Improved Aluminum Refining System with In Situ Gas Preheating and SCADA Capabilities

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Abstract

The LARS™ Aluminum Refining System, designed by Almex, Long Beach, California, is now enhanced with a newly patented in-situ gas preheating device (Figures 1 and 2). It now comes equipped with total SCADA capability. LARS is a acronym for Liquid Aluminum Refining System and is a registered trademark of Almex USA, Inc. SCADA stands for a completely computerized and remotely operable Supervisory Control and Data Acquisition System. This article reviews the metallurgical enhancements incorporated in the LARS System and describes various operating features of the SCADA package.

Introduction

Starter metal purity and internal metal cleanliness are the two dominating variables which govern the quality and end use application of aluminum alloys. The process specifications designed by an aluminum wrought alloy casthouse metallurgist have to comply with the quality demands of the customer and simultaneously accommodate the variables pertaining to an array of plant-specific conditions and restrictions. The plant specific conditions can often force variables which do not necessarily complement metal quality and the metallurgist has to do a balancing act of designing standard practices such that high confidence is maintained in the quality assurance function. From the year 2000 onwards, new significant restrictions may be imposed on use of chlorine (in bi-gas or tri-gas mixtures) in the fluxing of the holding furnace. This will exert pressure on the casthouse to optimize the performance of the in-line refining system. Also, with the advent of the philosophy that "holding furnace can be regarded as a redundant piece of equipment in the casthouse and adds substantially to the capital and operating cost of the casthouse," the demands and expectations made from an in-line fluxing, degassing and filtration system (collectively refered to as a refining system) are higher than ever before. It is to be noted that "holding furnaces" have served to maintain casthouse quality control over the past three decades, but with the availability of several new generation devices some plants have successfully moved away from use of a holding furnace. Many plants continue to experiment to bypass holding furnaces altogether or substantially reduce furnace fluxing time and expense.

The metallurgical enhancements of the LARS system described in this article are inspired from the aforementioned quality improvement, pollution reduction and cost savings criteria. Incorporation of the SCADA package in this System, which runs on Windows NT™, Wonderware Factory Suite 2000™ and PC Anywhere™ software, gives a total remote monitoring and adjustment capability. These features are used by metallurgists for metal quality control, by plant environmental engineer for pollution control and by operation managers (production, maintenance) for productivity and cost control.

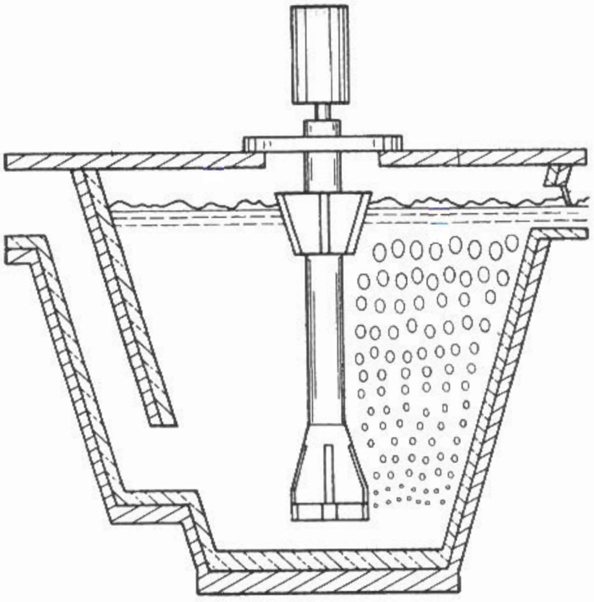

Figure 1. Schematic diagram showing natural variation in bubble size from bottom to top, the need to enlarge reactor volume to prevent bubble coalescence and the need to preheat gas to reduce thermal expansion.

