Control of Slag and Insoluble Buildup in Ladles, Melting and Pressure Pour Furnaces

By

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Introduction: During the past 30 years, the melting methods and associated molten metal-handling systems used by the U.S. foundry industry have changed significantly. During the same period, while ductile iron production has experienced continued growth, the quality of metallic scrap and other iron-unit feed stocks has steadily deteriorated. The result: slag related melting problems have become widespread issues in recent years. Yet, a search of the foundry technical literature from the past 30 years about slag control and buildup will result in only a handful of articles.

A new flux, Redux EF40L, has been developed that controls and minimizes buildup in pouring ladles, melting furnaces, pressure pour furnaces and magnesium treatment vessels with minimal to no adverse effects on refractory linings.

Slag Formation: The formation of slag in the melting of ferrous metals in the foundry is inevitable. The composition of slag varies with the type of melting process used and the type of iron or steel being melted. The cleanliness of the metallic charge, often consisting of sand-encrusted gates and risers from the casting process or rust- and dirt-encrusted scrap, significantly affects the type of slag formed during the melting operation. Additional oxides or nonmetallic compounds are formed when liquid metal is treated with materials to remove impurities or to change the chemistry of the system (inoculation and nodulizing). Because these oxides and nonmetallics are not soluble in iron, they float in the liquid metal as an emulsion. This emulsion of slag particles remains stable if the molten iron is continuously agitated, such as in the case of the magnetic stirring inherent in induction melting. Until the particle size of the nonmetallic increases to the point where buoyancy effects countervail the stirring action, the particle will remain suspended. When flotation effects become great enough, nonmetallics rise to the surface of the molten metal and agglomerate as a slag. Once the nonmetallics coalesce into a floating mass on the liquid metal they can be removed. The use of fluxes accelerates these processes.

In some instances, oxides may have a lower melting point than the prevailing metal temperature and a liquid slag is formed. In other cases, where the oxides have a higher melting point than the metal temperature, a dry, insoluble, solid slag is formed.

When slag makes contact with the refractory lining of a furnace wall (or other areas of the holding vessel) that is colder than the melting point of the slag, the slag is cooled below its freezing point and adheres to the refractory lining. This adhering material is called buildup. High-melting point slags are especially prone to promoting buildup. If not prevented from forming or not removed as it forms, buildup will reduce the overall efficiency of the metal handling system.

Three important physical characteristics of slags are the melting point, the viscosity and the “wetting” ability. Generally, a slag should remain liquid at temperatures likely to be encountered during melting, molten metal treatment, or molten metal handling. The viscosity of the slag needs to be such that removal from the metal surface is easy. At the same time, a fluid slag of low melting point promotes good slagging reactions and prevents buildup in channel furnace throats and loops as well as coreless furnace sidewalls. Slags must have a high interfacial surface tension to prevent refractory attack (wetting) and to facilitate their removal from the surface of the molten metal.

Slag Composition: The composition of furnace and ladle slag is often very complex. The slags that form in electric furnace melting result from complex reactions between silica (adhering sand and dirt from casting returns), oxides from scrap, other oxidation by-products from melting and reactions with refractory linings. The resulting slag will thus consist of a complex liquid phase of oxides of iron, manganese, magnesium and silicon, silicates and sulfides plus a host of other complex compounds, which may include alumina, calcium oxides and sulfides, rare earth oxides and sulfides. Examples of these complex compounds include spinels, anorthites, hibonites, oldhamites and fosterites that are predominate in slags of base ductile and treated ductile irons. These components tend to be present in channel furnace melting and holding applications. Table 1 illustrates the chemical analysis of a sample of buildup taken from the inductor throat of a 30-ton vertical channel furnace used to melt base ductile iron.

Table 1: Chemical composition of the slag buildup from a 30-ton vertical channel furnace*

Compound	Percent Present
MgO	45.2
SiO_2	31.0
Al_2O_3	17.4
Fe_2O_3	3.5
CaO	1.6
MnO	0.29

***Ref: DC Williams, Modern Castings, August, 1990**

Melting Methods

Coreless Induction Furnaces: The coreless induction furnace is a refractory-lined vessel with electrical current carrying coils that surround the refractory crucible. A metallic charge consisting of scrap, pig iron and ferroalloys are typically melted in such a vessel. Electrical current in the coil forms a magnetic field, which in turn creates thermal energy, melting the charge. The magnetic currents in the molten metal cause an intense stirring action, thus ensuring a homogenous liquid.

