Control and optimisation of material additions throughout the AOD refining cycle

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ABSTRACT: In this paper, the real time AOD process control system UTCAS is presented briefly with a focus on its ability to control and optimize cold material additions throughout the AOD refining cycle. In order to emphasise the benefits of this ability, different scenarios are discussed and evaluated. The system has been developed by Uvan Hagfors Teknologi AB in Sweden and is in use at the Outokumpu Avesta works and at the Acerinox Columbus works.

1. INTRODUCTION

The AOD process has dominated stainless steelmaking since its introduction on the market in the late 1960’s. Initially this was a slow, labour-intensive process that required much skill and experience from the operators to be handled efficiently. The converters were small and heat losses through the refractory were extensive. However, this has changed over time and today many new converters supplying slab casters handles weights well over 100 tons.

With the increasing converter sizes the heat losses has become less important and instead the ability to limit the temperatures in the converter and prevent the hot liquids to damage the refractory are key factors in ensuring good converter availability and high productivity. To manage the temperature in the converter, dilution of energy with more mass addition of cold materials is perhaps the most common strategy.

2. METALLURGICAL APPROACHES FOR COOLING THE AOD

Stainless steel refining has some basic features such as carbon removal, de-oxidation, de-sulphurisation. In the AOD process these operations are generally combined with some alloying with solid material as well as nitrogen control by means of gas introduction. But from an operational point of view the stainless steel refining is very much a matter of controlling the amount of energy available in the converter and how that energy is used.

The energy management situation is very different between producers due to varying local conditions:

- In converters that produce materials for stainless steel castings, the material range is wide, heat size is small and the treatment time is comparatively long and thus the energy is almost always in significant deficit in these cases.
- In converters where short series of special grades are frequent, the energy is similarly to foundry situation mostly in deficit. The deficit has the same cause as in the foundries but the problem is smaller. Locally during the process, heat surplus is found at the very end of the process when cooling is needed to obtain a suitable casting temperature. Heat surplus also occur when the temperature ended up higher than expected. Instability in the production is much more common for special steel-makers than for more bulk-oriented producers.
- In converters that produce bulk-grade coils in the US, Japan or Europe the scrap usually makes up a large portion of the total material input. In this case the energy is also in deficit- during much of the process. The exceptions to the heat deficit situation are similar for these converters as for the special steel producers but they occur to a lesser extent and with a lower frequency.
- In a Chinese, Indian, Latin-American or South-African situation the scrap part of the charge make-up is usually lower than in a European plant. As a consequence, the energy is often in surplus throughout the production cycle.

When a situation with energy deficit arises in the converter, it is easily handled by allowing excessive chromium oxidation. Chrome that is later recovered with silicon or aluminium. The situation with energy deficit is avoided as far as possible by melting in the Electric Arc Furnace where the energy is cheaper.

The situations with energy surplus are thus the more common situation. Essentially there are three practical strategies to deal with energy surplus:

- To remove the surplus by purging inert gases through the metal and heating it
- To dilute the surplus energy by melting material to make more steel
- To neutralize the surplus by energy consuming reactions

Each of the latter methods has its merits and applications. The dilution of the energy surplus by adding more material is probably the most frequently used approach.

This paper concentrates on dilution of the energy surplus and how this can be optimized and controlled with the aid of the UTCAS process control system.

Cold material additions in the AOD process can be grouped as follows:

- Alloys (added to meet product demand in terms of mass and composition)
- Slagformers (added to prepare a slag suitable for reduction and de-sulpurisation while maintaining conditions where refractory wear is limited and decarburisation is favoured)
- Strategic addition (added to take advantage of surplus heat for melting instead of using electrical energy in the EAF)
- Tactical addition (additions, mainly coolants, where need appear irregularly as a function of uncertainty in process behaviour)

