VAI-CON® Chem—A New Continuous Chemical Analysis System of Liquid Steel in Metallurgical Vessels

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VAI, in cooperation with the Institute of Experimental Physics of the Johannes Kepler University in Linz, Austria, has developed a new system which enables the continuous analysis of the chemical composition of steel baths in all metallurgical vessels. Marketed under the name of VAI-CON® Chem, this system has been successfully tested on an industrial scale in a vacuum degassing plant. For selected elements, VAI-CON® Chem furnishes precise analytical data over the entire steel-treatment period, offering considerable potential for improved process control in the steel production process.
The first order for VAI-CON® Chem was received from BOEHLER EDELSTAHL (Austria) to continuously measure the stainless steel composition in a 50-ton AOD converter which is currently being installed.

INTRODUCTION

Analytical Methods for Metallurgical Vessels

Precise knowledge of the chemical composition of steel baths is necessary in order to improve the control and efficiency of the steelmaking process. As early as the late 1960s, VAI commenced with the research and development of new methods for sample-taking and temperature monitoring of liquid steel in metallurgical vessels. A submerged lance (sublance) designed by VAI was already installed in the LD Steelworks No. 3 of VOEST-ALPINE Stahl Linz in May 1981. This was followed by the development of the less costly Slantec® system for smaller converters (< 100 t), which was installed in the LD Steelworks No. 2 of VOEST-ALPINE Stahl Linz in 1989/1990. However, these procedures for sample-taking and temperature measurements of the steel bath were discontinuous, involving an interruption in the converter steelmaking process. Furthermore, a production delay in the completion of a heat was also unavoidable until the analysis results from the laboratory were available.
In a drive for ongoing improvement, VAI developed—in close cooperation with the Institute of Experimental Physics of the Johannes Kepler University of Linz/Austria—a system for the continuous measuring of the chemical composition of steel baths. In December 1998, extensive laboratory analyses of both solid and liquid steel were carried out. For the liquid steel investigations, argon-purged gas tuyeres were inserted into metallurgical vessels and positioned immediately above the steel bath surface. As alloying elements were added to change the steel bath composition, an analysis of the melt was made on the basis of plasma spectroscopy. The system also simultaneously measured the steel bath temperature on the basis of the infrared radiation.
In late 2000, the construction of an industrial prototype for the chemical analysis system began. Following a series of successful laboratory tests with this prototype, the system was installed in a vacuum degassing plant at BOEHLER EDELSTAHL in Kapfenberg/Austria (Figure 1).
Encouraged by the success of the project, VAI decided to market this continuous measuring system under the proprietary name VAI-CON® Chem.
VAI-CON® Chem is characterized by the following features:

- Continuous non-contact analysis of all desired elements of the steel bath via laser-induced plasma spectroscopy
- Continuous measuring of the infrared radiation emitted by the steel bath for temperature measurements
- Use of submerged process tuyeres, a lance or a gas-swept observation window to provide visual access to the steel bath
- Installation of the measuring equipment outside the hot zone of the metallurgical vessel
- Injection of CnHm gas or a protective gas through the annular gap of the process tuyere into the steel bath to form a protective "mushroom" (steel crust) around the tip of the tuyere in order to dampen the effect of erosion
- Simple installation and disassembly of the VAI-CON® Chem measuring equipment (e.g., for maintenance of the vessel or measuring equipment).

The main advantage of VAI-CON® Chem is the permanently available, precise knowledge of the composition and temperature of the steel bath and of the slag without having to interrupt the metallurgical process.

Figure 1: View of the Protective Housing of the VAI-CON® Chem Measuring Equipment Installed at a Vacuum Degassing Plant, BOEHLER-EDELSTAHL, Kapfenberg/Austria

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FUNCTIONAL DESCRIPTION

The VAI-CON® Chem measuring system is comprised of the following components:

- Measuring tuyere or submerged process tuyere
- Lens and mirror system
- Laser system
- Ultraviolet and infrared spectrometer
- Camera
- Cooled system-protection housing
- Measuring computer.

In order to allow continuous measurements to be carried out on liquid steel, inert gas is first injected into the steel bath. A pulsating, clearly visible spherical cavity forms on the liquid steel surface immediately in front of the tuyere tip. The steel bath composition and temperature are determined at this point with the use of a pulsed laser beam which is focused on the steel bath to generate a plasma. The broadband radiation emitted by the plasma contains the emission lines of the excited atoms which is focused and guided back through the tuyere to the front end of a spectrometer via a special lens/mirror system. The frequency and intensity of the emission lines of specific elements are measured, which are directly proportional to the concentration of these elements at the measurement point of the steel bath. The electrical signal formed by the detector is then transmitted to the measuring computer and continuously evaluated using specially developed software. The infrared radiation is similarly evaluated to determine the temperature of the steel bath at the same measurement point. The measured data (chemical composition and temperature of the steel bath) are visualized and transmitted to a process computer for storage and statistical evaluation.
An outline of the operating principle of VAI-CON® Chem is shown in Figure 2.