During the melting process, slag is generated from oxidation, dirt, sand and other impurities. Slag can also be generated from the scrap, erosion and wear of the refractory lining, oxidized ferroalloys and other sources. In a coreless induction furnace, slags normally deposit along the upper portion of the lining or crucible walls and above the heating coils. Figure 1 shows typical slag buildup in a coreless induction-melting furnace.

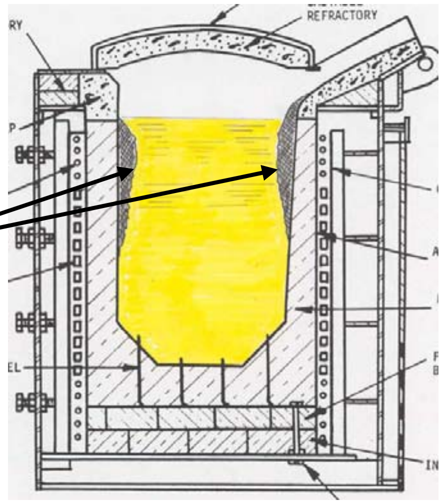


Figure 1: Typical slag buildup in a coreless induction furnace (gray shaded areas)

The hottest area of medium and high frequency coreless furnaces is at the mid-point of the power coil. All areas of slag deposit will be at a much lower temperature than those occurring at the center of the coil. Slag can also be deposited in areas midway down the crucible lining, where insufficient metal turbulence from magnetic stirring occurs.

Channel Furnaces: Another type of induction melting furnace is the channel furnace. The configurations can be either vertical or drum type furnaces. In a coreless furnace, the power coil completely surrounds the crucible. In a channel furnace, a separate loop inductor is attached to the upper-body, which contains the major portion of the molten metal bath. In a coreless furnace, solid charge materials are melted using the induction field, whereas in a channel inductor, the induction field is used to superheat colder molten metal within the channel loop. A vertical channel furnace may be considered a large bull ladle or crucible with an inductor attached to the bottom. Figure 2 illustrates how insoluble components, such as slag, accumulate over time in the inductor loop or throat area. Buildup on the sidewalls of channel furnaces is also a common occurrence.

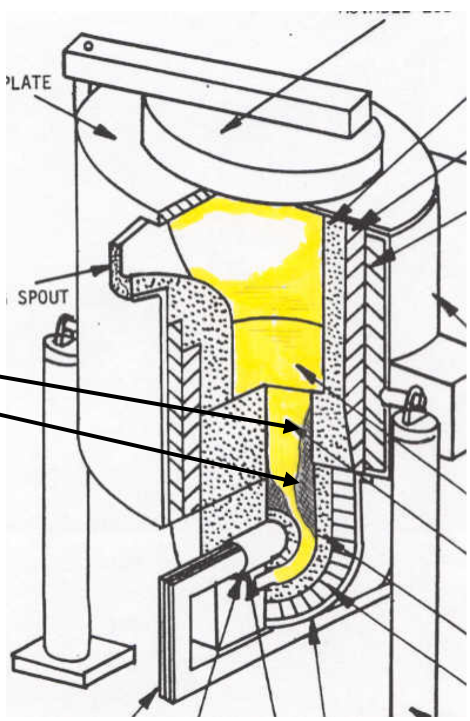
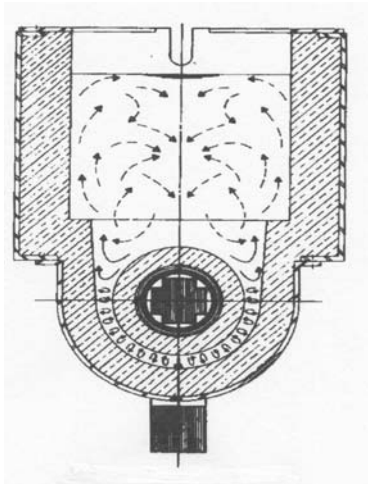
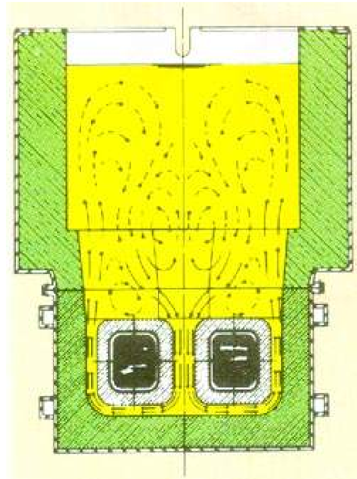