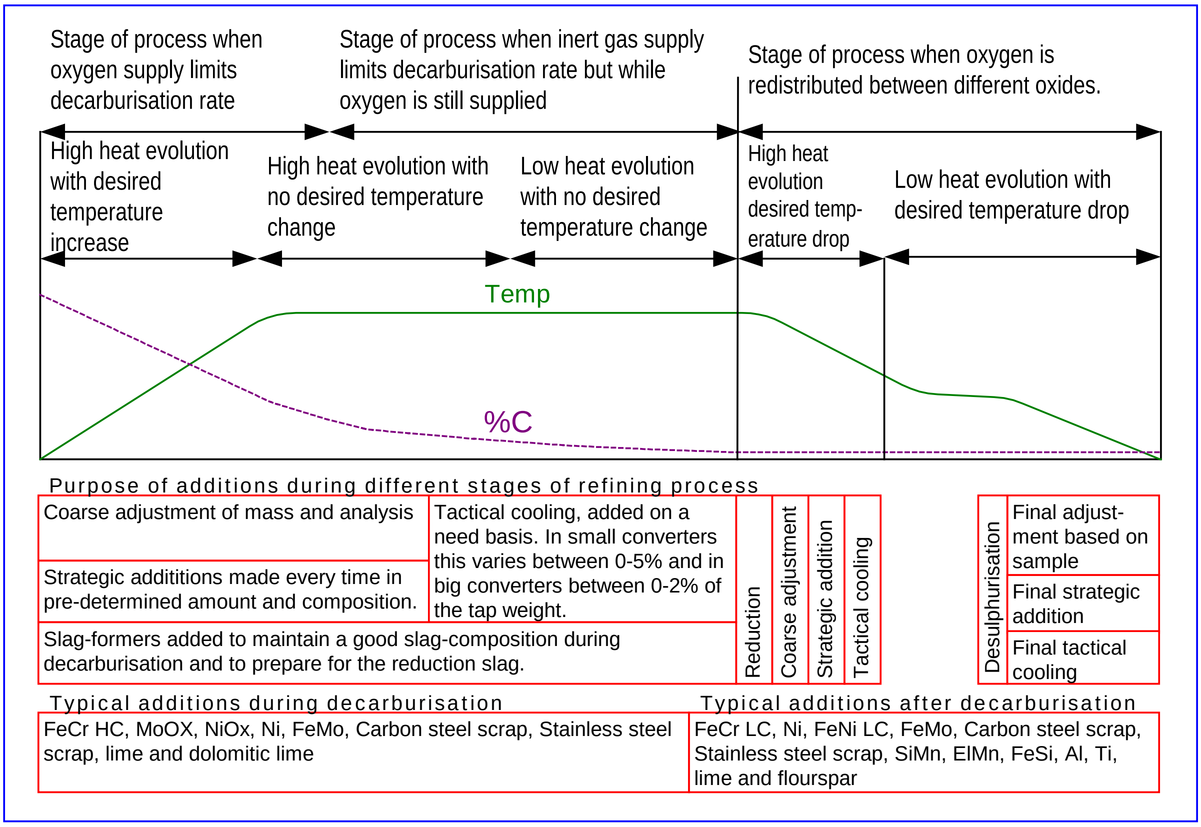

Fig. 1: Typical cold material distribution and purposes during AOD refining

3. COMPUTERIZED PROCESS CONTROL AND MANAGEMENT

UTCAS is an advanced computer system specially designed for the converter process management.

The system concept includes an effective real-time process control system as well as tools for process design and production evaluation (see figure 2).