Molten Metal Refining Variables

Molten aluminum, as derived from common sources such as primary metal, scrap and remelt stock, must be purified before being cast into ingot, sheet or bar. This may be done by bubbling an inert gas, i.e. nitrogen or argon, through the aluminum in molten form. In most instances, a halogen gas, usually chlorine, is also used. This type of treatment can remove dissolved hydrogen, alkali metals such as sodium, potassium and lithium, alkaline earth metals such as calcium, and small solid particles such as aluminum oxide and other nonmetallic inclusions. The effectiveness of a given volume of gas in such treatment is increased by reducing the bubble size of the gas in the molten aluminum, thereby increasing the total gas-metal surface area. The effectiveness of the gas bubbles is also increased by dispersion of said gas bubbles throughout the body of molten aluminum to be treated. One very effective way of making small bubbles and dispersing them is by the use of a spinning nozzle positioned in the body of molten aluminum. The refining rate of a spinning nozzle system can be increased by increasing the process gas flow rate employed therein. Additionally, it is usually necessary to increase the nozzle rotating speed to continue the desired making of small bubbles and the dispersing of said small bubbles throughout the molten aluminum in the refining zone of the system. Such increases in gas flow and nozzle rotating speed are usually accompanied by increased vortexing and turbulence on the surface of the molten aluminum. The maximum refining rate of a given refining system, however, is limited by the maximum vortexing and surface turbulence or roughness that can be tolerated therein.

Basically, this process involves the dispersion of a sparging gas in the form of extremely small gas bubbles throughout the melt. Hydrogen is removed from the melt by desorption into the gas bubbles, while other nonmetallic impurities are lifted into a dross layer by flotation. The alkali metals are removed by a chemical reaction with the anions present in the halogen gas. Hydrogen transfer from the melt to the inside of the inert gas bubbles is driven by the difference in the partial pressures. Hydrogen has a high diffusivity in aluminum melts, and the transport reaction is essentially interface controlled. The higher the interfacial area, the shorter the time required to achieve a given degree of degassing. Also, the higher the interface area, the greater the chance of encounter and entrapment of the inclusion of the bubble. Thus, the higher the surface area, the greater the refining efficiency. The dispersion of the sparging gas is accomplished by the use of rotating gas distributors which produce a high amount of turbulence within the melt. The turbulence causes the small nonmetallic particles to agglomerate into large particle aggregates which are floated to the melt surface by the gas bubbles. The turbulence also causes small gas bubbles to collide and grow. This turbulence in the metal also maintains the interior of the vessel free from deposits and oxide buildups. Nonmetallic impurities floated out of the metal are withdrawn from the system with the dross, while the hydrogen deposited from the metal leaves the system with the spent sparging gas. The rotating gas distributor of LARS has, among its other features of construction, a shaft and a vaned rotor (coupled to the shaft) and a vaned stator that interact to provide a desirable bubble pattern in the melt. The refining gas is discharged into the body of molten aluminum by way of the small clearance between the rotor and stator. The device, when in operation, induces flow patterns in the metal in the vicinity of the device such that the gas bubbles which are formed are transported along a resultant flow vector which is radially outward with a downward component relative to the vertical axis of the injection device. These flow patterns have several advantageous effects. First, essentially vertical stirring is provided in the body of the melt, whereby a downwardly directed flow along the device, in combination with the rotating vanes, causes subdivision of the gas into small discrete gas bubbles. Second, the rapid conveyance of the gas bubbles away from the point of introduction into the melt prevents bubble coalescence in the zone where the gas bubble concentration is the highest. Third, the gas residence time of the well-dispersed gas bubbles in the melt is prolonged because the gas bubbles do not immediately rise to the surface under the influence of gravity upon formation.

Excessive surface turbulence is undesirable in a refining system for several reasons. The increased metal surface area that is produced thereby leads to higher reaction rates with any reactive gas that might be present. For example, oxygen from air will react to form aluminum oxide films, and water vapor from the air will react to form hydrogen in the metal and oxide films. Furthermore, when solid particles are carried to the molten metal surface by the refining gas bubbles, surface turbulence may interfere with their desired separation from the bubbles and their incorporation into the floating dross layer formed over the body of molten aluminum. Excessive turbulence may also cause floating dross to be redispersed into the molten aluminum. Besides surface turbulence, surface and subsurface vortexing is also undesirable inside the reaction vessel. The presence of vortexing, especially along the central vertical axis, tends to capture and suck the dross and slag particles back into the melt, thereby internally increasing the loading on the refining apparatus. The problem is severe, especially for "in-line" treatment systems with high metal flow rates that provide nominal metal residence time of less than five minutes inside the reaction vessel. While the quantitative effects of excessive surface vortexing and turbulence are difficult to measure, it is well-known that high vortexing and surface turbulence are undesirable, and those schooled in the art have sought to limit such surface vortexing and turbulence. One result of increasing the rotational rate of the rotor in the body of molten metal and/or increasing gas flow rates in the refining apparatus is the formation of a fairly well defined generally torroidal flow of only a portion of the molten aluminum within the body of molten aluminum. This leaves a substantial portion of the body of molten aluminum unstirred and essentially untreated. The formation of the torroidal flow is discussed and depicted in U.S. Pat. No. 3,743,263 to Szekely. The formation of torroidal flow tends to result in a downflow of aluminum and, consequently, slag or dross in the immediate vicinity of the stator. Thus, the apparatus is to a small degree, at least, self-defeating in that impurities may actually be introduced or reintroduced into to the molten aluminum. The combined actions of vortexing and torroidal flow render only limited refining efficiency in the devices which do not avoid this problem. The only means available to reduce vortexing and deleterious effects of torroidal flow in all of the devices which do not circumvent their formation is to reduce the rotational velocity of the rotor. However, at lower rotor speeds, fragmentation of the gas stream into fine bubbles is not optimum and a fine bubble dispersion with a large surface area is not achievable.