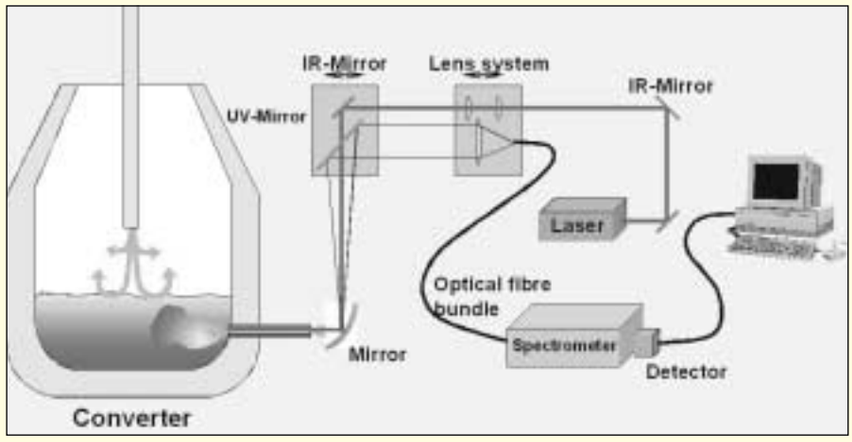

Figure 2: Schematic Outline of the VAI-CON"Chem Measuring System

Figure 3: View of Vacuum Degassing Plant with VAI-CON® Chem Measuring Equipment Mounted on Vessel Lid

EXPERIENCE WITH VAI-CON® Chem

Previous Laboratory Analyses

The first analyses with VAI-CON® Chem were conducted in collaboration with the Johannes Kepler University of Linz/Austria using an induction furnace. Previously analyzed samples were melted and calibration curves for the investigated elements were plotted. After comprehensive studies of the system parameters and influencing factors on the analysis values (e.g., melting temperature, distance to the measured object, various laser parameters, use of different gases and gas pressures), an industrial prototype was built. Once preliminary laboratory tests had confirmed the expected positive results, VAI-CON® Chem was tested on a standard Messo tank-type degassing plant at BOEHLER-EDELSTAHL, Kapfenberg (Austria) (Figure 3).

Application of VAI-CON® Chem in a Vacuum Degassing Plant

At the vacuum degassing plant of BOEHLER EDELSTAHL more than ten elements were tested with the VAI-CON® Chem system. The evaluation of the spectra for chromium, manganese and nickel proved to be highly satisfactory and the results are presented in more detail in the following sections. For several other analyzed elements (e.g., carbon) the resolution of the spectrometer used was insufficient to distinguish between superimposed spectral emission lines. A higher-resolution spectrometer would rectify this situation. Other factors negatively influencing the process were the strongly differing bath levels in the ladles and the violent bath movements during degassing. These factors, as well as the presence of process slag, led to different laser intensities on the surface of the steel bath.
With the use of a submerged lance or submerged tuyere many of these problems would not occur, since in a given melt the distance from the focusing mirror to the steel bath only changes minimally as a result of the consumption of the tuyere. This simultaneous detection of steel and slag is thus avoided.

Cr Content

Figure 4 shows a comparison of the chromium content as determined in the laboratory, and the VAI-CON® Chem analysis directly carried out in the vacuum degassing plant for twelve different special-steel melts. The evaluation was based on the intensity relationship between the chromium line at 435.5 nm and the iron line at 440.45 nm. The error bars indicate the deviations between individual measurements during a single melting charge.
At a chromium content of 1.4–2.0% the maximum deviation from the samples analyzed in the laboratory is smaller than 0.3%. These deviations are caused by analysis peaks of other elements in close vicinity of the Cr peak. A higher-resolution spectrometer helps to minimize this deviation.

Mn Content

Figure 5 shows a comparison of the manganese content as determined in the laboratory, and the VAI-CON® Chem analysis directly carried out in BOEHLER EDELSTAHL vacuum degassing plant for 24 different special steel charges. The plotted line is the intensity relationship between the manganese line at 323.07 nm and the iron line at 322.19 nm. The error bars indicate the deviations

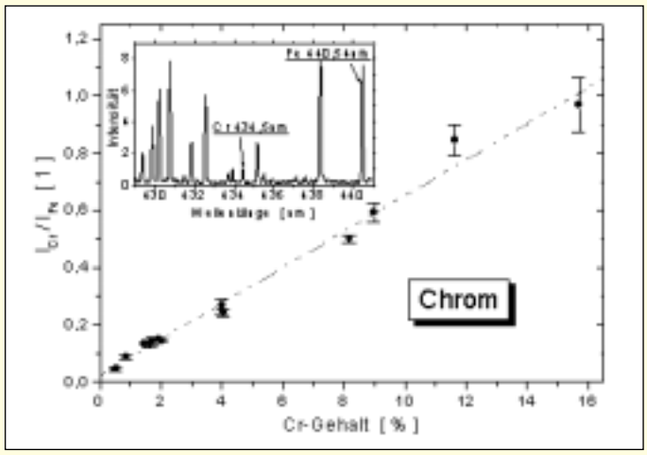

Figure 4: Comparison of the Chromium Content Measured in the Laboratory and Using VAI-CON® Chem for Samples from a Vacuum Degassing Plant, BOEHLER-KAPFENBERG, Austria

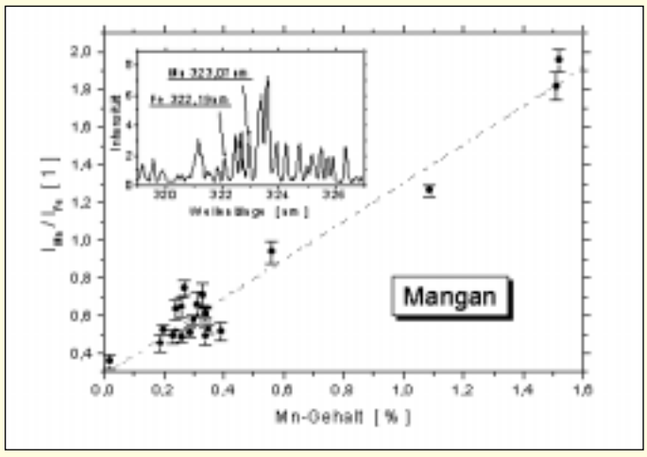

Figure 5: Comparison of the Manganese Content Measured in the Laboratory and Using VAI-CON® Chem for Samples from a Vacuum Degassing Plant, BOEHLER-KAPFENBERG, Austria

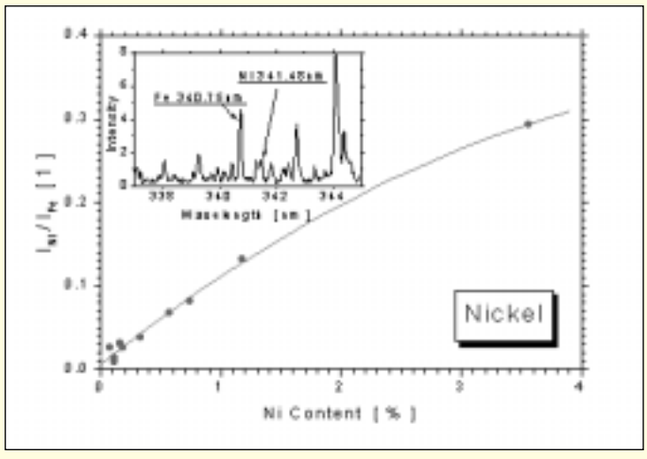

Figure 6: Comparison of the Nickel Content Measured in the Laboratory and Using VAI-CON® Chem for Samples from a Vacuum Degassing Plant, BOEHLER-KAPFENBERG, Austria

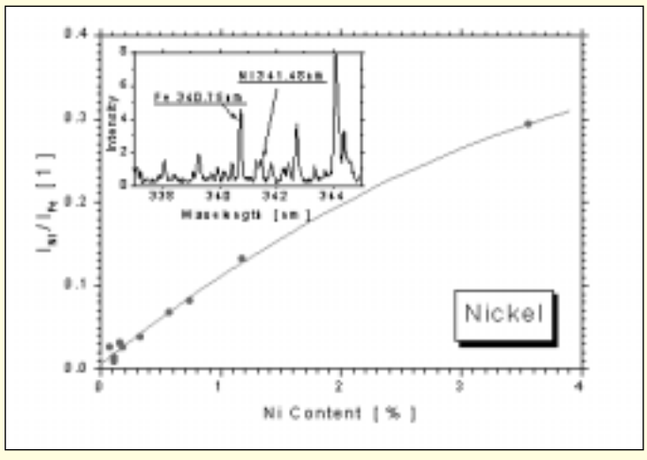

Figure 7: Spectra of a Special Steel Charge, Recorded at Different Times, BOEHLER-EDELSTAHL; Kapfenberg/Austria

between individual measurements during a single melting charge.
At a manganese content of 1.5% the maximum deviation from the samples analyzed in the laboratory is about 0.12%. These deviations are caused by analysis peaks of other elements in close vicinity of the Mn-peak.