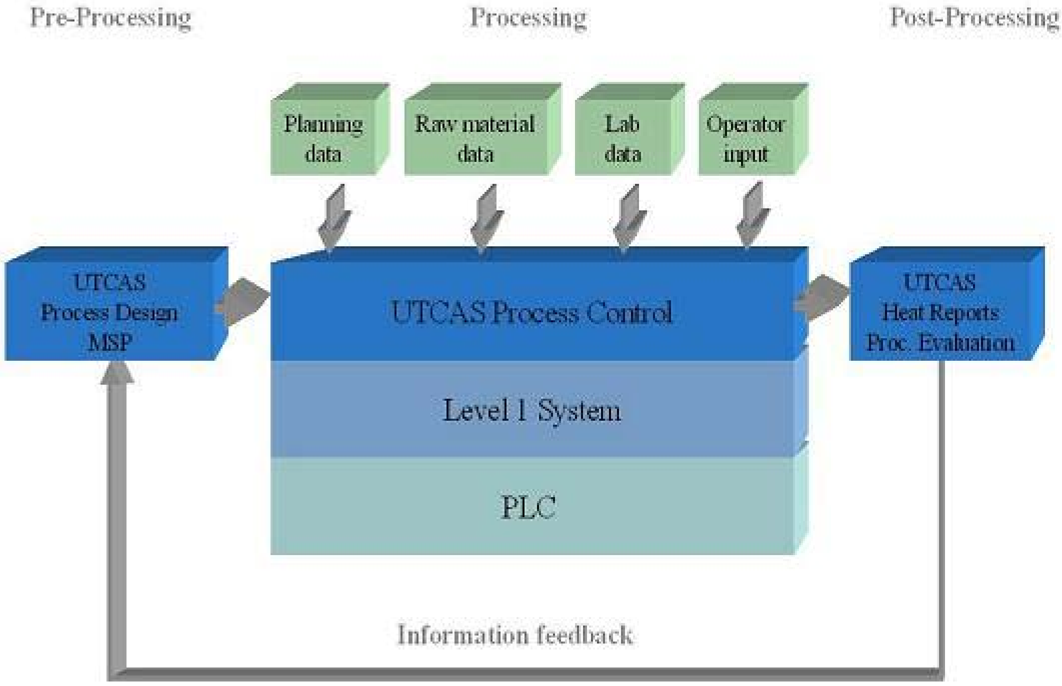

Fig. 2: The UTCAS concept for process control and management.

3.1 Process Design

The Process Design tool provides an environment for designing tailor-made process routes – or practices – for each different steel grade. The total process is within the system represented and built-up of different steps. Each step is defined with different properties for controlling the utilization and distribution of gases and materials. The start and end of the steps are controlled by defined conditions.

The steps serves as re-usable building blocks and can be put together into sequences in various combinations representing the most suitable practice for processing each grade – in accordance with the strategic decisions made on material distribution and mass build-up. In addition to the step sequence, the process targets and the presumptive start conditions are defined with respect to chemical composition, mass and temperature.

The practice as a whole will serve as a framework or a set of rules for the Process Optimization function. The Process Optimization function uses a mathematical model able to optimize the exact amounts of gases and materials in order to move from the given start conditions to the defined targets in the most economic way with respect to the rules and limitations set by the step sequence definitions.

The model is able to control and balance the temperature by means of

- Adjusting gas mixes (oxygen/inert ratio) over time
- Distribution of calculated amounts of alloys and slag formers
- Determining amounts and distribution of additional cooling additions

By combining these functions, the Process Optimization finds solutions to control both over all and local energy surplus generated as a consequence of the strategically defined practice.

3.2 Processing

When a heat is processed, the defined practice for the planned steel grade is selected from the database. The real-time process control system will then automatically execute a Process Optimization – the same function used during process design but based on the heat specific start conditions. UTCAS then initiates gas blowing, material weighing and addition according to the optimized process plan by giving set points to the PLC.

The process is then run fully automatic until UTCAS or the operator detects a deviation from the expected results which causes the process plan to be re-optimized and changed.

4. MODEL APPROACH TO SMART ADDITIONS

The Process Optimization uses three main calculation steps to determine the required material amounts and distribution:

- An advanced simplex kernel algorithm is used to determine the total amounts of alloys, mass build-up materials, reduction agents and slag formers in order to reach the defined final targets for steel chemistry, steel mass and slag composition.
- The materials are initially distributed according to the different properties and conditions defined in the practice.
- A repeated prediction of the process is used to adjust gas mixes, re-arrange additions and (if required) add extra cooling materials with the objective to balance the process within the boundary conditions of the practice.

By just changing the targets, and/or the start conditions, the model will automatically generate an adapted process plan with respect to material distribution and heat control. This means that even a dramatic change in strategic over all material distribution – for instance between the EAF and the AOD - easily can be made.

Several practices can be prepared for processing the same steel grade under different conditions and the operator can select the most suitable one for the current heat. In addition to this the operator can make almost any alteration during processing, for instance regarding target temperature, mass build-up and blowing conditions, and get full support by the Process Optimization in generating an adapted process plan.

5. SOME INTERESTING SCENARIOS

In the scenarios discussed below, the start and final conditions are the same except for the ones specifically pointed out not to be. The scenarios are all based on that AISI 316 with 0.02% C and 0.035% N is made in a 90 ton converter.

6. ENERGY SURPLUS AND LACK OF SUITABLE COOLING SCRAP

In everyday operation in the steel plant, refining is ideally done using a strategy where limited use of tactical cooling is required. This is obtained by good control of internal as well as external scrap and alloys, but also by design and maintenance of the raw-material handling system.

If, for some reason, attributable to operator mistakes or equipment failure, a very high temperature is detected, the control system must respond to this with a practical suggestion. The situation when a problem of this character appears is normally limited in options as well as time to realise them. Figure 3 illustrates two example of how such a situation can be resolved. Case 1 shows the calculated material amounts before the high temperature measurement. Case 2 shows the calculated material amounts after a high temperature measurement at the end of decarburisation. The need of extra tactical coolants has been covered by a mixture of “Iron” and alloys. Case 3 shows an alternative solution where the required cooling effect is achieved by adding shredded or granulated AISI 316.