Another serious limitation which exists in a normal refining vessel is the coalescence of gas bubbles after they were injected into the melt of aluminum. Gas coalescence places a severe limitation on the rate of refining. Coalescence produces fewer and larger gas bubbles as the bubbles rise toward the surface. Large bubbles increase the turbulence at the interface between the molten aluminum and the dross layer, causing some back flow or introduction back into the aluminum of the impurities of the dross. Smaller bubbles arriving at the top of the aluminum minimize this source of contamination. More important, as the bubbles coalesce into larger bubbles the gas to molten metal surface area is greatly reduced. This results in a substantial reduction in the rate of refining reaction because the reaction takes place only at the gas-metal interface. Hydrogen has a high difiusivity in aluminum melts, and the transport reaction is essentially interface controlled. The higher the interfacial area, the shorter the time required to achieve a given degree of degassing. Also, the higher the interface area, the greater the chance of encounter and entrapment of the inclusion by the bubble. Thus, the higher the surface area, the greater the refining efficiency. Furthermore, the probability that a given impurity domain will be contacted by and adhere to or react with a gas bubble goes down rapidly as the number of bubbles is reduced and the total interface area between the gas and metal is reduced.

Two means for reducing and substantially eliminating such gas coalescence and the resulting problems are included in the LARS system.

From the aforementioned points, it can be summarized that in the refining operation, highest refining efficiency results when:

- The surface area of the bubbles is maximized.
- Maximum surface area is maintained for the longest possible duration.
- Probability of gas bubble inclusion encounter is kept highest during bubble's residence time in the reactor.
- Bubble residence time (apart from metal dwell time) is kept as high as possible.

Background

For the purpose of this article, the word refining is used to denote all of the following:

- Degassing
- Inclusion removal

- Alkali metal removal
- Alkali salts removal

To maximize the refining efficiency of a system in a given casthouse environment, an interplay of several parameters must be considered.

The following parameters determine the refining efficiency of an in-line system in a given casthouse environment:

- Process specific parameters
- Casthouse specific conditions
- Refining equipment specific parameters

Process Specific Parameters
- Input loading (hydrogen, inclusion, alkalis)
- Alloy type
- Dwell time
- Sparging gas chemistry
- Sparging gas purity

Cast House Specific Conditions
- Presence/absence of holding furnace treatment
- Reaction temperature requirement
- Metal flow rates
- Fluxing, skimming, cleaning practice
- Atmosphere, humidity, winds etc.

Equipment Specific Parameters
- Dispersion energy input (rotor RPM, rotor diameter)
- Presence/absence of cover shroud gas
- Rotor configuration design
- Reactor column depth
- Discharge port design

Almex research during the past two years has identified additional critically important parameters

1. Process gas preheat temperature
2. Reaction vessel unit volume change/function of depth
3. Reaction vessel geometry to generate attrition mixing

Gas Temperature Effect

When cold gas is injected into the molten metal as fine bubbles, the gas immediately expands as set forth in the ideal gas law and larger bubbles are formed. From room temperature to liquid aluminum temperature, process gas (Ar or N2) expands three times in volume.

