

CH06 - Safe, Autonomous, and Energy Efficient Furnace Tending, Minimizing Waste

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Abstract

With casthouses looking to melt higher quantities of post-consumer scrap to lower the CO₂ footprint of their finished product it is even more critical to have reliable, safe and efficient furnace charging and skimming practices.

Automation of furnace charging, skimming and alloy charging operations gives a set of advantages that are unique, especially in a potentially hazardous casthouse environment where keeping well trained operators can prove difficult in today's competitive labor market.

Keeping the operator out of the dangerous situation in front of the furnace has many advantages on top the operator safety. Automated skimming with video optimization, has a significant impact on melt yield, energy use, CO₂ generation and final amount of salt cake waste created in the dross recycling process. Taking the skimming out of the hands of the operator, makes total dross removal a thorough practice every time. Automation of the process allows for no dross to remain on the furnace between cycles, eliminating the generation of more dross and lowering recoveries. Whilst also protecting furnace refractory lining from accidental collision through operator error and therefore reducing furnace down time, increasing furnace productivity.

Automated alloy charging and stirring distributes the alloy elements more evenly throughout the furnace with automated stirring to quicken the alloying procedure. Automated skimming and alloying shortens furnace cycles, further reducing door open time and wasted energy.

All advantages of these areas will be discussed in detail this paper.

Keywords: Charging, Skimming, Safety, Automation.

1. RiA Casthouse Engineering GmbH

RIA was established as a local maintenance service and special equipment supplier for the German Aluminum industry in 1997, RIA over the past twenty six years became an important international partner for aluminum billet cast houses, now with over 75 charging and skimming machines supplied to major aluminum companies around the globe. Building on high quality standards and continuous evolution has helped RIA to design the most reliable, robust, maintenance friendly and custom-made autonomous furnace tending equipment on the market. Recent success has seen RIA look at expansion into the sheet ingot and primary aluminum casting facilities.

RIA has worked with air-cooled in-furnace camera manufacturer Fioscope GmbH since 2014 and are Fioscope's exclusive supplier to the global aluminium industry, with RiA recognizing the value of Fioscope's machine learning, smart camera technology in providing autonomous furnace tending machines to the global aluminium industry.

2. Purpose of Automating the Furnace Tending Process

Trained reliable manpower is becoming hard to come by throughout the world. Yet, highly trained operators are the key to achieving efficient furnace practices with low cost production standards. Automated charging and skimming allow for this to be the norm in today's labor market. Using the best available technology allows for a significant reduction of energy consumption, shorter cycle times and lower furnace refractory maintenance cost as well as a safer environment for the operators. The latest generations of charging and skimming machines utilize full artificial intelligence (AI) to charge and skim aluminium melting and holding furnaces using cutting edge technology. These results can now be achieved with little or no operator input. New automated charging and skimming solutions achieve the lowest possible operational cost and the safest operating environment for this important part of the aluminium remelting process.

Operation of the automated systems can save up to 50 % in furnace cycle times by minimizing the door open periods. Saving energy cost and reducing greenhouse gas generation. Utilization of these systems also keeps operators away from the very hot, dangerous and uncomfortable environment in front of the furnace door, maximizing safety for casthouse personnel.

Combining savings on energy and .3 % metal loss, each 500 tonnes of production using an automated charging machine can :

- Reduce 27 tonnes of CO₂-e
- Eliminate 2.4 tonnes of saltcake waste
- Save 1.5 tonne of aluminium.

3. Key Tools in Automation

Latest generation machine mounted and air cooled in furnace camera systems are a key component of achieving fully autonomous operation of charging and skimming equipment. These new camera systems have smart capabilities, combining professional high resolution image acquisition with latest digital image processing technologies for accurate identification of process parameters. Typically video images are relayed to an off-site image processing device to train a neural network. This software is able to detect conditions like the height of the scrap heap or recognize dross on the molten bath and produce a PLC signal to indicate a certain action to the operating system computer or the Cast House operator, such as "Furnace Ready to Charge" or "Furnace Ready to Skim". This leads to obvious productivity benefits as the furnace may have been ready to receive more material or to skim earlier, however the operators were unaware or uncaring. All this is done, whilst maintaining a door closed operation, offering the safest environment to operators and saving energy.

