ALUMINIUM LOW-PRESSURE WHEEL PRODUCTION

ENERTEK - ENERGY EFFICIENCY OF CRUCIBLES

FCTM - CRUCIBLE FURNACE EFFICIENCY MONITORING

MELTMAP AUDIT - ASSESSING METAL QUALITY IN ALUMINIUM FOUNDRIES

SMARTT - AN INNOVATIVE PROCESS CONTROL FOR ROTARY DEGASSING OF ALUMINIUM ALLOYS

INSTALLATION OF DOSING FURNACES WITH INSURAL

ACHIEVING HOMOGENEITY IN LARGE CASTING FURNACES
There has been huge growth in the production of Aluminium Road Wheels over the past decade with the great majority being manufactured by the low-pressure diecasting process. The quality requirements of these safety critical castings are as high as any Aluminium component made today and Foseco has developed a suite of products aimed at improving the quality of the castings produced while also improving the profitability of the process. This concept of an Integrated Solution Package for a particular casting and process will be further developed in the future.

Energy efficiency is becoming an increasingly important factor in the use of crucibles. Rising energy costs and CO₂-emissions are becoming the centre of attention and energy efficiency is playing a much more important role. The energy consumption when operating a crucible furnace initially strongly depends on the type of furnace and the way it is operated and maintained, but is also strongly influenced by the thermal properties of the crucible material.

Studies have shown that the new and improved ENERTEK crucible quality is able to significantly reduce energy consumption in comparison to other crucible qualities. An additional effect in holding operations is the improved temperature control. This can lead to a reduction in the rejects for temperature related casting problems.

The effect of any one piece of equipment on overall aluminum foundry performance is generally not well understood. The Foseco Crucible Throughput Monitor (FCTM) was developed as a solution to challenges associated with tracking efficiency of an electric-resistance crucible furnace.

FCTM features molten metal throughput monitoring, plus continuous energy and temperature measurement. It has been used to compare relative performance among multiple furnaces but, perhaps more importantly, FCTM data analysis techniques can be used to isolate key process steps (casting, charging, rotary degassing, etc.) as a function of energy, time and temperature. With this, effects of individual process parameters on furnace performance can be observed, providing quantitative feedback and efficiency fine-tuning potential down to the level of a specific activity on an individual furnace.
To ensure that the correct casting quality is achieved then a more effective and technically sound melt treatment is essential. SMARTT is an innovative process control, installed on a PC and LAN connected to the PLC of the rotary degassing unit. It analyses all incoming parameters like ambient conditions or melt properties and calculates the best treatment parameters for the rotary degassing process just before each treatment. This optimisation guarantees a constant melt quality after each treatment and provides a data logging option.

Examples from foundry trials illustrate the influence on treatment parameters based on variations on incoming parameters and different customer requirements.

The solution for your dosing furnace: Completely dry installation with INsural precast shapes and high insulating backing materials. Huge energy savings, no sintering, low density index of the melt immediately, easy cleaning.

A market analysis among our customers showed clearly, that there is a strong need for optimisation in terms of cleaning and avoidance of corundum growth. To solve these problems, extended trials with different INSural recipes have been made.

This paper investigates the use of pumping rotors applied on a rotary degassing machine that offers a practical and affordable method of retaining consistent melt quality within a radiant heated holding furnace. Segregation and lack of homogeneity can result in cold defects, shrinkage porosity, irregular grain refinement, inclusions or porosity defects.

A series of water model trials compare the mixing capabilities of different rotor designs. Trials in Montupet Ruse (BG) have been undertaken to confirm the positive model results of the pumping XSR and FDR rotor designs under foundry conditions.
The application of aluminium wheels on light vehicles has become hugely popular over the past 10 years. The reasons behind this are both technical as well as aesthetic as the castings are safety critical as well as pleasing to the eye. Aluminium wheels need to offer mechanical strength and lightness, toughness and rigidity, dimensional precision and style with a perfect aesthetic finish and so today aluminium wheels have become a technologically advanced product required to offer a high level of quality, reliability and safety.

The wheel is a safety critical component which has a decisive effect on the performance of the vehicle. and is responsible for propulsion, steering, supporting the vehicle, braking as well as suspension and so must possess characteristics of mechanical strength, plastic reserve and fatigue strength capable of resisting fracture during the full life cycle. In addition to this roundness and balance must also be maintained over time.

Testing will include dimensional accuracy, alloy composition, hardness, grain size and eutectic structure, fatigue testing and die penetrant inspection after fatigue testing, X-ray inspection, pressure tightness, crash test, detailed visual inspection, radial load testing, meaning that aluminium wheels receive as much inspection as any other aluminium casting and more than most.

The process by which aluminium wheels are manufactured is almost always low-pressure diecasting and this process can be segmented into the following process steps:

- Alloy material selection
- Melting
- Holding
- Melt transfer by ladle
- Melt treatment in the ladle
- Transfer into the low-pressure furnace
- Die filling and solidification
- Removal and initial inspection
- X-Ray inspection
- Heat treatment
- Machining
- Painting
- Pressure test and visual inspection

The Foseco approach is to develop a suite of products and services which can add value to the foundry in all of these Process Steps.

**Alloy material selection**

In order to achieve the mechanical properties, particularly the elongation, it is essential that the iron content of the alloy is controlled and so commonly primary ingot is used along with foundry returns and the swarf and chippings from the machine line. Around 40% of the as-cast wheel is removed during the process and so, although the swarf and chippings from machined wheels will have a very large surface area and be the potential source of oxide inclusions, it is commercially essential that this material is recycled and the value retained. A separate process to melt and clean this material is normally used and the use of a powerful cleaning flux, such as COVERAL® GR 6512, is an integral part of this process.

Once cleaned to an acceptable quality level this material can be used, under control, as part of the alloy charge, either as cast ingot or in liquid form.

**Melting**

Melting in wheel foundries today tends to be by tower melter or reverberatory furnace and there are three key properties that are expected from the furnace itself: High melting rate, energy efficiency and the ability to avoid oxide formation.

In the melting and holding zone there is a strong need for a refractory material that is compatible with aluminium – Silicon alloys, which has good mechanical strength and is non-wetted by aluminium alloys, resisting the growth of corundum. The lining material must also have a high resistance to mechanical damage in impact areas and have as long a service life as is practical.

Figure 1. Tower melting furnace showing different refractories for different requirements
Melt treatment

In order to achieve the required quality of melt it is necessary to carry out a controlled melt treatment in the transfer ladle.

To ensure the correct eutectic structure is achieved and that excellent elongation properties are assured then the alloy is modified with Strontium. This can be done by using pre-modified ingot, which has already had a Strontium addition, or by adding aluminium – Strontium master alloy prior to degassing.

In addition to the Strontium modification the alloy is also grain refined with Titanium and Boron to achieve optimum mechanical properties and to reduce the chances of shrinkage in thicker sections. In addition to an improvement in elongation and the consistency of mechanical properties, grain refinement also increases resistance to fatigue, improves machinability, reduces the tendency for hot tearing and helps to disperse micro-porosity.

This treatment is best carried out by chemical additions which form fresh Titanium diboride particles within the melt. A tablet addition with NUCLEAN* 70 SS or NUCLEAN 100 SP will have this effect but best of all a cleaning and grain refining flux, COVERAL MTS 1582 applied through a MTS 1500 Metal Treatment Station, will give excellent grain refinement, remove oxides and inclusions while ensuring that a very dry dross is generated thereby reducing metal loss.

Melt cleaning and hydrogen control can best be done simultaneously and the traditional method is to add a granular flux COVERAL GR 6512 to the surface of the ladle and then to carry out rotary degassing with a pumping graphite FDU XSR rotor or a GBF rotor.

The stirring action of the rotor will activate the COVERAL GR 6512 and create an exothermic reaction while the finely dispersed inert gas bubbles will help oxides to float to the surface to be collected in the dross. After several minutes of treatment the melt is cleaner and lower in hydrogen content.

A more modern version of this melt treatment is with MTS 1500 technology using a more powerful MTS FDR rotor. In the early stages of the rotary degassing treatment the baffle plate rises from the melt and a vortex is formed. A specially developed cleaning flux, COVERAL MTS 1565, is then added into the vortex. The flux is taken down to the lower parts of the ladle where it can react with the bulk of the melt and after less than 60 seconds the baffle plate moves back into the melt and the vortex disappears.

**Figure 2.** Range of INSURAL 140 lining inserts and INSURAL ATL in service

**Figure 3.** Foseco pumping rotor technology

If the service life of the ladle lining is of particular importance then INSURAL 270 offers good insulation and oxide resistance coupled with excellent erosion resistance. INSURAL 270 will therefore offer an extended service life.

**ALUGARD** CE-S is a high alumina, low cement castable specifically designed for use with aluminium – Silicon alloys and is well proven in aluminium tower and reverberatory melting furnaces. The ALUGARD CE-S lining will offer a long service life and good resistance to corundum growth and be easy to clean.

Within the range of refractory products there is also a lighter weight material for the furnace door, roof and upper walls, TRIAD* 45 AL and BLU-RAM* HS.

For general maintenance and repair DURAGUN* 66AL can be used for application by trowelling or gunning methods.

The same range of refractory materials can also be applied if the melting takes place in a reverberatory furnace.

Product selection is vitally important as is correct installation and Foseco can advise and sometimes supervise the installation of our refractory lining products.

In melting furnaces temperature measurement can also offer advantages if it is fast and accurate. Highly conductive ISO-PRIME or 3MSILICIUMNITRID thermocouple sheaths can both achieve these aims with the later also offering longer service life.

Correct refractory selection and fast response thermocouples can help to maintain the high quality standard of the aluminium alloy melt, the essential foundation of a sound foundry process.

**Melt transfer**

Once melted the alloy is then poured into a transfer ladle in which the melt treatment is made prior to the ladle being moved to the low-pressure casting machines. This treatment of grain refinement, strontium modification, cleaning and hydrogen adjustment (degassing and sometimes regassing) can take around 10 minutes and so temperature loss can be an issue. Good insulation and easy cleaning is therefore an essential characteristic of the lining material and Foseco have two options to offer.

**INSURAL** 140 is supplied as a pre-cast insert which has already been fired to over 700 deg C and when installed within the **INSURAL** 10 insulating backing will offer excellent insulation and non-wetting properties. When installed using the **INSURAL** 140 lining system the ladle will have a heat loss of less than 3 degrees C per minute, depending upon the capacity, and will also be very easy to keep clean and free of oxide build-up.
Normal rotary degassing then continues but because the flux is low in the melt a much more effective cleaning process follows. The MTS 1500 process will therefore remove more oxides than FDU alone.