If this expansion is not allowed to happen before the gas is sheared into fine bubbles, expansion of bubbles results in reduced efficiency. Also, the expansion in bubble volume increases the buoyancy on the gas and its upward mobility in the melt. It also results in reduced surface area of the bubbles for identical initial mass entry rates. It is, therefore, extremely important that sparging gas be preheated close to liquid aluminum temperature prior to its entry into the molten metal. In the LARS system, gas preheating is achieved by an ingeneous in situ device which lengthens gas flow path in the shaft 20 times. The gas is made to flow intimately between the inner wall of the graphite sleeve and through a groove machined in the outer wall of the shaft. The larger surface area of the gas allows for rapid transfer of heat from the sleeve (or reaction chamber) to the gas in transit. The details of the arrangement is given in Figure 2. This patented feature of the LARS system has resulted in significant levels of refining efficiencies as described in the next section.

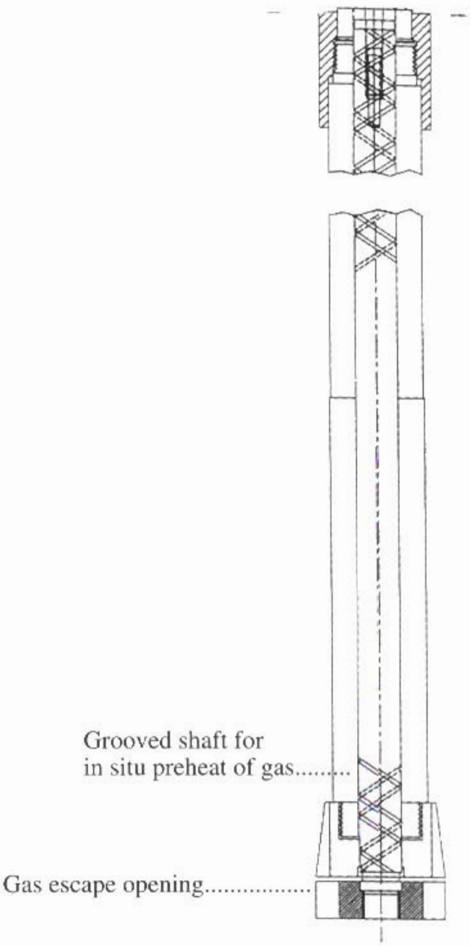

Figure 2. Arrangement for in situ preheating of process gas.

Reactor Vessel Volume Change

As gas bubbles move upward in the reaction chamber they undergo volume expansion due to reduced metallostatic pressure. If this natural expansion of the bubbles is not accommodated by unit volume change in the reaction vessel, bubble impingement occurs, leading to nonoptimal refinement efficiency.

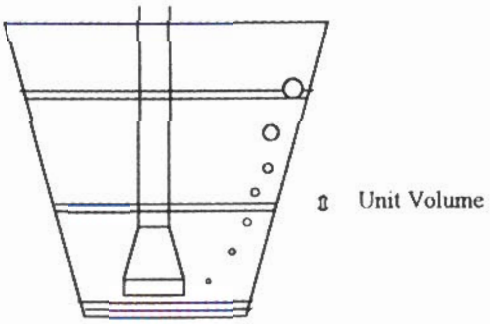

Figure 3. Reaction vessel elevation cross section.

As shown in Figure 3, the rate of change of reaction vessel unit volume must equate with the rate of change of gas volume to avoid bubble impingement and coalescence. LARS reaction chambers are designed to provide an optimal rate of volume change from the floor to the working metal line level.

Attrition Mixing Effect

The attrition mixing effect is achieved in the LARS reaction chamber by use of a highly specialized geometrical design of the chamber. As depicted in Figure 4, the top view of the reaction chamber, when molten metal passes through region p. It has larger cross sectional area to move than when it passes through area q. Consequently, the velocity vector of the melt in area p is much smaller in magnitude than the one in area q. As the rotor energy induces rotational momentum in the melt, the velocity vectors are cyclically dampened and extended as the metal moves in the reaction chamber. The net effect is the reduction in the vortex-forming tendency and formation of shearing currents in the melt. They lead to attrition mixing (i.e. intimate and thorough mixing) and much higher probability of gas bubble inclusion encounter. This also increases the dwell time of the bubble in the melt. Currents induced in the melt due to attrition (intense agitation) are strong and easily carry a bubble in the anti-gravity direction (opposing the buoyancy force); thus, an average bubble takes a longer time to reach the top of the reactor as its path has become longer than it would be in the simple trajectory of helical motion.

