TECHNICAL ARTICLE

Benchmark for Tap-Hole Lifecycle Management Practices in Silicomanganese Production When Submerged Arc Furnace Technology of Circular Design is Applied

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A holistic conceptualisation of the variables forming part of tap-hole lifecycle management and performance was defined previously for coke bed-based processes in which submerged arc furnace technology of circular design was applied. In the work presented here, the variables were applied to silicomanganese production comparing the tap-hole lifecycle management practices and performance among five furnaces on one site. The quantified independent variables were divided into four functions associated with the tap-hole lifecycle (operations, relining, maintenance, and repair), and a selection of the results is reported here. Having the benchmark available will contribute to comparative studies in future.

INTRODUCTION

The tap-hole lifecycle typically consists of a combination of four functions: operation, relining, maintenance, and repair.¹ Management practices associated with each of these functions typically form part of day-to-day furnace operations, and benchmarking allows for furnace operators to evaluate their practices against those of their peers. The more participants in a benchmarking exercise, the greater the potential for comparison and therefore for improvement by participants in such an exercise. Nolet² reported on a project where nine plants participated in a study specifically aimed at tap-hole lifecycle management in platinum group metal (PGM) and nickel matte smelting. Her study is an example of across-commodity, across-country, and even across-technology (to some extent) benchmarking exercises.

At the most local scale, furnace operators can compare their practices amongst furnaces operated on one site. The article presented here reports the results of such an exercise conducted in South Africa on a site where silicomanganese (SiMn) is produced using five submerged arc furnaces (SAFs). The aim is to encourage similar work to be done across commodity, especially for coke bed-based

ferroalloy production, i.e., SiMn, ferrochromium (FeCr), and high-carbon ferromanganese (HCFMn) production utilising SAFs of circular design, and across countries, as South Africa currently has only one producer of SiMn.^{3,4}

BACKGROUND

To contextualise the work presented here, a few concepts related to furnace tapping in SiMn production are defined (for more in-depth discussions of these concepts, refer to^{5,6}).

Pyrometallurgy is the branch of science and technology concerned with the use of high temperature to extract and purify metals.⁷ *Smelting* is the liquid state processing applied in pyrometallurgy to extract the alloy from the ore. The alloy is extracted through melting of the ore and chemical reaction with a suitable reductant such as coal. The liquid oxide phase that remains is called slag. To ensure that the slag remains liquid and has properties that support the chemical reactions required, a flux, i.e., quartz is added.

During smelting, the liquid alloy and slag produced gradually fill the furnace with liquid materials. At some stage, the liquid materials have to be removed from the furnace through an action called

tapping. During tapping, a hole is made in the sidewall of the furnace containment system, allowing for the liquid material to run from the furnace in a controlled fashion. Once the material of choice is removed, the hole is plugged to allow for further build-up of liquid material. The hole made in the process of tapping is referred to as the *tap-hole* and the material typically used to plug the tap-hole as *tap-hole clay*.

Physical separation of the alloy from slag is important and the potential first stage of separation is in the liquid phase. In some furnace designs, tap-holes are installed at two different vertical positions: a lower level tap-hole through which the alloy is tapped and a high-level tap-hole through which slag is tapped. This tap-hole configuration is referred to as *dual-level* tapping. The tap-hole configuration acts as a weir for the separation of metal from slag inside the furnace. In other furnace designs, tap-holes are installed at the same level with alloy and slag being tapped from the same tap-hole. This tap-hole configuration is referred to as *single-level* tapping. During single-level tapping, the separation of liquid slag from liquid alloy occurs in either the tapping channel (*launder*) or the containers used to collect the liquid material (*ladles* and/or *pots*).

When a series of containers, consisting of a ladle (mainly to collect the alloy) and pot (to collect the bulk of the slag) stacked in *cascade configuration* is used, the bulk of the separation between the alloy and slag occurs during tapping. In the cascade configuration, the slag and alloy stream runs from the tap-hole via the launder into the ladle. As the density of slag is typically 50% less than that of the alloy, the slag will overflow into the pot once the ladle is full. The bulk of the separation between the alloy and slag occurs in this fashion. Once the tap-hole has been closed, the remainder of the slag floating on top of the liquid alloy is *skimmed off* by either slightly tilting the ladle or using a mechanical scraper. For mass balance purposes, the weight of the empty ladle is recorded as well as the weight of the full ladle after skimming. The amount of alloy tapped is then calculated by difference.