However for the most effective and automated treatment the COVERAL MTS 1565 flux can be replaced by COVERAL MTS 1582, which when added using the MTS 1500 unit, will offer hydrogen control, melt cleaning and grain refinement as well as generating a dry dross low in aluminium as shown in FIGURE 6 below, all in one automated treatment.

To monitor the effectiveness of the modification and grain refinement treatments a cooling curve can be plotted using THERMATEST® equipment. As well as producing a cooling curve, where the undercooling of the liquidus and solidus can be observed, the software also calculates a Eutectic Structure Index; where S is the maximum reading and a Grain Index, with 9 being the maximum reading. Thermal analysis is a very effective way of checking that each melt has been correctly treated.

As shrinkage is such a common issue in aluminium wheels it is sometimes advisable not to reduce the hydrogen content of the melt to the lowest possible level. The overall treatment time must be maintained because of the need to clean the alloy and so shortening the degassing is not an option. It is therefore beneficial to degas to a low level and then to reintroduce a small amount of hydrogen at the end of the treatment. In order to retain the advantage of automation and consistency it is possible to programme the FDU, GBF or MTS 1500 unit to make a late addition of Argon – H2 gas for just a few tens of seconds at the end of the treatment. This will adjust the hydrogen content to an acceptable level which will not create porosity but will control the level of shrinkage found in the final casting.

The use of a programmable MTS 1500 treatment to clean, grain refine and control the hydrogen content of the melt gives the foundry excellent process control and repeatability.

**Melt transfer**

After treatment the melt is poured into the low-pressure furnace, ready for production. This is another critical stage of the process as turbulent filling of the low-pressure furnace can result in oxide creation and an increase in hydrogen content. A specially designed INSURAL 140 pouring basin to suit the particular low-pressure furnace can help to control the filling process.
Low-pressure diecasting furnace

As these furnaces can be in service for up to 7 years it is vital to select a refractory which will avoid oxide and corundum growth. **ALUGARD A 95** has been used for several years in these types of furnace and will avoid many of the problems which can be experienced where furnaces run in production for long periods of time. When **ALUGARD A 95** is installed in front of a highly insulating backing system then external steel shell temperatures can be as low as 65 deg C, reflecting a very energy efficient system.

An alternative to casting the lining in the furnace body it is possible to install a pre-cast and pre-fired shape in **INSURAL 270**. This option offers a very fast reline and guarantees that all combined moisture has been removed before installation begins. A furnace relined with the **INSURAL 270** system can therefore be put immediately into service after relining, without the need for additional drying and firing.

For the furnace roof an insulating lining is appropriate and **LITEWATE* 80 AL** is an ideal material for this application.

The low-pressure furnace is heated by electric radiant glow-bars in the roof and their service life can be extended by covering them with a highly conductive protection tube.

**ISO-PRIME Heater Protection Tubes** ensure good heat transfer from electrical element to the furnace atmosphere while protecting the element from mechanical damage, metal splashing and chemical attack during general use or metal treatment and furnace cleaning.

**ISO-PRIME heater protection tubes** will extend the life of the heater elements. Reducing the running costs of the furnace.

For accurate temperature control a thermocouple sheath with high conductivity is required and **ISO-PRIME thermocouple sheaths** are well proven in the specific application of a pressurised furnace. Again fast response will result in more accurate temperature control and less variation on casting temperatures.

In order to have accurate control of the filling process and to retain pressure for effective feeding during solidification a pressure tight LPS tube is essential.

Two materials are offered for this application. **ZYAROCK** and **ZYACAST**, both based on fused silica and being well proven in these applications. These LPS tubes can be supplied with a **SEDEX** or **STELEX** ZR foam filter installed in the bottom to prevent oxide inclusions entering the tube from the furnace floor.

Casting

Above the LPS tube there is the opportunity to apply highly insulating ceramic inserts and **INSURAL 140** is an ideal material for these applications. The use of these inserts allow the foundry to increase the amount of water cooling in the die, thus extracting heat from the casting while retaining heat in the feed areas. Castings quality is therefore improved while cycle time is kept short to improve productivity.

To improve metal flow and trap oxide inclusions a filter can be positioned in the upper bush. Foam filters are the most effective at flow control and **SIVEX** FC filters are light-weight and can be remelted from the carrot.

The die itself must be coated to control the thermal balance, ensuring good filling while also controlling heat loss during the feeding cycle. The aesthetic quality of the casting is also defined by the surface finish on the main face of the wheel and so a smooth coating is used on the front face, **DYCOTE 39**. For an extended service life **DYCOTE 3900** or **DYCOTE 3950** can be used.

For the side and top cores a more insulating coating is required and this can be **DYCOTE 34**. As service life of the coating is important to retain the insulating properties for a longer period a primer coating **DYCOTE DR 87** can first be applied to the die with the other **DYCOTES** applied on top.

To ensure that the **DYCOTE** used is correctly prepared a special mixer **DYCOTE CARRY and MIX** is offered. This mixer will also maintain the quality of the coating during standing.

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**Figure 11. Low-pressure furnace showing different refractories used, LPS riser tube and heater protection tubes**

**Figure 12. Ceramic assembly**

**Figure 13. Typical INSURAL 50 inserts**
Conclusions
The important attributes of the low-pressure diecasting process are:
• Productivity
• Energy usage
• Metal Yield

The important attributes of the casting itself are:
• Surface finish
• Mechanical properties
• Soundness
• Pressure tightness
• Freedom from oxides and porosity
• Machinability

The products listed above form a valuable suite for the low-pressure wheel producer and when used together will have a positive impact on the quality and performance of the castings as well as the commercial success of the foundry. Research and Development projects are now underway to add further elements to this suite and to increase the end to end value offered to the industry.
**ENERTEK - Energy efficiency of crucibles**

**Introduction**

ENERTEK crucibles are available in most standard shapes and capacities and can be fitted to the majority of crucible furnaces without any changes to current practice. Customized solutions are also possible and they can be supplied optionally with a stand and thermocouple sheath.

ENERTEK is most suited to aluminium holding furnace applications, particularly electrically heated furnaces but they can also be effective in gas fired furnaces.

Relatively small differences in thermal performance can lead to a considerable cost saving relative to the cost of the crucible.

ENERTEK crucibles have been specially designed to maximize thermal conductivity and offer the most thermally efficient crucible for holding molten aluminium. Performance differentials over competitive crucibles will vary according to the quality of the competitive material but are typically between 5 and 15%.

The table below gives a breakdown of the features of Foseco’s research and design methods and the benefits derived by the ENERTEK brand in achieving this balance.

<table>
<thead>
<tr>
<th>Features:</th>
<th>Benefits derived</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis and modelling of thermal conductivity and specific heat capacity results in a deep understanding of the elements of crucible design and production.</td>
<td>Reduced energy required during melting and holding</td>
</tr>
<tr>
<td>Highest quality refractory materials are selected and formulated to maximize thermal conductivity in any given application.</td>
<td></td>
</tr>
<tr>
<td>Precise processing and maximizing of density profiles through iso-static pressing in conjunction with proper material selection.</td>
<td></td>
</tr>
<tr>
<td>Refractories that are designed to withstand the effects of use and ageing that can reduce thermal conductivity.</td>
<td>Minimal increase in thermal resistance over time</td>
</tr>
<tr>
<td>Proper balance and attention paid to baseline thermal conductivity in conjunction with stability of refractories as they age.</td>
<td>Maximized life time and energy savings</td>
</tr>
<tr>
<td>Energy reduction leads directly to reduced greenhouse footprint</td>
<td>Environmental advantages</td>
</tr>
</tbody>
</table>

The table below gives a breakdown of the features of Foseco’s research and design methods and the benefits derived by the ENERTEK brand in achieving this balance.

![ENERTEK crucibles](image)

Figure 1. ENERTEK crucibles consume 5.5% less energy over the first 3 months.
Durability and cost

Crucibles are often regarded as a commodity product with the customer making purchasing decisions based on the purchase price of the crucible rather than its performance when in use. If performance is a factor in the purchasing decision then lifetime is the most likely parameter that the crucible buyer focuses on.

However, the performance parameter that has the most significant impact on foundry costs is in fact the thermal performance because the energy consumption of a crucible over its lifetime is many times that of its original purchase price.

It is clear that crucibles generally become less energy-efficient as they are used. This phenomenon can be controlled by careful selection of the design parameters of the crucible, but it cannot be eliminated. Extensive research and development has allowed Foseco to balance out the life-time costs so as to achieve maximum energy and hence cost savings overall.

Thermal performance

Another important factor for the foundry is precise temperature control in holding furnaces during the casting process.

A crucible with higher thermal efficiency does not just have a positive impact on energy costs but also yields the benefit of more constant metal temperature during holding.

The example below shows the temperature distribution in an electric resistance holding furnace with a constant setting for the aluminium temperature of 677 °C.

As the lower conductivity of the crucible material slows down the heating reaction of the metal temperature (Immersion T/C - shown in blue in Figure 4 in the next column) inside the crucible, the delta of liquid metal temperature is 42 °C. By contrast the higher conductive ENERTEK crucible shows a delta temperature of 26 °C with the same setting.
Case study 1

Foundry: Aluminium die-casting foundry
Crucible capacity:
• 1,000 kg aluminium
Application:
• Holding of aluminium in an electrical resistance furnace serving an automatic casting cell
Problem:
• Reduction of energy costs and CO₂ footprint of the foundry
Improvements:
• A 13.4 % lower energy consumption was measured at the same production volume due to the higher energy efficiency of the ENERTEK crucible.

![Figure 5. Total energy consumption over the life of the crucibles](image)

An overall cost saving of more than 1,200 € per furnace with ENERTEK crucibles was achieved as a result of accumulated energy savings.

![Figure 6. Weekly and accumulated energy savings in € per furnace](image)

Environmental benefits
• The corresponding reduction of the CO₂ emissions is 7,993 kg per year.

Case study 2

Foundry: Aluminium die-casting foundry
Crucible capacity:
• 900 kg aluminium
Application:
• Holding of aluminium in an electric resistance furnace
Problem:
• Increasing energy costs
Improvements:
• A 4.2 % lower energy consumption was measured at the same production volume due to the higher energy efficiency of the ENERTEK crucible.
• ENERTEK crucibles use less electricity over the 12 month lifetime of the crucible resulting in an overall cost saving of 315 € per crucible (at 0.06 € per KW/h).

![Figure 7. Total energy consumption over 12 months](image)

Summary

ENERTEK crucibles deliver the following advantages over their competitors:
• Optimized thermal efficiency for lowest energy consumption and therefore cost savings
• Durability and longer crucible life
• Faster melting times with no negative influence on melt quality
• Greater reduction of CO₂ emissions
• More constant metal temperature in holding applications
• Improved temperature control in holding applications
Introduction

Within the aluminum foundry community there is a continual desire to improve efficiency as a means of countering rising utilities prices and production costs. Since the 1970’s, the cost of electricity has been increasing across all major sectors [1, 2]. There have been recent periods of relative stability in the industrial sector, but it still remains at an all-time high. This is a problem for businesses like aluminum foundries, many of which rely heavily on electrical power to operate.