Charging and Skimming machines are utilized in conjunction with smart cameras to charge and skim furnaces without an operator needing to be on the machine, the process can be watched safely from an operator pulpit or a remote desk in a safe location.

New camera systems are constantly developing with new and innovative features, smart camera technology, for example can monitor the burner flame for changes in shape, colour, size. It is also capable of monitoring refractory for signs of damage and wear as well as monitoring the combustion chamber for anomalous and potentially dangerous conditions to alert operators.

4. Autonomous Furnace Charging

In typical operations, the melt cycle cannot be observed without opening the door and losing heat and energy, as well as the associated safety risk to the operators. Therefore, valuable minutes can be lost if the furnace is ready to receive the next charge, but the operators are unaware since the

contents are not visible. For several years, smart cameras have been onboard charging machines and in furnaces to enable autonomous operation. Significant advances in process control are then possible using air-cooled smart cameras. High-temperature resistant cameras allow for real time observations of melting process. They provide a safe and real-time process development benefit that was in the past impossible to even observe let alone monitor, without opening the furnace door. Opening the furnace door then changed the process conditions and was unsafe to the operators making real time observation impossible.

Artificial intelligent vision camera's monitor the progress of the scrap pile, as it melts. The camera's determine the earliest possible moment in which the charging machine can deliver the next charge. Through this, autonomous operation is possible. Figure 1 shows 3 still images taken for the purpose of this paper from the operator station at a fully autonomous charging machine installation. Three different stages of the melt cycle are shown, following a charge. The first image shows the furnace with a scrap pile that has recently entered the furnace, using a 'traffic light' visual for the operators, the smart cameras not only relay the image but also highlight using the red light that the furnace is not ready to receive the next charge.

A yellow signal on the second Image indicates that the smart cameras are detecting that the scrap pile has lowered in height and is therefore getting closer to the point in which the charging machine can enter the furnace without contacting the scrap pile. Operators are now alerted to the fact that within the next few minutes they must conclude loading scrap into the container to ensure the charging machine can deliver the next charge at the earliest possible moment, ensuring valuable production time is utilized.



Figure 1. Screenshots of AI system smart cameras relaying real time information of melt progress to the cast house.

Finally, the third image and green light indicates that the furnace is ready to receive the next charge. Previously, the furnace door would need to be opened for the operators to confirm this information and make informed decisions, however in this case, AI system with smart cameras detect the scrap pile is now low enough for the charging machine to enter, deposit the next load and retract from the furnace without contacting the scrap already inside. Whilst ensuring maximum productivity through charging at the earliest appropriate time.

There are also significant safety benefits as the requirement to open the furnace door is significantly reduced, combined with giving operators the assurance that they are not charging the next load into liquid aluminium. As operators can be shown the estimated time period they have to ensure the charging machine is loaded, this helps to ensure the furnace contents will not be in a molten state, an important safety feature of high value to many customers.

There can also be a function if selected by the customer to not allow the door to open if the bath is flat and in the molten phase and about to be charged. The system mandates the the operator get permission from the floor supervisor and a "safe" dry charge be selected to push into the molten bath to avoid potential hazardous situations.

No time is lost during the charging phase of the melt cycle ensuring maximum productivity of your cast house. Once the charge machine is loaded, operators can complete other tasks as the AI system smart camera observations trigger the cycle to begin, requiring no further operator interaction. Once the cycle is complete, the charge machine moves back to the loading position to prepare for the next charge. As Figure 2 shows, the furnace charging cycle can be viewed safely from the monitor in the operator pit via another camera mounted at the rear of the machine.



