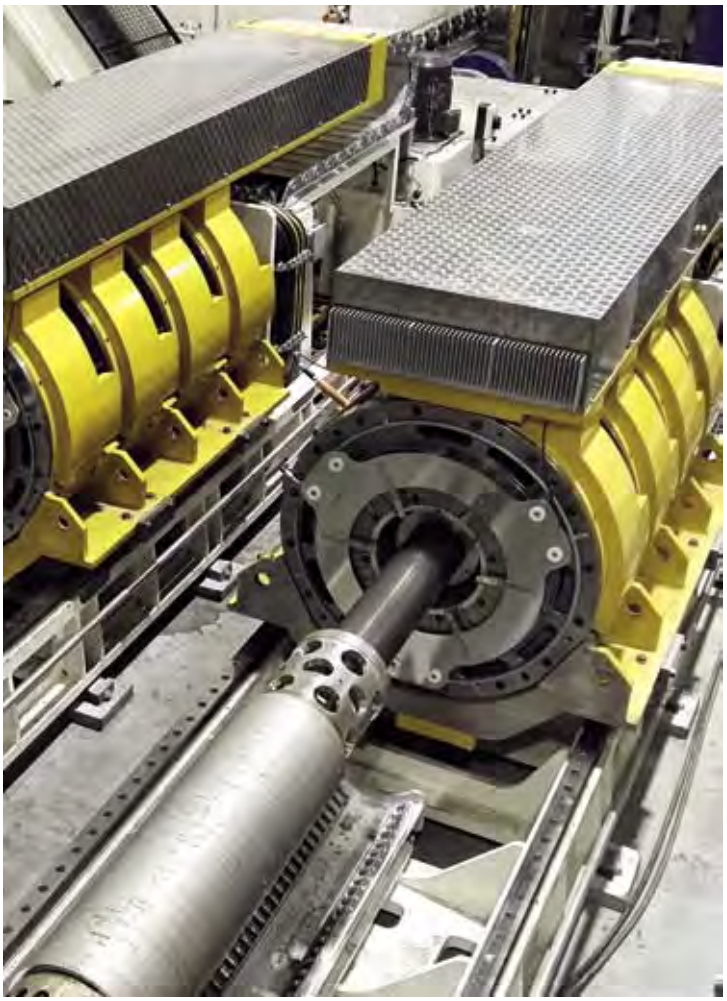
INTERNATIONAL
ALUMINIUM
JOURNAL



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Volume 97 · May 2021
International Journal for Industry, Research and Application
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Performance optimization of aluminium furnaces based on real-time elemental analysis of the molten metal

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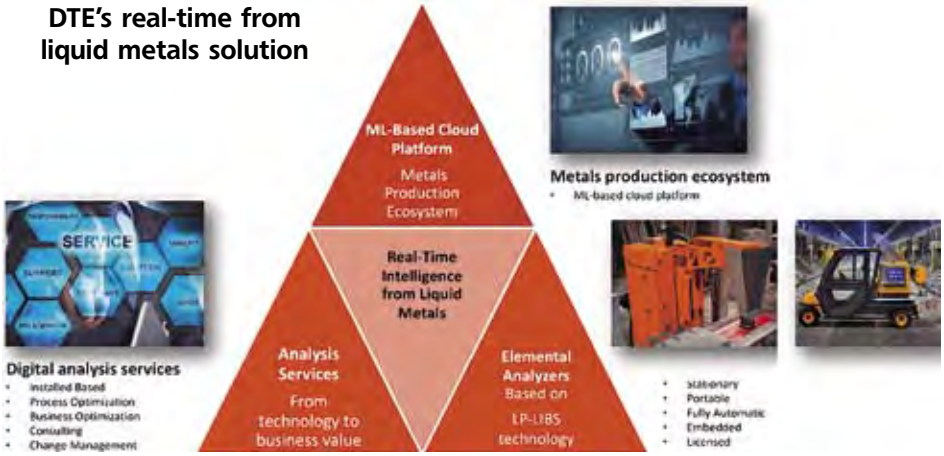
DTE's real-time from liquid metals solution