There are several crucible furnace-related variables that an aluminum foundry manager could potentially manipulate to improve efficiency, but there is no way to gauge the existing condition nor effects of introduced changes on performance. The easiest metric by which an electric resistance crucible furnace can be judged is its energy use, in kWh. Monitoring electricity use of a furnace can quickly give an impression of operating efficiency, though it does not tell the entire story. There are costs associated with the energy required to initially melt the metal, maintain a molten charge, and overcome heat losses. Furnace melt rate, crucible selection, how often the lid is open, and insulation quality are a few of the main variables that influence how efficiently the energy is utilized.

A typical example of annual electric energy costs for a medium-sized electric-resistance crucible furnace is shown below:

<table>
<thead>
<tr>
<th>1. Demand Charge</th>
<th>$ 7,560</th>
</tr>
</thead>
<tbody>
<tr>
<td>@ $ 0.30/kW x 100 kW x 12 monthly/year</td>
<td></td>
</tr>
<tr>
<td>2. Melting Cost</td>
<td>$ 17,464</td>
</tr>
<tr>
<td>@ 0.389 kWh/kg x 2286 kg/day x 22 day/month</td>
<td></td>
</tr>
<tr>
<td>@ $ 0.075/kWh</td>
<td></td>
</tr>
<tr>
<td>3. Holding Cost</td>
<td>$ 3,822</td>
</tr>
<tr>
<td>@ 10 kWh/hour x (10 hours/day x 5 day/week)</td>
<td></td>
</tr>
<tr>
<td>+ 48 hour/weekend x 52 weeks/year x $ 0.075/kWh</td>
<td></td>
</tr>
<tr>
<td>TOTAL ANNUAL ELECTRIC ENERGY COST</td>
<td>$ 28,846</td>
</tr>
</tbody>
</table>

Table 1. Annual electric energy costs for a 100 kW Electric Resistance Furnace

For simplicity this example ignores time-of-day or seasonal adjustments. A large foundry can have 50 or more furnaces, so based on this simplified calculation the cost of electric energy can very easily reach millions of dollars per year.
Consider the above example but with the foundry deciding to change to a more energy efficient crucible, saving them 50 kWh/day. Casting the same quantity reduces the energy/throughput ratio from 0.389 kWh/kg to 0.367 kWh/kg and the total Melting Cost down to $16,611, a savings of $853 per furnace. At the same time, the holding cost drops by 0.5 kWh/hour, generating an additional annual savings of $192, for a grand total of $1,045 per furnace. In some cases this is nearly equivalent to the cost of the crucible itself. The problem seeing the wisdom of this decision is that there is no easy way for the customer to benchmark current performance against any supposed efficiency improvements. This is because any realized savings are hidden within the all-inclusive energy bill several orders of magnitude larger.

Foseco has developed a novel instrument making it possible to simultaneously evaluate performance of multiple electric resistance crucible furnaces long-term, focusing on three metrics that heavily influence efficiency—energy use, throughput, and temperature. This device is termed FCTM (Foseco Crucible Throughput Monitor), however its capabilities are not limited to throughput monitoring alone. With the addition of continuous energy and temperature monitoring capabilities, it is possible to create a very detailed profile of an individual furnace. Not only can the efficiency of several furnaces be compared—with some training the user can also learn to identify data patterns corresponding to specific furnace activities (degassing, charging, metal treatment, etc.), such that the overall impact of those activities can also be observed. It is by these methods a foundry manager can learn the shortcomings of a furnace and/or operating practices and make changes to the process or equipment resulting in a positive effect on efficiency, measurable by FCTM.

With FCTM, for the first time the results of deliberate efficiency upgrades to a furnace can be easily quantified, a furnace that is underutilized due to inefficient workflow can be observed, and poor efficiency of an underperforming furnace can be singled out. It is many incremental improvements to individual crucible furnaces that collectively adds up to a large savings in time, energy, and money.

**Background**

The FCTM was developed in response to a complication discovered trying to utilize existing technology to compare relative efficiency of two different crucibles residing inside electric-resistance furnaces. Off-the-shelf power meters connected to each furnace measured and logged the daily energy (kWh) usages. The idea was to compare the results and determine which crucible helped the furnace better, assuming the furnaces themselves were equally performing. What was learned from the first series of experiments was that, although the instruments could record energy use very accurately, the direct comparisons between furnaces were not valid. The fundamental reason behind this is that in many cases furnaces are not all utilized the same, even among those dedicated to the same tasks. Unless the energy expenditure of the crucible was normalized to the amount of activity, the data were often misleading. For example, if one furnace was consistently used more often (casting more metal, more times recharged, etc.), then the energy results would be biased toward the furnace with lower throughput, even if it contained a less energy-efficient crucible.

Metal throughput at a foundry is a complicated topic. Foundry managers generally know how many aluminum castings they produce on a daily basis and the casting mass of each pattern. However, since there are typically multiple casting lines and multiple furnaces that supply them with metal, it is often a challenge to accurately keep track of which metal originated in which furnace. Even if there is only one furnace supplying the metal to patterns of known mass, there is still the matter of accounting for metal that fills the gating systems, is skimmed off as dross, and spillage. The best-run foundries may not have a way to determine daily throughput on one specific furnace, and this is in part because this level of detail is not required for the foundry to operate effectively.

Consequentially, this leaves a nebulus way to compare furnaces; one has to assume those compared are being used identically in order to consider the energy difference as valid. More often than not, this is a false assumption and there is no way to obtain specific enough information for an individual furnace. It was this realization that sparked the idea for FCTM—an instrument to measure furnace energy usage as a function of throughput (metal in, metal out), a much more precise way to compare two different furnaces’ efficiencies.

**FCTM - Overview**

Figure 3 shows a photograph of the FCTM control cabinet along with a close-up of one of the laser sensors. This compact, modular design can house hardware for up to four separate furnaces, with a fully-upgradeable custom operating system. The way the FCTM works is basically twofold—furnace energy is tracked as a function of time and the metal throughput is tracked as a function of time and event (addition or subtraction of molten metal from the crucible). Temperature can also be measured/logged as an add-on feature for advanced data analysis.

Energy monitoring is accomplished by tapping into the furnace control panel with a wattmeter that measures real-time current and voltage. Temperature is measured using a dedicated thermocouple or via a 5 – 20 mA retransmit signal from the furnace controller. Throughput measurement is slightly more complicated, making use of the laser sensor and a proprietary algorithm to determine mass change within the crucible each time metal is added or withdrawn. The sensor must be placed directly above the bath so the laser target points directly at the metal surface. Interference with the laser caused by objects obstructing the beam (i.e. lid closure) are anticipated by the software and a series of artifact prevention subroutines were built into the software to handle these types of occurrences, filtering out false or artifact data points.

![Figure 3. Photographs of the FCTM-2 control cabinet (left) and a close-up of a laser sensor (right).](image-url)
Figure 4 shows illustrations that summarize the overall functionality of the FCTM laser sensors, which includes calibration and measurement as well as a basic description of how the artifact detection system works.

Figure 5 shows a schematic of a typical FCTM setup for two furnaces. There are separate configurations for each individual furnace channel. Currently, FCTM only supports electric resistance furnaces, but future versions could be adapted to gas or induction.

Figure 6 shows a typical energy trace for two crucible furnaces holding molten aluminum over a 24-hour period. This is the most basic level of information that can be gathered to compare relative furnace performance.

Since there is no throughput on either furnace, energy is only expended maintaining set point temperature. In this case, Furnace 1 uses less energy than Furnace 2 on this particular day (318 kWh vs. 344 kWh). To generate these particular plots, measurements were taken every 5 seconds; however, the collection rate of the FCTM channels are fully adjustable- data can be recorded as rapidly as once a second, or slow as once every 10 minutes if desired.

What this plot suggests is that Furnace 2 uses less total energy than Furnace 1 on this day (787 kWh vs. 678 kWh). Recall these are the same two furnaces from Figure 6; the results appear reversed, with Furnace 2 being the more energy efficient. These simplified examples precisely demonstrate the conflicting results that can occur by only comparing total energy consumption. They do not account for circumstances within the foundry that bias the results. In reality, Furnace 1 was emptied and refilled this day, whereas Furnace 2 was partially emptied, and not refilled. Dissimilar use patterns are hinted at by the differences in slope changes for Furnace 1 and 2. Melting of a solid charge demands a lot of energy, as does opening the furnace lid to cast result in heat losses.

In addition to basic functionality as an efficiency-monitoring device, it also has integrated features that take advantage of the laser sensor tracking of the metal level. Warning lights can illuminate to alert operators that the metal height has reached a critically low level (refill alarm), a critically high level (overflow alarm), and an arbitrary level, preset by the operator (ingot alarm). These alerts could potentially be tied in to a much larger foundry safety system that includes audible alerts that sound whenever one of these alarms is triggered.

**FCTM – Data**

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If a furnace is used more in a day, it will use more energy. This is a logical concept, but one that simply cannot be observed using a standard energy monitor. The FCTM, however, with its continuous monitoring, allows it to be documented.

Figure 8 is the same energy plots as in Figure 7, but with metal height and throughput plots included. These are the three main traces that the FCTM generates in each data file (Temperature is a fourth, but in this trial temperature monitoring was not done). The metal height is tracked by the laser scanner as part of the mass calculation for the throughput algorithm, but it also creates a visualization of the furnace metal level throughout the day. With all three data sets plotted, the utilization of furnaces 1 and 2 are much clearer. The casting of the metal out of the furnace can be seen as gradual decreases in metal height and corresponding increase in throughput. Refilling of the furnace is expressed as a semi-abrupt increase in metal height (A) resulting in no additional throughput. Throughput is defined as the total amount of molten metal added to or removed from the furnace - not both.

As shown, the timing of refill events is coincident with a rapid increase in rate of furnace energy use (increases power output to melt it). The throughput trace increases gradually as the metal is cast out of the furnace (B) and then is flat when the furnace is being recharged or not in use (C).

Overall, it can be said that for this example, Furnaces 1 and 2 were used sequentially, with Furnace 1 emptied then Furnace 2 cast while Furnace 1 was refilled. Furnace 1 was used a second time while Furnace B was being recharged. After only a portion of metal was cast, Furnace 1 was stopped but not refilled. Note that (D) coincides with the end of operations for the day, about 16:00. This particular foundry operates only one shift and their practice is to cast furnaces sequentially.