Figure 2. On-board camera monitoring the furnace charging cycle, relaying the footage to operators who can be situated in the safety of the operator pit.

Door open time and scrap placement inside of the furnace is also key to a fast melting cycle with the lowest melt loss and lowest energy consumption. The door open time must be at a minimum. Modern systems can charge up to 35 tonnes in 90 seconds. This is important in that it allows for the maximum amount of heat to be retained in the ceilings and walls of the furnaces accelerating the rebound time from charging. The system can select the placement of the charge to be evenly distributed within the furnace or if certain scrap types demand an orderly placement from back to front of the furnace. This is all possible within the programs.

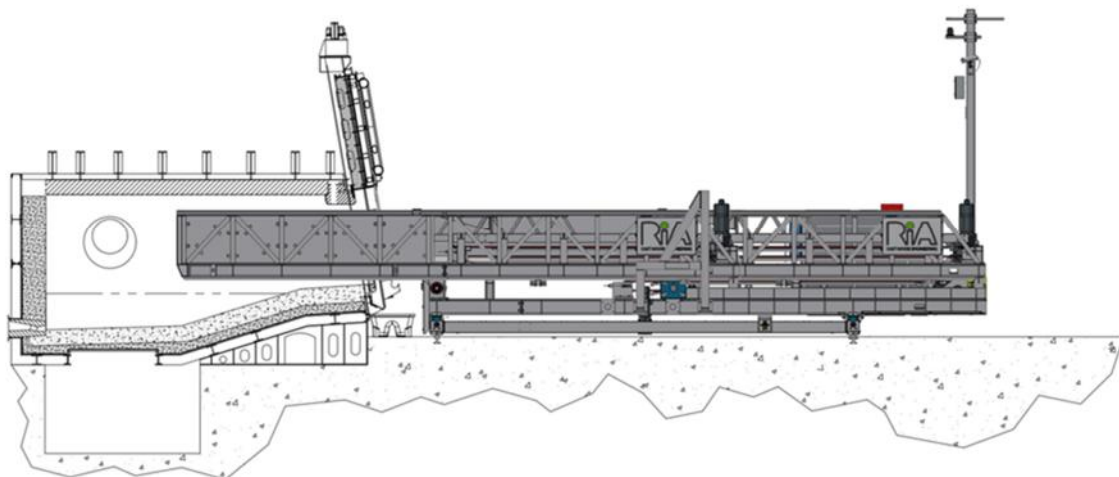


Figure 3. Charging machine extended into the furnace for even scrap distribution.

In-furnace camera technology can be used without automated charging equipment and would allow the cast house to safely recognize when it is the optimum time to charge the melting furnace. The decision of course would be up to the operators judgement.

The benefits of implementation of such technology in your cast house include:

- Significantly increased productivity and reduced energy consumption due to shorter charging cycles and less heat loss. Typically 6 – 8 minutes vs 45 – 60 minutes.
- Reduced refractory damage ensuring significantly longer refractory life and more furnace operational uptime.
- Reduced forklift movements in the cast house leading to increased operator safety and reduced maintenance.
- Removal of operators from the charging process, increasing operator safety and reducing the level of operator training required.

5. Autonomous Furnace Skimming

Good furnace practices dictate removing all of the dross off the furnace every skimming cycle which is optimally before every transfer. Leaving dross behind on top of the liquid bath between cycles causes more dross to generate in the next cycle, increasing operational melt losses. Quickly removing all the dross is better for overall metal recovery, bath temperature control and energy conservation. The goal of the automated skimming process is to minimize these effects on operational costs as much as possible.

In typical operations, melting and holding furnaces are skimmed by either a wheeled vehicle or a rail mounted machine. Typically, both are driven by an operator present on board the machine to give them a direct view in to the furnace to locate the dross to skim from the melt surface.

