ABSTRACT

The primary focus is to explore the advantages of coreless coating and premelt pots on continuous hot dip galvanizing lines for Zinc-Aluminum based coatings as compared with traditional channel inductor technology. To start we first explore some basic theory behind induction melting in order to provide a better understanding behind the fundamental differences between a coreless inductor and a traditional channel inductor.

We then take a closer look at how these fundamental differences impact induced current densities and distributions as well as electromechanical stirring effects to provide unmatched temperature and bath chemistry uniformity, the two key process advantages of coreless technology. Three specific case studies of bath temperature and chemistry uniformity are presented including field measurements from production units.

Both single- and two-phase electromechanical stirring are then explained complete with models results generated using FEA software.

Finally, we explain the other operational advantages of coreless coating pot technology concluding with an in-depth comparison showing total cost of ownership for coreless versus traditional channel inductor coating pots. Total cost of ownership is broken down into several sub-categories including initial capital investment, maintenance, downtime (lost production) and operational costs including a look into energy consumption.

KEYWORDS

induction; coreless; coating pot; premelt pot; continuous galvanizing; hot dip galvanizing

INTRODUCTION

The primary focus is to explore the advantages of coreless coating and premelt pots on continuous hot dip galvanizing lines for Zinc-Aluminum based coatings as compared with traditional channel inductor technology.
1. THEORY OF INDUCTION HEATING

A coreless furnace is distinguished from a channel inductor by its shape and means of energy transfer. Here we will take a closer look at the modes of energy transfer. A traditional channel inductor consists of an air or water cooled multi turn coil wrapped around a magnetic core made up of laminated silicon steel sheets. The channel when filled with molten metal acts as a single shorted secondary turn and behaves much like the secondary of a traditional wound transformer. Induction heating is achieved inside the channel by passing an alternating current through the primary coil, which in turn generates an electro-magnetic field orthogonal to the direction of current. It in turn induces a secondary current in the channel (see Fig. 1). The magnetic core serves to attract the magnetic field generated by the primary coil and efficiently redirect that energy into the channel. This in addition to the small cross section of the channel, which effectively increases load resistance and thereby power generated \( P = I^2R \), are reasons why channel inductors can achieve very high electrical efficiencies on the order of 90% or better.

(Fig. 1) A varying magnetic field induces current in the channel of an Inductor

In contrast a coreless furnace operates on essentially the same principals but lacks a magnetic core and replaces it by a molten bath. Induction heating is achieved by passing an alternating current through a primary coil, which generates an electro-magnetic field orthogonal to the direction of current which in turn induces a secondary current into the molten bath centered inside of the coil in a direction opposite to that of the primary coil current (see Fig. 2). As this type of furnace lacks a traditional magnetic core the electrical efficiency is almost entirely dependent on the distance between the bath and the coil. Therefore, refractory thickness in a coreless furnace must be carefully selected to provide long lining life without sacrificing too much efficiency and is the main reason why coreless furnaces typically achieve lower efficiencies on the order of 55-65% considering typical refractory thicknesses in a range between 5 to 8in respectively.

(Fig. 2) A varying magnetic field induces current in the molten bath of a coreless furnace

For both, coreless and traditional channel furnaces, molten metal heats up due to a combination of the induced current and the electrical resistance of the bath resulting in Joule heating, also known as eddy current heating (see Fig. 3).
Fig. 3) Induced currents cause metal in the molten bath to heat up as a result of Joule Heating

The induced current does not necessarily penetrate all the way to the center of the bath. This is known as skin effect, by which current density is highest on the surface and falls off exponentially moving in towards the center. Depth of Penetration is used to describe the thickness of the surface layer containing 86% of the induced power and is defined by the following formula:

\[
d = 5.03 \sqrt{\frac{\rho}{\mu f}} \text{ [cm]}
\]

\[
d = 3160 \sqrt{\frac{\rho}{\mu f}} \text{ [in]}
\]

Where,
\[
\rho = \text{resistivity in } \mu \Omega \cdot \text{cm} [\Omega \cdot \text{in}]
\]
\[
\mu = \text{relative magnetic permeability and}
\]
\[
f = \text{frequency in Hertz.}
\]

Table I illustrates the inverse relationship between depth of penetration and frequency and the direct relationship between depth of penetration and resistivity for pure zinc having a resistivity of 37 µΩ*cm versus a common 55% Aluminum, 45% Zinc alloy with a resistivity of 32 µΩ*cm.