The rate function is one measure of furnace efficiency, a simple ratio of energy divided by throughput (kWh/kg), which the FCTM calculates and logs throughout the day. The rate data used for comparison are those collected at the end of each day (23:59:00), when the values have stabilized. For the example represented in Figure 8, the calculations are as follows:

**Furnace 1:** Max. Energy = 787 kWh; Max Throughput = 887 kg; Rate = 0.89 kWh/kg

**Furnace 2:** Max. Energy = 678 kWh; Max Throughput = 578 kg; Rate = 1.17 kWh/kg

When the daily energy expenditure is normalized to the daily throughput, data suggest that Furnace 1 is more energy efficient than Furnace 2, agreeing with the result observed in Figure 6. Even though Furnace 1 used more energy than Furnace 2, it was also more productive- a fact completely missed by measuring energy use alone (Figure 7) but readily captured by also measuring throughput with FCTM.

Figure 9 shows another application of FCTM where the incremental and cumulative rates are plotted (days of inactivity = 0.0). What develops are clear trends that represent relative efficiencies of the furnaces via the rate function.

**Advanced analysis**

What is interesting about the data in Figure 9 is that both furnaces are the same model and cast the same alloy using the same method, yet the results are very different. Some variables that are different: crucible type, pouring weight, and average throughput/day. Also the two furnaces have different operators. The point is that rate function is really a dependent variable, the product of not only hardware efficiency (furnace, crucible) but also more productive- a fact completely missed by measuring energy use alone (Figure 7) but readily captured by also measuring throughput with FCTM.
Because the FCTM monitors furnaces continually, it is possible for a foundry manager to utilize the FCTM as a tool for continuous improvement. It allows data analysis to the level of detail where the effects of an individual process step on furnace performance can be isolated. The foundry manager can then trial different ways of approaching the process step and then, using the data, review its effect on furnace performance.

For example, Figure 10 shows an abbreviated plot of metal height and energy use from a foundry furnace as a function of several minutes time. The plot has been divided into six different zones, each of which can be scrutinized to generate information about how the furnace was being used:

Zone A: The furnace lid is closed and idle; energy use is to compensate for heat loss to the environment through the furnace shell.

Zone B: The furnace lid is opened for rotary degassing. Metal level remains the same, but the open lid and degassing results in heat losses that trigger energy demand from the furnace.

Zone C: After degassing, the furnace lid is closed and idle; rate of energy use is almost same as in A but there is a slight depression indicating that there was some temperature overshoot.

Zone D: The furnace lid is open for casting. Slight increase in energy consumption rate to compensate for heat losses from the open lid.

Zone E: As casting is completed, solid ingot and scrap charges cause a high demand for energy, causing an abrupt change in slope.

Zone F: After charging is complete, the furnace lid is closed to facilitate melting of metal. The furnace energy demand is the same (100% power) as the metal continues to absorb heat before melting.

There is a lot of heat loss associated with having a furnace uncovered; to save energy some foundries opt to minimize the time the lid is open. Other foundries will operate with no lid or keep the lid open the entire time the furnace is in use. Using FCTM a foundry manager could potentially test the effect of covering the furnace more against overall energy use. Keeping a furnace sealed more to save energy is not a novel concept, but the ability to measure precisely how much energy is being wasted when it is not done is. This type of change would have a direct effect on FCTM rate function (kWh/kg). With the ability to discern when specific activities are taking place, the foundry manager could also verify operators are not deviating from established practices.

Another example, in Figure 11, shows FCTM traces of metal height and energy. This plot has been divided into five different zones, each of which is described thusly:

Zone A: Metal height in the crucible decreases as metal is cast. There are some interim periods where the lid is closed (horizontal lines). Energy use is commensurate with heat loss due to open lid during casting.

Zone B: Furnace is at minimum metal level, and is refilled by liquid charge in two stages. Energy trace slope increases steeply because furnace increases to full power to raise temperature of new charge.

Zone C: Furnace lid is closed and metal is allowed to reach the set-point. Energy demand slope is still high, as the charge is brought up to temperature.

Zone D: Metal temperature crosses set point, the furnace shuts off (0% power) until temperature drops back below the set point.

Zone E: With the lid closed and metal molten, the furnace draws nominal power to compensate for heat loss to the environment.

Since this is a function of time, one can get a reasonably accurate measure of furnace recovery time (233 minutes) or melt rate (kg/min) if the charge weight were known. These are potentially good metrics because by improving the R-value of the furnace insulation, changing the crucible type and/or changing the form of the recharge material, it can generate some time and energy savings that can be directly observed via FCTM.

One final example is the ability to use FCTM data for coordinating the more timely use of multiple furnaces. Another way to bring down the FCTM rate function (kWh/kg) is to increase the amount of casting per day/shift. In many foundry cells with multiple furnaces, after one is empty, they move to a second while the first is refilled and degassed. When the second is empty, they move back to the first, and so on. Figure 12 shows an example where two furnaces monitored by FCTM are used in series; first Furnace 1, then Furnace 2, then Furnace 1.
Note the amount of time spent in transition between casting from Furnace 1 and Furnace 2 (Zone B = 88 minutes) and then Furnace 2 back to Furnace 1 (Line C = 0 minutes). There are many steps necessary in preparing a furnace for casting (melt recharge, achieve set point, rotary degassing), but through the use of FCTM data, opportunities for efficiency improvement can be identified. The foundry manager could identify Zone B as lost time and subsequently make changes to the recharge program (abbreviated process, quicker turnaround) to minimize this gap, using future FCTM data as a measure of success. As a side-note, the features shown in the region marked ‘A’ occur because in this application solid recharge material is placed in the furnace and then the lid is closed. As that charge melts and raises the metal level, FCTM can detect the overall increase until the next time the lid is opened, resulting in a discontinuity.

If incremental improvements are made on each of several furnaces, the combined effect could be a very significant amount of time and energy savings. If, for every two furnaces, a foundry could realize savings equivalent to the price of one crucible, it equates to a 50% reduction in crucible costs. Evidence suggests that in some trial applications where FCTM is used to monitor energy use as a function of crucible type alone, with an energy-efficient crucible such as ENERTEK, the customer has the potential to recoup almost the full cost of the crucible over the course of its lifetime. This is even without scrutinizing nuances in the FCTM data to optimize customer operations. Without the FCTM to reveal this, the foundry manager may notice a change in the energy bill, however have no way to reconcile the changes nor understand to what extent a crucible influences the efficiency of the whole operation.

This is the advantage that FCTM provides—collecting large amounts of information the foundry manager can use, in multiple ways. The basic FCTM outputs are simple metrics that are universally understood; energy use/time, throughput/time, temperature/time. These describe a crucible furnace’s performance in relatively simple terms. The remaining data can be used, if desired, to delve deeper into the basic operating principles of the foundry, to understand how the furnace is being used and how this affects these metrics. For these reasons FCTM is not only a furnace energy monitor, but also a comprehensive tool for any foundry quality management system.

**Acknowledgements**

The authors would like to acknowledge their respective companies for the resources provided and the opportunity to publish this work. Special thanks are due to Mr. Michel Dussud, Operations Director with Aevem, for coordinating the development of the FCTM prototype. We also wish to thank Mr. Corentin Picard (Vesuvius), Mr. Andrew Moores (Foseco), and Mr. Ron Schaar (Foseco) for their expertise and insight on the subject material. Thanks also to Mr. Doug Harty (Foseco), Mr. Larry Bauer (Foseco), and Mr. Andrew Walker (Foseco) for alpha and beta trial site support. Finally, thanks to Mr. Mike Hankin (Foseco) for conceiving the idea that eventually grew to become FCTM.

**References**


**Additional resources**

+ www.foseco.com
+ www.vesuvius.com
The types of casting being made today in aluminium foundries are very varied. Thinner and lighter castings are being expected to perform in more arduous conditions than ever before and sophisticated Aluminium alloys are being developed to raise their potential properties to new heights. With ever increasing demands being placed on the foundry, there is an increasing need to control the individual processes that are involved in making the casting.

The starting point for any casting is the analysis and quality of the alloy with which it is to be made; there is therefore a growing need to measure, understand and control the quality of the melt before pouring.

Until the recent past, foundries have generally made castings and then subjected them to non-destructive testing to ensure that they were fit for service. The industry now has to move forward and the melt itself should be tested, prior to casting, to ensure that it is of sufficient quality to pour into the die or mould. If the quality of the melt can be measured first, then this is the first step towards it being controlled.

There are a number of different concerns relating to the melt for any foundryman; the major ones of these are:

- the hydrogen content of the Aluminium alloy immediately prior to casting
- the cleanliness of the melt and subsequent freedom from inclusions of the casting
- the microstructure of the finished casting.

To improve productivity and reduce production costs, many foundries have moved to central melting; the molten alloy must therefore be transported, treated and transferred several times before entering the mould cavity. Each of these transfers can potentially introduce hydrogen and create inclusions within the melt.

Because melt quality can change throughout the transport system, it is vital that the foundry thoroughly understands its own processes and has the ability to map the melt quality and conditions through the various stages, these include:

- Charge
- Melting
- Holding
- Melt treatment
- Transfer
- Casting

To be able to carry out a detailed investigation of melt quality in all these areas it has been essential to develop a set of tools that makes accurate measurement possible.

Over the past five years, Foseco has followed a process control strategy that has allowed such a set of tools for measuring the quality of the melt to be developed.

This paper will describe these tools and discuss some of the results that have been generated by them to date.

**Implication of dissolved hydrogen**

Molten aluminium is highly reactive and easily reduces water vapour to form aluminium oxide and hydrogen. The hydrogen then dissociates into its atomic form and then diffuses into the melt. This atomic hydrogen is readily taken into solution in the molten aluminium, however during solidification this results in a drastic reduction in solubility. The consequence of the hydrogen content in the melt being high is that the hydrogen becomes liberated during solidification to form very fine porosity throughout the casting. This porosity is not interconnected but will form points of weakness in the casting as well as becoming unsightly on machined surfaces.

Conversely if the hydrogen content is very low, then any shrinkage which forms in the casting will tend to be concentrated in those areas of the casting that solidify last. This results in a very low hydrogen content that can encourage gross shrinkage porosity if the feeding practice is not 100% effective. It is therefore advantageous to measure the hydrogen content prior to casting when the hydrogen level can still be adjusted, if required, against a predefined tolerance for that particular casting and feeding technique.
Typical results from the field

| Safety critical components 1000 kg transfer ladle | Hydrogen cc/100g Before 4 minutes degassing with XSR rotor | Hydrogen cc/100g
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Before treatment</td>
<td>0.27</td>
<td>0.11</td>
</tr>
</tbody>
</table>

| Cylinder heads 1000 kg transfer ladle | Hydrogen cc/100g Before 8 minutes degassing with XSR rotor | Hydrogen cc/100g | Density Index
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Before treatment</td>
<td>0.43</td>
<td>0.08</td>
</tr>
<tr>
<td>Before treatment</td>
<td>0.27</td>
<td>0.08</td>
</tr>
<tr>
<td>Before treatment</td>
<td>0.22</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Table 1. Safety critical components

Rotary degassing with an XSR rotor gives very consistent hydrogen removal. However over the course of time and during production, hydrogen can re-enter the melt from the atmosphere or from damp refractories. This gradual re-entry of the hydrogen results in an inconsistency of casting quality. By continually measuring the hydrogen to identify the problem early before any castings are poured, one can potentially reap real rewards.