All LARS system chambers are designed on the principle shown in Figure 4. The design geometry balance is maintained irrespective of metal entry and exit locations on the system (i.e. side to side, end to end, end to side etc.) An end to end device is shown in Figure 5. This special shape, along with diverging side walls, results in minimal turbulence and vortexing of the melt (even up to 425 rpm rotor speed) and has been found extremely helpful in the effective removal of alkali metal salts.

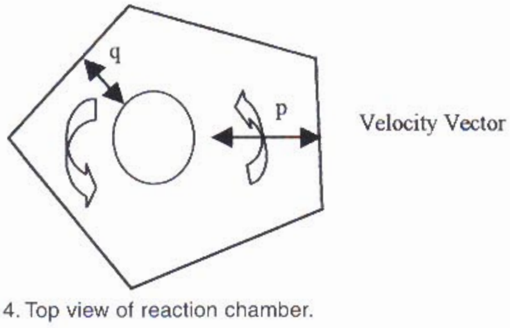

Figure 4. Top view of reaction chamber.

Alkali metal salts typically pose the strongest challenge to any refining system. This is due to their high fluidity, nonwetting surface and compatible density compared to liquid aluminum. Refining systems with high vortexing tendency and insufficient gas bubble dispersion fall short of removing alkali and alkaline earth metal salts. This condition is typically evidenced in the cast or finished product during ultrasonic inspection. LARS treated aluminum alloy slab, billet and bar from alloy 1100 to 7050 pass ultrasonic test to Mil-2154 class AA criteria. The following subsections detail the operational experience with LARS treatment and ultrasonic evaluations.

Reactor Description

Metal Path: The molten metal vessel is provided with two reaction chambers. Molten aluminum enters reactor #1 via the inlet port. Metal flows down reactor #1 where it is intimately contacted with finely dispersed bubbles of argon and halogen gas mix (approximately 2 per cent halogen by volume). The finely dispersed bubbles float most of the inclusions present in the metal feed. The chlorine gas removes trace metals such as calcium, lithium and sodium. The geometry of the vessel is designed so as to minimize introduction of nascent metal salts into the molten aluminum. The mixed gas also removes much of the dissolved hydrogen. The impurities contained in the dross on the surface of the metal are removed by periodic skimming.

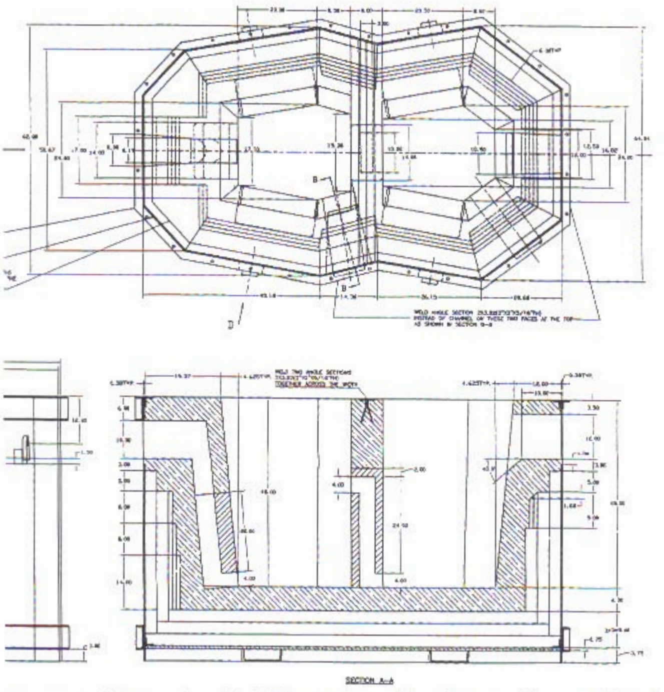

Figure 5. Schematic of LARS reactor, side view and top sectional view. Entry and exit ports are on the opposite sides. Vessel capacity: 4,400 lbs.

Molten metal exits at the bottom of reactor #1 via a graphite up comer. This up comer exits at the top of reactor #2. Molten metal flows down reactor #2 where it is intimately contacted with finely dispersed argon gas (note that there is no halogen gas introduced into reactor #2 . The argon gas floats inclusions and further reduces the hydrogen content of the molten aluminum. The molten alkali salts are also lifted by the gas bubbles in reactor #2 as there is no halogen present in the sparging gas.