The above process presents two main concerns for the aluminium cast house. The first concern being that operators have to be on board the machine, exposed to the heat and potential dangers of molten aluminium. Splashing molten metal and exposure to high heat levels present a risk to operators. Secondly, operator driven wheeled vehicles typically have long skim booms that move over rough floors with little control or precision when skimming the furnace. Often, this causes unnecessary damage to the refractory lining within the furnace leading to the earlier replacement of refractory walls and the furnace sill and lintel. Not only does this incur the cost of replacing the refractory lining more frequently, but also the lost production time with the furnace being down to conduct the necessary repairs, often for several weeks.

Combining savings on energy and 0.2 % metal loss, each 500 tonnes of production using an automated skimming machine can:

- ✓ Reduce 14.5 tonnes of CO₂-e,
- ✓ Eliminate 1.6 tonne of saltcake waste,
- ✓ Save 1 tonne of aluminum.

To address these historical problems with manual furnace skimming, automated skimming machines were developed with smart camera's on board the skimming machines, as shown in Figure 4. The camera's are air-cooled to manage the radiant heat from the furnace, which typically operators would be exposed to.

Camera images are relayed to the operator pulpit and the operator can watch the skimming cycle from a safe location, away from the furnace. Skimming machines have been capable of automatic skimming for some years. Through precise position measurement and control, it is possible to follow a pre-determined skimming pattern, lane-by-lane, to remove the dross from the furnace, without contacting or damaging the refractory nor the need for an operator to be onboard the machine.

However, the machine will skim the entire surface of the bath regardless of the location of the dross, or if the dross moves into an already clean and previously skimmed lane, the machine was effectively blind and would not react. The solution was to install smart cameras on the skimming machine that have a view of the bath surface. The cameras identify the difference between dross and a clean surface and drive the skim blade to the location of the dross and remove it from the furnace.



Figure 4. Air-Cooled smart camera technology for high temperature applications, onboard a rail-mounted skimming machine.

Figure 5 shows the smart cameras automatically recalculating the bath cleanliness based on the image from the camera. Using an internal neural network, the system “trains” the cameras to differentiate between a dross layer and the molten aluminium. With a predetermined desired cleanliness, the skimming machine will autonomously skim the bath until this cleanliness percentage is achieved across the grid overlayed onto the bath surface. Smart cameras allow for the recalculation, if dross were to move past the skim blade as it moved through the dross layer, something that a blind robotic machine does not see.

Once again all of this is possible, without human interaction, other than to initiate the cycle. The systems can determine when flat bath conditions are achieved, and the furnace is ready for skimming. Saving valuable minutes and shortening cycle times saving energy.

Overall cycle time for skimming can be reduced by at least by 30 % over manual operations and are much more efficient.

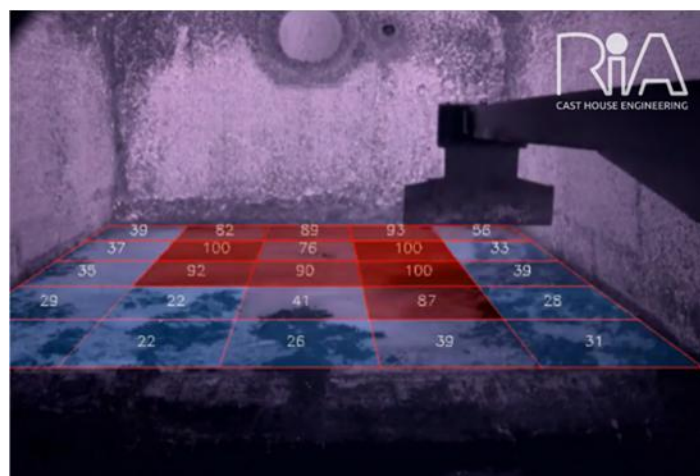


Figure 5. Skimming machines with on-board smart cameras calculating bath surface cleanliness in real time during the skimming process.