(Table I) The effect of changing frequency and resistivity on depth of penetration due to “Skin Effect”

<table>
<thead>
<tr>
<th>Frequency</th>
<th>D.P. Zinc</th>
<th>D.P. 45% Zn 55%Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Hz</td>
<td>4.33 cm [1.70 in]</td>
<td>4.02 cm [1.58 in]</td>
</tr>
<tr>
<td>100 Hz</td>
<td>3.06 cm [1.20 in]</td>
<td>2.84 cm [1.12 in]</td>
</tr>
<tr>
<td>200 Hz</td>
<td>2.16 cm [0.85 in]</td>
<td>2.01 cm [0.79 in]</td>
</tr>
<tr>
<td>500 Hz</td>
<td>1.37 cm [0.54 in]</td>
<td>1.27 cm [0.50 in]</td>
</tr>
<tr>
<td>1,000 Hz</td>
<td>0.97 cm [0.38 in]</td>
<td>0.90 cm [0.35 in]</td>
</tr>
</tbody>
</table>

2. HEATING UNIFORMITY

With this basic understanding of induction theory, we will now compare the mechanisms for heat transfer in a coreless furnace vs. a traditional channel type inductor to see how they differ in heating uniformity in the molten bath.

Considering a traditional twin loop channel inductor at 50 Hz operation the current conducting area of the channel is calculated as the depth of penetration multiplied by the channel width (see Fig. 4).
For the purpose of this example we evaluate a 500kW twin loop inductor for Zinc-Aluminum (55%Al, 45%Zn) at 50 Hz having a depth of penetration 1.58in and a channel width 5in on a 24in diameter channel connected to a modern solid state power supply producing 1,450 Coil Amps per loop with an 18:1 coil to channel turn ratio for an induced channel current of 26,100 Amps per loop. The resulting current density for a single loop is then calculated as the channel current divided by the current conducting cross section or 26,100 Amps / (1.58in * 5in) = \( \text{3,300 Amps/in}^2 \).

Now taking a look at a comparable Coreless Premelter at 100 Hz operation the current conducting area of the bath is now calculated as the depth of penetration multiplied by the active coil height inside of the molten bath (see Fig. 5).

For the purpose of this example we evaluate a comparable 1,500kW coreless premelt furnace for Zinc-Aluminum (55%Al, 45%Zn) at 100 Hz having a depth of penetration 1.12in and an active coil height of 55in on a 57in diameter lining connected to a modern solid state power supply producing around 6,600 Coil Amps with a 25:1 coil to bath turn ratio for an induced bath current of 165,000 Amps. The resulting bath current density is again calculated as the bath current divided by the current conducting cross section or 165,000 Amps / (1.12in x 55in) = \( \text{2,670 Amps/in}^2 \).

Now looking at a typical Coreless Coating Pot at 100 Hz operation we apply the same principals for determining the current conducting area of the bath as we did for the coreless premelt furnace in the example above (see Fig. 6).
For this example we evaluate a common 2,500kW coreless coating pot furnace for Zinc-Aluminum (55%Al, 45%Zn) at 100 Hz having a depth of penetration 1.12in and an active coil height of 56in on a 150in diameter lining connected to a modern solid state power supply producing around 21,000 Coil Amps with a 7:1 coil to bath turn ratio for an induced bath current of 147,000 Amps. The resulting bath current density is again calculated as the bath current divided by the current conducting cross section or 147,000 Amps / (1.12in x 56in) = \(2,340 \text{ Amps/in}^2\).