Chip melting 800 kg gas-fired furnace

<table>
<thead>
<tr>
<th>cc/100g</th>
<th>cc/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before treatment</td>
<td>After 20 minutes degassing with FDR rotor</td>
</tr>
<tr>
<td>Before treatment</td>
<td>After 10 minutes degassing with FDR rotor</td>
</tr>
</tbody>
</table>

Table 2. Chip melting

More foundries are re-melting their machining swarf and chips to remain commercially competitive. Even when dried and cleaned this material can still generate hydrogen and oxide formation during melting. Rotary degassing with an FDR rotor is efficient enough to remove even these high levels of hydrogen and oxides

Wheel foundry 800 kg transfer ladle AS115G

<table>
<thead>
<tr>
<th>cc/100g</th>
<th>cc/100g</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before treatment</td>
<td>After 8 minutes FDR rotor</td>
<td>2.587</td>
</tr>
<tr>
<td>Before treatment</td>
<td>After 8 minutes FDR rotor</td>
<td>2.597</td>
</tr>
<tr>
<td>Before treatment</td>
<td>After 8 minutes FDR rotor</td>
<td>2.585</td>
</tr>
</tbody>
</table>

Table 3. Wheel foundry

Degassing model

Working with our partner, Technology Strategy Consultants, we have developed a mathematical model from first principles that models the rotary degassing process.

This model takes into account the following variables in the foundry process:

- Alloy
- Atmospheric conditions
- Kinetics of degassing
- Interface mass transfer coefficients
- Parameters of the rotary degassing unit
- Rotor design
- Hydrogen reabsorption

By using the model, one can therefore reproduce the current degassing performance achieved at present. Additionally you can demonstrate how to improve efficiency by changing rotor design, rotor speed or inert gas flow.

This enables the foundry to achieve optimum degassing performance without the need for expensive foundry trials.

Following the initial MeltMap Audit the Foseco Degassing Model can be used to optimise the degassing parameters as shown below in Figure One for an XSR 190 mm rotor in a BU 700 crucible at 770 °C.
Measurement of melt cleanliness

There are several devices already available for measuring the cleanliness of an Aluminium melt, some very sophisticated and too expensive for foundries and others that are simple but that have not been adopted for regular use on the foundry floor.

To find a balance, there are two testing modes that have been adopted by Foseco:

- Sampling using a K-mould die
- Vmet

Sampling using a K-mould die

After using a K-mould die to sample the melt, it’s then possible to break the resulting initial sample along the notch and examine the fracture face.

Vmet

The K-Mould die test described above can only identifying coarse inclusions however.

To conduct testing that yields more comprehensive results, the individual samples can then be polished and examined further on a Scanning Electron Microscope with image analysis, using a technique known as "Vmet".

The image analysis will detect the following features:

- Porosity
- Aluminium oxides
- Other oxides from alloying elements

The Vmet analysis then identifies, counts and measures those features. See Tables 5 and 6 for details of a report produced by the Vmet analysis.

MeltMap Audit

By combining the techniques described above, we have developed a very powerful auditing process that can measure the melt quality throughout the foundry. The data can also be used to investigate different types of charge material and different furnaces. The final melt quality can be assessed and the quality of the final metal poured into the mould can be assured.

The auditing process contains results from the field in the following categories:

1. Melt treatment
2. Swarf melting
3. Melt transfer
4. Standing time
1. Melt treatment

<table>
<thead>
<tr>
<th>Typical sample from as-cast melt</th>
<th>Sample after 5 minutes MTS 1500 treatment with COVERAL MTS 1524 flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1</td>
<td>Sample 2</td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td></td>
</tr>
<tr>
<td>Inclusion Index</td>
<td>Before Treatment</td>
</tr>
<tr>
<td></td>
<td>After 5 minutes MTS 1500 with COVERAL MTS 1524 flux</td>
</tr>
<tr>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>0.5 – 2.5 micron</td>
<td>Total number of defects (porosity and inclusions included)</td>
</tr>
<tr>
<td>2.5 – 5.0 micron</td>
<td>176</td>
</tr>
<tr>
<td>5.0 – 15 micron</td>
<td>187</td>
</tr>
<tr>
<td>&gt; 75 micron</td>
<td>29</td>
</tr>
<tr>
<td>Aluminum Oxide</td>
<td>178</td>
</tr>
<tr>
<td>Clusters</td>
<td>41</td>
</tr>
<tr>
<td>ALSEP H</td>
<td>0.31 cc/100g</td>
</tr>
<tr>
<td></td>
<td>0.18 cc/100g</td>
</tr>
</tbody>
</table>

Table 5. Vmet analysis before and after MTS 1500 treatment

Table 5 shows the Vmet analysis from a melt before and after treatment with MTS 1500 and COVERAL MTS 1524.

In the as-melted condition there is a medium number of features: 555 in number. Most of these features are in the 0.5 to 15 micron range, although we must consider that the inclusions are bigger than measured as they have been sectioned and polished. However there are 29 inclusions in the 30 – 75 micron range and 1 greater than 75 micron.

A 5-minute treatment with MTS 1500 technology using an FDR rotor and COVERAL MTS 1524 reduces the number of features from 555 to 81. Significant reductions in the number of features are reported across all the micron size ranges.

Only one feature remains in the 30 – 75 micron range; there are no features over 75 microns in size reported.

Clusters are inclusions which could be very large and these are reduced from 41 down to only 5.

You can see a graphical interpretation of these results in Figure 9 below.

2. Swarf melting

<table>
<thead>
<tr>
<th>Sample 3</th>
<th>Sample 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>In as-melted condition</td>
</tr>
<tr>
<td>Features (pores, aluminium oxide, alloy oxide)</td>
<td>4510</td>
</tr>
<tr>
<td>0.5 – 2.5 micron</td>
<td>205</td>
</tr>
<tr>
<td>2.5 – 5.0 micron</td>
<td>797</td>
</tr>
<tr>
<td>5.0 – 15 micron</td>
<td>2490</td>
</tr>
<tr>
<td>&gt; 15 micron</td>
<td>703</td>
</tr>
<tr>
<td>Aluminum Oxide</td>
<td>295</td>
</tr>
<tr>
<td>Clusters</td>
<td>20</td>
</tr>
<tr>
<td>ALSEP H</td>
<td>0.46 cc/100g</td>
</tr>
<tr>
<td></td>
<td>0.16 cc/100g</td>
</tr>
</tbody>
</table>

Table 6. Vmet of swarf material before and after treatment

The swarf charge contains a large number of oxides as well as a lot of porosity associated with the oxide films. These are efficiently removed by the MTS 1500 vortex treatment and COVERAL 1565 flux treatment.
3. Melt transfer

Many foundries carry out melt treatment in transfer ladles before finally transferring the melt to a casting furnace. Although this is a very efficient way of utilising a central central treatment station it can result in a reduction in melt quality.

Table 7 shows the impact of turbulent transfer on a well-treated melt. The increase in pores further confirms that the problem is turbulent flow.

Table 7. Impact of turbulent filling on melt cleanliness

<table>
<thead>
<tr>
<th>Features (pores, aluminium oxide, alloy oxide)</th>
<th>Inclusion Index</th>
<th>Ladle after 150 treatment</th>
<th>Furnace after filling from the ladle</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 – 2.5 micron</td>
<td>298</td>
<td>1885</td>
<td></td>
</tr>
<tr>
<td>2.5 – 5.0 micron</td>
<td>558</td>
<td>645</td>
<td></td>
</tr>
<tr>
<td>5.0 – 15 micron</td>
<td>367</td>
<td>1465</td>
<td></td>
</tr>
<tr>
<td>15 – 30 micron</td>
<td>62</td>
<td>522</td>
<td></td>
</tr>
<tr>
<td>30 – 75 micron</td>
<td>22</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>&gt; 75 micron</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Pores</td>
<td>918</td>
<td>2936</td>
<td></td>
</tr>
<tr>
<td>Aluminium Oxide</td>
<td>626</td>
<td>237</td>
<td></td>
</tr>
<tr>
<td>Alloy Oxide</td>
<td>289</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Clusters</td>
<td>59</td>
<td>236</td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Impact of turbulent filling on melt cleanliness

4. Standing time

It is common practice in certain foundries to allow the melt to stand for 30 minutes both after the treatment and transfer stage and before casting begins. One advantage of this practice is that it allows time for the dense inclusions to sink to the bottom of the crucible and for the low density inclusions to float into the dross level, to be skimmed off before casting begins.

Vnet analysis can recognise this if samples are taken immediately after treatment and then again after 30 minutes. Table 8 below gives details.

Table 8. Impact of standing time on melt cleanliness

<table>
<thead>
<tr>
<th>Features (pores, aluminium oxide, alloy oxide)</th>
<th>Inclusion Index</th>
<th>Ladle after 150 treatment</th>
<th>Furnace after filling and 30 minutes standing</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 – 2.5 micron</td>
<td>8.8</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2.5 – 5.0 micron</td>
<td>1654</td>
<td>433</td>
<td></td>
</tr>
<tr>
<td>5.0 – 15 micron</td>
<td>1076</td>
<td>313</td>
<td></td>
</tr>
<tr>
<td>15 – 30 micron</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>30 – 75 micron</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>&gt; 75 micron</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pores</td>
<td>485</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>Aluminium Oxide</td>
<td>1139</td>
<td>212</td>
<td></td>
</tr>
<tr>
<td>Alloy Oxide</td>
<td>30</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Clusters</td>
<td>74</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

Table 8. Impact of standing time on melt cleanliness

Conclusions

- Foseco and their partners have developed a family of tools to assess the quality of an Aluminium melt with regard to hydrogen content and cleanliness.
- The Degassing Process can be modelled to optimise the process without trials.
- A rough test of metal cleanliness can be made by fracturing a K-Mould sample and then examining it by eye.
- A very detailed analysis of the melt quality can be made using the Vnet image analysis technology.
- Different qualities of melt charge can be assessed and by using MTS 1500 vortex / flux treatment, the melt can then be cleaned to an excellent level for casting.
- The use of the MeltMap audit can give the foundry a thorough understanding of their melt treatment and handling process, identify weaknesses and in that way generate Process Improvement projects.
- The level of detail provided by such an audit enables foundry groups to benchmark their individual operations and gives all foundries the base information by which to make annual assessments of quality improvement.

