of injecting lime and other powdered materials into the electric arc furnace is one readily appealing to most steelmakers:

- Faster dissolution of lime because of the larger surface area provided by smaller particles injected directly into the slag/metal interface
- improved lime yield
- slag chemistry control
- reduction in housekeeping efforts, and improved environmental conditions
- savings in mechanical repairs to material handling conveyor systems
- reduction in operating cost.

The key issues involving the injection of lime are consistency and control. Challenges that impact this involves:

- degradation and segregation of product from lime plant to steel plant
- flowability of various materials for injection in the EAF
- distances to injectors from silos to day bins to furnace
- the number of bends in delivery system to injector
- design of mechanical systems for feeding into the flow line and the path to the injector
- variability of pressures influenced by these factors

The need to provide consistency in delivery of product and control requires improved sensing systems and feedback to the operator in the pulpit. Today's furnaces cannot perform well without control of lime for foamy slag.

A variety of improvements in dispensing systems for lime can be noted:

- rotary style valves where pockets can be filled consistently, tank and line pressures are equaled and flow rates are controlled by the rotational speed of the rotary for consistent flow of lime to the injector.
- improvement in slide gate systems using slide gate knife edges
- booster air flows to fluidize the material in the bottom cone of the tank and feed line with transmitters to track pressure drops allow for additional flow control adjustments continuously.
- accuracy in weigh systems, pressure control and computer interfaces at EAF

Design of lime injectors has centered on the flow design, location in the furnace, flow rate requirements, and reliability. This prevents any clogging of the injector related to steel or slag splashing. In general the injector(s) should:

- be located in the vicinity of an oxygen source or hot spot to assist in the delivery of product and avoid plugging of the orifice
- injector orifice sizing of 50.8 mm to 76.2 mm
- Injection rates from 160 kg/min to 250 kg/min common
- injector angled downward at 40^o to 45^o
- injector positioned from 50.8 cm to 71.12 cm above the slag line
- oxygen / gas shrouding of the lime from the injector nozzle

Maintenance of injectors has been made accessible to steelmakers to avoid downtime or loss of lime feeding during the heat.

The variety of lime injectors supplied has unique characteristics that provide a choice to steelmakers for the variety of furnace applications in the industry. The following examples give an overview of the different types used for injecting lime into the furnace.

Typical sizing that is being used in lime injectors today relates to the orifice size and whether they are using dense phase or dilute phase conveyance. Larger pebble size with large orifice and pipe diameters use dilute phase where fine particle sized lime with a reduced orifice opening to the diameter of the pipe require dense phase conveyance.

Sidewall Injectors: Various designs of sidewall injectors are available. Injector design can be optimized to inject 100% of fine dolomitic lime and high calcium lime in the range from 9mm to 0 mm. Dense phase is required for this application. (Figures 3 and 4)