Comparing the results for each example above you can see that the current densities in a traditional channel inductor are on an order of magnitude ranging from 25% to 40% higher versus coreless furnaces for the same application. One can therefore conclude that under steady state conditions before taking into consideration any other effects of stirring or heat transfer, covered in separate sections, that the resulting peak metal temperatures inside of a channel inductor are on an order of magnitude higher than the peak metal temperatures seen inside comparable coreless furnaces resulting in greater bath temperature variations with traditional channel inductor pots, a well known and documented source of metal oxides and spinels, “dross”, formed inside the molten metal bath.

3. STIRRING

Coincidentally, the same reasons that contribute to the poor electrical efficiency in a coreless furnace are also what makes them exceptional stirring furnaces. Rather than concentrating the electro-magnetic forces through a magnetic core those forces are instead exerted onto the molten bath producing an electro-mechanical stirring action further described below.

There are two main factors influencing the stirring patterns developed inside of a coreless furnace. They are the geometry of the bath with respect to the coil and phasing between electrical currents circulating through the coil.

The coil inside of a typical coreless furnace is comprised of several different sections which are generally described in order to understand the impact that they have on stirring. First there is an active coil section which comprises the center turns of the coil and are connected to a power source thereby generating a magnetic field. At both ends of the centrally located active coil section there are stainless steel cooling turns which are mostly invisible to the magnetic field generated by the active coil section and mainly serve to maintain a constant thermal gradient through the refractory lining and provide a space for the magnetic fields to turn 180º at the ends. After each section of cooling turns is a single copper turn located one at each end of the coil which serves to squeeze the magnetic fields at the ends containing the field entirely between these two turns to avoid unwanted parasitic heating of the furnace frame or nearby steel structures located directly above and below the coil (see Fig. 7).

(Fig. 7) Half cross section through a coreless furnace showing the magnetic field around the coil

The resulting mechanical forces imposed on the bath are perpendicular to the magnetic field lines generated. Near the center of the coil these field lines are parallel however at the ends of the coil where the field lines turn 180º the forces are turned at a slight outward angle (see Fig. 8).
In a symmetrical-centered furnace design (typical for most coreless furnaces used today) where the active coil section is vertically aligned with the bath (centered) and the inside diameter of the coil is perfectly parallel to the walls of the bath along its height and coil currents are all in phase, the resulting forces cause a “squeezing” effect at the center of the bath pushing metal in towards the center where the strongest forces occurring at the vertical midpoint of the active coil section. Molten metal is consequently pushed in towards the center of the bath and outward towards the top and bottom of the bath creating two separate eddy currents which rotate in opposing directions referred to as a “Figure 8” stirring pattern (see Fig. 9). This would be a very similar effect to that of repeatedly squeezing and releasing the center of a balloon.

In a shifted coil the vertical alignment of the bath with respect to the coil active section is shifted off center causing the point where the two eddy currents converge to shift in the same direction. This shifted design is typical for most coreless furnaces used for pre-melting ingot on continuous galvanizing lines, with the walls of the bath are nearly parallel to the coil ID, and the center of the bath is shifted up above the coil active center and coil currents are all in phase. The resulting flow pattern is a top dominant eddy current also referred to as “Center Up” (see Fig. 10).
In an asymmetrical coil design the walls of the bath may be heavily tapered, flared at one end or a combination of both. The result is an asymmetrical profile along the height of the active coil such that the thickness of refractory between the I.D. of the coil and the O.D. of the bath decreases as you move up. Because the mechanical forces exerted on the bath diminish with increasing distance from the coil this has a similar effect as shifting the center of the active coil and favors a top dominant “Center Up” stirring pattern. The typical design of a coreless coating pot used on continuous galvanizing lines usually employs both an asymmetrical and a shifted coil design. The resulting flow pattern when coil currents are all in phase is dominated by the top eddy current “Center Up” leaving only a small bottom eddy current in the far corner of the floor (see Fig. 11).

