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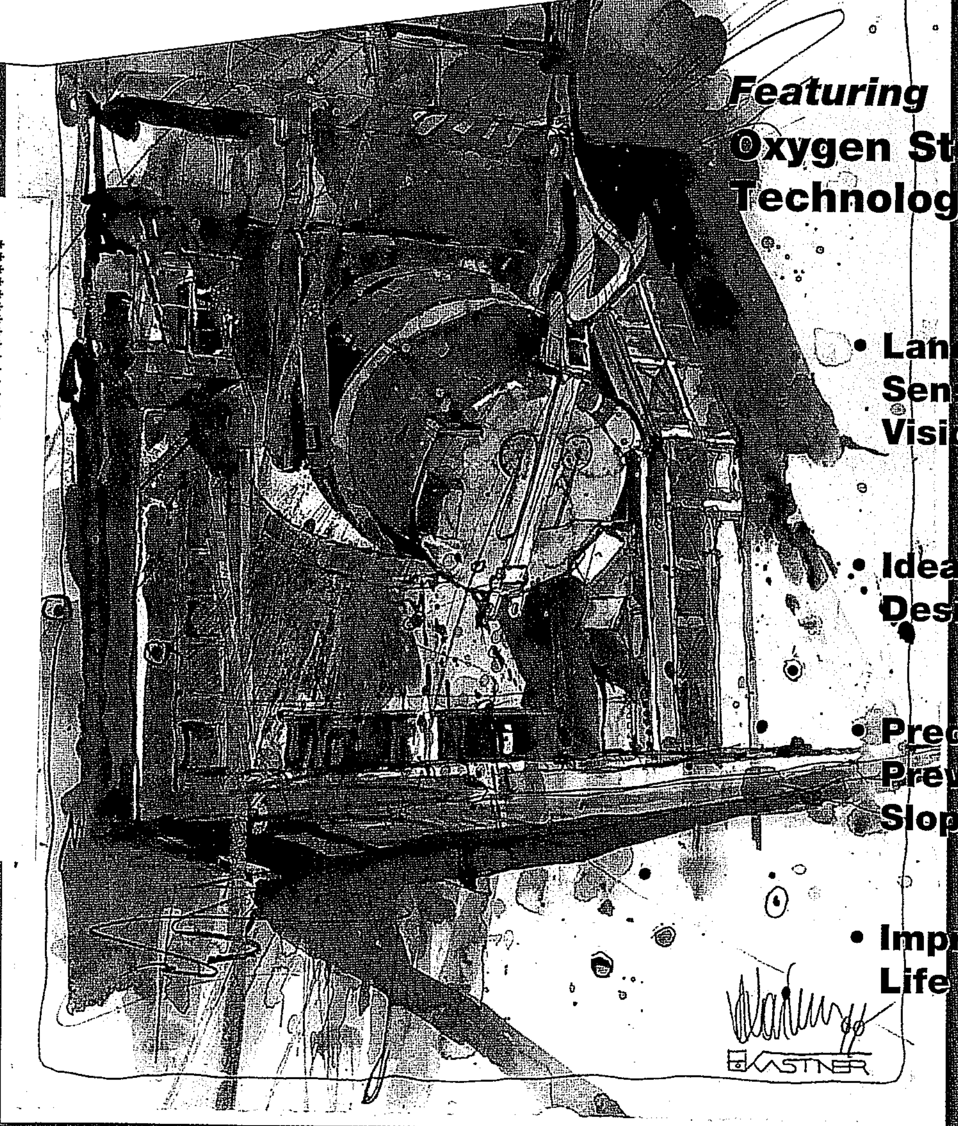

Featuring

Oxygen Steelmaking Technologies

- Lance-Based Sensing and Vision Systems
- Ideal Converter Design Aspects
- Predicting and Preventing Slopping
- Improving Hood Life Cycle Costs