References

More than a filter
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Advances in the determination of hydrogen concentrations in Aluminium Alloys
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TMS 2010
Introduction

The production of aluminium castings globally is dominated by the automotive industry and the growing importance of emissions and fuel economy has resulted in a rapid increase in the use of aluminium castings. For these demanding applications many of the attributes in terms of mechanical strength, elongation and fatigue strength can no longer be satisfied by standard alloys and so new alloys with greater potential have been, and will continue to be, developed. To exploit the potential of these alloys completely then pore-free castings of high cleanliness and fine structure must be produced. Safety critical castings now require elongation in excess of 10% from the casting itself and this is moving close to the limit for the alloy. The ‘window’ for melt properties to fulfill these requirements becomes smaller and smaller whilst the starting conditions such as ingot quality, melting and holding furnace condition, temperature control and melt transfer can become limiting factors. To ensure that the correct casting quality is achieved then a more effective and technically sound melt treatment is essential followed by a well-designed and controlled pouring practice.

Another important attribute required by the automotive industry is reproducibility and so any melt treatment adopted must be capable of achieving consistent levels of cleanliness and hydrogen control. Many quality management systems also require a 100% record of production data so again a sophisticated melt treatment system with data storage becomes more attractive to the automotive industry.

An innovative process which can automatically achieve the same melt quality regardless of the external environmental conditions will be the key to the future production of truly high quality castings meeting the needs of this growing market segment.

Degassing simulation

Foseco’s non-ferrous Marketing and Technology team have worked with tsc - Technology Strategy Consultants to develop a web-based batch degassing model. It has been designed as a tool to analyse quickly foundries’ operations, and make suggestions for their improvement.

The mathematical model behind this software is based on the best available published information concerning the kinetics of hydrogen degassing (e.g. hydrogen solubility, diffusivity, mass transfer rates and stable bubble sizes). An extensive trial program was undertaken to provide specific information about individual rotors under different conditions.

To characterise different rotors the following trials were carried out:

- Power analysis of degasser rotors
- Mixing capabilities of degasser rotors
- Gas solubility tests in water
- Foundry trials in aluminium melts

A full description of the development work is given in Foundry Practice 256 (2011).

Parameters influencing degassing results

Three main groups of variables influence the degassing efficiency: ambient conditions, rotary degasser parameters, and melt properties. The hydrogen concentration in the melt has been calculated using the Degassing Simulation for the following widely common set of parameters (Table 1); and variations of the parameters illustrate the influence on the degassing result and the final hydrogen content in the melt after treatment.

<table>
<thead>
<tr>
<th>Parameter Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATL 1000 with 850 kg melt</td>
<td>XSR 220 rotor</td>
</tr>
<tr>
<td>AISi7Mg</td>
<td>420 rpm</td>
</tr>
<tr>
<td>750 °C melt temperature</td>
<td>20 l/min inert gas</td>
</tr>
<tr>
<td>50% relative humidity</td>
<td>0.30 ml H2 / 100 g Al starting level</td>
</tr>
<tr>
<td>25 °C outside temperature</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Model simulation parameters
1. Ambient conditions

The melt forms an equilibrium with the water in the surrounding atmosphere; a warm and humid climate gives much higher hydrogen content in the melt than a dry and cold climate (picture 1).

During rotary degassing the melt is in interaction with the atmosphere and picks up hydrogen again. The degassing simulation shows the effect of different ambient conditions (diagram 1):

![Diagram 1. Degassing curves for different ambient conditions](image1)

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Water Vapour Pressure (atm.)</th>
<th>Hydrogen (ml/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>0.005</td>
<td>0.000</td>
</tr>
<tr>
<td>700</td>
<td>0.050</td>
<td>0.005</td>
</tr>
<tr>
<td>800</td>
<td>0.100</td>
<td>0.010</td>
</tr>
<tr>
<td>900</td>
<td>0.150</td>
<td>0.015</td>
</tr>
<tr>
<td>1000</td>
<td>0.200</td>
<td>0.020</td>
</tr>
</tbody>
</table>

![Diagram 2. Degassing curve for inert gas flow variations](image2)

![Diagram 3. Degassing curves for rotor speed variations](image3)

2. Rotary degasser parameters

The rotary degasser can run a treatment with different rotation speed and inert gas flow rates. Each rotor design has minimum and maximum values for those parameters – working conditions – for rotor speed and inert gas flow rate. It is important that both parameters are within the limits; running a treatment at very high rotation speed and extensive flow rates would create too much turbulences or in extreme cases an aeration of the rotor with a complete loss of degassing performance.

The diagrams 2 and 3 show degassing behaviour for typical parameters of an XSR 220 rotor under varying conditions:

![Diagram 2. Degassing curve for inert gas flow variations](image2)

![Diagram 3. Degassing curves for rotor speed variations](image3)

3. Melt properties before treatment

The alloys composition has a huge influence on the degassing performance. Elements like Magnesium increase hydrogen solubility whilst Silicon or Copper slightly decrease it (diagram 4). The melt temperature influences the equilibrium with the atmosphere; melt at higher temperature dissolves more hydrogen (diagram 5).

The starting hydrogen level is often unknown, but the diagram shows that variations in the initial hydrogen does not change the final result (diagram 6).

![Diagram 4. Degassing curves for different alloys](image4)

![Diagram 5. Degassing curves for different melt temperatures](image5)

![Diagram 6. Degassing curves for different initial hydrogen levels](image6)
SMARTTT – an innovative process control

SMARTTT is the acronym for self-monitoring adaptive recalculation treatment and an innovative process control that analyses all incoming parameters and calculates the treatment parameters for the rotary degassing process just before each treatment. The target for the optimisation is a constant melt quality after each treatment.

The SMARTTT software is installed on a Windows PC, input and output of data is carried out on a comfortable touch screen panel. The SMARTTT PC is LAN connected to the Siemens PLC that controls the degassing unit.

Picture 2. Schematic setting of SMARTTT

The SQL data base system makes it to an open interface and enables the operator to define a nearly unlimited number of crucible or ladle shapes, alloy types and treatment programs.

The target for all simulations is the hydrogen content in the melt and used for both degassing and upgassing procedures.

1. Ambient conditions

Relative humidity and outside temperature are measured by a standard sensor, mounted next to the control cabinet in the area where the treatment takes place. The actual readings are on-time transferred to SMARTTT and recorded over time.

2. Alloy composition and vessel geometry

SMARTTT comes with a number of pre-defined alloys and crucible or transfer ladle geometries. The user can easily modify, add or delete these. Alloy and treatment vessel become part of each program together with a recommended rotor type and diameter (picture 4).

3. Customer requirements

SMARTTT offers four different treatment schemes to choose from. The calculation is based on a minimum and maximum gas flow rate and rotor speed depending on rotor type and diameter as well as on vessel size. The minimum degassing time is a parameter to ensure proper oxide removal.

**High-speed degassing** – shortest possible treatment time at highest possible rotor speed and inert gas flow rate. A minimum treatment time is observed to allow homogenisation and oxide removal.

**Low gas degassing** – runs the treatment for a given time at lowest gas consumption and correlated rotor speed to achieve the target.

**Long life** – runs at lowest possible rotation speed to reduce the shaft and rotor abrasion. The corresponding inert gas flow depends on the total treatment time.

**Standard degassing** – the average of low gas and low speed provides a balance between the two extreme schemes.

The high-speed scheme is used if the degassing process is the bottleneck in the foundry and huge amounts of melt are needed for the following casting steps. The high-speed treatment can be used for certain times i.e. during morning shift with high melt demand or if the castings are heavy at short cycle time. The other schemes are depending on the local requirements.

4. MTS 1500 settings

SMARTTT is suitable for degassing machines with the optional MTS 1500 automated granulate addition as well. The MTS parameter setting is carried out on the touch screen in the conventional way, those parameters are not part of the optimisation. Nevertheless the different MTS programs are part of the treatment programs and combined with optimisation schemes and hydrogen targets (picture 5).
5. Product screen

The product menu brings all pre-defined program parameters together: treatment vessel geometry, alloy and MTS 1500. Additionally the limits for the degassing time are defined. The required hydrogen content in the melt is the target for the optimisation process (picture 6).

The different optimisation schemes enable the foundry to achieve the same degassing result in the same time using different parameter settings. The low gas options should be used for regions with high inert gas costs; the long life option reduces the erosion of shaft and rotor whilst standard degassing is a good balance between the two extremes. High-speed degassing is an option where the degassing procedure is the bottleneck in the melt shop.

A product name differentiates the different settings and makes it easy for the operator to choose the right one.

6. Operator screen

All previously described screens are accessible for the administrator only. The operator sees a specially designed interface to make an easy choice from 10 different administrator defined products. Additionally the ambient conditions and remaining treatment time are displayed (picture 7).

Results from field trials

During the foundry trial phase the SMARTT software was installed on a DUK Mark 10 mobile degassing unit with a 1 hopper MTS 1500 dosing system. The trials were started with a simple degassing procedure; the target was to achieve a standard melt quality with a minimum hydrogen level of 0.08 ml hydrogen per 100 g aluminium.

The parameters in table 2 - similar to the model simulation in the beginning of this paper (table 1) - were used for the SMARTT trials:

<table>
<thead>
<tr>
<th>Product</th>
<th>XSR 220 rotor</th>
<th>0.30 ml H₂ / 100 g Al starting level</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATL 1000 with 850 kg melt</td>
<td>750 °C melt temperature (*)</td>
<td>300 s minimum treatment time (*)</td>
</tr>
<tr>
<td>AlSi7Mg</td>
<td>50 % relative humidity (*)</td>
<td>25 °C outside temperature (*)</td>
</tr>
</tbody>
</table>

(*) – might vary for some examples

Table 2. SMARTT simulation parameters

The following tables compare the optimised SMARTT treatment parameters to reach the target under varying conditions and parameters. Table 3 illustrates the different optimisation schemes, table 4 compares the parameters for three different ambient conditions and table 5 provides parameters for different melt temperatures before treatment.

1. Optimisation schemes

The standard degassing, low gas and long life start their optimisation procedure at given minimum treatment time and try to find a logical result to reach the target. If no result is found the treatment time is increased. The low gas option runs with maximum rotor speed and according inert gas flow to reach the hydrogen target in time whilst the long life option is following the opposite strategy with lowest possible rotor speed and inert gas at maximum limit. The standard degassing scheme takes a result just between the two extremes. High-speed degassing runs the treatment close to the maximum for both rotor speed and inert gas flow and calculates the shortest possible treatment time to reach the hydrogen level at the end of the treatment (table 3).
The low gas option consumes 55 litres of inert gas less per treatment compared to the long life scheme. Foundries with 4 treatments per hour can save up to 1,500 Nm³ per year. This is an equivalent to more than 150 gas cylinders.