DTE contributes to maximizing value, sustainability, safety, and efficiency for all the metals industry stakeholders through its unique, connected 'real-time intelligence from liquid metals solution', combining chemical composition analysis based on Liquid-Phase Laser-Induced Breakdown Spectroscopy (LP-LIBS) and a machine-learning, cloud-based platform, engine of DTE's metals production ecosystem. DTE's purpose is to be a relevant contributor to sustainability and the 1.5-degree challenge through its vision of transforming the metals industry, driving its digital transformation towards Industry 4.0, delivering valuable intelligence and predictive insights from liquid metals across the entire value chain.

This article's essence is about how DTE through its breakthrough solution – 'real-time intelligence from liquid metals' – maximizes value, sustainability, safety and efficiency, in this case optimizing the performance of aluminium smelting and holding furnaces in primary and secondary aluminium production. Also, we discuss, at a high level, the benefits of deploying DTE's solution along with additional components of the value chain, like launders, which are closely related to furnaces.

Innovation and technology for value creation, safety, sustainability and efficiency

At DTE, we believe that breakthrough innovation and constant technological evolution open doors to new value creation possibilities. Since our inception, we have focused our innovation efforts on bringing technologies to market to solve evident, well-defined problems that our customers have to propose them solutions that deliver a beneficial business outcome. Whenever we do that, we do it thinking of the overall business challenge in front of us, from having excellent products that perform as expected in a rugged industrial environment to ensure that the solution provides the business outcome sought out by our customers.

Mixing, melting and holding aluminium furnaces

Aluminium production: The benefits of recycling aluminium are well known; it requires approximately 5% of the energy needed for primary aluminium production. Primary aluminium production consumes approx. 100 GJ of energy (some sources indicate up to 170 GJ), with aluminium smelting consuming almost 50% of it – or around 14,000 kWh. Alumina refining consumes approx. 15% of the energy (most electrical) while casting and anode production takes in the order of 1.5 GJ each. The actual energy consumption of primary aluminium smelting is roughly double what the theory indicates it should be.

Out of the total energy consumed in secondary aluminium production, roughly 5 GJ, approx. 75% is due to the melting and holding furnaces, which may have a thermal efficiency under 50%.

Energy consumption (of any kind) is always a source of concern, especially at the levels is consumed in aluminium production. If fossil fuels are the source of energy generation, then there are GHG emissions. If renewables are the source of energy generation, there is an environmental impact, even though not always noticeable. Besides, energy consumption is a direct source of costs and waste, the last one resulting from low equipment efficiency or undesired process reactions.

At DTE, we like to think of any industrial process the following way: production resources (energy, people, assets, raw material and others) = optimized operation * (output (volume, cost, quality) + (1 - optimized operation) * waste.

Therefore, without getting into the aluminium production details, we aim to emphasize how resources-intensive the aluminium industry is and how important is the continuous focus in optimizing operations using the latest technology, which is a crucial success factor for a sustainable aluminium business.

The role of the mixing, melting and holding furnaces: In primary aluminium production, mixing furnaces receive molten aluminium from the electrolysis potroom, where alloying elements are added to create the alloy desired. In secondary aluminium production, solid metal or scrap is supplied to the melting furnaces, where alloying elements are added to generate the alloy wanted. In both cases, from the mixing and melting furnaces, the alloys are sent to the holding furnaces through the launders where, if needed, further treatment is performed, and metal is held awaiting casting.

Furnaces are a significant component of the aluminium production value chain, and therefore their optimization will undoubtedly drive optimization of the whole production process, upstream and downstream.

The business value of the furnaces in the aluminium production value chain: As mentioned in the previous section, furnaces play a vital role in the aluminium production value chain. They are the principal contributors to the output of an aluminium-making operation: volume, quality, and cost.