(Fig. 11) Half cross section through a typical coreless coating pot with an asymmetrical-shifted coil showing velocity fields for a “Center Up” Dual Stirring pattern when coil currents are all in phase.

For a coil designed with a single active electrical section or for one having two or more active sections that are electrically connected either in parallel or series the currents are always in phase and will therefore produce a “Figure 8” stirring pattern (see Fig. 9).

When a coil has two or more active sections which are electrically independent from each other it is possible to shift the currents in each section out of phase. When currents are shifted out of phase the stirring patterns are also modified in the direction of the coil section where current is leading. For example a two section coil were the current in the bottom section is leading the current in the top section the resulting effect will be a bottom dominated eddy current where the flow of molten metal is predominantly in towards the mid-point of the bath and down towards the bottom of the furnace or “Center Down” (see Fig. 12).

(Fig. 12) Half cross section through a symmetrical-centered coreless furnace showing particle streamlines for a “Center Down” stirring pattern when top active coil current lags bottom active coil current.

The CPC coil design by Inductotherm Corp. for coreless coating pots gives users the ability to adjust the phase shift between top and bottom coil currents to modify the flow pattern from Dual Stirring (see Fig. 13) to Quad Stirring (see Fig. 14) or anything in between. This flexibility provides users the ability to adjust stirring patterns depending on their specific needs to minimize dross formation and accumulation, making it possible to maximize the furnaces useful lining life and improve quality of the final product.
(Fig. 13) FEA generated velocity fields for a typical coreless coating pot with an asymmetrical-shifted coil with CPC setup for **Dual Stirring**.

(Fig. 14) FEA generated velocity fields for a typical coreless coating pot with an asymmetrical-shifted coil with CPC setup for **Quad Stirring**.

4. TEMPERATURE UNIFORMITY

Temperature uniformity in the molten bath of any induction furnace is dependent on the combination of induced current densities inside the molten bath which causes the metal to heat up as well as the stirring patterns and average metal velocities which controls the exchange rate of molten metal in the current conducting areas of the bath. From this, one can pretty easily conclude that a coreless coating pot having a larger current conducting area, the lowest current densities and the strongest stirring forces and fastest average metal velocities, will in turn have the least variation in metal temperatures throughout the bath when compared to a traditional cannel type furnace.

To better demonstrate this, we have put together three independent field studies comparing bath temperature uniformity in a traditional (4) inductor channel coating pot and a (2) inductor channel pre-melt versus comparable coreless furnaces.

First, we look at a four (4) inductor channel coating pot \(^{(1)}\). For this study eight temperature measurements were taken at 4 separate locations around the sink roll (see Fig. 14) with one thermocouple at each location a depth 2ft and a second thermocouple at a depth of 4-5ft below the surface of the bath. The temperature measurements were all recorded at a single instance under steady state conditions with a bath temperature setpoint of 1100°F. The results are summarized in (Table II) below. The resulting variation in metal temperatures within the region of interest around the sink roll was 33°F, and even higher in the corners.
Next, we look at a two (2) inductor channel premelt furnace with each inductor rated 400Kw\(^2\). For this study numerous thermocouples were a total of 26 thermocouples installed at various locations throughout the bath and the measurements were recorded over a four-hour run while charging separate Zinc and AlSi ingots at a rate of 4,600 lbs/hr with a bath temperature setpoint of 1300°F. For the purpose of this paper we selected only the 4 thermocouples which are most representative (see Fig. 15) and the results plotted in a temperature vs. time graph (see Fig. 16).