In most pyrometallurgical smelters, the furnace containment system consists of a combination of refractory materials—materials that maintain their physical integrity at high temperatures—steel and, in some instances, copper components cooled by water or some other cooling medium. The tap-hole forms part of the containment system and is frequently formed by a specially shaped refractory brick or copper component, or combinations of these, referred to as the *tapblock*. The side of the tapblock towards the inside of the tapblock is referred to as the *hot face* and towards the outside, the *cold face*. When the tapblock consists of a series of blocks, the block towards the cold face is often referred to as the *Mickey*.

METHOD

A holistic conceptualisation of the variables forming part of tap-hole lifecycle management and performance was defined previously for coke bed-based processes applied to circular SAFs.⁵ In the research presented here, the holistic conceptualisation was applied in the context of SiMn production in South Africa on a single site using five SAFs.

The dependent variable was tapblock life. The independent variables were chosen to be related to tap-hole lifecycle management. Data were collected through interviewing key operating personnel and studying production records and design drawings. The data were collected during a 3-day plant visit in February 2018. Production data for 2017, during the period 1 January 2017 to 31 January 2018 inclusive, were studied. The averages for all of the variables were calculated on a per-tap basis except where noted and discussed separately.

Table II. Composition of tapped alloy, mass%

Furnace #	1	3	5	6	7
Mn	66.2	66.2	67.4	66.2	66.2
C	1.7	1.7	2.3	1.7	1.7
Si	16.4	16.4	14.5	16.6	16.5
Fe	15.3	15.3	15.4	15.0	15.2

Table I. Data on process conditions

Variable	Unit	F1	F3	F5	F6	F7
p : Furnace pressure	kPA	All furnaces open to atmosphere				
$X\%$: concentration of individual components in alloy or slag determined by bulk chemical analyses of tapped alloy or slag	Mass%	See Table II for alloy compositions				
M_{alloy} : Alloy mass per tap (weighed)	Tonnes	11.6	12.3	26.2	12.5	26.3
M_{slag} : Slag mass per tap (estimated)	Tonnes	13.0	13.3	28.3	13.9	28.7
Total mass per tap (weighed)	Tonnes	24.6	25.5	54.5	26.4	55.0
$T_{\text{alloy}}/T_{\text{slag}}$: Alloy/slag tap temperature	°C	Neither alloy nor slag tap temperatures were measured				

Table III. Data on tap-hole operations

Variable	Unit	F1	F3	F5	F6	F7
t_{tap} : Tap duration	Minutes	31.3	30.2	34.1	24.0	30.6
TR : Tap rate	Tonnes/minute	0.8	0.9	1.6	1.1	1.8
TH_{cf} : Tap-hole cycle frequency (when more than one tap-hole)	Taps/tap-hole	N/A	N/A	N/A	N/A	N/A

Table IV. Data on tap-hole drilling parameters

Variable	Unit	F1	F3	F5	F6	F7
Drilling applied	Yes/no	Yes	Yes	Yes	Yes	Yes
Drill duty	Number of tap-holes serviced/drilled	One	One	One	One	One
Drill support configuration		Pedestal	Rail	Pedestal	Pedestal	Pedestal
Drilling frequency	Tap-hole drilled/tap	One	One	One	One	One
Drill depth [#]	mm	666	677	N/A	623	N/A
Drill rod length	mm	2500	2500	2500	2500	2500
Drill rod diameter	mm	32.5	32.5	32.5	32.5	32.5
Drill bit diameter (alloy, slag)	mm	76	76	76	76	76

[#]Drill depth measurement had only been implemented during the last 5 weeks of the 12-month period covered in the analysis. Drill depth measurement had not yet been implemented on furnace #5 and #7

Table V. Data on tap-hole lancing parameters

Variable	Unit	F1	F3	F5	F6	F7
Lancing frequency	Tap-hole lanced/tap					
Lancing extent	Number of lances/tap	1.8	1.7	2.9	1.1	3.8
Gas used when lancing				Oxygen		
Type of lance used				Mild steel		
Alloy lance length	mm			7000		
Alloy lance diameter—external and (internal)	mm			17 (12)		
Reaming of tap-hole applied during tap	Yes/no			Yes		
If ream, type of reaming applied				Poking bar		
If steel bar applied, diameter of bar	mm			25		
If steel bar applied, length of bar	m			6		
Steel bar consumption per tap	Bars/tap	1.0	1.0	1.2	1.1	1.0

A selection of non-confidential results is presented here as an example of tap-hole lifecycle management and performance in SiMn production in SAFs of circular design.

RESULTS AND DISCUSSION

Results are presented and discussed according to the four functions associated with tap-hole lifecycle management and performance, namely operation, relining, maintenance, and repair. The definitions

and especially mathematical descriptions presented previously are applied.⁵ For ease of comparison, data sets are presented in table format.