Molten metal exits at the bottom of reactor #2 via a graphite up comer. This up comer exits at the top of reactor #2 where it discharges to the exit port. Normally the molten metal is then processed through a ceramic foam filter prior its introduction to the casting system.

Process Gas Systems

The system is provided with controls for the following gas systems:

1. Blanket gas reactor #1. The blanket gas is nitrogen.
2. Idle gas reactor #1. The idle gas is argon.
3. Main gas reactor #1. Main gas is a mix of argon and widely adjustable percentage of halogen (i.e. chlorine).
4. Blanket gas reactor #2. The blanket gas is nitrogen.
5. Idle gas reactor #2. The idle gas is argon.
6. Main gas reactor #2. The main gas is an argon.

The purpose of the blanket gas is to maintain an oxygen and moisture-free environment in the reaction chambers so as to minimize the oxidation of graphite components above the metal line as well as diminish the generation of inclusions and reduce the possibility of regassing of the molten aluminum. The blanket gas is introduced through electrical junction boxes and maintains the heating element terminal connections in a protective atmosphere.

Heating System

The electric heating system has been specifically designed for the purpose of maintaining molten aluminum temperatures due to heat losses from the vessel and to rapidly achieve (one degree F per minute) temperature adjustment in the molten aluminum.

The heating system is composed of four temperature control zones. Two zones for reactor #1 (heater A and heater B) and two zones for reactor #2 (heater A and heater B). Each control zone is composed of one graphite block. Each graphite block is equipped with 12 metallic heating elements, one control thermocouple and one limits thermocouple. The heating rods are made of thick wall inconel tubing with nichrome wires embedded in specially formulated magnesium oxide dielectric. The graphite blocks receive custom designed antioxidation treatment to prolong service life.

Operating Results with LARS Treatment

The results given below pertain to a large number of casts made (over forty million lbs of total cast weight) on 7075, 7175 and 7050 alloys. These alloys were chosen for the study because they present the maximum challenge to achieving refinement. The casting set up consisted of two 80,000 lbs capacity melters equipped with heat recuperation. No furnace treatments were used of any kind. Forty ppi and fifty ppi ceramic foam filtration was used downstream of the LARS unit. Rigid media ball filter was not employed. Entire casting was accomplished with level pour througing. Casting setup consisted of Almex supplied custom billet tooling for hard alloys (Tables I and II).

Rotor # 1 RPM = 400, Rotor # 2 = 400
Total # of helical grooves on shaft = 30
Reactor metal temperature = 1,350°F
In situ gas preheat temperature = 1,150°F
F reaction chamber volume = 2,000 lbs each
Reaction vessel depth = 38" (Active)
Argon gas volume: 70 cfh at 20 psig / rotor
Percentage of chlorine: 2% to 4 %
Visual observation of carryover: No bubbles seen on the exit side of the LARS reactor
Furnace treatments: none
Nitrogen shroud gas: 160 scfh per reactor
Chlorine percentages: various as given

Table I. Parametric conditions used in LARS.

SCADA Package
Control Sytems and Alarms

The SCADA-based control panel of LARS utilizes an InTouch Wonderware graphic interface (HMI) and an Allen-Bradley SLC500 Programmable Logic Controller (PLC) to monitor and control the process equipment. The HMI and the PLC communicates over an Allen-Bradley data highway. The PLC collects data from the field instrumentation and tabulates it for HMI access. In addition, the PLC receives data from the HMI which is used to control field devices, many of which are also safety interlocked (Figures 6 and 7).

OBSERVATIONS:

Conditions: **1. In-Situ Gas Preheat**
2. Specialized Reaction Chamber
3. 2% Cl_2 by Volume

ALLOY	Flow Rates lbs/hour	Number of drops	In Coming Hydrogen cc/100 gm	Outgoing Hydrogen cc/100gm	Ultrasonic Result
7050	40,000 to 50,000	60	0.39 – 0.44	0.13 +/- .01	Passed Sonic Class A
7050	30,000 to 35,000	75	0.39 - 0.42	0.12 +/- .01	Passed Sonic Class A
7050	18,000	84	0.42	0.09 +/- 01 (76% Eff)	Passed Mill 2154 AA

Table II. LARS efficiency results.