However, when discussing furnace optimization, the main focus is on decreasing energy consumption or increasing efficiency. This focus also covers emissions, either from energy generation or waste. →

However, not enough emphasis is placed on equally important business variables like optimizing the value chain, increasing the return on capital employed, maximizing the quality of the alloys produced, and tracing with more precision the metals made.

One of the main reasons for this limited focus on additional critical variables may have been the lack of real-time chemical composition information of the molten metal coming out from the furnaces. Without frequent, real-time data from the molten metal, the possibility to execute real-time and forward-looking process control is very remote. Therefore, the impact on the process and business variables mentioned before is minimal.

Real-time chemical composition from liquid metals

DTE's real-time intelligence from liquid metals: DTE has brought to the market its unique, connected real-time intelligence from liquid metals solution, combining chemical composition analysis based on Liquid-Phase Laser-Induced Breakdown Spectroscopy (LP-LIBS) and a machine-learning, cloud-based platform, engine of DTE's metals production ecosystem.

A new dawn for the aluminium production business: As described later on in this article, DTE's solution not only delivers tangible business value to today's operations but also redefines the horizon in terms of process and business optimization in aluminium production. By delivering valuable intelligence and predictive insights from liquid metals across the entire value chain, DTE's solution opens up the door to already thought optimization opportunities, like decreasing even further energy consumption and GHG emissions.

Besides, DTE's solution allows innovation around new grounds, like optimizing alloy production using machine learning and melting curves and maximizing traceability along the entire value chain by defining the aluminium dynamic DNA or passport. The latter, as an example, will allow members of the value chain to know the details of the aluminium they are using in their product: their energy consumed along the journey, the evolution of its chemical composition, the origin of the raw materials, and how much emission was generated during its manufacturing, among many other things.

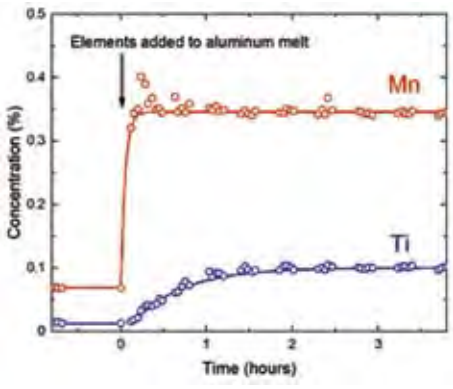
LP-LIBS technology uses a highly energetic laser pulse to excite the liquid metal surface to form a plasma plume with temperatures over 30,000 K.

A sensor detects the atomic emission spectra of each element in the material being analyzed, which are then converted into a quantitative reading.

LP-LIBS performance – precision, accuracy and operation on the ground: As reported in DTE's research paper *Accurate Real-Time Elemental (LIBS) Analysis of Molten Aluminum and Aluminum Alloys* [1], LIBS analysis of aluminium and aluminium alloys in their molten state is, for most of the investigated elements, superior to any other laboratory analysis of solid process samples. Furthermore, LIBS measurements can provide an unprecedented level of detail about melt dynamics in real-time.

LP-LIBS technology has demonstrated, so far, in laboratories and on the plant floor, that in terms of accuracy, measurement to measurement repeatability, stability, and real-time measurement, it can perform better than the current technologies used.

Besides, and as stated in the research report *Automated Chemical Analysis of Liquid Aluminum for Process Control* [2], a fully automatic LIBS-based analysis of chemical composition from liquid primary aluminium gives the most accurate representation of melt chemistry. In some cases, this analysis shows improved internal consistency of measurement results compared to laboratory analysis of process samples.



The melting dynamic of the elements added to the aluminum melt for a given furnace is the basis for the alloying optimization system's model, optimizing the alloying process by defining the loading volume, sequence, and order

On top of this, the online analysis provides rapid results (typically ~1 minute from the time of sampling), improves worker safety, and eliminates the risk of human error. The LIBS analyzer can run unattended for weeks or months and is ideal for continuous process control where fast and secure feedback is required.

