Abstract: Growing interest in pneumatic injection of lime in the electric arc furnace is a result of improvements in injection equipment, development of flow-optimized lime products and refinement of foamy slag practices. Benefits in environmental aspects of the steel plant, operational costs and flexibility in design of slag chemistry have been realized by steelmakers who have installed lime injection systems. This paper will provide an overview of development in lime injection equipment, practices and evaluation of lime products required to meet the variety of designs in this process.

INTRODUCTION

The electric furnace process has evolved to a highly efficient scrap melter incorporating technology for enhancing energy using oxygen, gas, carbon, and lime injection. Improvement in reducing electrical energy in the EAF via injection technology is well documented. The efforts concentrating on use of oxygen and carbon for injection has resulted in attention being shifted to other solid materials for further improving performance in the EAF. In recent years, injection of waste materials and lime has been shown to be a viable technology with benefits for the steelmaker.

Typically lime additions to the electric arc furnace were added in the scrap bucket through conveyor systems or conveyed directly to a fifth hole in the roof using a pipe or even with supersacks dropped into the hot furnace. Issues with lime emissions during scrap bucket charging can be seen in figure 1. Further emissions resulted in the shop when the bucket was opened over the open bath with the intense heat pushing the lime fines throughout the shop area. Even with some improvement in reducing lime emissions in the shop using the fifth hole through
the roof as seen in figure 2, lime fines are still generated through the various drop points to the opening and then are transferred to the baghouse through the furnace fourth hole evacuation system. The lime charged is not evenly distributed in the furnace as is possible with multiple lime injection points through the sidewalls.

The impact from these mechanical systems could be seen in lime yield being lost to the baghouse and in the shop environment. Lime injection now provides an opportunity for the steelmaker to reduce cost related to safety, 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. Improvements in these key factors are discussed later in this paper.

**HISTORICAL OVERVIEW**

**Lime Injection – Past and Present**

In the past, injection equipment was limited to the roof or door instead of sidewall injection through water cooled panels as is possible today. Consumable pipes or submergible lances provided limitations for efficient injection of lime related to sizing restraints and flow rates achieved.

Attempts using hollow electrodes with lime and argon in the late 70’s provided improvements in arc flicker, but no additional benefits were seen in power. Time constraints involved when changing electrodes for connection to lime dispensing systems resulted in additional heat times. Hollow electrodes are still seen in use with plasma furnaces today.

Introduction of lime injection was with the first slag door lance for injecting lime in the EAF at
Eschweiler, Germany in 1980. Roof dosing of lime using a pneumatic system to three points in the roof of the EAF was first achieved at Krupp-Stahl AG in Geisweid, Germany in 1984. The first sidewall injection of lime appears to have been with a two point injection system at Triest, Italy in 1990.

The history of lime injection installations worldwide can be seen in figure 3. This graph shows the cumulative number of units of door injection systems, roof injection systems and sidewall injection systems. Door injection systems began in 1980 and leveled off in the late 90’s. Roof injection systems gained popularity until the late 90’s with only two additional units installed in 2002 and 2006. Sidewall injection units started in 1990 and begin to surge in 2002 surpassing the total number of roof systems in 2006.

![Figure 3: History of lime injection installations by technique. Source: More’srl, Core Furnace Systems, Stein Injection Systems](image)

![Figure 4: Sidewall injection by year in Europe, North America and South America. Figure 4 shows the growth of sidewall lime injection lances with Europe predominately in the lead](image)
lead in early 2000, however, North American installations have gained ground since 2005 with additional units planned past 2007. South America is now following suit with the first installations in 2006. This recent spurt 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.

Examples of the various injection technologies for lime can be seen below in figures 5, 6 & 7:

![Figure 5: Roof lime injection system](image1)

Maximum flow-rate:
Up to 300 kg/min in 50-m distance to the furnace.