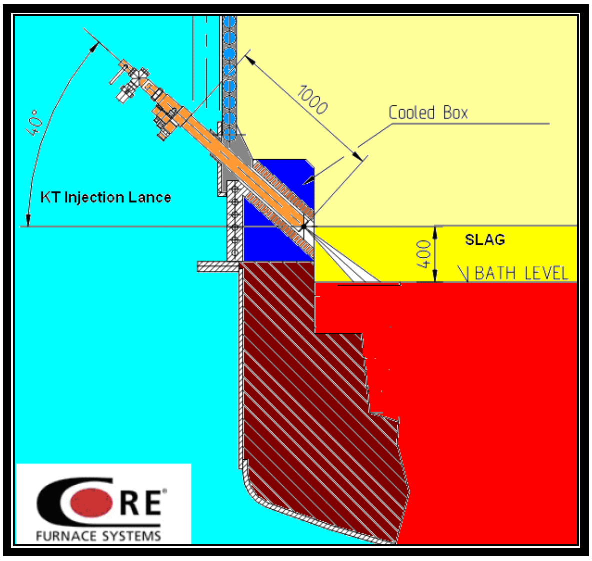

Figure 3. Sidewall injector design - Consteel
Courtesy: Core Furnace Systems

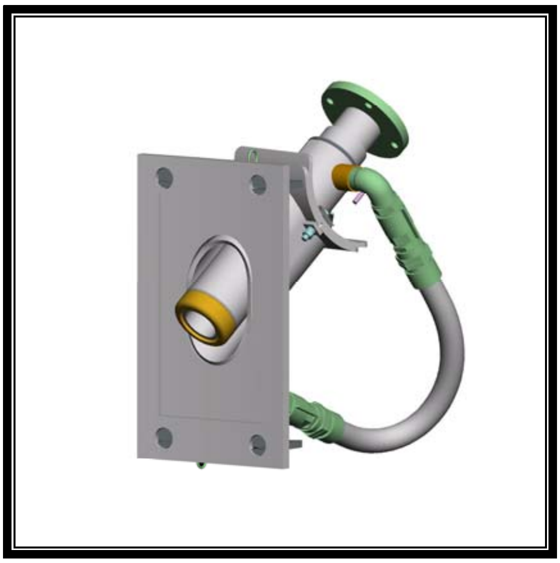

Figure 4. Sidewall injector design
Courtesy: More' srl

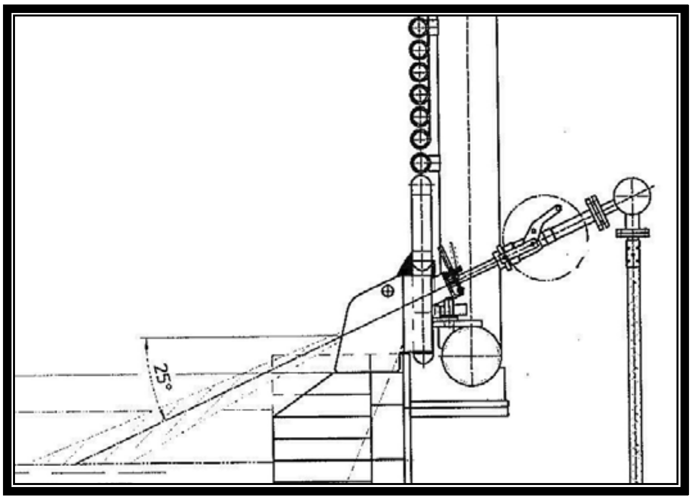

Figure 5. Drawing of pipe in sidewall
Courtesy of BSE

Sidewall Pipe:

Pipes are simple systems positioned close to the slagline with a wide range of orifice sizes. These injectors may be susceptible to plugging compared to higher technology sidewall injectors. These can range from 38.1 mm to 152.4 mm in diameter feeding 6mm x 0 mm lime size to 19mm x 0 mm lime size. Dilute phase is required for pipes of 101.6 mm and larger and dense phase for 76.2 mm or less. (Figure 5)

Comparison of Lime Injection – Europe vs. North America

Figure 6 shows the growth of sidewall lime injection lances with Europe predominately in the lead in early 2002, however North American installations have gained ground since 2005 with additional units planned past 2008. This recent spurt for North America in growth of lime injection systems in 2005 may be related to the availability of capital spending seen from the upsurge in steel company profits as well as available technology allowing steelmakers to improve furnace performance through injection technology.

