INTELLIGENT DEGASSING –
STUDIES ON CONTROLLING THE PROCESS OF
HYDROGEN REMOVAL FROM ALUMINIUM

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ABSTRACT

Hydrogen removal and control are a vital part of the metal treatment process in Aluminium casting production. Many years ago the options were only chemical addition in tablet form or inert gas bubbled through a lance. Degassing times were long and often the bottleneck in production but this situation changed with the introduction of rotary degassing. The use of highly efficient pumping rotors has now given the foundry the option of removing hydrogen in a short time. Rotary degassing is now the Industry standard but a greater understanding is required for full process control. This study looks at rotor wear and the impact on degassing efficiency comparing the advanced pumping rotor with a simple non-pumping design and the findings help to further improve the rotary degassing process. A degassing process with an intelligent Foundry Degassing Unit offers a further step forward in Process Control.

Keywords: Aluminium. Aluminium alloys, Hydrogen solubility, Hydrogen removal, Degassing, Rotor design, Process control

1. INTRODUCTION

In order for an Aluminium foundry to remain competitive then productivity and cost effectiveness becomes ever more important. Quality standards need to improve continuously as reject rates are now measured in parts per million and so every step of the production process must be carefully controlled. The target is for every stage of the process to be stable and consistent all year round and where metal treatment is concerned there is often little chance for a second metal treatment should the first not achieve the required specification. In order to avoid problems, the degassing parameters are normally set for the worst case conditions and so for most of the year the melt is over-degassed, wasting nitrogen, and using excessive energy and in the most severe cases making metal treatment the controlling factor in the foundry production rate. Two major factors outside the control of the foundry are atmospheric temperature and humidity and in many locations in the world there can be massive changes between the summer and winter seasons. To achieve true Process Control it is essential to take these factors into account.
Another important factor is the rotor itself which changes in shape during its full service life. The greater the variation in rotor performance over service life so the more certain it is that over-degassing is required in the early stages of its service. The use of a rotor that performs equally well from Day One to the end of its service life would enable the foundry to work to closer tolerances on degassing time, inert gas usage and rotor speed. If this is not possible then a Foundry Degassing Unit that takes rotor life into account would be beneficial.

As we considered this subject to be of such great importance FOSECO decided to make a series of laboratory and foundry trials to link the scientific and practical aspects of rotor design and rotor wear.

2. ROTOR CHARACTERISATION

The purposes of mixing are manifold, and can be summarized generically across most industries as follows:

- Homogenization
- Gas dispersion
- Suspension of solids
- Liquid-liquid blending
- Heat transfer
- Reactions.

The objectives of an aluminium batch degasser can now be considered in the light of the preceding discussions of stirred tank reactors. Hydrogen removal is still frequently the primary function of a batch degasser to remove dissolved hydrogen from molten aluminium. This is accomplished by the passage of an inert purge gas through the melt. The dissolved hydrogen seeks to equilibrate with the initially hydrogen free purge gas bubbles, which rise to the surface, carrying hydrogen out of the system². The finer the gas bubbles, the greater the surface area and therefore the longer the residence time for the inert gas in the melt.
Batch degassers are also used to clean aluminium melts. Aluminium generally has a variety of non-metallic solid inclusions which can be detrimental to properties of castings. Nowadays the addition of salt fluxes supports the inclusion removal. The fluxes are typically granular and entrained in the melt, for example by creating a vortex and pouring flux onto the surface or into the vortex. The flux is distributed throughout the melt, where it encounters inclusions, which become attached, and carried to the surface when the stirring stops.

![Figure 2: Different gas bubble distribution](image)

FOSECO favors rotors that offer a pumping action as opposed to the simpler and less effective bubble choppers offered by competitors. The pumping action of these powerful rotors draws metal from below and creates intensive mixing of the inert gas and the melt within the rotor chamber.