Material grain size recommended:
Lump-lime: 0 - 15 mm.
Dolomite lime: 0 - 5 mm

Material grain size distribution specification:

<table>
<thead>
<tr>
<th>Grain Size</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1 mm</td>
<td>3%</td>
</tr>
<tr>
<td>1 - 3 mm</td>
<td>20%</td>
</tr>
<tr>
<td>3 - 12 mm</td>
<td>70%</td>
</tr>
<tr>
<td>12 - 15 mm</td>
<td>7%</td>
</tr>
</tbody>
</table>

![Figure 6: Sidewall lime injection system](image2)

Courtesy: Core Furnace Systems

![Figure 7: Lance Manipulator for lime injection](image3)

Courtesy: Badische Stahl Engineering

These systems utilized pneumatic conveyance to transfer the lime from a pressurized system to the
the injectors. The impetus from foamy slag practice to protect the furnace sidewalls and refractory created the need to efficiently introduce lime during melting. The popularity of the various systems changed according to changes in furnace practices and introduction of improved technologies in delivery systems and injector lance systems.

Comfort of steelmakers in accepting 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

The diagram below shows the basic reactions and various injection systems used in the EAF with oxygen injection, deep carbon injection, foamy slag injection, lime injection and waste material injection. (Fig. 8)

Figure 8: Various injection systems in electric arc furnace.  

Courtesy: More’ srl.

PROCESS APPLICATION
**Lime Dispensing Equipment - Factor One.**

The heart of the injection system in the electric arc furnace lies with equipment that moves the lime to the injection system located at the furnace. There are different designs of lime injectors that are unique in how they fit into the furnace and direct the lime to the slag/metal interface. It is the dispensing equipment that is key to consistency and control of lime injection.

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 back 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. This system often operates in batches such as those seen in lime injection at the electric arc furnace. An example of conveying material from point A to point B can be seen in figure 9 provided by Clyde Materials Handling:

![Figure 9: Dilute Phase vs Dense Phase flow characteristics](image)

In the case of dense phase where fine lime is injected into the EAF from a larger diameter pipe to a
a restricted orifice in an injection lance, deeper penetration into the slag/metal interface can be achieved through the higher pressure seen in this system. Typical pressures depending on distance can range from 45 PSI to 55 PSI compared to dilute phase pressures of 15 psi. In the case of dilute phase, material is typically conveyed from a point using the same diameter pipe to an outlet point such as a copper block in the EAF.

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

<table>
<thead>
<tr>
<th>Overview</th>
<th>Dense Phase</th>
<th>Dilute Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conveying velocity</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Air Pressure</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Pipe bore sizing</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Abrasive materials</td>
<td>Low wear</td>
<td>High wear</td>
</tr>
<tr>
<td>Product size</td>
<td>small</td>
<td>large and small</td>
</tr>
<tr>
<td>Product degradation</td>
<td>Negligible</td>
<td>Greater</td>
</tr>
</tbody>
</table>

The key issues involving the feeding of lime to the injector is control. Issues that impact this control involve segregation of materials, variability of pressures, design of mechanical feeding into the flow line and the path to the injector.

Typical dispensing tanks such as seen with the butterfly valves in refractory guns were influenced greatly by variability in product and air pressures. The combination of variable pressures in the tank and flow lines, and the mechanical shortcomings of the valve opening accuracy influenced control of material delivery that was not consistent. With the improvements in 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, a consistent flow of lime can be seen to the injector. Additionally, improvements in gate systems using such as knife edges, booster air flows to fluidize the material in the line and transmitters to track pressure drops allow for additional flow control adjustments continuously.

**Lime Injectors – Factor Two**

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 allows for improved lime yield, reduction in housekeeping efforts, savings in mechanical repairs to material handling conveyor systems and reduction in operating cost.

Design of lime injectors has centered on the design, location in the furnace, flow rate requirements, and reliability. It is well known that the injector(s) should be located in the vicinity of an oxygen source or burner to assist in the delivery of the product to the slag. Additionally, the injector should have an orifice sizing of 2” to 3” angled downward at 42° to 45° and positioned 18” to 22” above the slag line. This prevents any clogging of the injector related to steel or slag splashing.

The amount of lime delivered per injector is typically 600 lbs per minute based on a 2” orifice injecting fine lime material. Dolomitic and high calcium lime are both introduced through the same
same injector alternating the time in the melt and amounts required to control the basicity of the slag. Removal or cleaning of the injectors has been made accessible to steelmakers to avoid any downtime or loss of lime feeding during the heat.

Location of lime injectors can be seen in the drawings below depicting a single injector and one with multiple injector sites:

**Figure 10- Single lime injector location**

*Courtesy: More’srl*

**Figure 11: Multiple point injector location**

*Courtesy: Core Furnace*

**Design of lime injectors:**
The variety of lime injectors supplied has unique characteristics that provide a choice to steelmakers for the variety of furnace designs in the industry. The following gives an overview of the different types used for injecting lime into the furnace:

**Copper Block:** This block is positioned close to the slagline with a larger orifice than other sidewall injectors. These can range from 4” to 6” in diameter feeding ³⁄₄” x down lime size. Dilute phase is required for this application.

![Figure 12: Copper Block in EAF](Courtesy: Berry Metals)

**Furnace Roof:** This system provides 3 orifice points on the roof which are able to dose dolomitic lime down the walls of the furnace at hot spots and high calcium towards the electrodes. The conical injectors are 3” to 4” in diameter. Dolomitic lime size is ¼” x down and high calcium is ½” x down. Dilute phase is typically used for this application.

![Figure 13: Roof Injectors](Courtesy: Stein Injection)

**Sidewall Injectors:** Various designs of sidewall injectors are available. Common to them are that they are typically located close to the slagline in the range of 18” to
22” with orifice diameters of 2” to 3”. Feed rates are around 600 lbs per minute. These injectors are designed to inject fine dolomitic lime and high calcium lime. Dense phase is required for this application.

Flux practices: Factor Three
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.

The efforts were directed to injecting lime deep into the liquid metal and not at the slag/metal interface. The goal was to achieve lower carbon, phosphorous and sulfur levels in the EAF and not through secondary metallurgy as is available today.

Work done by Dr. Peter Koros at LTV Steel in the mid 80’s showed it was possible to achieve lower carbon content, improved rates of sulfur and phosphorus removal through deep lime injection using a submerged lance. Basicity ratios of 3.3 or higher and efforts to remove sulfur with high oxygen activity slag resulted in long heat times and additional lime injection created a thick slag not conducive for slag/metal mixing. Foamy slag characteristics were also not acceptable with today’s standards.

The slag practices today which 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 and not into the liquid metal. 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.

Steel plant practices can range from 100% injection of dolomitic and high calcium lime to injection of only dolomitic lime. The added flexibility in designing slag chemistry for various steel grades can be enhanced through blending of dolomitic lime and high calcium lime from the silos to the dispenser and then injected into the EAF. An example of this can be seen in the drawing by the SemcoTBS system figure 16.

Additional benefits realized from lime injection were the improved environment of the shop, reduction in waste disposal cost related to lower CaO in the baghouse dust of 10% to 25%, and reduced maintenance of mechanical conveyor systems. The concern for improved safety for employees on the shop floor from dust emissions were reduced as compared to the lime charged in scrap buckets and roof feed systems.

Injection technology has allowed plants to process waste brick and 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 KT-slag process.

Process improvements have been noted in the area of energy savings of 10%, refractory improvements, and reduction in lime consumption of 10% or higher for the furnace.
Lime for injection: Factor Four

Lime 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 can be attributed to segregation of product size during mechanical handling and in the case of dolomitic lime the abrasiveness of the product is similar to carbon.

Steelmakers are used to various sized materials for injection including fine carbon for foamy slag practice. When comparing the bulk densities of the various materials used in the steel plant it can be seen in figure 17 that there is little difference in granular coal, carbon, dolomitic fines or high calcium fines. The differences noted may be for magnesite, granular graphite and refractory material. The dispensing equipment is flexible for delivery of various materials to the injectors.

However, it is the improved flowability of lime using flow aids where applicable that make this product suitable for the lime injection equipment supplied today.
Typical sizing that is being used in lime injectors today relate 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.

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

- Mechanical size degradation with subsequent handling to the injection system
- Segregation of the product in transfer from silos to trucks and back to silos
- Differences in lime properties related to 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.
Development in the use of flow aids by Carmeuse Lime 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. Work achieved in the laboratory and in the field 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.

**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
- Faster dissolution of lime related to increased surface area
- Flexibility in controlling slag characteristics throughout the heat
- Improved steel process performance

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