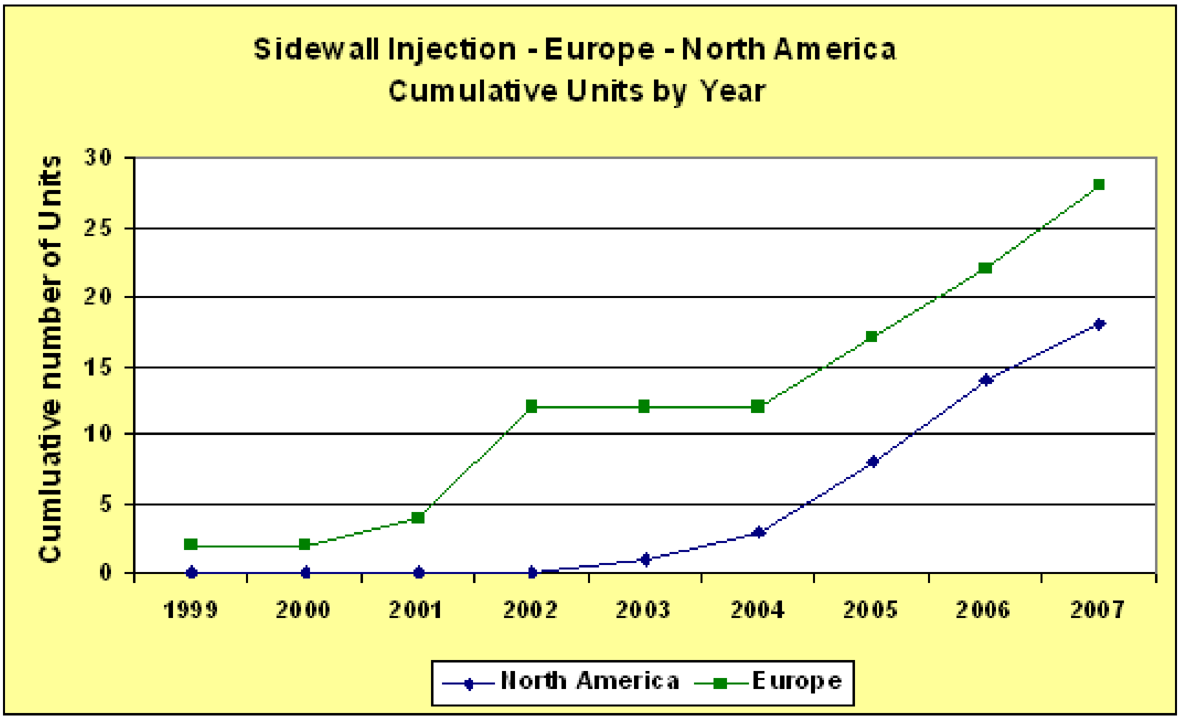

Figure 6. Sidewall injection by year in Europe, North America and South America
Sources: More' Srl, Tenova, Semco TBS, and Carmeuse Lime

The following table provides a comparison of lime injection systems at various plants in Europe and North America. At the beginning of 2008 there are 28 injectors in use at 18 steel plants in Europe and 18 injectors in use at 12 steel plants in North America. Comparisons of various parameters are shown for heat sizes, number of injectors, injector size, flow rates, lime sizing, injection practice and type of lime being injected: (Figure 7)

European Lime Injection Summary

Steel Plant	Plant Location	Heat Size Size	# Injectors	Injector Type	Injector Bore Size	Flow Rate	Lime Sizing	Injection Practice	Lime Type
Duferco La Louvriere	Belgium	93 t	2	More Limejet	76.2 mm	350 kg/min	3mm -13mm	Supplemental	Dolo
Thy Marcinelle	Belgium	155 t	1	More Limejet	63.5 mm	200 kg/min	2mm -20mm	Supplemental	CaO
Siderurgica Balboa	Spain (2 Fce)	105	1/Fce	More Limejet	63.5 mm	200 kg/min	5mm-15mm	Supplemental	CaO
BGH Edelstahl Siegen	Germany	42 t	1	More Limejet	76.2 mm	330 kg/min	3mm -13mm	Supplemental	Dolo
Sovel S.A.	Greece	100 t	1	More Limejet	63.5 mm	200 kg/min	2mm -20mm	Supplemental	Dolo
Acciaierie Bertoli Safau	Italy (2 Fce)	90 t	1/Fce	More Limejet	76.2 mm	350 kg/min	3mm-13mm	100% Injection	CaO-Dolo
Tenaris-Dalmine	Italy	100 t	2	More Limejet	76.2 mm	350 kg/min	0mm - 1mm	100% Injection	CaO-Dolo
Acciaierie Venete Padova	Italy	90 t	1	KT Lance	63.5 mm	220 kg/min	0mm - 1mm	Supplemental	Dolo
Ferriere Nord	Italy	100 t	2	KT Lance	63.5 mm	220 kg/min	0mm - 1mm	Supplemental	All Fines
Stefana Ospitaletto	Italy	130 t	2	KT Lance	63.5 mm	220 kg/min	0mm - 1mm	Supplemental	All Fines
Venete Sarezzo	Italy	80 t	1	Pipe sidewall	63.5 mm	200 kg/min	0mm - 1mm	Supplemental	Dolo
Stefana Montirone	Italy	75 t	1	KT Lance	63.5 mm	200 kg/min	0mm - 1mm	Supplemental	Dolo
Lucchini Sidermeccanica	Italy	70 t	2	Elti Lance	63.5 mm	200 kg/min	0mm - 1mm	Supplemental	All Fines
Riva Acciaio, S.p.A.	Italy	76 t	2	KT Lance	63.5 mm	201 kg/min	0mm - 1mm	Supplemental	CaO
Huta	Poland	100 t	2	BST LimeJet	63.5 mm	80 kg/min	3mm -6mm	Supplemental	Cao
Habas - Aliago	Turkey (2 Fce)	150 t	1/Fce	Pipe sidewall	63.5 mm	200 kg/min	1mm-12mm	Supplemental	Dolo
Ege Celik - Aliago	Turkey	130 t	1	Carbon lance	63.5 mm	200 kg/min	0mm-3mm	Supplemental	Dolo
Icdas - Karabiga	Turkey	175 t	2	Pipe sidewall	63.5 mm	200 kg/min	0mm-3mm	Supplemental	Dolo