Real-time intelligence: DTE's real-time intelligence definition refers to providing actionable information on time, as soon as it happens, every time is required, for everyone that needs it, everywhere is needed.

The role of the machine-learning-based cloud platform: DTE's ML-based platform converts real-time chemical composition data into intelligence or actionable information to allow process control, management systems, and aluminium operators to make real-time and forward-looking decisions. Besides, the cloud platform provides the environment to ensure that the decisions made are based on a single version of the truth and achieve a common business goal.

Benefits when applying 'real-time intelligence from liquid metals' in mixing, melting and holding aluminium furnaces

The value that DTE's 'real-time intelligence from liquid metals' solution brings to the aluminium industry is vast and goes from point value – in the particular case of this editorial to the furnace operations – to an end-to-end optimization. From suppliers to customers, from the raw material to the final manufactured product, from the plant floor to the business levels, and the trading desks. We summarize it as 'faster, better aluminium to market'.

Opportunities for process and business optimization: In its most basic format, most frequent, real-time (as soon as it happens, every time, everywhere, for everyone) information helps aluminium producers to uncover value never uncovered before. Process control and business management can now be executed in real-time, with actions following the chemical composition input from the process a few milliseconds or seconds later, not minutes or tenths or minutes as it is happening today with traditional elemental analysis.

But real-time, frequent, chemical composition from the process combined with other Industry 4.0 digital technologies allows for powerful predictive insights that enable forward-looking decision making and process control, predicting an undesired future and avoiding it in advance. It also drives high accuracy product traceability, which is the foundation for a future dynamic metal's DNA. And it also enables alloying optimization by leveraging on the alloys melting curves in a defined environment to optimize alloying elements' loading volume, speed, and sequence.

Benefits summary: Next, there is a summarized, high-level list of opportunities for furnace optimization based on more frequent, real-time chemical composition analysis from the molten metal in the furnaces. They are grouped based on the impacted business vari-

able, and they drive faster, better aluminium to market.

These opportunities for improvement vary per customer, depending on their technological evolution and the financial position of the production variables. Therefore, more frequent, dynamic, real-time intelligence from liquid metals applied to the furnaces drives:

- **Enhanced production planning and optimized value chain:** Frequent, real-time chemical composition information from the furnaces permits the execution of real-time process control. It generates continuous historical data that enables building behaviour models of the melt for optimized production planning and process simulation. It also allows training machine-learning systems that provide predictive insights about undesired future states, enabling ad-hoc, forward-looking decision-making and process control. Real-time chemical composition analysis from liquid metals is the only path towards simulating the value chain to optimize it, plan production efficiently, execute real-time process control, and decide and controlling ad-hoc based upon predictive insights.
- **Increased Return on Capital Employed (ROCE):** The machine-learning-based alloying optimization system relying on the melting curves built for a particular furnace developed with real-time elemental analysis from the molten metal minimizes the time of the melt in the furnace to produce a target alloy.

The alloying optimization system also optimizes the charging process – volume, order, and sequence – of raw material and alloying elements into a furnace to speed up dissolution and minimize evaporation.

Real-time information from the alloying process optimizes the performance and availability of the assets to load aluminium, alloying elements, and scrap into the furnace, the process machines and equipment downstream the furnaces, and the casting process.

Proper production planning and prescriptive decision-making and control minimize raw material in stock, scrap, aluminium, and alloying elements.

- **Decreased energy consumption and GHG emissions:** Optimizing the alloying process decreases energy consumption, emissions and waste.
- **Decreased production cost:** Frequent, real-time chemical composition information minimizes the production resources (assets, raw material, energy, people, and others) consumption and cost because of volume and selected input for the desired output (product, quality, volume, and cost).

Just-in-time availability of the raw material and alloying elements is now a real opportunity, decreasing inventory cost and avoiding plant stops.

Avoiding out-of-specifications casting decreases scrap and dross generation.