### 3. HOMOGENIZING CAPABILITY OF ROTORS IN WATER

A well designed degassing system will have two key attributes. Firstly the melt will be rapidly mixed to achieve and maintain chemical and thermal homogeneity throughout the process. It is important that the time required to achieve good mixing is substantially less than the metal treatment time, otherwise the applied treatment will be spatially inhomogeneous in the melt. Whilst of concern in a degassing process, this is even more problematic if the rotary system is being used for chemical dissolution (e.g. chemical grain refiner, modifier or master alloy addition). Secondly, the turbulence generated by the rotor will result in a small average size of inert gas bubbles, which the well mixed flow patterns will ensure are well distributed throughout the melt.
Previous water model trials and experiences from the field have shown a huge difference in mixing capability of different rotors. The pictures (Fig 3a) are taken 4 seconds after adding an ink; the FDR pumping rotor provides an almost homogenous ink distribution whilst the non-pumping rotor results in insufficient mixing:

Pumping rotor  Non-pumping rotor

Figure 3a: Rotor operating in Perspex tank filled with water after ink addition.

Figure 3b: QR code link to a movie with mixing trial results

FOSECO has undertaken a series of experiments to further determine the mixing characteristics of different rotors under a range of operating conditions. In order to quantify the mixing behavior, a small quantity of hot water was added to the main water tank, and a series of thermo couples located around the tank were used to log the temperature as the tank became thermally homogeneous.

Figure 4: Thermo couple positions for homogenizing trials
Various degassing rotors were attached to a FOSECO Foundry Degassing Unit, and immersed in a water-filled Perspex tank. The same tank was used as in the previous experiments to measure rotor power: diameter 60 cm, water depth ~90 cm, with the rotor positioned 20 cm above the base. The mass of water in the tank was typically 250-260 kg. A series of Type T thermocouples were located in the tank, at the locations indicated in Figure 4.

For each experiment approximately 7 kg of hot water (80 °C) as added to the tank once steady mixing conditions were established. Typically the addition time was 15-20 s. The complete tests ran for 1-2 minutes. A small nitrogen flow of 10 liters/minute was maintained during all tests. The average homogeneous temperature rise in the complete series of tests was ~1.3 K. The temperatures were logged at 100 ms intervals using a multi-channel Data Logger; the plotted data were normalized to compare the mixing efficiency of different rotor designs.

The MTS FDR rotor shown in Figure 5 – designed to give a good mixing for the MTS 1500 automated granulate addition – provides an excellent mixing. The temperature in all three measurement levels is the same almost from the beginning; the water is completely homogenized during the first 10 to 15 seconds after hot water addition.

![Figure 5: Temperature distribution for an MTS FDR rotor at 400 rpm](image)

The non-pumping rotor shown in Figure 6 runs with the same parameters. Over the whole logging period of time the temperature in the three measurements levels varies widely. During the 20 seconds of recording the temperature the melt is not fully homogenized.
A highly efficient mixing is of vital importance where:
- Large ladles or furnaces, with potential dead areas, are being treated.
- Degassing is being carried out in a ladle where temperature loss is a concern. Fast degassing results in energy savings.
- Chemical additions are being made to the melt and the stirring intensity results in higher efficiency, better yields and shorter reaction time.

4. DEGASSING EFFICIENCY OF DIFFERENT ROTOR TYPES OVER ROTOR LIFE

In order to develop the Foseco Degassing Model for simulating rotary degassing with our various rotors FOSECO had to carry out a comprehensive series of laboratory tests to measure their performance. One of the key facts, which we uncovered, was that the actual shape, design and size of the rotor all have a significant impact on the ability to remove hydrogen. On consideration of this fact two questions immediately came to our mind:
- Does each particular rotor perform well throughout the entire service life?
- What is the true valuable life of a rotor and therefore when should a rotor be changed?

In practice many foundries replace a rotor when it becomes worn while others continue to use it until it almost disappears. Which foundry is correct and at what point is a rotor no longer cost effective?

Most degassing operations are not optimal, and generally rely on standard operating practices. A moment’s consideration shows that a fixed, standard operating practice for a degasser will either be wasteful, or will lead to quality variations in the final product. This is because the efficiency of the degassing process depends on a number of factors which vary from day to day, and batch to batch, such as: ambient humidity, alloy composition, incoming hydrogen level and the age of the rotor. Such variations are not taken account of in a standard operating practice.
FOSECO also has a novel probe for measuring dissolved hydrogen in molten aluminium, marketed as ALSPEK H. One of the attractive features of ALSPEK H is its suitability for measuring degassing curves in real time, in a stirred melt purged with inert gas.