The reduced speed causes a reduced graphite shaft wearing. Based on customers experiences the lifetime of shaft and rotor increases by 25 % at 150 rpm lower speed. Depending on treatment conditions a foundry with 4 treatments an hour can save up to 15 sets of consumables – rotor and shaft – per year.

2. Ambient conditions
SMARTT measures the ambient conditions just before each treatment and starts the optimisation procedure based on the product settings. At higher humidity levels in the atmosphere the rotor speed and gas flow rate increase for standard degassing and vice versa. This is an expected result due to interactions of the melt surface with the atmosphere. The SMARTT software finds results up to ambient conditions of 75 °C and 28 °C, for higher humidity levels the 0.08 ml hydrogen target is not achievable due to the regassing on the turbulent melt surface during the treatment.

Table 3. Results for different optimisation schemes

<table>
<thead>
<tr>
<th>Optimised</th>
<th>Rotor Speed (RPM)</th>
<th>Gas Flow (std. l/min)</th>
<th>Process Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard degassing</td>
<td>404</td>
<td>404</td>
<td>360</td>
</tr>
<tr>
<td>Low gas consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimised</td>
<td>Rotor Speed (RPM)</td>
<td>Gas Flow (std. l/min)</td>
<td>Process Time (sec)</td>
</tr>
<tr>
<td></td>
<td>404</td>
<td>404</td>
<td>360</td>
</tr>
<tr>
<td>Standard degassing</td>
<td>404</td>
<td>404</td>
<td>360</td>
</tr>
<tr>
<td>Low gas consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Results for different ambient conditions

<table>
<thead>
<tr>
<th>Optimised</th>
<th>Rotor Speed (RPM)</th>
<th>Gas Flow (std. l/min)</th>
<th>Process Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard degassing</td>
<td>404</td>
<td>404</td>
<td>360</td>
</tr>
<tr>
<td>Low gas consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimised</td>
<td>Rotor Speed (RPM)</td>
<td>Gas Flow (std. l/min)</td>
<td>Process Time (sec)</td>
</tr>
<tr>
<td></td>
<td>404</td>
<td>404</td>
<td>360</td>
</tr>
<tr>
<td>Standard degassing</td>
<td>404</td>
<td>404</td>
<td>360</td>
</tr>
<tr>
<td>Low gas consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Melt temperature
Aluminium dissolves more hydrogen at higher temperatures and takes even more hydrogen back at the melt surface from atmosphere. The treatment is carried out at faster rotor speed and higher inert gas flow rates with increasing temperature and conversely. SMARTT found a logical solution for up to 780 °C, no parameter setting could be predicted for 800 °C due to too high initial hydrogen content and the re-pick-up on the surface (table 5).

Table 5. Results for different optimisation schemes

<table>
<thead>
<tr>
<th>Optimised</th>
<th>Rotor Speed (RPM)</th>
<th>Gas Flow (std. l/min)</th>
<th>Process Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard degassing</td>
<td>404</td>
<td>404</td>
<td>360</td>
</tr>
<tr>
<td>Low gas consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimised</td>
<td>Rotor Speed (RPM)</td>
<td>Gas Flow (std. l/min)</td>
<td>Process Time (sec)</td>
</tr>
<tr>
<td></td>
<td>404</td>
<td>404</td>
<td>360</td>
</tr>
<tr>
<td>Standard degassing</td>
<td>404</td>
<td>404</td>
<td>360</td>
</tr>
<tr>
<td>Low gas consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Data logging
The SMARTT software runs a data logging system that enables a complete parameter tracking for date time and all pre-defined and optimised degassing functions. This very comfortable function replaces complex systems that run on external computers using 3rd party data logging software. The treatment data can be exported to standard office applications for further analysis.

Summary
- Casting requires a melt on a constant hydrogen level.
- Inconsistent starting conditions in a foundry make it impossible to always reach this in the cost effective way.
- Foundries today compensate this effect in mostly overrunning the treatment which wastes inert gas and graphite consumables.
- SMARTT offers a comfortable interface to program all necessary treatment steps.
- The innovative degassing control predicts the best treatment parameters for different schemes under given conditions.
- SMARTT saves inert gas or extends graphite consumables lifetime.
- SMARTT records all treatment parameters.
- An innovative process control is the best solution for foundries that treat high melt volumes with a number of different castings that require the same or similar quality levels.
Installation of dosing furnaces with INSURAL

Target: Quicker availability

The solution for your dosing furnace: Completely dry installation with INSURAL precast shapes and high insulating backing materials. Huge energy savings, no sintering, low density index of the melt immediately, easy cleaning.

A market analysis among our customers showed clearly, that there is a strong need for optimisation in terms of cleaning and avoidance of corundum growth. To solve these problems, extended trials with different INSURAL recipes have been made. Foseco now offers a completely dry installation with INSURAL precast shapes which provides a number of benefits:

- Installation in the foundry is possible
- No sintering process needed
- The desired density index of the melt can be achieved much quicker
- The growth of corundum is reduced to a minimum
- Easy cleaning
- Huge energy savings

To the precast shapes belongs a launder, which holds the molten metal and two roof plates, two heating element plates and six tubes for the heating elements. All elements will be assembled without plaster or glue. The installation can be done by untrained operators within 65 - 70 working hours (depending on circumstances). There is no need for special tools.

The area of the heating elements with separated plates and tubes is not sensible for cracks anymore. The changing of heating elements is simplified.

The INSURAL precast shapes are installed together with a high insulating backing material. High insulating plates get installed on the inside of the steel shell. The gap between the plates and the INSURAL piece is filled with a high insulating bulk material. The heating is separated with plates.

As no plaster is in use, parts of the backing materials can be reused in the following installation.

After the installation, the furnace can be switched on and is ready to use after achieving the desired working temperature.

The diagram shows clearly the huge time saving only in this step. Depending on the quality requirements, the density index of the melt plays an important role.

Due to the dry installation, the required density index can be achieved a lot quicker than general.

The use of the INSURAL material provides a minimised corundum build up and easy cleaning due to its non wetting ability.
An alloy change in the furnace is possible at any time. The only need is a cleaning process with only one flushing batch.

As INSURAL has a good insulating property, it is the basic material for the concept.

The case study shows that a dosing furnace with a capacity of 650 kg can be heated up to 720 °C within 11 hours.

The measurements of the power consumption shows the reduced energy need (up to 17 %).

The heating element stays on the lowest level for 98 % of the time (positive for low corundum growth). This fact also reduces the energy consumption in the stand-by stage (on weekends etc).

Another case study with a dosing furnace with a capacity of 1050 kg shows an energy saving of approximately 80 kWh per day. This high values is obviously caused by the high melt temperature of 780 °C.

The installation with InsurAl precast shapes provides a number of benefits:

- Quick installation on site possible
- No need for sintering
- No hydrogen pick-up
- Minimised corundum growth
- High energy saving
- Easy cleaning

Summary

The installation with INSURAL precast shapes provides a number of benefits:

- Quick installation on site possible
- No need for sintering
- No hydrogen pick-up
- Minimised corundum growth
- High energy saving
- Easy cleaning
Introduction

This paper investigates the use of pumping rotors applied on a rotary degassing machine that offers a practical and affordable method of retaining consistent melt quality within a radiant heated holding furnace. The furnace is located in a casting cell making automotive cylinder heads.

In order to improve productivity and remain competitive, most medium and large aluminium foundries have moved to central melting.

By using large tower or reverberatory furnaces it is possible to increase melting rates, reduce energy usage and improve metal yield by controlling oxidation and metal loss.

Once molten, the alloy is then normally treated in transfer ladles to give many hours of production, being regularly topped up to maintain a fairly full bath.

These furnaces can be crucible furnaces, electric radiant-heated bath furnaces or dosing furnaces and often they are of a capacity to give many hours of production, being regularly topped up to maintain a fairly full bath.

Although this practice guarantees a sufficient supply of metal to maintain production it does however also entail long standing times for the melt.

On standing over periods of several hours, the following issues may arise in aluminium furnaces:

1. In radiant-heated furnaces there can be temperature instability with the lower part of the bath being considerably cooler than the top surface.
2. Heavy elements and intermetallic compounds can sink to the bottom of the bath and, over the course of time, form a sludge that can remain in the furnace for a long time as these furnaces are difficult to clean. If suddenly disturbed the sludge can temporarily rise in the bath to result in a cloud of inclusions that may affect a whole production batch of castings.
3. The hydrogen content of the melt can change in time depending upon the melt temperature and humidity in the foundry atmosphere.

This segregation and lack of homogeneity can therefore result in the following outcomes:

- Cold defects in castings if the casting temperature is low
- Shrinkage porosity in castings if the casting temperature is high
- Irregular grain refinement due to settling of Titanium Diboride nuclei
- Inclusions in castings from time to time
- Intermittent porosity defects depending upon atmospheric conditions

It is common in very large holding furnaces, of many tonnes, to use electro-magnetic or mechanical pumping systems to circulate the melt; however this is rarely seen on holding furnaces of 1-2 tonnes capacity.

Montupet is a French-owned aluminium foundry group and has long been recognised as an industry leader in the manufacture of complex cast aluminium components for the automotive industry worldwide. AUDI, BMW, CITROËN, DAEWOO, FORD, GENERAL MOTORS, NISSAN, PEUGEOT, RENAULT and VOLVO are long-standing customers of Montupet for cylinder heads and other engine parts. These other engine parts include hub carriers and steering knuckles, pump and turbocharger housings, brake master cylinders and calipers. The Montupet Group comprises seven foundries in France, UK, Spain, Mexico and Bulgaria. They use the most appropriate casting processes depending on the design and specifications of the particular product. As Montupet are making diesel and gasoline cylinder heads and sometimes need to grain refine with Titanium Boron, there is concern about possible settling of the TiB₂ particles when left standing in a holding or casting furnace. To retain their high quality assurance level Montupet wish to improve the homogeneity of their holding / casting furnaces. This therefore poses the question what is the best method for stirring these furnaces during production and avoid TiB₂ settling?
Several reasons can drive the choice of rotor type. The viscosity of the liquid, stirring capability, or the process that it is being used in, for example:

- Homogenisation
- Degassing
- Redistribution of solids
- Mixing melt and liquids
- Heat transfer
- Chemical reactions

In the case of this study, the following specific key target areas of a holding furnace were scrutinised:

- Heat transfer
- Solids distribution
- Homogenisation

We looked at the effectiveness of the following rotor types across all these target areas:

- Propeller rotors
- Paddle rotors (also known as Rushton-Turbine)
- Foseco’s MTS FDR pumping rotor
- Foseco’s FDU TDR pumping rotor

Rotors can be divided into two categories depending on the direction in which they mix:

- Axial rotors (stirring liquid axially in the direction of the shaft axle—see Figure 3 and 4)
- Radial rotors (stirring liquid transversely away from the shaft—see Figure 5 and 6)

**Propeller rotors**

These are designed with three blades like a ship’s propeller, driving liquid in the direction of the axle, used in liquid suspensions, homogenisation or heat transfer.