Figure 2: Slag buildup in the inductor and throat of a vertical channel furnace (gray shaded area)





(a) (b)

Figure 3: Circulation and metal flow (shown by the arrows) in a (3a) single loop inductor and (3b) double loop inductor.

Figure 3 illustrates circulation and metal flow through both single and double loop inductors. Not only can buildup occur in the inductor loop and throat areas, but it also occurs in the stagnate or low metal flow areas immediately above the inductor loops. When this build occurs, insufficient metal flow between the inductor and uppercase limits heat transfer and interferes with the melting operation. It is difficult to remove buildup from the inductor loop or throat area. Often a furnace operator will attempt to insert a steel rod or green wooden pole into the throat area even though accessibility is often severely limited. When significant accumulations of buildup cannot be removed, the furnace is taken out of operation, the throat(s) are scraped clean and a newly lined inductor(s) is (are) installed. Normal inductor life may be as long as 18 months, however, if buildup occurs, the useful life may be reduced to only a few months and in some cases, a few weeks.

Pressure Pour Furnaces: Pressure pour furnaces are sealed holding/pouring furnaces blanketed with either an inert or air atmosphere and have an inductor attached to the bottom or side. Pressure pour furnaces are designed to hold liquid metal at a constant temperature for extended periods of time. When the furnace is pressurized, a stream of molten metal exits the vessel for mold filling. These furnaces are not designed to melt metal. Circulation of liquid metal through the inductor loop provides the continuous superheating of liquid metal to keep a constant temperature of the remaining liquid metal in the furnace. Pressure pours are widely used in the processing of magnesium-treated ductile irons; they are usually pressurized with an inert atmosphere. As in a vertical channel furnace, slag often builds up in the inductor loop and throat areas (Figure 4). Slag buildup also occurs along the sidewalls, effectively reducing the capacity of the vessel. Additional buildup in the “fill (receiver) siphon” and “pour (exit) siphon” areas restricts metal flow rates into and out of the vessel. The “choking” or “formation of restrictions” in the siphons often is an ongoing battle that must be maintained throughout each heat or shift. Careful refractory selection and proper back-up insulation can help to lessen the degree of build-up that forms.

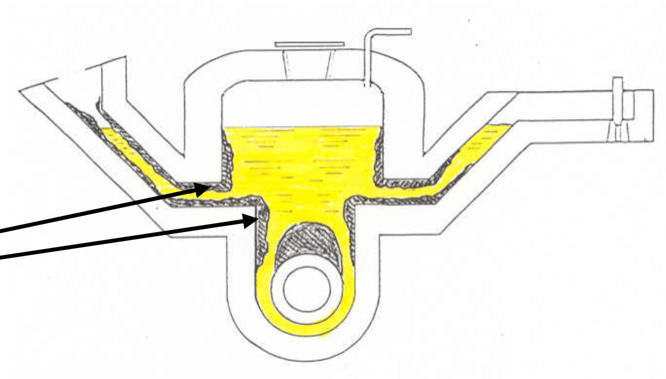


Figure 4: Traditional throated pressure pour vessel showing slag buildup in (gray shaded areas)

When sufficient buildup forms that prevents adequate heating of the metal, the inductor will have to be replaced because it can be extremely difficult to remove the buildup. Attempts to modify the furnace design with a throatless inductor (Figure 5) have been partially successful in eliminating buildup, but a periodic rigorous cleaning procedure is still necessary.