Chemical analysis of the molten metal is less costly than the traditional elemental analysis process, which requires sample preparation and transportation.

- **Increased operator's safety and health:** When applying DTE's fully automatic process to analyze the liquid metal, there is no need for operators to go through the hassle of performing elemental analysis using traditional methods.
- **Increased quality:** Using real-time, frequent, precise chemical composition information increases the possibility to produce high-quality, premium products.

The stirring process at the furnaces can be optimized, increasing quality and decreasing

alloying time. Energy consumption, emissions, waste and cost will reduce while increasing ROCE.

Systematic, real-time chemical composition analysis decreases the probability of casting products out of specifications and makes products on specifications available faster. It also reduces analysis errors that drive quality and traceability issues.

Benefits when applying 'real-time intelligence from liquid metals' along the aluminium production value chain

Real-time chemical composition analysis from liquid metals can be performed on the mixing, melting and holding furnaces and on any process, machine or equipment where liquid aluminium is present. DTE's solution delivers maximized benefits when deploying a complete system along the value chain, from the potrooms and before to the gates and beyond.

Benefits when applying real-time intelligence from liquid metals in the launders: As a complement to the benefits described for the furnaces, considering the close relationship (process-wise) between furnaces and launders and as an example of deploying real-time intelligence from liquid metals along the value chain, we provide below a high-level list of the potential benefits along the launders.

- Analyzing chemical composition along the launders, either before the holding furnaces or before casting, increases the final product's quality and minimizes production errors.
- Measuring constantly along the launder the performance of the high volatile elements allows optimizing the transfer between mixing and melting furnaces and holding furnaces.
- The quality of long products increases when analyzing the chemical composition of the metal flowing through the launder, avoiding uneven segregation.
- Real-time process control optimizes the grain feeder and the cooling process.
- A more efficient elemental analysis process on the launders decreases cost and increases health and safety.
- During continuous casting in tandem, having real-time information of the alloy change reduces scrap and increases product availability.
- Scrap decreases, and product availability increases when knowing in real-time potential out-of-specifications casting and undesired product flowing through the launders.
- More frequent, real-time elemental analysis provides better statistical accuracy on the batch throughout the cast and allows for continuous product identification or labeling.

DTE's stationary, fully automatic, elemental analyzer EA-2500 to measure chemical composition analysis from furnaces and launders, directly from the equipment (DTE EA-2000) or taking samples from them (DTE EA-2500)

Reinventing aluminium production

In the paragraphs before, we have presented the benefits that can be achieved today or in the short-term by applying DTE's 'real-time intelligence from liquid metals' solution to the aluminium production process.

Besides, we are already working on long-term benefits, expanding the possibilities of DTE's technology, innovating around topics like machine-enabled LP-LIBS, augmented elemental analysis, and the metals dynamic DNA or passport.

DTE is continuously innovating and using the latest technologies to reinvent the way metals are produced to ensure an impactful contribution to a sustainable future and the 1.5 degrees challenge.

Conclusion

Throughout this editorial, we highlighted how DTE, through its 'real-time intelligence from liquid metals' solution, maximizes value creation, safety, sustainability and efficiency for all aluminium-producing stakeholders. We emphasized the benefits of DTE's solution when applied to furnaces and when applied along the end-to-end value chain, providing the example of its use in launders.

We also highlighted that DTE's new solution and technology open up the door to realize benefits that could not be realized before and to uncover new, never thought before, advantages. DTE's real-time intelligence from liquid metals generates tangible short-term benefits, fosters the imagination that will drive medium-term transformative solutions, and redefines the long-term landscape.

And even though it is always challenging to rethink new approaches, change ways to do things, retrain people, and adapt to new processes, as discussed in this article, the benefits outweigh the initial hurdles.

DTE's 'real-time intelligence from liquid metals' solution is a breakthrough innovation poised to transform the metals industry, driving its digital transformation towards Industry 4.0, delivering valuable intelligence and predictive insights from liquid metals across the entire value chain.

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