TC# 7 was inserted to a depth of approx. 2.5ft below the surface and represents the middle bath temperature. TC#8 was inserted to a depth of 4th – 5ft below the surface and represents the bottom bath temperature. TC#9 & 10 was inserted to a depth of 12in below the surface and represent the top bath temperature. The maximum variation in metal temperatures recorded within the bath at a single instance in time was 334 °F (see Fig. 16).

Furthermore, the data shows variations in recorded temperatures at each thermocouple over the entire 4 hour period reach as high as 412 °F (see Table III).

<table>
<thead>
<tr>
<th>Plan View Location</th>
<th>Depth Below Surface</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 ft</td>
<td>1092°F</td>
</tr>
<tr>
<td></td>
<td>4 – 5 ft</td>
<td>1092°F</td>
</tr>
<tr>
<td>2</td>
<td>2 ft</td>
<td>1086°F</td>
</tr>
<tr>
<td></td>
<td>4 – 5 ft</td>
<td>1076°F</td>
</tr>
<tr>
<td>3</td>
<td>2 ft</td>
<td>1061°F</td>
</tr>
<tr>
<td></td>
<td>4 – 5 ft</td>
<td>1059°F</td>
</tr>
<tr>
<td>4</td>
<td>2 ft</td>
<td>1065°F</td>
</tr>
<tr>
<td></td>
<td>4 – 5 ft</td>
<td>1059°F</td>
</tr>
</tbody>
</table>
(Table III) Two (2) inductor Channel Premelt Pot bath temperature variation measured over a 4 hour period

<table>
<thead>
<tr>
<th>TC#</th>
<th>Level</th>
<th>Temperature</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>9, 10</td>
<td>Top</td>
<td>Min</td>
<td>1274 °F</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max</td>
<td>1402 °F</td>
</tr>
<tr>
<td>7</td>
<td>Middle</td>
<td>Min</td>
<td>1152 °F</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max</td>
<td>1480 °F</td>
</tr>
<tr>
<td>8</td>
<td>Bottom</td>
<td>Min</td>
<td>1074 °F</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max</td>
<td>1486 °F</td>
</tr>
</tbody>
</table>

(Fig. 16) Two (2) inductor Channel Premelt Pot bath temperature plotted over a 4 hour period of production

In (Fig. 16) the vertical markers indicate each drop of an ingot into the bath and are labeled as Zn for pure Zinc or Al for Aluminum ingots. The Aluminum ingots are charged in stages indicated by a number. For example, Al1 represents the first drop of an Aluminum ingot, Al2 the second drop, and so on. During the final stage what remains of the ingot released into the bath and represented by the label AlD. Each Zinc ingot on the other hand is released on the first drop and quickly sinks to the bottom. Prior to starting the test the furnace had been sitting idle. From the temperature plots it can be seen that TC#7 (Bath midpoint), TC#9 (Bath Top) & TC #10 (Bath Top) are all nearly equal at approx. 1325°F, however, TC#8 (Bath Bottom) is much lower at approx. 1075°F. This dis-uniformity in temperatures can occur because the zinc and aluminum have separated out of solution yielding a zinc rich bottom layer with an aluminum rich layer above it. When the first Zinc ingot is dropped into the bath it falls immediately to the bottom bringing with it hot aluminum rich metal from the top and forcing cold zinc rich metal up from the bottom. This is represented in the temperature plot (Fig. 16) where one can see the temperatures of TC#7 (Bath midpoint) & TC#8 (Bath bottom) rapidly rise
while TC#9 (Bath Top) & TC#10 (Bath Top) begin to fall. As subsequent ingots are charged one can see that as the bath chemistry changes rapidly with each new ingot addition represented by the wide swings in temperature as the barrier between the top Aluminum rich layer and the bottom Zinc rich layer fluctuates up and down. It is not until 4 hours into the production run when all four temperatures begin to converge indicating that the bath is approaching a more uniform chemistry.