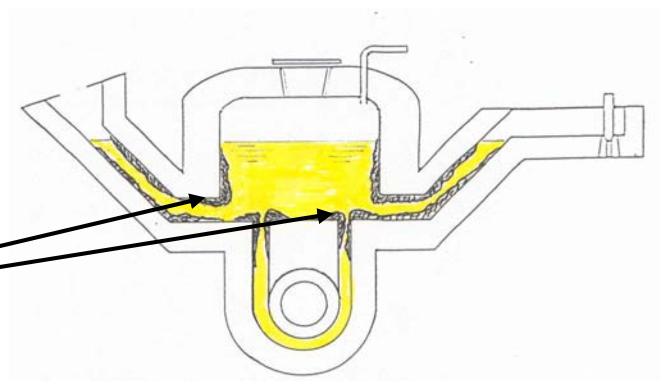


Figure 5: Throatless pressure pour vessel showing slag buildup in (gray shaded areas)

Depressurizing a ductile iron pressure pour vessel and removing the top hatch for cleaning allows outside air to enter the vessel. This increases metal oxidation and can aggravate buildup problems since oxygen is introduced into the vessel. The buildup must be scraped from the sidewalls, inductor channel and throat. If the buildup is hard, it is very difficult to remove. If the buildup is soft, then it is possible that routine maintenance (scraping the sidewalls and rodding the inductor throat area with a metal tool or green wooden pole) can minimize accumulations. When the buildup becomes severe, power factor readings of the inductor drop and the efficiency of the pressure pour is dramatically reduced.

Ladles: Slag from the melting methods detailed above, if not totally removed at the melting furnace, will be transferred to the metal pouring ladles, along with new slag generated during the metal transfer process. Because the walls of the pouring ladle are much thinner with little insulation, more heat loss occurs in ladles when compared to the furnace refractory lining and thus slag buildup is inevitable. The task of continually keeping the pouring ladles clean requires a significant amount of labor and maintenance materials. Failure to maintain pouring ladles may result in costly casting scrap from slag inclusions.

Slag and insoluble buildup formation are usually very troublesome problems in the production of ductile irons. Buildup occurs initially in treatment ladles and then may continue in downstream holding vessels.

Buildup is also a major problem in ductile iron treatment vessels utilizing pure magnesium and in the Flotret® process treatment chamber.

The pressurized magnesium converter process is very susceptible to buildup constituents of magnesium oxide and sulfides. These are residual by-products of the treatment process. Similarly, rare earth metallic oxides and sulfides can also form. In large converter vessels, significant buildup on inner surfaces can accumulate in just a few days, necessitating converter replacement and re-lining. Premature chamber plate failure due to slag buildup can also result.

The Flotret® process utilizes a refractory-lined reaction chamber for nodulizing. The reaction chamber is filled with a nodulizing alloy such as magnesium ferrosilicon. Slag buildup occurs rapidly in the reaction flow-through chamber and it tends to clog both the opening of the chamber and exit hole.

Slag Additives and Fluxes: Additives to the melting process that ensure that slags have a melting point below the coldest temperature in the system are called fluxes. Fluxes can help prevent slags and other insolubles from freezing on the cooler refractory surfaces. The use of a flux allows floatation of the emulsified oxides; it also reduces the melting point of the slag to below the lowest temperature encountered in the melting furnace and associated liquid metal handling system.

Fluxes are widely used throughout the basic steel industry and their extensive use is considered a science. In the foundry industry, however, there has historically been a reluctance to use fluxes. Refractory suppliers, often without knowledge about the chemistry or potency of fluxes, have convinced foundrymen that the use of any flux will greatly shorten refractory life. Improper use of fluxes can rapidly erode refractory furnace linings, especially if potent fluxes are used. However, if a flux is carefully engineered for specific applications and used properly, reduced refractory life isn't an issue. Redux EF40L flux meets these criteria. In fact, some users of Redux EF40L have reported increased refractory life that directly results from reduced slag buildup. Improved refractory life associated with using Redux EF40L flux results from reductions in lining damage due to mechanical chipping required to remove tenacious slag deposits.

Fluxes undergo complex reactions with slags at elevated temperatures. They will dissociate into alkaline metal oxides that disrupt the silica space lattice structure of almost all slags. By disrupting the bonds of the three-dimensional slag space lattice, fluxes reduce slag viscosity. Fluxes also affect the surface tension of slags. Lastly, fluxes allow for the coalescence of low melting point slag droplets that otherwise may become emulsified in the liquid metal bath of high frequency induction furnaces.