This fully Intelligent capability is already implemented in several cast houses in the European and US markets. The AI driven skimming machine will not only skim, but also stir and mix the bath contents as well, to ensure homogeneity and can also clean the refractory between cycles or alloy changes. When cleaning the refractory, because the refractory internal dimensions have been programmed into the PLC, the approach speed and pressure of contact is reduced, minimizing refractory wear and damage but stopping builds ups of dross that shorten refractory life.

Autonomous skimming machines incorporate accurate laser position sensors and laser safety scanners. The units are rail mounted for ultimate accuracy and all cast house personnel are aware of the possibilities and direction of movements. Even then if a person or an object is in the path of movement, the machine will slow down and stop without contacting the object in its path.

The benefits of implementation of such technology in your cast house include:

- Significantly increased productivity and reduced energy consumption due to shorter skimming cycles and less heat loss. Typically 8-12 minutes vs 15–20 minutes.
- Reduced refractory damage ensuring significantly longer refractory life and more furnace operational uptime.
- Reduced forklift movements in the cast house leading to increased operator safety and reduced maintenance.
- Removal of operators from the skimming process, increasing operator safety and reducing the level of operator training required.

5.1 RiA In Furnace Dross Processing (IFDP)

The concept behind the RiA patented IFDP is to compress the dross whilst still hot and in the furnace, before removal from the furnace. After removal from the furnace it can either get too cold and freezes or too hot and thermites, in both cases preventing effective recovery of the entrapped aluminum by secondary hot processing.

The removal of the dross is enabled by a special skim blade coupled with the cold stationary plate. In-Furnace Dross Processing is achieved in harmony with the skimming cycle adding only a 1 – 2 minutes to the cycle. The dross will be dragged onto the furnace sill and squeezed against the cold plate. The liquid Aluminum flows back into the furnace through openings between the skim plate and the furnace sill. After the squeezing action is finished, the remaining dross will be transferred to specially designed cooling dross pans in front of the furnace. The cold plate is used for a precise positioning of the dross cake. The procedure will be repeated until the dross is completely removed from the furnace.

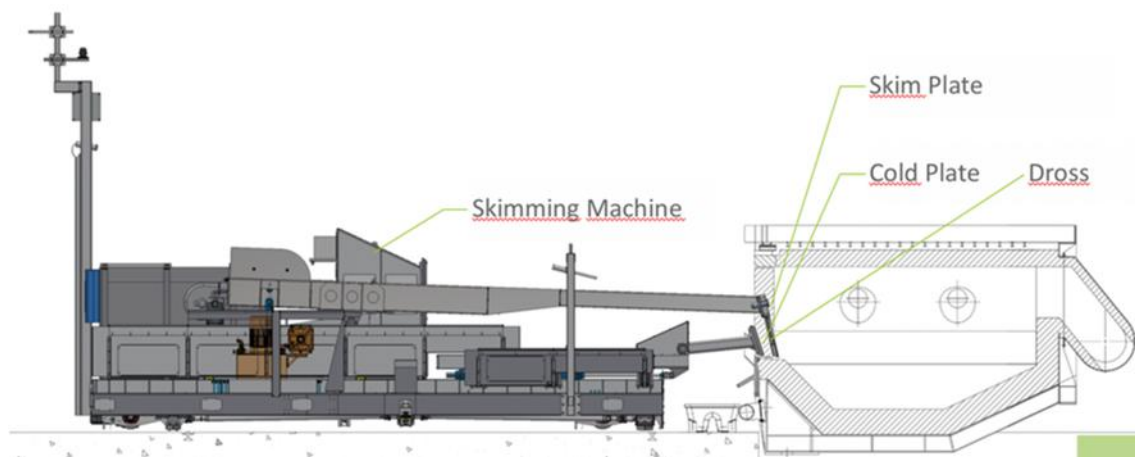


Figure 6. Schematic of RiA patented IFDP process.