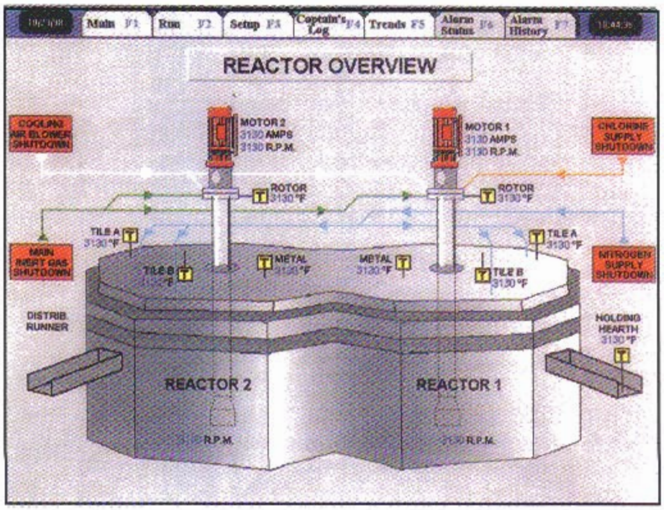

Figure 6. Reactor overview.

The Master control panel (MCP) is also equipped with an emergency manual override capability. This allows an operator to manually control the reactor in the event of a power loss to the PLC or failure of PLC or HMI.

Figure 7. Larger diameter (675mm) alloy 7050 billets cast with LARS refining system. The SCADA control cabinet and HMI can be seen in the background.

In Touch Wonderware Graphic User Interface

Microsoft Windows NT 4.0 operating system is the heart of the LARS HMI. There are several screens that supply operators with information and control capabilities.

The HMI has eight main menus. The menu bar contains tabs that are used to navigate the various screens.

Screen F1 provides overall information and reactor status including thermal data, gas flow data, rotor data and alarms status.

Screen F2 is the run screen which operators use to start the system just before casting commences.

Screen F3 is the set up screen from which all values pertaining to run and idle variables and alarm conditions are entered. This screen is password protected. The screen prevents entry of abnormal value for run/idle variables and/or alarm criteria. Thus, system damage is prevented. It also enhances operator safety in the casthouse.

Function F4, Captain's log, is designed for engineers, quality inspectors and operations personnel to write and record notes related to equipment and process. This helps in shift to shift communication and also in retrospective analysis. This screen helps to maintain all information pertaining to the equipment at the site.

Function F5 gives the trends on a variety of parameters. This screen has six subscreens, each containing a wealth of information on each parameter and combinations thereof as a function of time. The data can be analyzed for up to 90 days prior with a resolution of 0.1 seconds. A total of 56 variables can be watched in the historical trending mode. The screens of this function are of immense help in quality control and maintenance planning.

Function F6 displays alarms status with use of three subscreens. The first is dedicated to temperature alarms, the second to gas line alarms and the third to rotor alarms. Alarm notices are designed to safeguard equipment and personnel and to assure the quality of treated metal. The following major alarm conditions are reported on the screen in addition to several minor conditions.

1. Tile temperature beyond high limit
2. Tile temperature below low limit
3. Reactor bath temperature beyond limits
4. Thermocouple failure
5. Idle gas not detected
6. Cooling air pressure not sensed
7. Chlorine valves not opened/shut
8. PLC fault
9. Heating element short/broken: indicates tile # and phase # (must periodically monitor fuse box and tile current)
10. Drive motors pulling high/low amps
11. Inadequate supply pressures for argon, nitrogen and chlorine
12. Rotor RPM too high/low
13. Reactor cleanliness monitoring (Delta T)
14. Chlorine leak detection: main/chlorine panel

Function F7 pertains to alarm history analysis. For each alarm condition, three times get recorded.

1. Time when alarm condition occurred
2. Time when alarm condition was acknowledged
3. Time when alarm parameter was brought back within the limits of acceptable values.

Remote Accessibility

The HMI used in LARS is not just a passive operator terminal but an industrial PC with a powerful built-in modem. It can be easily accessed from anywhere in the world at various levels of program architecture. All of the system screens are then shared with the remote logger. The system can then be remotely worked on, including changing parametric set point values, defining new alarm windows or downloading enhancements in the PLC program.

Conclusion

LARS, Liquid Aluminum Refining System, with patented gas preheat arrangement, attrition mixing and SCADA capability provides a superior means for refining of molten aluminum and for improved monitoring of the quality of the cast product.

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