Operations

The variables and associated data associated with tapping operations are presented in a number of tables. Data sets on process conditions, including chemical analyses of the product, are presented in Tables I and II. The data set on tap-hole operations is presented in Table III, on tap-hole drilling

Table VI. Data on tap-hole clay parameters

Variable	Unit	F1	F3	F5	F6	F7
Tap-hole clay preheated	Yes/no	No	No	No	No	No
Tap-hole clay preheating method, temperature	°C	N/A	N/A	N/A	N/A	N/A
Tap-hole clay composition—type of aggregate used		Quartz	Quartz	Not specified but contains SiO ₂ and Al ₂ O ₃	Not specified but contains SiO ₂ , Al ₂ O ₃ , and C	Silica and alumina raw materials
Tap-hole clay composition—type of binder used		Organic	Organic	Tar free	Tar free	Chemical
Tap-hole clay moisture content	Mass%	Not reported				
Tap-hole clay workability		30–36%	30–36%	Not reported	Not reported	40–50%
Tap-hole clay consumption	kg/tap	41	33	46	36	30

Table VII. Data on claygun parameters

Variable	Unit	F1	F3	F5	F6	F7
Claygun applied	Yes/no			Yes		
Claygun duty	Number of tap-holes serviced/claygun			One		
Claygun support configuration		Pedestal	Rail	Pedestal	Pedestal	Pedestal
Claygun press-on pressure	MPa			4.8		
Claygun nozzle duty	Tonnes alloy or slag/nozzle	Replaced once per year or when damaged when no clay in claygun				
Clay capacity of claygun barrel	Litres			50		
Claygun holding time at tap-hole	Minutes			2		
Clay injection rate	Litres/second			Estimated at 3.5–6.0		
Claygun energy supply method				Hydraulic		
Methods used to ensure perfect mating between tap-hole and claygun (mechanical alignment/ceramic or clay gaskets)				Swinging in only		
Manual plugging applied	Yes/no	Only under emergency conditions, which does not happen frequently as tapping strategy is to tap furnace empty at each tap				
Manual plugging method used		Form a cone using tap-hole clay, which is then pushed into the furnace with a round bar to which a steel disk was attached previously				

parameters in Table IV, on tap-hole lancing parameters in Table V, on tap-hole clay parameters in Table VI, and on claygun parameters in Table VII.

Maintenance

Tap-hole monitoring practices (which trigger maintenance activities) consist primarily of visual inspections at appropriate intervals as described in

Table VIII below. Simple activities executed in less than 2 h are considered maintenance activities.

Repair

Tap-hole monitoring practices (which trigger repair activities) consist primarily of visual inspections at appropriate intervals as described in

Table VIII. Tap-hole monitoring practices for maintenance

Variable	F1	F3	F5	F6	F7
Tap-hole condition monitoring techniques that trigger tap-hole maintenance	None	None	Visual inspection, diameter and shape of hole	None	Visual inspection, diameter and shape of hole
Tap-hole maintenance intervals	None	None	Face inspection at shutdowns	None	Face inspection at shutdowns
Tap-hole maintenance practices including tap-hole repair, maintenance at the interface between the tapblock and the claygun	None	None	Replace front Mickey $\pm$ every 8–9 months	None	Replace front Mickey $\pm$ every 8–9 months
Use of reconstructive tap-hole clays	Yes	Yes	Yes	Yes	No

Table IX. Tap-hole monitoring practices for repair

Variable	F1	F3	F5	F6	F7
Tap-hole condition monitoring techniques that trigger tap-hole repairs	Furnace burn-through (elsewhere or next to tapblock), bricks observed in ladle, visual inspection				
Tap-hole repair practices	Rebuild by breaking out refractory until clean and build from there	Rebuild by breaking out refractory until clean and build from there	Dig out area below lintel and reinstall tapblock	Rebuild by breaking out refractory until clean and build from there	Dig out area below lintel and reinstall tapblock
Lining life (years)	7	10	5	3	9

Table IX. Complex activities requiring > 2 h are considered repair activities.

CONCLUSION

The goal of this research was to support the benchmarking of tap-hole lifecycle management practices in plants producing SiMn using circular SAFs. Specifically, the research output was to create a benchmark for the independent variables that affect tapblock life based on a comparative study conducted on one site that operates five SAFs. The independent variables were identified and described previously. The quantified independent variables were then divided into the four functions associated with the tap-hole lifecycle (operations, relining, maintenance, and repair) and the non-confidential results reported here. Having the benchmark available will contribute in future to comparative analysis studies in the field where confidential results could be shared amongst participants. Potentially, once the data set available is large enough, the effect of the independent variables on tap-hole life can be quantified.

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