North American Lime Injection Summary

Steel Plant	Plant Location	Heat Size Size	# Injectors	Injector Type	Injector Bore Size	Flow Rate	Lime Sizing	Injection Practice	Lime Type
Charter Electric	Wisconsin	93 t	1	More Limejet	76.2 mm	350 kg/min	0mm -9.5mm	Dolo Only	Dolo
North Star Bluescope	Ohio (2 Fce)	195 t	2/Fce	More Limejet	63.5 mm	200 kg/min	6mm -19mm	100% Injection	CaO-Dolo
Gerdau-Ameristeel	Florida	93 t	1	More Limejet	63.5 mm	200 kg/min	0mm - 6mm	100% Dolo	Dolo
Sterling Steel	Ilinois	400 t	2	More Limejet	76.2 mm	330 kg/min	0mm -12mm	100% Injection	CaO-Dolo
Gerdau-Ameristeel	New Jersey	84	1	KT Lance	63.5 mm	240 kg/min	0mm -6mm	100% Injection	CaO-Dolo
Nucor Steel	South Carolina	90 t	1	Semco TBS	152mm	350 kg/min	6mm -19mm	100% Injection	CaO-Dolo
Nucor Steel	North Carolina	100 t	2	Semco TBS	152mm	350 kg/min	6mm -19mm	100% Injection	CaO-Dolo
Gerdau-Ameristeel	North Carolina	90 t	1	Semco TBS	152mm	220 kg/min	6mm -19mm	100% Injection	Lime Blend
Timken Steel	Ohio	160	2	Semco TBS	152mm	220 kg/min	6mm -19mm	100% Injection	CaO-Dolo
Gerdau-Ameristeel	Tennesee	125	1	PTI	38.1 mm	80 kg/min	0mm - 6mm	Supplemental	MgO fines
SDI-Columbia City	IN (2 Fce)	120	1	Pipe sidewall	63.5 mm	125 kg/min	0mm - 6mm	Supplemental	Dolo
Deacero Celaya	Mexico	75 t	1	More Limejet	63.5 mm	200 kg/min	0mm - 1mm	Supplemental	Dolo

Figure 7. Comparisons of injection systems for Europe and North America.

Flux Practices:

In reviewing the reasons why lime injection was not accepted so easily in the past had to do a lot with the slag philosophy and steelmaking philosophy compared to today's steelmakers.

Previous practices of using highly basic slags in the electric arc furnace were not designed for efficient foamy slag height and refractory protection. This created additional slag problems through further lime additions in the furnace. Slags were highly saturated and would not foam.
The slag practices today allow for early foaming and sustained foaming due to lower basicity ratios and sufficient MgO levels allows faster dissolution of lime through injection of lime fines into the slag/metal interface. The higher powered furnaces are successful because of the ability to improve control of the slag throughout the heat. Lime injection is proving to be another tool in the process. Optimum mass balance control in the furnace has now efficiently included 100% injection of fluxes using state-of-the-art injection technology.

Steel plant practices can range from 100% injection of dolomitic and high calcium lime to supplemental injection of only dolomitic lime. Utilization of oxygen /gas shroud around the lime being injected provides a solid core of material to the slag metal interface as seen in the diagram of the LimeJet designed by More'srl as compared to a non-shrouded injector. The advantage of using the burner mode to cut through scrap and then allow shrouded lime injection promotes 100% lime injection in the EAF and faster dissolution of lime. (Figure 8)

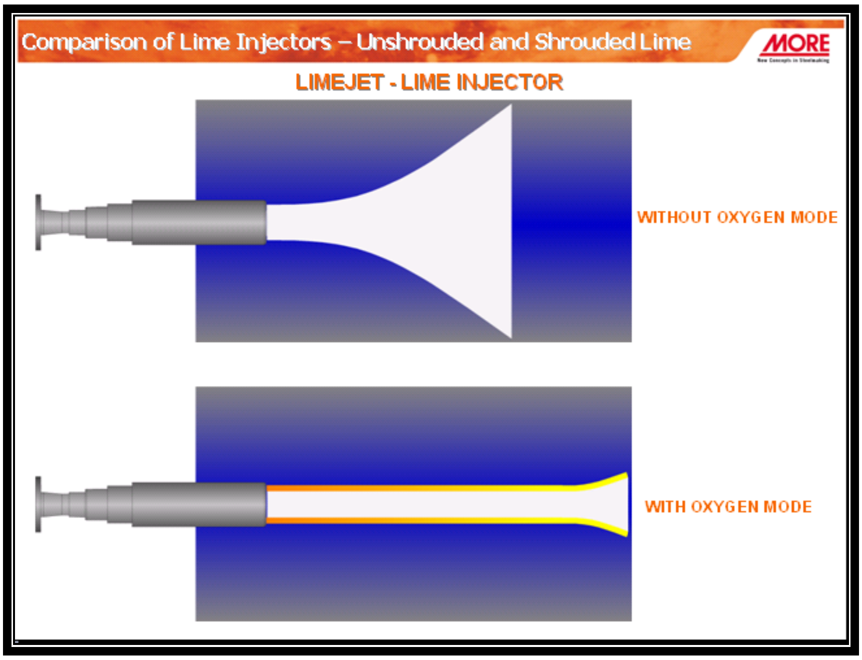

Figure 8. Depiction of shrouded lime injection vs. un-shrouded Courtesey: More' srl