Finally, we compare this to an equivalent Coreless coating and premelt pot, the results of which are summarized in Table IV, below, and show a variation in bath temperatures of 0 °F. During this test samples of bath chemistry were also measured, and the results are summarized in Table IV.

(Fig. 17) Coreless Coating & Premelt Thermocouple and Sample Location Arrangement in the Bath

(Table IV) Coreless Coating & Premelt Data from bath measurements

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>% Al (Eff.*)</th>
<th>% Al (Total)</th>
<th>% Fe</th>
<th>Temp (°C)</th>
<th>Sample No.</th>
<th>% Al (Eff.*)</th>
<th>% Al (Total)</th>
<th>% Fe</th>
<th>Temp (°C)</th>
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<tr>
<td>1</td>
<td>0.165</td>
<td>0.1744</td>
<td>0.0295</td>
<td>466</td>
<td>1</td>
<td>0.412</td>
<td>0.4125</td>
<td>0.0042</td>
<td>478</td>
</tr>
<tr>
<td>2</td>
<td>0.169</td>
<td>0.1801</td>
<td>0.0311</td>
<td>466</td>
<td>2</td>
<td>6.405</td>
<td>6.4057</td>
<td>0.0042</td>
<td>478</td>
</tr>
<tr>
<td>3</td>
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<td>0.1644</td>
<td>0.0298</td>
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<td>4</td>
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<td>0.1617</td>
<td>0.0295</td>
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</tr>
<tr>
<td>5</td>
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<td>0.1748</td>
<td>0.0316</td>
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<tr>
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<td>0.1631</td>
<td>0.0289</td>
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<tr>
<td>8</td>
<td>0.16</td>
<td>0.1610</td>
<td>0.026</td>
<td>466</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The calculated value of effective aluminum was with DEAL™ from Comanco.

5. OPERATIONAL ADVANTAGES OF CORELESS

- Excellent Temperature & Chemistry Uniformity due to:
  - Lower current densities vs. channel inductor
  - Electromechanical stirring forces
- No restrictions on power input
- Smaller volume means reduced inventory
- Fast response time to line changes
- No maintenance costs or downtime required for inductor changes
- Reduced bottom dross
- Long refractory life.
- If power is lost the coreless pot can remain without power for longer periods or pumped empty and later restarted for extended outages.
- Shorter refractory installation and dry out times.
- Able to charge zinc and aluminum ingots as opposed to premix.

6. TOTAL COST OF OWNERSHIP
When evaluating the capital equipment costs and calculated payback for a coreless furnace as compared to a traditional channel furnace it is important to take into consideration each of the following:

- Capital equipment cost & spares
- Installation cost
- Maintenance cost
- Downtime (Lost Production)
- Operational cost

7. CAPITAL EQUIPMENT COSTS

We will now take a look at the capital equipment costs for a coreless coating pot and coreless premelt pot versus comparable channel pots for a hot dip galvanizing line having the following specifications:

- 62 Inch (1575 mm) Maximum Strip Width
- 650 fpm (198 mpm) Maximum Process Speed
- (120 g/m²) Maximum Coating Weight
- 114 st/hr (104 mt/hr) Full Hard Production
- Entry Strip Temperature: 550 ºC (1022 ºF)
- Pot Temperature: 600 ºC (1112 ºF)
- 3.025 st/hr (2.75 mt/hr) Maximum Dragout Rate

For this example, we have compiled two equipment lists for comparable systems as detailed in (Fig. 18).

(Fig. 18) Comparable equipment list for a Channel vs. Coreless Coating and Premelt Pot combination

The total initial capital investment cost including spares for the Channel option above can be as much as 50% more costly than the equivalent Coreless option.