Flux additions produce a nonmetallic liquid to absorb extraneous impurities. Fluxes assist in producing a liquid slag of absorbed nonmetallics, providing the slag is sufficiently low in viscosity at existing furnace operating temperatures. Fluxes also modify slags so they will separate readily from iron and facilitate nonmetallic removal. In ductile iron processing, fluxes assist in the removal of silica and metal oxides, such as magnesium oxides and rare earth oxides, all of which have a relatively high melting point. The high melting point of these nonmetallic materials fosters the formation of a viscous or a pasty constituent in electric melting furnaces.

The formation of viscous nonmetallics can negatively affect the operational efficiencies of any coreless, channel or pressure pour furnace. For instance, they can cause slag buildup on the furnace and/or inductor walls. The adhesion of buildup interferes with melting, thereby decreasing furnace efficiency. Many of the materials in the slag are acidic. The acidity interferes with the absorption of sulfur. Iron and steel fluxes normally contain alkali elements that assist in the reduction and removal of sulfur.

Fluorspar, a calcium fluoride mineral (CaF_2), is a powerful supplemental fluxing agent that is commonly used in small proportions with limestone and lime to improve slag fluidity. Fluorspar is a very aggressive flux and works extremely well in integrated steel mills as well as cupola operations. Fluorspar, though effective, has serious disadvantages. The overuse of fluorspar or fluorspar-containing fluxes in electric-melting furnaces can result in severe lining attack and erosion. In addition, as fluorspar decomposes in the furnace, it releases highly reactive gaseous fluorides. In electric melting operations with emission control systems that use fiberglass bags as a filtration device, the gaseous fluorides attack the glass fibers.

Other supplemental fluxes may include sodium carbonate, calcium carbide, borates, olivines, sodium chloride (rock salt), calcium aluminates and ilmenite. Again, overuse of any of these supplemental fluxing compounds can cause refractory attack.

Within the past year, a new flux based on proprietary chemistry (Redux EF40L) been developed specifically for use in electric melting furnaces, pressure pour furnaces, ladles and for certain ductile iron treatment methods. Redux EF40L provides excellent fluxing action comparable with that of fluorspar, however, it is not aggressive toward furnace linings and is environmentally friendly. This new flux is available in a 50-gram size for ease of use in ladles and pressure pour furnaces. A larger size weighing 5.5 pounds is available for large furnaces during metal charging. The addition of 1 to 2 pounds of flux per ton of molten metal is sufficient to cleanse the metal, remove slag, prevent buildup of slag and other insolubles on furnace walls, and in channel furnace throats and inductors. Figure 6 illustrates the shape and size of the new flux.

Figure 6: Illustration of Redux EF40L electric furnace, pressure pour and ladle flux.

Production Results: To date, many gray and ductile iron foundries in the United States, Japan, China, the United Kingdom, and Spain are using Redux EF40L flux to solve buildup problems in coreless induction furnaces, channel furnaces, pressure pour furnaces, Fisher converters and ductile iron treatment ladles. The production experience of seven foundries, each of which has different needs, is discussed in detail in this section.

Foundry A is a medium sized foundry that manufactures gray iron and ductile iron valves. Daily production capacity is 150 tons. The foundry has historically experienced extensive slag buildup on the upper sidewalls of its three 3 – 15 ton coreless induction furnaces. Each coreless furnace is lined with a silica refractory. During operation, the buildup reduced furnace capacity and contributed to slag-related casting blowholes. In addition, considerable refractory repair on weekends was required from buildup removal.

Initially, 12 pounds (approximately 1 pound per ton) of Redux EF40L flux was added to each 23,000-pound charge. The EF40L was placed in the furnace before back charging. After about a week, buildup along the sidewalls and weekend maintenance on pouring ladles were virtually eliminated. In addition, slag-related casting defects were significantly reduced. No evidence of refractory wear or attack was present. However, melting personnel objected to the reduced viscosity of the slag. They had greater difficulty removing the lower viscosity slag – because of its fluidity – from the furnace. The addition rate was reduced to 0.5 pounds of Redux EF40L flux per charge; which allowed easier removal of furnace slag. Refractory lining life has been extended mainly because of reduced mechanical damage from slag buildup. The foundry has been using EF40L fluxes for more than a year and is extremely satisfied with the results.

Foundry B is a high-production ductile iron foundry that produces automotive castings. Melting is accomplished in two 10-ton coreless induction furnaces. The induction furnaces each have silica linings. A 65-ton vertical channel furnace, lined with a high alumina castable, is used as a holder. Iron from the holder is nodulized with a low calcium, low aluminum containing magnesium ferrosilicon, post-inoculated with a 1.5 percent magnesium containing ferrosilicon alloy and then transferred into a 9-ton pressure pour furnace. The uppercase of the pressure pour furnace is also lined with a high alumina castable refractory. The inductor is lined with an alumina-magnesia spinel forming dry vibratory mixture.

Buildup in the pressure pour furnace has long been a serious problem. The buildup is extremely tenacious and high in magnesium oxide (MgO). Table 2 lists the composition of the buildup removed from the inductor loop.

Table 2: Composition of buildup from 9-ton pressure pour furnace

Compound	Percent Present
MgO	85.6
Fe_2O_3	9.4
Al_2O_3	1.4
CaO	1.5
SiO_2	0.2
TRE oxides	0.3

Because of the high levels of magnesium oxide in the slag, inductor life averaged only two and a half months, rather than a hopeful life of 8 to 10 months.

In an attempt to increase inductor life, Foundry B investigated the use of sodium chloride (rock salt); however, the rock salt additions failed to reduce buildup. In addition, the generation of chlorine gas from sodium chloride (NaCl) dissociation created an extremely unpleasant working environment.

The foundry then tried Redux EF40L flux briquettes. Foundry B added 18 pounds of EF40L to its pressure pour furnace at the end of each week. The life of the inductor after treatment with EF40 flux has tripled – inductors now last more than seven months. Foundry B has been using the flux for more than a year; no erosion or refractory attack has been observed during this period. It has been suggested that more frequent flux additions, made at the end of each shift, would be more effective and further increase inductor life. Foundry B is considering making this change in the future.

Foundry C is a producer of specialty high-chrome wear-resistant mining parts. It melts a total of 250 to 300 tons per day in three 5-ton, magnesite-lined arc furnaces. The high-chrome irons from the arc furnaces are transferred to a 7.5-ton pressure pour furnaces via a mullite-lined transfer ladle. The pressure pour furnace has a high alumina, spinel-forming castable uppercase lining and a high alumina, spinel-forming dry-vibratable lining in the inductor. Slag buildup and premature inductor clogging has been a continuing problem for Foundry C. Inductor failure in a month or less was common. The composition of the buildup taken from two locations in the pressure pour furnace is shown in Table 3.

Table 3: Composition of samples removed from a 7.5- ton pressure pour furnace

Compound	Slag from PP	Build-up from PP
Al_2O_3	60.9%	76.5%
Fe_2O_3	9.5	4.6
MgO	7.2	4.8
Cr_2O_3	11.1	5.9
SiO_2	5.2	5.1
MnO	4.8	2.6

After consulting with its refractory supplier, Foundry C purchased 2,000 pounds of Redux EF40L flux for a trial. After using the initial sample, Foundry C found that the slag buildup was considerably softer and could be more easily removed with periodic "rodding" of the inductor channel. Without the flux addition, the buildup was "rock" hard and almost impossible to scrape loose from the walls and inductor throat. The foundry stated that before they switched to the Redux EF40L flux, rodding the inductor produced marginal and inconsistent results. Before the change to Redux EF40L flux, inductor current often dropped to as little as 360 amps, from the normal level of 480 amps.

Foundry C has been using the Redux EF40L flux for close to one year. One pound of Redux EF40L is added per ton of metal melted. The flux briquettes are added into the transfer ladle, the ladle is slagged off and then the molten metal is transferred into the 7.5-ton pressure pour furnace. Flux additions are made to every ladle; as many as 60 taps of 5 tons each per day are treated with flux additions. Foundry C has found that although some buildup remains in the inductor loop, it is soft and easily removed. Current readings now consistently run between 460 to 480 amps. Foundry C's inductor replacement target is now six to eight months. The foundry also plans to modestly increase flux additions to the transfer ladle in hopes of reducing the amount of soft slag that still forms in the pressure pour furnace.

Foundry D is a large high production foundry that produces both gray and ductile automotive and truck castings. Melting is accomplished in two 121-inch cupolas with a melt capacity of 3,000 tons per day. The metal handling system is composed of three 150-ton capacity rotary drum channel furnaces, four 15-ton transfer ladles and four 25-ton tilt pour furnaces on the molding lines. Because of the high volume, slag buildup in the treatment and holding vessels has been a continuous battle. Buildup also occurred in the inductors of all three rotary drum-holding furnaces and, to a lesser extent, in transfer ladles. However, the major problem area was significant buildup in the 12-ton Fisher converters and downstream tilt pour furnaces.

Buildup in the Fisher converter was severe and converter life before lining maintenance was two days of operation, or roughly 2,600 tons of processing. Buildup between 12 to 18 inches thick in the converter body was normal, and was of sufficient magnitude to reduce the working volume of the converter by almost 4,000 lbs per treatment. Chamber plate buildup was also a problem, necessitating weekly replacement. Emulsified slag carryover from the converters also reduced the efficiency of the tilt pour furnaces and inductor clogging became troublesome.

To solve these problems, Foundry D adds 11 pounds of Redux EF40L flux directly to the body of the Fisher converters prior to each magnesium treatment. Buildup in the converters has been drastically reduced. Converter life is now approaching five days before routine refractory maintenance is needed. Buildup is now only about an inch in thickness. Foundry D reports that the silicon carbide refractory chamber plate looks almost brand new after 6,500 tons of ductile processing. Further, buildup in the tilt pour furnaces from magnesium oxide carryover has been greatly reduced.

Foundry E is a medium size ductile iron foundry producing automotive castings. Foundry E melts with three 9-ton, medium frequency induction furnaces lined with a silica refractory. Daily production is 250 tons. Ductile iron is produced using the sandwich technique; treatments are 6,000 pounds. Significant buildup in the treatment ladle occurred along with slag carryover in the two 8.5-ton pressure pour furnaces. A ladle flux based on a blend of calcium fluoride and ferrosilicon fines was initially used as a ladle flux with marginal results. Ladle life was limited to a maximum of three shifts before buildup in the ladle and ladle pocket prevented its continued use. Further, slag carryover and buildup in the pressure pour furnaces significantly reduced inductor life. In fact, buildup became so bad that a hot spot in one of the pressure pour furnace's inductor caused a serious run-out.

To eliminate these problems, Redux EF40L was incorporated into the magnesium treatment process. The Redux EF40L flux is added with the magnesium ferrosilicon at the rate of 0.66 pounds per ton of metal. Incoming ductile treatment temperature is 2,700^{o}F.

Starting with a new ladle lined with a 70 percent alumina castable refractory, Foundry E quickly discovered that their sandwich ladles now last three full days of production or nine shifts before refractory maintenance is required.

Redux EF40L flux also has a carryover effect on the pressure pour furnaces. The pressure pour uppercase is lined with a 90 percent alumina castable refractory and the inductor is lined with a high alumina, spinel-forming dry-vibratable refractory. Slag buildup in the inductor loop of the pressure pour furnace has been significantly reduced.

Foundry F is a captive foundry pouring gray, ductile and high alloy irons for the mining, transportation and oil well industries. Foundry F operates two 55-ton vertical channel furnaces for melting Class 30 grey iron. Pouring temperature is 2700^{o}F. Each furnace has one 1,750-kilowatt double loop inductor attached to the bottom. Both uppercases are lined with a zoned lining of dry-vibratable refractories that include an alumina-based mix in the sidewalls and a chrome-alumina in the floor and throat. Each inductor contains a dry vibratable magnesia-based, spinel-forming mix. Average lining life is approximately 12 to 14 months. Typical conductance readings from the inductor will be between 72 to 85 percent during normal operation after several months of operating.

Recently, Foundry F developed a severe buildup problem in the throats of both furnaces in a matter of 48 to 72 hours. One of the furnaces, which was only 3 months into a service campaign, had the conductance ratio drop from 80 percent to below 60 percent in a 24-hour period. Continued operation of this furnace caused the conductance ratio to drop below 55 percent. The foundry was ready to take the furnace out of service. The second furnace was showing a similar drop in conductance ratio but not as severe; conductance ratios declined to 65 percent. Foundry F took many slag samples before and after the occurrence and found that the silica and calcium oxide content of the slag had increased. Many different methods of buildup removal were tried including green-poling, periodic superheating of the inductor and oxidized steel additions on a low molten metal level. Nothing reduced the buildup and the conductance ratio continued to drop.

Foundry F contacted their refractory supplier who recommended the use of Redux EF40L flux. The foundry decided to try the Redux EF40L as a last resort before removing both furnaces from operation. By this time, the conductance ratio had dropped to less than 50 percent on one furnace. Twenty pounds of Redux EF40L flux was added to 20 tons of molten metal left in the furnace. During this period, furnace operators superheated the molten metal to 2825^{o}F for 2 hours. Furnace charges were reduced by 50 percent to 1,500 pounds and 1.75 pounds of Redux EF40L flux was added with each charge. Within the first 24 hours, the conductance ratio had improved to 65 percent. After 72 hours, the conductance ratio improved to 73 percent, which was considered acceptable. Recently, the molten metal level within both furnaces was dropped in order to inspect the refractory sidewalls for any sign of erosion from the flux and none was observed. This furnace continues to operate satisfactorily.

Foundry G is a gray and ductile iron producer of continuous-cast bar stock. They currently pour between 250 and 300 tons of iron per day. One particular alloy produced at Foundry G generates a tremendous amount of ladle slag. The metal pourers know that when this alloy is scheduled for production that it's going to be a difficult day. Typically, the 1,800-pound ladles will completely bridge with slag at the top of the ladle. This occurs every few hours and requires constant chipping by the operators as they try to maintain ladle functionality. The chipping of the slag off the sidewalls and spout is hot, dirty and tedious work and an ongoing battle during the melting campaign.

Starting with a new 1,800 pound castable alumina-lined ladle, one half pound of Redux EF40L flux was added to the pouring ladle. Within the first hour of operation, it was apparent that slag buildup on the sidewalls and spout was virtually eliminated. After 3 hours of operation, the ladles showed only a slight slag buildup at the metal line and no chipping was required. Foundry G ran an entire shift adding Redux EF40L to their ladles. At the end of the eight hour-shift, the iron pourers needed to chip the ladles just once. Foundry G now uses Redux EF40L on a regular basis.

Other U.S. foundries with coreless induction furnaces have reported similar operating benefits after using Redux EF40L flux. The foundries have stated that using Redux EF40L flux on a daily basis consistently results in cleaner pouring ladles and reduced maintenance. One ductile iron producer reported that adding 1 pound of EF40L flux to his treatment pocket during the course of a week resulted in negligible slag and dross buildup.

Redux EF40L flux may also help to remove the harmful tramp element boron from ductile base iron. Boron levels as low as 20 parts per million (ppm) have been reported to significantly reduce Brinnel Hardness values of pearlitic ductile irons. Theoretical thermodynamic reactions studied by Martin Gagne from Rio Tinto Iron and Titanium indicate boron removal with sodium oxide based fluxes during melting is possible. (see Ductile Iron News, 2003, issue no. 3).

Recent trials by a pearlitic ductile iron producer have produced some encouraging results. The addition of two pounds of Redux EF40L flux per ton of molten metal reduced boron levels by 47%. Additional tests using larger quantities of Redux EF40L flux are planned at this foundry. In addition, research is underway at Case Western Reserve University, sponsored by the Ductile Iron Society, to further define the effectiveness of fluxing boron from pearlitic ductile irons using Redux EF40L flux.

Conclusions: The incorporation of 0.5 to 2.0 pounds of Redux EF40L flux per ton of metal has significantly improved the inductor life of pressure pour furnaces, coreless induction and vertical channel furnaces. Redux EF40L has been successfully used in the production of gray and ductile irons as well as high alloy irons and steels to minimize slag buildup on furnace sidewalls and ladles. Using recommended addition rates, Redux EF40L flux effectively combats slag buildup without the adverse effects of aggressive refractory attack or emissions of fluorine or chlorine gases. Flux additions can significantly improve furnace performance and prolong useful ladle life.

Acknowledgements: The authors would like to thank Ms. Kelly K. Naro for her assistance in editing the manuscript.