A sequential degassing experiment was undertaken to quantify the influence of the changes in rotor diameter and design over rotor service life. Before its first use, the rotors were given a standard annealing practice designed to remove residual moisture. Periodically a series of typically 3-5 degassing curves were obtained using ALSPEK H. Prior to each of these runs, the melts were either initially up-gassed with N₂-H₂ mixed gas to a reasonable level of dissolved hydrogen, or new melt coming from the melting furnace was used.

All trials were carried out in a 200 kg crucible furnace with AlSi10Mg alloy at 750 °C. The rotors run at recommended rotation speed with 15 l/min nitrogen purging gas. The ambient conditions were checked on a daily base, the humidity was always between 52 and 54 % rH.

For a better comparability the rotor life in this study is given in a percentage of total rotor life. The target for degassing was 0,08 ml H₂ / 100 g Al.

4.1. MTS FDR PUMPING ROTOR:

The MTS FDR high efficiency rotor is a further development of the SPR and XSR types range. An innovative design is the key for its advanced functionality, which guarantees a fast degassing and optimised melt homogenising. The trials run at 320 rpm with a 175 mm rotor diameter.

Table 1: FDR pumping rotor performance over service life

<table>
<thead>
<tr>
<th>Before trial</th>
<th>After 25 % of total life time</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.jpg" alt="Rotor before trial" /></td>
<td><img src="image2.jpg" alt="Rotor after 25% of total life" /></td>
</tr>
<tr>
<td>Limit reached after 230 s</td>
<td>Limit reached after 230 s</td>
</tr>
<tr>
<td>Time Passed</td>
<td>Limit Reached</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>After 50% of total life time</td>
<td>Limit reached after 240 s</td>
</tr>
<tr>
<td>After 75% of total life time</td>
<td>Limit reached after 250 s</td>
</tr>
<tr>
<td>Overdue</td>
<td>Did not reach the limit</td>
</tr>
</tbody>
</table>
The various FDR rotor degassing curves in Figure 7 are very similar to each other. The degassing efficiency over rotor life decreases slightly from 230 seconds to 250 seconds to reach a very low hydrogen level of 0.08 ml H₂/100 g Al. In our trials the 20 seconds time increase reflects less than 10 percent change in degassing efficiency. A loss in outer diameter and more rounded edges are mostly compensated by oxidation of the graphite actually increasing the pumping chamber size thereby increasing efficiency. The combination of design and pumping effect ensures a stable degassing behaviour over rotor service life.

All parameter settings which are normally done during the commissioning process, with a set of consumables at the beginning of its life cycle, must take into consideration the extra degassing time required to reach the quality limits when rotors near the end of their service life.

Moreover the trials show that the rotor loses efficiency dramatically once its replacement is overdue. As soon as efficiency reduces significantly as critical parts of the rotor are fully consumed, or parts of the bottom plate, which generates the pumping effect, have gone then the rotor must be changed. Foundries should introduce a system to define the limits to a rotor change. This can be done by either a fixed treatment number or a limiting sample.

4.2. NON-PUMPING ROTORS:
Non-pumping rotors are simple bubble choppers offering little or no mixing, inefficient gas distribution and untreated volumes near the bottom area of round treatment vessels. This makes it impossible to treat rectangular or other non-round shapes.

The trials run at 320 rpm with a 175 mm rotor diameter. The non-pumping rotor as shown in Figure 8 did not reach the 0.08 ml H₂/100 g Al limit, even with variations in the treatment parameters it was impossible to degas to this level. The limit for the comparison is 0.10 ml H₂/100 g Al now.
Table 2: Non-pumping rotor performance over service life

<table>
<thead>
<tr>
<th>Time</th>
<th>Condition</th>
<th>Hydrogen Limit Reached</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before trial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>After 10%</td>
<td>Higher hydrogen limit reached</td>
<td>220 s</td>
</tr>
<tr>
<td>After 36%</td>
<td>Higher hydrogen limit reached</td>
<td>240 s</td>
</tr>
<tr>
<td>After 95%</td>
<td>Higher hydrogen limit reached</td>
<td>260 s</td>
</tr>
</tbody>
</table>
The non-pumping rotor did not reach the target level of 0.08 ml H₂ / 100 g Al at all. The alternative limit has been achieved after 220 s with a new rotor compared to 260 s degassing time with used rotor. The rotor efficiency fell by more than 20 percent over rotor life. The simple shape of the bubble chopper rotor has no possibility to compensate the loss of the sharp edges, oxidation of the graphite will always reduce efficiency of these rotors.

