New Developments of the I-60 SIR Melt Refining Unit

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Abstract

The Hycast® inline melt refining unit, I-60 SIR, has during the last few years been modified to be able to meet several demands in the market.

The latest development of the I-60 SIR technology is to be able to control the alkaline metal level in the unit and being able to perform inline metal treatment of alloys containing high amounts of Zink (7xxx alloys). In this paper the challenges related to these new features, and how they were solved, will be described and discussed.

Introduction

There are several methods in use to remove alkaline metals from Aluminium today. The most common methods are listed below with together with some comments to each method.

- Stirring and holding in furnace
  - Time consuming, creates more dross, increased metal loss
- Use of Chlorine gas in furnace
  - Toxic gas, safety hazard, highly corrosive, increased maintenance cost
- Use of Chloride containing salts in furnace
  - Hygroscopic, creates corrosive atmosphere, increased maintenance cost
- Use of Chlorine or salt in the de-gasser
  - Limited removal, danger of salt carryover, corrosion/maintenance
- Use of Aluminium Fluoride (AlF_3) in crucible
  - A better working environment and less corrosive atmosphere in cast house compare to Chlorine or salt additions.

The preferred method in a primary casthouse is to perform fluxing with AlF_3 in the potroom crucible upstream the casthouse. For some alloys, especially 5xxx alloys with high content of Mg, there will still be a need for alkali control inline to achieve the very low specifications typical for these alloys. These specifications can be as low as max 1ppm in sum for Na, Ca and Li.

For remelters fluxing with AlF_3 is normally not an option. Here Chlorine gas (+Argon) or Chlorine containing salts in-line is common for the alloys with low specifications on alkaline metals. This may be done in combination with treatment in the furnace.

The I-60 SIR melt refining unit is presented in several publications, see e.g. [1] and [2]. This unique technology utilizes siphon to elevate the metal inside the reactor. This allows for a long residual time for each gas bubble together with the possibility of draining the unit completely between casts. This together with bottom mounted rotors and the Hydro rotor for optimal bubble distribution gives an unmatched performance when it comes to process gas consumption and operation cost. Today approximately 40 I-60 SIR units are installed in casthouses around the world.

The I-60 SIR was developed for the Hydro casthouses. This is a melt refining unit primarily design to remove Hydrogen and inclusions from liquid Aluminium in-line. The main driver for this development was to eliminate static metal between casts and to eliminate the usage of Chlorine in the casthouse. The elimination of Chlorine was for the primary casthouses achieved when combining the I-60 SIR and the Hycast RAM technology, see e.g. [3].

When introducing this technology for the market outside Hydro Hycast got several requests for a version with minor additions of Chlorine to control the alkaline metal content. This work describes the development to meet the need for alkaline metal removal inline.

Theory

Alkaline metals are a group of elements that have negative impact on mechanical and hot forming properties of some alloys, most known is the effect of Na in high Magnesium containing alloys, see e.g. [4]. Sodium (Na), Calcium (Ca) and Lithium (Li) is the most common alkaline metals. Some of the most known sources of these elements are cryolite, alumina and anode material used in the electrolysis process (Na, Ca and Li) [5] and paint residuals in recycled material (Ca), To remove alkaline metals in-line the most common method is to add some Chlorine together with the process gas, normally Argon, in the de-gasser. The typical addition rates are 0.5-5vol% of Chlorine dependent on the alkaline metal content. Addition of salts containing MgCl is also used by some to control alkaline metal content in-line, see e.g. [6].

The removal of Sodium (and other alkaline metals) from Aluminium melt by Chlorine gas or salt is known to follow a first order reaction kinetic, see e.g. [5]. The Sodium concentration in aluminum in a batch process may then be expressed by (1):

$$C_{Na} = C_{Na}^0 \exp(-kAt) \qquad (1)$$

C_{Na}^0 is the initial concentration of Sodium, k is the mass transfer coefficient assumed to be dependent on the Cl addition, A is the contact area between the process gas and the melt and t is the time. For an in-line situation (1) may be rewritten to (2):

$$C_{Na}^{Out} = C_{Na}^{In} \exp\left[akV \frac{\dot{Q}_g}{\dot{Q}_m} \right] \qquad (2)$$

Here the contact area A is assumed to be proportional with the gas flow rate, $A = a \cdot \dot{Q}_g$. Further the average residual time of metal in the reactor is assumed to be given by the metal volume in the reactor, V, divided by the metal flow rate, $\dot{Q}_m$. Since the volume of metal in the reactor and the proportional factor a is assumed to be constant (2) may be simplified to:

$$C_{Na} = C_{Na}^0 \exp\left[-bF_{Cl} \frac{\dot{Q}_g}{\dot{Q}_m} \right] \qquad (3)$$