Fig. 3: A scenario predicted prior to a high temperature measurement (case 1) and as re-calculated after the high temperature measurement when granulated AISI 316 is available (case 3) and when cooling with alloys is used (case 2)

7. INFREQUENT AVAILABILITY OF LIQUID FERROCHROME

The possibility to use liquid ferrochrome is very attractive when available. Hot transfer is for instance done at Outokumpus Tornio plant[1,2] and on occasions also at Acerinox South-African Columbus operation [3,4]. The obvious advantages with the use of liquid ferrochrome are that there is no need to melt the metal, the yield is higher and the time to market for the ferrochrome is shorter.

When liquid ferrochrome is transferred on a regular basis it is normal to melt less chrome in the EAF. A normal amount of liquid ferrochrome to transfer is about 15-25% of the total tap weight of stainless steel.

To efficiently solve an operational situation when the availability of liquid ferrochrome is not ascertained, it is necessary to have the ability to switch between different standard practices. One which considers the addition of chrome units in the converter and one where the chrome arrives with the pre-melt. These practices are both different from the practice optimised for a case when liquid ferrochrome is not considered at all.

The practice where chrome must be added requires significantly more oxygen, slag-formers, reduction agents, time and tactical coolants due to its un-predictability (case 2; table 1). The practice where liquid chrome is used is much leaner and more suitable for strategic use of cheap raw materials such as slab crops or skulls to consume surplus energy in the converter (case 1; table 1).

Case	Mass	%C	%Cr	HCFeCr	NiOx	FeNi	316	FeSi	Time	Mass
1	80000	2.48	18.5	0	1973	736	7675	1234	55	90821
2	68000	1.2	6.9	14745	2000	1021	6006	2312	51	92129

Tab. 1: Case 1 is for liquid ferrochrome and case 2 is without. All masses in kg and time is in minutes.

The liquid ferrochrome transfer requires the operator to have different strategies available to choose from. Each of the strategies optimised for the condition that it occurs in.

8. Rapid change in demand

In August 2008, the high demand forced most plants to produce as much as possible rather than focusing on cost control. But only two months later cost control was the key issue. Many different methods are used in a situation like this one - each of them unique to the local situation. Some measures are however quite general:

- Melting is moved from the converter to the EAF.
- Cheaper scrap and alloys are preferred even if more treatment is necessary.
- Scrap and alloys can travel further as transport costs decrease.
- More effort is paid on using internal scrap to improve liquidity.
- Stocks are emptied to improve liquidity, in the producing end this means that production demand decrease and more time becomes available for refining.

In the converter operation this means a lot of changes. Double slag practice will probably be preferred. Coarse alloying will increase as well as the tactical cooling while strategic additions will decrease.

A typical converter bottle neck removal case is when very little chrome is added in the converter and when the nickel that is used has high purity (case 1; table 2). This ensures rapid processing with little room for error. On the contrary is a situation where more chrome is added and a lower grade nickel is utilised (case 2; table 2).

Case	Mass	%C	%Cr	HCFeCr	NiOx	FeNi	FeNiL	FeSi	Time	Mass
1	80000	1.6	17.8	1112	0	2977	0	1111	43	91524
2	80000	1.6	16.56	3282	1998	260	1780	1297	47	90812

Tab. 2: Case 1 is for high productivity and case 2 is for lower cost. All masses in kg and time is in minutes.

There is no room to develop practices like this for several hundred steel grades in a few weeks time. Instead, this must be premeditated and strategies must be available for immediate implementation when the need arise. Of course responsiveness to the reverse situation will be equally important when the demand to produce more rapidly returns.

This highlights another important feature of the process control system, namely the possibility to create and store alternative practices ready to be used for the current situation.

9. Conclusions

To ensure that available raw materials, equipment, time and product demands are optimised for each situation it is necessary:

- To prepare for each expected strategic situation that may appear and to provide tools so that the operator easily can adapt the process in a timely manner.
- To prepare for any possible process deviation and raw material situation that may appear.
- For operations to jointly develop scenarios with raw material purchasers and market staff to rapidly be able to respond to changing market conditions.

This can only be achieved effectively when the engineers and operators has adequate system and modelling support. The UTCAS system has been found to provide such a support on a reliable and easy to use daily basis.

10. References

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