Ni Content

Figure 6 shows a comparison of the nickel content as determined in the laboratory, and the VAI-CON® Chem analysis directly carried out in the BOEHLER EDELSTAHL vacuum degassing plant. The plotted line represents the intensity relation between the nickel line at 341.48 nm and the iron line at 340.75 nm.
At a nickel content of between 0.1% and 3.6%, the maximum deviation from samples analyzed in the laboratory is about 0.1%. These deviations are caused by analysis peaks of other elements in close vicinity to the Ni-peak. A higher-resolution spectrometer would minimize this deviation.

Analysis of Slag-Steel Mixture

Figure 7 shows a typical transition from slag to steel in a special steel melt, recorded at different times and coinciding with the onset of gas-sweeping. The area between 315 and 319 nm is dominated by two distinct calcium lines (probably derived from calcium oxides in the slag), while the area from 320 to 325 nm shows thick iron lines (steel bath). The iron lines become prominent only gradually as measuring proceeds. This is due to a reduction of the slag at the surface of the melt.

Temperature Monitoring in the Vacuum Degassing Plant

In addition to the VAI-CON® Chem analysis, the temperature of the steel bath in the vacuum degassing plant was measured using the VAI-CON® Temp system, also developed by VAI. The measurements confirmed the good results achieved during a previous two-year trial campaign. Figure 8 shows the superstructure with the adapter for continuous temperature measurement.
The infrared radiation emanating from the surface of the steel bath is transmitted via a beam waveguide to the detector and the evaluating equipment. Temperature variations are due to the circulation inside the bath which caused the relatively cold slag to be also included in the continuous temperature measurements.

SUMMARY OF ADVANTAGES

Extensive tests with VAI-CON® Chem, performed both under laboratory conditions and at an industrial vacuum degas-

sing plant, showed the following advantages over conventional measuring systems:

- The chemical composition of the steel bath is determined continuously for all defined elements, which opens up an enormous potential for process improvements.
- The deviations vis-à-vis laboratory analyses are marginal.
- Tap-to-tap times are reduced, since the processes need not be interrupted for sampling or temperature measurements.
- The exact knowledge of the steel bath composition and temperature immediately prior to tapping dispenses with the need for repeated blowing in certain applications.
- Enhanced work-site safety.
- Lower operating and maintenance costs.
- System installation possible within a normal maintenance shift.

CONCLUDING REMARKS AND OUTLOOK

With VAI-CON® Chem analysis system the chemical composition and temperature of steel baths can be continuously measured on the basis of the spectroscopy of laser-induced steel plasmas. Access to the steel bath is provided by existing process tuyeres, a lance or through an observation window. Clear visibility of the steel bath must be assured at all times to enable continuous monitoring of the steel bath composition.
In principle, the described analysis system is suitable for any metallurgical vessel, including LD, OBM and AOD converters, EAFs, electric low shaft furnaces (production of ferro-alloys), hot-metal ladles, all secondary metallurgical plants (e.g., vacuum degassing systems, VOD, RH), hot metal mixers or tundishes of continuous casting plants, etc.
The compact design of the VAI-CON® Chem system allows for a rapid and easy installation outside of the hot zone of existing metallurgical vessels. A considerable advantage over conventional measuring technologies (manual sample-taking or use of sublance with subsequent lab analysis) lies in the fact that continuous analysis is possible during the entire steel production cycle. Thus, the system offers the possibility for 100% dynamic process control.
Finally, as a confirmation of the accuracy and effectiveness of the VAI-CON® Chem, BOEHLER EDELSTAHL placed an order in January 2002 with VAI for the installation of this system at a new 50-ton AOD converter, which also will be supplied by VAI in early 2003.

Figure 8: Installation of VAI-CON® Temp Continuous Temperature Measurement System at the Vacuum Degassing Plant of BOEHLER EDELSTAHL, Kapfenberg, Austria (Provisional Arrangement)

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