RIA In Furnace Dross Processing gives a lot of advantages compared to traditional technologies.

- It foremost allows up to 0.5–2 % more of the metal charged to be cast into product every cycle. Reducing overall cast house cost and increasing overall cast house recovery.
- By leaving 50–70 % of the molten aluminum normally contained in the dross in the furnaces, overall dross recovery increases by about 5–10 %. There is no remelt recovery loses from secondary processing of the metal that has remained in the furnace.
- Decreased dross generation means less secondary recovery cost for processing the remaining dross. These processing cost go down by as much as 45 %.
- Retained higher alloy value because the metal in the dross is not mixed with other alloys of dross. The value of that metal is higher than dross secondary ingot.
- Secondary ingot remelt energy savings because the metal now remains in the furnace and fewer secondary ingot need remelting.
- Reduced material handling for up to 45 % less dross being removed from the furnaces and moved to secondary processors.
- Reduced greenhouse gas emissions due to reduction of secondary remelting.

The process works consistently because dross is always hot for processing for maximum metal drain back into the furnace but can be cooled immediately during skimming for later mechanical processing. This maximizes metal recoveries within the furnace and from the remaining dross that is removed

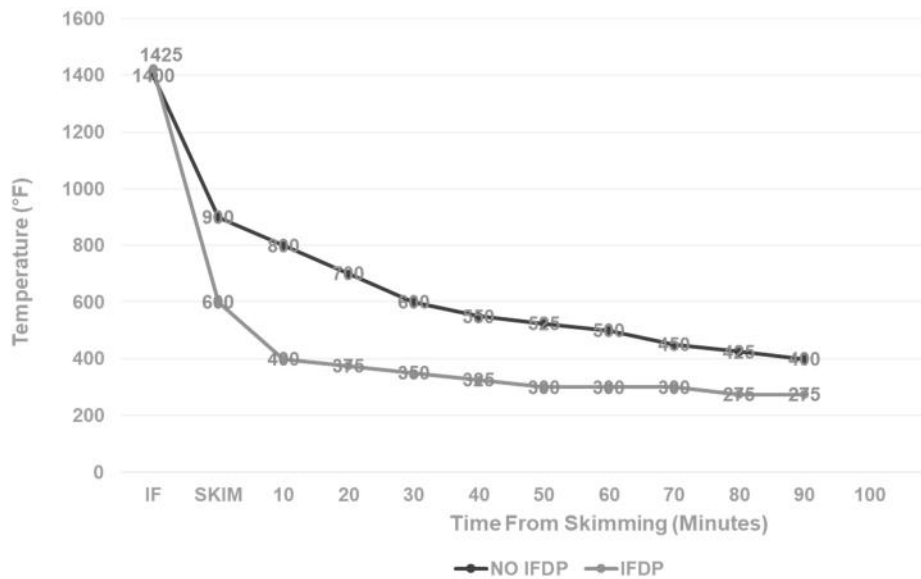


Figure 7. Graph detailing faster cooling of dross through automated IFDP process.

Aluminum dross is a material that is unusually susceptible to rapid oxidation and the thermite reaction. Oxidation of aluminum in dross stops below 350 °C (660 °F). The IFDP system, cools this material below this temperature by the time it is collected in the skim pan. Normally this can take anywhere from 30 minutes on the shortest side to hours if thermiting starts.

Through similar trials the automated IFDP Skimming Process has also proven to lower quantity of dross skimmed from the furnace, meaning alloyed material is transferred to the casting table instead of the secondary reprocessor, reducing the energy required to remelt the dross and reducing tolling fees. Figure 8 shows trial data from an installation site and Figure 9 shows dross pans post skimming both with and without the use of automated IFDP° skimming process.