8. INSTALLATION COSTS

In addition to capital equipment costs you must also take into consideration the additional installation costs for a channel furnace including:

- Additional piping, control and power wiring for each additional power supply
- Additional automatic transfer switches and cabling for Emergency Power
- Additional floor space required for equipment in electrical room and pot basement
• Additional ventilation equipment for the added heat load in pot basement
• Additional cost for refractory installation (20-22 days compared to 1-2 days for coreless)
• Additional cost for refractory sintering, inductor priming and pot filling
• Additional cost for lining and hanging each inductor

Below is a comparison of channel and coreless pot refractory installation and sintering times.

Channel Pot
• 20-22 days for refractory installation (bricking the pot and casting the throats; casting or ramming the inductors)
• 1-2 days for hanging inductors
• 12-15 days for dry-out, sintering, and fill-up
• Total Time = 33 to 39 Days

Coreless Coating Pot
• 1-2 days for dry vibratable refractory installation
• 7-9 days for dry-out, sintering, and fill-up
• Total Time = 8 to 11 Days

Coreless PM Pot
• 1-2 days for dry vibratable refractory installation
• 3 days for dry-out, sintering, and fill-up
• Total Time = 4 to 5 Days

9. MAINTENANCE COSTS

Then factor in routine maintenance costs for Inductor changes:
• Every 6 mo – 1 year for channel Premelt pot
• Every 2 – 4 years for channel Coating pot

Estimated Costs Including
• Inductor repair and rebuild
• New lining material and installation
• Pumping out and remove old inductors
• Hang & prime new inductors
• Sintering and refill

10. MAINTENANCE DOWNTIME (LOST PRODUCTION)

Channel PM Pot Inductor Hot Change (Every 6mo – 1yr)
• 1-2 days for dry vibratable refractory installation
• 2 days for pumping out and removing old inductors
• 1-2 days for hanging inductors
• 4-6 days for heat up and fill-up
• Total Time = 7 to 10 Days

Coreless PM Pot Reline
• 2-3 days for pumping out and remove old refractory
- 0-4 days for coil change
- 1-2 days for dry vibratable refractory installation
- 3 days for dry-out, sintering, and fill-up

Total Time = **6 to 12 Days**

### 10. OPERATIONAL COSTS

Due to the reduced electrical efficiency of coreless coating pots there is an added cost of energy consumption to be considered.

- Typical efficiency for a channel inductor is around 87% versus 65% for an equivalent coreless coating pot.
- The additional energy costs must be factored in when evaluating total cost of ownership and determining payback.
- We provide a detailed energy consumption comparison of the various coreless options provided with some basic information about current and future production needs of the plant in addition to the cost per kwhr of energy usage.

### 11. CONCLUSIONS

The advantages of coreless furnace technology include:

- Direct energy transfer for fast response to line changes
- Controlled stirring for temperature and alloy uniformity
- Stirring is an effective way to reduce bottom dross by keeping dross particles in suspension
- Virtually unlimited power capability
- Short refractory installation and sintering times
- Little to no emergency power requirements
- Long refractory life as compared to channel inductors
- Additional energy costs are more often offset through reduced maintenance costs; more specifically:
  - For a coreless premelt pot the additional energy costs are more than offset when taking into consideration total cost of ownership resulting in a net return on investment and short-term payback for brownfield projects.
  - For a coreless premelt pot plus coreless coating pot combination the additional energy costs are about equal to the additional maintenance costs of an equivalent channel pot however the lower initial capital investment can still result in a lower total cost of ownership while providing additional benefits not possible with traditional channel pots.

### ACKNOWLEDGEMENTS

{1} AM Dofasco Maintenance and Operations Team for their support collecting data for the channel Coating Pot temperature study from #1 GL Pot. Hamilton, Ontario Canada.
{2} Ternium USA Maintenance and Operations Team for their support collecting data for the channel Premelt Pot temperature study. Shreveport, Louisiana USA.

### REFERENCES
References indicated in the text by number in brackets: example [1], and listed at the end of the paper using the abbreviations as indicated in the world list of Scientific Papers:

References of journals, books and conference proceedings: