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CHARACTERISTIC FEATURES OF THE GAS INJECTION PROCESS IN OXYGEN CONVERTERS THAT USE IRON-CONTAINING SLAG PRODUCED DURING STEEL SMELTING

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We describe the characteristic features of the steel smelting process in the 160-metric-ton converters at EVRAZ Consolidated West Siberian Metallurgical Plant JSC for the case where 10–50% of the solid metal charge consists of ferrous converter-slag waste products. Information on the chemical composition of the slag materials and the metal and slag components of the slag/scrap mixture was combined with the scrap consumption rate to quantitatively estimate the change in fundamental process statistics. The parameters of the traditional oxygen-injection process for the 160-metric-ton converters were compared against those for the technology to be discussed in this paper. Both the decrease in the concentration of non-ferrous-metal impurities and the required impurity removal levels at the exit from the converter are specified. The oxidative metal refining production data for the 160-metric ton converters at EVRAZ Consolidated West Siberian Metallurgical Plant JSC and the cost reductions from slag/metal scrap usage indicate that the process is economically promising.

Key words: Steel smelting; converter; scrap metal; slag/metal scrap; high-magnesium flux; primary slag; production data; steel quality; cost reduction.

Modern steel-smelting process designs based on the traditional use of scrap metal as a cooling agent in the converter melt must be adjusted to compensate for progressive deterioration of scrap-metal quality. Improvements in continuous steel casting have also been found to reduce the amount of plant scrap used, while the use of old scrap has also decreased because repeated remelting increases the concentrations of various elements that adversely affect the quality of the resulting metal product. These components are extremely difficult or virtually impossible to remove during smelting or ladle processing.

A variety of scrap preparation procedures have found practical application in metal production; however, none of these processes are very efficient. Under these conditions, it is necessary to improve on the traditional composition and production process for the solid metal charge, specifically, through the use of processed waste converter slag, including slag/metal scrap [2]. The latter is a conglomerate of the metal and slag components left in the slag pot after the liquid converter slag has been poured into the slag separation pit.

At Evraz WSMP JSC Oxygen Converter Shop 1 (KKTs-1), slag/steel crust is removed from the slag pots and loaded into the convertor together with the scrap metal in an amount equal to 10–50 wt.% of the solid metal

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charge, with corresponding adjustments being made to the thermal processes. We studied the slag formation process when slag/metal scrap is used in the metal charge for the purpose of enhancing the steel smelting process in the 160-metric-ton converters, .

For purposes of this study, the metal charge (cast iron and scrap metal) was 153–155 metric tons, of which 24–27% was in the form of a solid metal charge. The chemical composition of the cast iron was within the following limits, wt.% Si 0.35–0.65; Mn 0.35–0.65; P 0.08–0.12, and S 0.020–0.028. The cast iron was poured at a temperature of 1290–1320 °C. The scrap metal in the converter was generally heated up before the cast iron was poured. Grade TOM Kuzbass coal was used as the primary heat transfer agent. The oxygen flow rate during coal ignition was 150–250 m^3/min, with a minimum heating duration of 6 min.

Oxygen injection when metal is in the converters is accomplished using a five-Laval-nozzle tuyere where the nozzles have critical diameter 0.035 m and are aimed at an angle of 15 ° relative to the vertical axis. The injection operation was initiated with the tuyere 2.0–2.6 m above the quiescent metal level, guiding the slag for 3–4 min, and the tuyere was then lowered to the 1.0–1.5 m level. Injection continued for approximately 20–21 min at oxygen flow rate 350–450 m^3/min. A total of 6–8 metric tons of lime, 0.9–1.1 metric tons of FOMI high-magnesium flux, and 2.7–3.1 metric tons of coal were used per heat. Metal and slag samples were collected, and the temperature recorded, at the converter turn-down for subsequent analysis.

One characteristic feature of the Evraz WSMP JSC converters — gas injection during production of low-manganese cast iron — causes special difficulties during slag smelting and oxidative refining of metals. The use of high-magnesium fluxes for steel smelting and the high lining strength of the oxygen converter means that the converter slag has high viscosity and reduced refining capacity [3]. Increasing the vat temperature to pre-heat the scrap metal and slag improves the kinetic parameters of the process; however, the slag often forms too slowly, resulting in incomplete absorption of lime by the slag and extended times for removal of harmful impurities.

The composition and physical properties of slag are known to follow approximately the same pattern throughout the converter smelting process [4]. In the converter, slag is formed by oxidation of the oxide impurities and slag ingredients (lime and high-magnesium flux) added to the vat. The slag initially formed by oxidation of the iron and the impurities in the cast iron (primarily silicon and manganese) has high absorption of calcium and magnesium oxides. The dissolution rate for lime and high-magnesium flux depends on the temperature throughout the process and the properties of the slag components: There is an increase in slag basicity and a simultaneous increase in magnesium oxide content.

Some of the CaO in the slag component of the slag/metal scrap is bound to SiO_2 and P_2O_5, while the remainder forms slag, in free form, or as calcium ferrites or calcium aluminum ferrites. For example, given a typical slag-component composition (CaO 35–40%; SiO_2 13–15%; P_2O_5 1–1.5%), 24.31–28.05% of the calcium oxide will be bound into silicates, and 0.79–1.19% will be bound into phosphates. Thus, 5.69–14.83% of the CaO is available to the process.

The eutectic for the slag component of the slag/metal scrap in the charge is rich in CaO-containing minerals due to the fact that such minerals have a low melting point [3]; as a result, we can expect them to rapidly melt and become involved in the slag formation process within a few minutes at the beginning of the process.

Information on the chemical composition of the slag materials and metal and slag components of the slag/scrap mixture was combined with the scrap consumption rate to obtain a quantitative estimate for the change in process statistics. According to the calculations, if the slag/metal scrap consumption rate is 10–50% of the weight of the solid metal charge, the concentration of calcium oxide available to the process in the slag may increase by 4–9% during the initial gas injection period.

The slag component of the scrap being used in the charge contains ≈ 10% MgO, primarily in the form of ferropericlase (magnesiowustite) and magnesioferrite; thereby ensuring that the concentration of magnesium oxide in the converter slag is higher at the beginning of the injection process. Extreme oversaturation of

Table 1
Chemical Composition of Converter Slags

Heat	Mass fraction in slag (wt.%)							Basicity
	CaO	SiO_2	FeO	MgO	MnO	P_2O_5	S	
Test	35.2–46.1	12.9–19.2	22.5–27.4	6.1–8.4	4.1–6.3	1.3–1.9	0.07–0.10	2.40–2.73
	40.9	15.4	24.45	7.32	4.97	1.62	0.09	2.66
Comparison	34.7–45.3	12.1–18.7	21.1–23.9	6.4–9.1	4.9–7.1	1.4–1.9	0.07–0.09	2.42–2.82
	40.6	15.1	21.6	7.9	6.61	1.74	0.08	2.69

Note: Numerator — range of variation; denominator — mean value.

the converter slag with MgO near the end of the injection process should be avoided, since such oversaturation reduces the viscosity of the initial slag and increases the homogeneity of the final slag. The overall effect is to enhance the kinetic capacity for refining the metal and removing harmful impurities.

The test melts manifested some features typically associated with early formation of active slag due to the presence of calcium, magnesium, and iron oxides in the slag component of the slag/metal scrap loaded in the charge together with the scrap metal.

Thus, dissolving the slag component of the slag/steel crust in the converter makes slag form more rapidly at the beginning of the operation, but this occurs at the price of increasing the total amount of slag. At peak consumption rate (which occurs when slag is 50% of the metal charge by weight), the calculated increase in the slag is 40–45%, which will definitely affect the hydrodynamics in the converter and require appropriate corrective action to adjust charging during the heat to prevent bursts of slag from escaping the converter.

Analysis of the theoretical results revealed that the increased slag levels can be compensated for using a 0.05–0.27% reduction in the silicon content of the cast iron or a 3–14-metric-ton reduction in the mass of the metal charge, while taking the physical and chemical characteristics of the metal and slag into account. Under actual production conditions, it is preferable to use a combined approach for process optimization.

There were very few rapid variations in gas injection during any of the test heats. Lime and FOMI high-magnesium flux consumption decreased by an average of 0.7 kg/metric ton and 0.5 kg/metric ton, respectively, thereby compensating for the slag component of the slag/metal scrap entering the converter vat; however, this also cut the refining capacity of the final slag (Table 1) and, most importantly, its basicity and, therefore adversely affected efficiency of removal for harmful impurities.

Under these conditions, the phosphorus oxidizes in a reaction with iron oxides at the beginning of the converter smelting process when the vat temperature is low, including the iron oxides from the slag component of the slag/metal scrap being dissolved in the vat. This is due to the relatively low silicon content (0.4–0.5%) of the cast iron being recycled (and the resulting relatively low concentration of silica in the initial slag),the slow increase in vat temperature (because of the greater cooling effect from the slag/metal scrap), and the availability of calcium oxide for binding the P_2O_5 into complexes that lock up the phosphorus and reduce its activity.

The average phosphorous content of the metal prior to the test heats using slag/metal scrap was 0.017% (Table 2). The final slag had basicity 2.66, iron oxide content 24.45%, metal temperature 1629 °C, and cast-iron phosphorus content 0.08–0.12%.

The average phosphorus content of the metal prior to the comparison heats was similar; however, this facilitates a greater distribution rate of phosphorus between the slag and the metal, which appears to result in a larger

Table 2
Chemical Composition and Temperature of Metal Prior to Pouring

Heat	Mass fraction of element (wt.%)				Temperature (°C)
	C	Mn	S	P	
Test	0.04–0.10 0.049	0.08–0.13 0.105	0.22–0.030 0.029	0.014–0.020 0.017	1620–1650 1629
Comparison	0.05–0.12 0.062	0.10–0.16 0.155	0.020–0.030 0.028	0.015–0.020 0.017	1625–1650 1630

Note: Numerator — range of variation; denominator — mean value.

amount of phosphorus entering the vat. Under typical converter smelting conditions, the slag generally has a higher iron-oxide content, that on balance is not advantageous to sulfur removal. The average sulfur content of the material prior to the test heats using slag/metal scrap was 0.029% and 0.028% prior to the comparison heats (see Table 2). Note that the slag oxidizability for the test heats was somewhat higher than for the comparison heats, even though the basicity of the slag and the temperature conditions for the process are virtually identical.

Analysis of the chemical composition of the metal produced in the test heats revealed that the undesirable non-ferrous metal impurities (specifically, Cu, Ni, and Cr) were substantially reduced due to a qualitative change in the composition of the solid metal charge. The use of slag/metal scrap and the corresponding reduction in scrap-metal consumption, which is the primary source of non-ferrous metal impurities in the converter vat in the traditional steel production process enabled us to reduce the copper content by an average of 16% and the nickel content by an average of 12.5% prior to discharge from the converter.

CONCLUSION

Steel production in an oxygen converter using iron-bearing products from recycled waste slag can be used to reduce operating costs in steel production, and shows real commercial promise [5]. The projected cost savings is approximately 250 million rubles per year at current prices for raw materials and consumables.

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