Where F_{Cl} is a reactor constant assumed to be dependent on the relative Chlorine addition, defined as the Cl added relative to the theoretical stoichiometric amount needed to remove all Na in the melt. The removal efficiency may be calculated from (3):

$$E = 1 - \exp\left[-bF_{Cl} \frac{\dot{Q}_g}{\dot{Q}_m} \right] \qquad (4)$$

The removal mechanism of the removal of Sodium by Chlorine fluxing is believed to be following the reactions, see e.g. [5];

1. $Cl_2(g)$ reacts with liquid Al and forms $AlCl_3(g)$ (and $AlCl_2(g)$). Then the bubbles are a mix of these gases and Ar and Cl_2.
2. $AlCl_3(g)$ reacts with Mg in the melt and forms $MgCl_2(l)$ and liquid Al. This liquid will form on the bubble/melt interface.
3. $MgCl_2(l)$ will react with dissolved Na and form NaCl(s) and liquid Mg (that will dissolve in the melt).

In addition Aluminium Chloride gas may react directly with Sodium and form NaCl(s).

Technology

The I-60 SIR unit concept is shown in Figure 1. The reactor has two rotors and one common design for all metal flow rates. The unit is validated from 10-65mt/h, see Figure 2 for a typical installation.

The main challenge when introducing Chlorine in the process gas was to avoid corrosion in the high temperature areas of the rotor assembly. The rotor bearing package had to be re-designed and new materials had to be found for the rotor and the rotor shaft. Several rotor materials and design were tested, see Figure 3 for some examples. Figure 4 shows the new rotor bearing package compared to the standard.
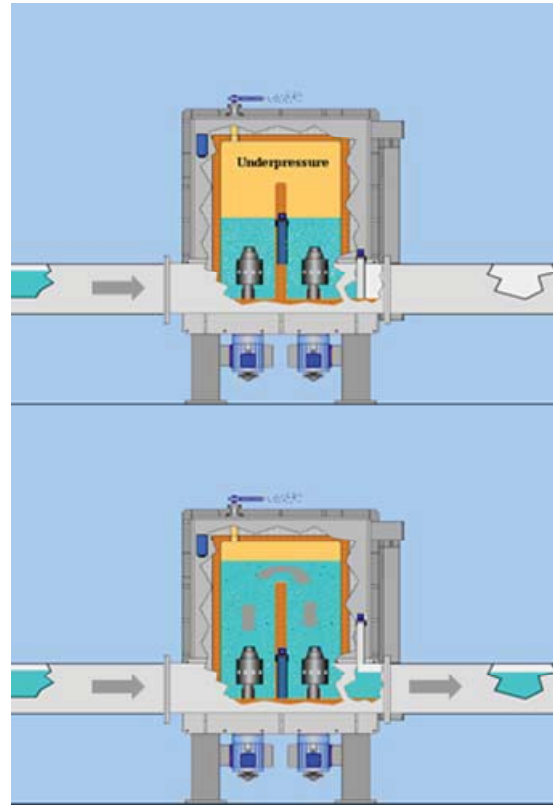

Figure 1. Illustration of the I-60 SIR concept and flow pattern, top: start-up and bottom; steady-state.

Figure 2. The I-60 SIR unit installed in a casting line.

New dust filter system is implemented on the I-60 SIR unit. This filter prevents any dust particles to exit from the reactor and will prevent any clogging in the ejector system, see Figure 5.

Figure 3. Some of the different rotor materials and designs that were tested.

Figure 4. The new rotor bearing package (left) compared to the standard version (right).

Figure 5. The new dust filter on the I-60 SIR. The filter is placed on top right corner of the top figure.

Results

Several experiments with varying Chlorine additions and varying Sodium concentrations of the incoming metal were carried out in an Aluminium melt containing ~5wt% Magnesium. Chlorine was added in the first rotor (chamber) of the reactor only. The relationship between the gas flow rate and the metal flow rate were kept constant equal to 290Nl/mt. This is somewhat higher than the normal flow rate used in the I-60 SIR unit which is ~150Nl/mt. Disk samples were taken upstream and downstream the I-60 SIR unit. The Sodium concentrations were measured using a mass spectrograph. The removal efficiency for varying relative Chlorine addition rates is shown in Figure 6.
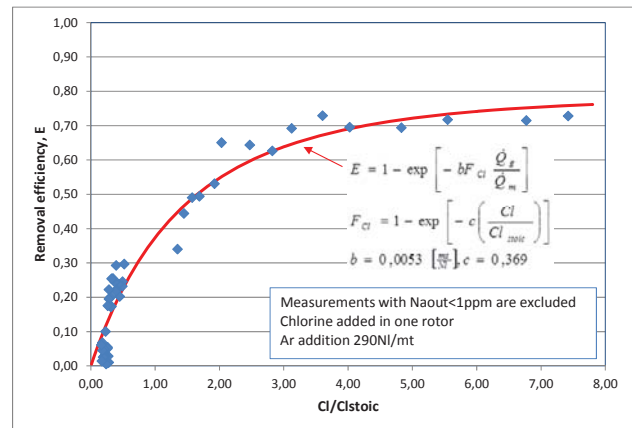

Figure 6. The removal efficiency of Sodium in Al-5wt%Mg. Chlorine added in rotor 1 only.

The red line in Figure 6 shows an empirical relationship between F_{Cl} and relative Cl addition given in equation 5. This relationship may be used to predict the removal efficiency for a given relative Chlorine addition, gas flow rate and metal flow rate through the I-60 SIR unit. The standard deviation in removal efficiency (E) between this relation and the measurements is 0,0637. Figure 7 is a graphical presentation of equation 5 showing the predicted removal efficiencies for varying relative chlorine addition and gas flow rate.

$$E = 1 - \exp\left[-bF_{Cl}\frac{\dot{Q}_g}{\dot{Q}_m}\right]$$

$$F_{Cl} = 1 - \exp\left[-c\left(\frac{Cl}{Cl_{stoic}}\right)\right]$$

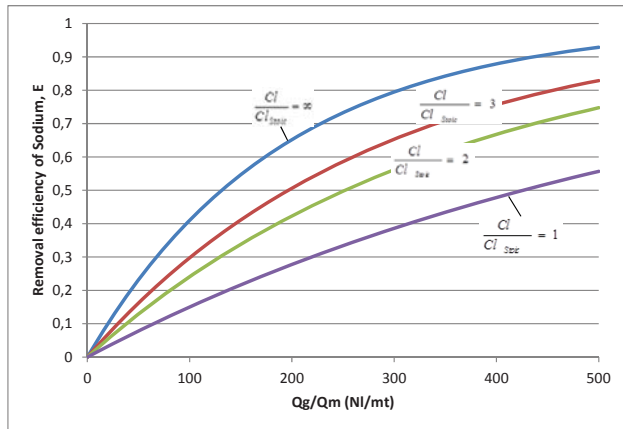$$b = 0,0053\left[\tfrac{mt}{Nl}\right], c = 0,369$$

(5)

Figure 7. The predicted removal efficiency of Sodium in Al-5wt%Mg for varying chlorine addition and gas flows.

The new dust filter shown in Figure 5 has demonstrated an impressive efficiency. No signs of clogging in the ejector system could be observed during our experiments. The filter system was also tested to see how it performed with high Zinc alloys (7xxx). These alloys have occasionally caused clogging problems in the I-60 SIR unit. Several hours of operations of up to 6% Zn showed no sign of clogging, and no dust particles leaving the ejector. Solving the 7xxx issue with the I-60 SIR unit was thus a spin-off effect of the implementation of the new dust filter.

Discussion

The removal efficiency shown in Figure 6 shows a maximum of E~0.74 even though the Chlorine addition is the multiple of the theoretical amount necessary to remove all Na. This means that the reaction is limited by factors other than the number of Cl atoms in the reactor. One limiting factor may be the total contact area which is dependent on the gas flow rate. This is the assumption in this work. Other but less likely possible limiting factor is that the bubbles are not completely mixed in the reactor volume, or that reaction products are carried over and measured in the disk samples.

The removal efficiency of other alkali metals than Na is not treated in this work. The basic mechanism for removal is the same for all the alkali metals. However the kinetics is somewhat slower for Ca and Li compared to Na. This means that we can assume that the process described in this work will remove also Ca and Li but the removal efficiencies will be somewhat lower.

Although the removal efficiency increase with Cl additions one should avoid adding too much Cl into the melt. Too much Cl may result in HCl gas in the exhaust gas of the reactor or salt carry over ($MgCl_2$) into the cast product.

The results in this work shows that we need approximately three times the theoretical (stoichiometric) amount of Cl to have a maximum removal of Na. The reason for this may be that Cl is used for the removal of other alkaline metals. Other explanations may be that the residual time is insufficient and some Cl_2 (or $AlCl_3$) gas leaves the reactor without reacting with any alkaline metal (Mg, Na, Ca, Li..).

Conclusions

The Hycast™ I-60 SIR unit is modified to be able to control the alkaline metal content of Aluminium alloys in-line. The rotor assembly had to be redesigned and new materials had to be selected for both rotor and shaft to be able to avoid corrosion when adding Chlorine into the Argon process gas (typically 2-5%). The removal efficiency of Sodium in Aluminium melt containing ~5wt% Mg has been investigated. The typical removal efficiencies were ~70%.

Based on the results from these experiments an empirical relationship was made between the first order rate constant and the relative Chlorine addition.

During the development of being able to add small additions of Chlorine in the I-60 SIR unit a new dust filter is implemented. This new filter has demonstrated an impressive efficiency in removing any dust or particles prior to the ejector. The new filter is also tested with 7xxx alloys with ~6wt% Zn. No visible dust escaped the reactor during these trials: Thus the previous issue with clogging due to ZnO was eliminated as a spin-off form the alkaline work.

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