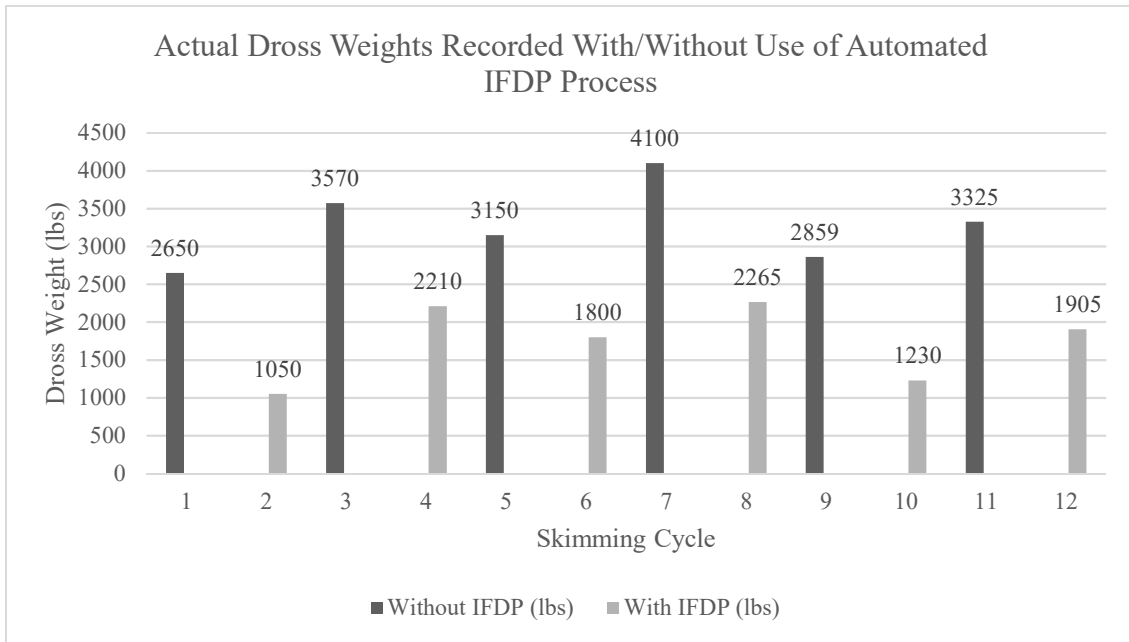


Figure 8. Dross weights with and without the automated IFDP process.



Figure 9. In-furnace dross processing skim and cold plate.

The precise machine movements that have been programmed with the refractory contours as well as the adjustable plate's pressure against the refractory eliminates collisions with and damage to the refractory lining. This in turn reduces maintenance on the refractory significantly and therefore increases a furnaces uptime and overall productivity.



Figure 10: IFDP in melting furnace.

Using an autonomous skimming machine increases the occupational safety in all modes of operation, because even in manual mode the operator is protected by an insulated operator cabin.

6. Summary

Modern scrap charging machines with AI system smart cameras reduce unnecessary door openings, reduce melt loss, shortening cycles and saving energy. These systems can increase safety and potentially avert accidents. Smart cameras also allow the melt cycle to be optimized, ensuring charging can take place safely, at the first opportunity. Facing a significant shortage in skilled labor, the aluminum industry is having problems obtaining and retained trained operators. These automated systems take dangerous jobs and make them safe for furnace operations with operators with less training in a more livable environment for cast house processes.

Furnace monitoring systems allow playback, trouble shooting and diagnostics. It is believed that in the future all new furnaces will incorporate in-furnace cameras.

RIA Cast House Engineering provides tailor-made rail-bound cast-house-proven charging and skimming equipment for Aluminum cast houses worldwide. The design and development of all machines takes reliability, durability, maintenance and occupational safety into account. Adding the innovative features of full AI camera-based charging and skimming as well as In-Furnace Dross Processing, assures the best equipment maximizing productivity and lowering cost in the casting operation.