Due to a 20 percent efficiency loss the treatment for new rotors must be unnecessarily extended to ensure best quality over the total rotor life. The longer treatment time required creates additional costs due to the higher temperature loss, greater inert gas consumption and increased melt oxidation.

5. ROTOR COMPARISON

The efficiency loss is a gradual process that is very difficult for the operator to define and to recognise the right time at which to exchange the rotor.

Pumping rotors are far more effective than non-pumping because of better melt mixing and greater power being applied into the melt. This increased performance offers improvements in metal quality, consistency and a reduction in cost per treatment. Some rotors lose up to 20% of their efficiency through life but the FOSECO designed pumping rotors, such as FDR, lose less than 10% of their performance.

If no allowance is made for this in the programming of the Foundry Degassing Unit then the efficiency loss must be added to the treatment time for new rotors if we are to reach the limit throughout their life, but this extra degassing time costs energy, time and therefore money.
6. INTELLIGENT DEGASSING

It is clear then that for maximum process control it would be advantageous to include atmospheric conditions and rotor performance into the program controlling the Degassing Process. If a Foundry Degassing Unit was capable of considering the prevailing conditions then it could adjust the treatment parameters to achieve optimum degassing.

Several years ago FOSECO worked with Technology Strategy Consultants (tsc) Ltd to develop a batch degassing model, called the Foseco Degassing Model. It was developed from first mathematical principles and was designed as a tool to help FOSECO to analyse quickly our customers’ operations and to make suggestions for their improvement. The Foseco Degassing Model has already proven to be valuable when commissioning new Foundry Degassing Units to ensure optimum performance.

The model makes rapid calculation of the likely degassing performance, given basic data concerning a customer's operation. These include the composition of the alloy being degassed, the Degassing Unit operational parameters (rotor speed, rotor size, rotor type and purge time), the geometry of the crucible, and the ambient temperature and humidity. Any or all of this data can be modified, and the degassing performance instantly recalculated.

The mathematical model behind this software is based on data generated in FOSECO’s Research and Development facility while also using published data concerning the kinetics of hydrogen degassing (e.g. hydrogen solubility, diffusivity, mass transfer rates and stable bubble sizes). An extensive program of experimental work was undertaken to measure rotor power and degassing kinetics in water, in order to provide specific information about individual rotors.

It is therefore possible to use this mathematical model to make the decisions needed to convert the incoming information from the Foundry Degassing Unit and to convert this into an instruction of which parameters to use during the treatment itself. The Foundry Degassing Unit can therefore decide which rotor speed and nitrogen flow rate should be used to achieve a certain quality standard of alloy. The foundry can decide whether to aim for the fastest degassing time or the lowest consumable use in order to hit specification and changes in atmospheric condition and metal temperature can be easily overcome. As the rotor ages so the treatment will adjust accordingly.

7. CONCLUSIONS

- Pumping Rotors are far more efficient than non-pumping rotors in terms of mixing, improving metal quality, offering melt quality consistency and reducing the cost per treatment
- All degassing rotors lose efficiency over rotor life, but depending on the design the loss can be less than 10 % for the FDR pumping style and more than 20 % for very simple designs. So the less efficient non-pumping rotor becomes even less effective during service.
Currently the efficiency loss experienced must be added to the treatment time for new rotors to reach the limit throughout their service life, this results in inefficiency of the treatment process.

Extensive laboratory work has enabled FOSECO and tsc to develop a mathematical model which can be the basis of an intelligent system.

Changes in external conditions can now be catered for during normal foundry production conditions.

Degassing with such a Foundry Degassing Unit offers a further step forward in Process Control.

ACKNOWLEDGMENTS

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REFERENCES