Injection technology has allowed plants to process waste brick and waste lime for injection to reduce the waste disposal cost and gain additional MgO units for use in the EAF. Recycling of waste products have been achieved in Italy by Ferriere Nord S.p.A. and recently with Stefana S.p.A. using the Tenova KT-slag process.

Process improvements are noted in the area of energy savings of 15%, refractory improvements, reduced P.O.T., and reduction in lime consumption of 10% or higher for the furnace.

Lime for injection:

Lime quality is a key factor for improved steelmaking operations through injection into the slag/metal interface. It is well understood that lime has the characteristics of being friable and variable from truckload to truckload. Variability in sizing can be attributed to degradation and segregation for the product during mechanical handling especially for dolomitic lime due to its softness related to the characteristics of the limestone compared to high calcium limestone prior to calcination.

Steelmakers are use to various sized materials for injection including high calcium lime and dolomitic lime. The dispensing equipment is flexible for delivery of various materials to the injectors. There has been some experiences by steelmakers in regards to flowability of dolomitic lime from day bins to dispensers and finally to the injectors. This can be related to some factors that influence how the material reacts in a gravity flow situation compared to an aerated situation.

Consistency of flowability for lime can be of concern because of the following reasons:

- Mechanical size degradation with subsequent handling to the injection system
- Improper design of lime injection systems
- Segregation of the product in transfer from silos to trucks and back to silos
- Variability in lime properties related to particle shape, particle attraction and size distribution.

There is no advantage in restricting lime size gradations since in the mechanical handling during load out at the lime plant, transporting the lime, filling the silo at the steel plant and subsequent charging of the dispenser for injection leads to gradation from the original desired sizing requirements. In the case of dolomitic lime, fine particles tend to adhere to each other due to surface electrical charges and can influence flowability depending on the distribution of particle sizing. Techniques to evaluate flowability of different materials rely on data provided by the density of materials, angle of repose, size distribution and gravity flow rates.

The need for flow aids can be determined with bench tests in the laboratory using a flow tube designed to provide flow rates. Work achieved in the laboratory using the evaluation methods mentioned above and tests at steel plants has resulted in the knowledge for better application in use of fine lime for improved injection in the electric arc furnace. Earlier work on flow aids for lime injection in the QBOP provided insight to the differences in the lime products used for the electric arc furnace.

The Carr Index provides an indication of flowability and the need for utilization of flow aids to improve the flow of material. Carr Index = (tamped density – loose density)/tamped density. A Carr Index of 3 to 13 indicates good flowability, 14 to 16 indicates the material may not flow in some equipment situations and 17 to 20 indicates poor flowability and requires a flow aid to help it flow. For example, sand has an index of 7.2, carbon fines – 11.3 and ¼’ x 0 dolomitic fines from a southern location in North America - 12.9, all show flowability. Crushed brick has a Carr Index of 15.7 and may cause some flowability problems while a sample of dolomitic lime ¼” x 0 from a northern location in North America – 19.8 and requires a flow aid to provide good performance because of the physical characteristics of the lime particles.

Development in the use of flow aids by Carmeuse Lime and Stone, Inc has provided the ability to even out the difference seen in lime characteristics on the flowability. This allows for improved control of flow to the lime injectors and consistency in operation. The design of lime for injection relies on the characteristics of flowability in transfer from truck to silo, in a gravity situation such as silo to receiving hopper, and injection when aerated from a distance to the injectors in the EAF.

Summary:

Lime injection technology has improved over the last few years to be a viable tool for electric furnace operations compared to past experiences. The growth of sidewall injection has opened the possibilities for injection of various materials that can provide cost effective operations. The following benefits can be realized:

- Cleaner environment for the shop
- Reduced lime to furnace evacuation system
- Less quicklime used in the melting process
- Reduced maintenance cost compared to mechanical systems

- 100% injection of lime requirements for the EAF
- Faster dissolution of lime related to increased surface area of lime particles
- Flexibility in controlling slag characteristics throughout the heat
- Improved steel process performance

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