Axial flow in propeller rotors stops deposits from forming in the stirrer tank and results in liquid suspensions being formed.
Paddle / Rushton-turbine rotors:
These are formed of circular disks usually with 6 blades pointing upwards and outwards arranged in a circle around the shaft. These are also known as Rushton-turbine rotors. They provide transverse flow, and generate a powerful slicing action for use in emulsifying and degassing processes.

Transverse flow from the disk-shaped rotors (Figure 6) facilitates distribution of gas bubbles (Figure 5).

Foseco high-performance pumping rotors
Foseco rotors are characterized by an innovative pumping design that is key for advanced functionality and excellent homogenization. Because of their pumping action, the melt is drawn into the rotor chamber (see Figure 9 below). This results in the treatment and homogenization of untreated melt volumes from the bottom of the treatment vessel.

The MTS FDR (Figure 7) and FDU TDR (Figure 8) rotors have developed from the series, a well proven rotor which is still used in many applications today.

Trials with models using water
Foseco has tested several rotor designs in trials using a scale model, to ascertain those that can achieve a consistent quality of melt in a holding furnace. To determine the quality of fluid mixing, we compared non-pumping rotors, of the Rushton-turbine and propeller varieties, with Foseco pumping rotors.

There are two essential requirements for a successful homogenization system:

- Rapid mixing of the melt that ensures equal distribution - both thermal and chemical.
- Significantly shorter homogenisation times compared with the treatment times required to achieve these.

In the past, trials using perspex model tanks have shown large differences in rotor power when mixing - see the dispersal of red dye in Figure 10 for an example: after an additional 4 seconds, the Foseco pumping rotor gives an almost perfect homogenization of particles, whereas the non-pumping rotor by contrast has not achieved anything like the same homogenisation.

Trials with non-pumping rotors
Based on these trials, Foseco set up a series of further tests, to define the various stirring characteristics of contrasting rotor designs when using different parameter settings.

To do this, models of rotors were used with a diameter in the ratio of 1:3 when compared to the standard sized original rotors. Foseco conducted all trials in a specially-designed perspex model of a holding furnace. Eight Type-T thermocouples were distributed across the container as shown in Figure 11 to record the temperature after adding a pre-determined volume of hot water over a period of 12 minutes.

Figure 10. Mixing behaviour of different rotors when compared in a Perspex model tank

Four of the thermocouples were positioned in the immediate vicinity of the tank floor. The remaining four were positioned in the upper part of the tank. For each test, approximately 7 litres of hot water at around 70 °C were added to the container once steady mixing conditions had been established. The temperatures were logged at 10 ms intervals using an 8 channel USB TC 08 Data Logger from Pico Technology.

Figure 12 shows the results from the thermocouples of the hot water trial without any rotors. After 12 minutes temperature levels have not evened out and there are clear temperature differences between the areas of water around separate thermocouples.
Significantly shorter homogenisation times compared with rapid mixing of the melt that ensures equal distribution - homogenisation system:

There are two essential requirements for a successful turbine and propeller varieties, with Foseco pumping rotors. Mixing, we compared non-pumping rotors, of the Rushton-turbine model, to ascertain those that can achieve a consistent quality of fluid. Foseco has tested several rotor designs in trials using a scale model of a holding furnace. Eight Type-T thermocouples were distributed across the container as shown in Figure 11 to record steady mixing conditions had been established. The temperatures of hot water at around 70 °C were added to the container once the pump rotors. The FDR and TDR rotors optimize the mixing of the layers among themselves and allow the flow through the chamber.

As noted earlier, heavy elements and intermetallic compounds can sink to the bottom of the bath forming sludge in large holding furnaces. To simulate the dispersal and mixing of this sludge with the rest of the melt, a certain amount of dye was mixed in with the rest of the tank, and the dispersal of this red dye was measured over the course of 12 minutes. As before, we compared the performance of non-pumping rotors against Foseco rotors at different speeds. As soon as test conditions in the tank had become stable, 5 ml of coloured dye was added. The stirring effectiveness of each rotor could then be captured on a high speed camera.

We can conclude that lower differences in temperature result from the Foseco pumping rotors than from the non-pumping rotors (Figures 16 and 18). This is ensured by the combination of axial and radial flow of the pump rotors. The FDR and TDR rotors optimize the mixing of the layers among themselves and allow the flow through the chamber. As noted earlier, heavy elements and intermetallic compounds can sink to the bottom of the bath forming sludge in large holding furnaces. To simulate the dispersal and mixing of this sludge with the rest of the melt, a certain amount of dye was mixed in with the rest of the tank, and the dispersal of this red dye was measured over the course of 12 minutes. As before, we compared the performance of non-pumping rotors against Foseco rotors at different speeds. As soon as test conditions in the tank had become stable, 5 ml of coloured dye was added. The stirring effectiveness of each rotor could then be captured on a high speed camera.

![Figure 12. Results from hot water trials without rotors](image1)

The charts below (Figures 13 and 14) show the difference in temperature measurements after twelve minutes between the top and bottom parts of the pouring and casting wells of the perspex model. The charts display the results for differing rotor types being run at differing speeds (shown on the X axis in RPM).

![Figure 13. Temperature difference – upper part of the tank after 12 minutes](image2)

![Figure 14. Temperature difference – lower part of the tank after 12 minutes](image3)

![Figure 15. Stirring performance of non-pumping rotors at 450 RPM in the scale model over the course of 12 minutes](image4)

![Figure 16. Homogenising performance of non-pumping rotors at 450 RPM in the scale model](image5)

![Figure 17. Stirring performance of Foseco pumping rotors at 450 rpm in the scale model over the course of 12 minutes](image6)

![Figure 18. Homogenising performance of Foseco pumping rotors at 450 rpm in the scale model](image7)

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![Figure 13. Temperature difference – upper part of the tank after 12 minutes](image9)

![Figure 14. Temperature difference – lower part of the tank after 12 minutes](image10)

![Figure 15. Stirring performance of non-pumping rotors at 450 RPM in the scale model over the course of 12 minutes](image11)

![Figure 16. Homogenising performance of non-pumping rotors at 450 RPM in the scale model](image12)

![Figure 17. Stirring performance of Foseco pumping rotors at 450 rpm in the scale model over the course of 12 minutes](image13)

![Figure 18. Homogenising performance of Foseco pumping rotors at 450 rpm in the scale model](image14)
Results of earlier tests have shown that the most effective homogenisation results were achieved at 450 rpm.

Field trials
A FDU Mark 10 degassing unit was used to continuously stir a furnace in Montupet Ruse utilising a TDR 190 rotor. During the period a series of Thermal Analysis curves were plotted to assess the degree of grain refinement. After one and half hours of rotor application a recalescence of 0.5 °C was achieved and remained stable, over a period of 3 hours, between 0.5 and 1 °C, indicating good grain refinement. The thermal analysis unit also indicated an excellent grain refinement index.

It was also found that the metal temperature in the casting well rose by 5 °C (from 735 °C to 740 °C) almost immediately after the rotor began stirring the melt. The electric heating system in the roof of the furnace could therefore be reduced offering an immediate saving in energy.

Conclusions
- Settling and segregation over time can be an issue in large casting furnaces
- Pumping rotors such as TDR are capable of circulating aluminium quickly around furnaces of 2 tonnes
- Efficient stirring of the bath can assist in retaining good grain refinement in the bath over a long period of time.
- Effective stirring of large furnaces can also result in better heat distribution in the bath leading to energy savings ensuring low temperature gradients in vertical as well in horizontal direction. (Metal surface temperature reduction of 20 - 30 °C while stirring in heating area is not unusual)
- Reduced metal surface temperature in heating chamber (below heating elements) reduces Sr loss and slag generation. Likewise susceptibility of corundum building is restrained.
- Use of a FDR or TDR pumping rotor is a practical and effective method of stirring furnaces in a production environment.

References
- The Technology of Batch Degassing for Hydrogen Removal from Aluminium Melts using different Rotor Designs - Foundry Practice 256
- Degassing efficiency of different rotor design over rotor life - Foundry Practice 259
- The XSR Rotor: A new development in FDU degassing technology - Foundry Practice 241

Simulation conditions and parameter settings:

<table>
<thead>
<tr>
<th>Perspex tank:</th>
<th>Scale model in a ratio of 1:3 with the standard holding furnace</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid:</td>
<td>Tap water</td>
</tr>
<tr>
<td>Coloured dye:</td>
<td>5 ml, Allura red (C18H14N2O8S2Na2)</td>
</tr>
<tr>
<td>Rotor speed:</td>
<td>450pm</td>
</tr>
<tr>
<td>Rotor design:</td>
<td>Propeller, Rushton Turbine, FDR, TDR</td>
</tr>
<tr>
<td>Rotor diameter:</td>
<td>a ratio of 1:3 in comparison with the Standard Foseco rotor diameter size</td>
</tr>
</tbody>
</table>
Results of earlier tests have shown that the most effective homogenisation results were achieved at 450 rpm.

Inspecting the times required for a complete mixing of the fluid using the same speed in RPM with the coloured dye, you can draw the following conclusions:

The use of non-pumping rotors results in negligible or zero mixing of the fluid with the coloured dye. By contrast, use of Foseco pumping rotors ensures a thorough mixing of the coloured dye with the liquid across the entire cross-section of the furnace thereby providing faster and more thorough homogenisation.

Simulation conditions and parameter settings:

- Perspex tank: Scale model in a ratio of 1:3 with the standard holding furnace
- Liquid: Tap water
- Coloured dye: 5 ml, Allura red (C18H14N2O8S2Na2)
- Rotor speed: 450rpm
- Rotor design: Propeller, Rushton Turbine, FDR, TDR
- Rotor diameter: a ratio of 1:3 in comparison with the standard Foseco rotor diameter size

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A FDU Mark 10 degassing unit was used to continuously stir a furnace in Montupet Ruse utilising a TDR 190 rotor. During the period a series of Thermal Analysis curves were plotted to assess the degree of grain refinement. After one and a half hours of rotor application a recalescence of 0.5 °C was achieved and remained stable, over a period of 3 hours, between 0.5 and 1 °C, indicating good grain refinement. The thermal analysis unit also indicated an excellent grain refinement index.

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COMMENT

Editorial policy is to highlight the latest Foseco products and technical developments. However, because of their newness, some developments may not be immediately available in your area. Your local Foseco company or agent will be pleased to advise.

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