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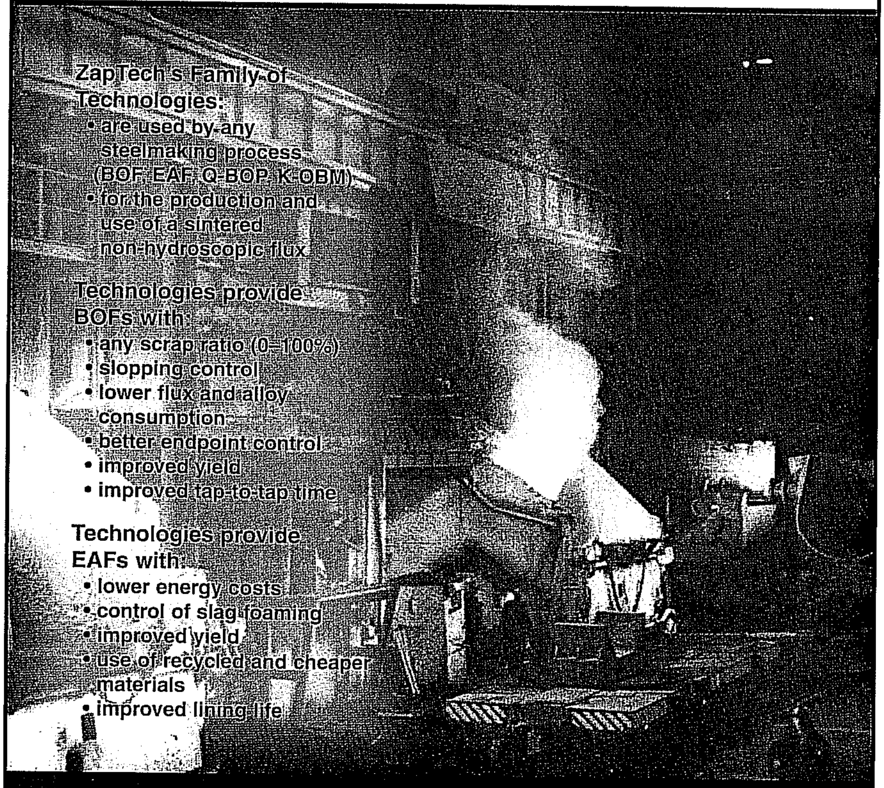
873611 5140 S 96 356
ANATOLI BOUTCHENKOV
PROJ. MGR.
ZAPTECH CORPORATION
4275 SHACKLEFORD RD STE 200
NORCROSS GA 30093-2933



Prediction and Prevention of Slopping in a BOF

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A model was developed to predict and prevent slopping in a BOF by controlling slag height in the vessel in real time. The system modifies charging and blowing practices based on actual conditions experienced in the BOF.

The losses caused by slopping from a BOF vessel are well-known. A few examples are pollution to the environment, lower yield and equipment damage. All existing methods to control slopping require measurement devices, and these methods are reactionary in nature.

Slopping is suppressed by reacting to signals received from measurement devices. These devices attempt to measure the slag height in the vessel during the blow by various methods. Most of these measurements are indirect. An example is the use of a sonic meter to measure the sound emitted from the vessel during the blow. The lower the sound, the higher the slag in the vessel. When the device indicates that the slag is rising beyond an acceptable level and slopping is imminent, operating practices are modified to lower the probability of slopping. The main practice is to lower oxygen flow and/or to add material in order to break the foam.

The apparatus works according to the principle "no signal — no reaction." Slopping control is thus based on reacting to events that have already occurred, e.g., the sonic signal changes indicate that the slag height is increasing. When the sonic signal indicates that an acceptable level is exceeded, actions are performed. As a rule, the actions taken to prevent slopping are too late. As a result, many heats slop despite the actions. The measurement methods are expensive and only somewhat effective. These methods require additional equipment (capital) and operational expenses. When the reaction is to lower the oxygen flow, productivity decreases.

To address this situation, ZapTech has developed a new technology. This technology predicts and prevents slopping through material input changes and operational changes before the slag level begins to rise. A computer model is used to make the prediction and calculate the changes. The method is predictive rather than reactive. The approach is not based on reacting to a signal but rather on the use of predicted results. The potential for the heat to slop is estimated from the earliest stage of preparing to produce the heat. The computer model is used to forecast slopping and then uses raw material and process changes to prevent slopping.

The technology and its associated model were tested at two BOF shops. The No. 4 BOF at Ispat Inland was the first test. Unfortunately, at the time of this writing the technology has not been placed into full operation at Ispat Inland. The second test of the model was at Trinecke Zelezarny in the Czech Republic, where the technology has been fully implemented.

Implementing the slopping prediction technology requires two steps. The first phase in implementation is the collection of specific plant operating data. These data are analyzed to determine the critical factors controlling slopping for the particular shop. The nature of the model is not changed — rather, it is tuned. The nonmetal content of scrap, vessel volume, blowing practices and flux addition practices are tuned for the specific shop. In other words, the model is tuned to the real-world situation specific to the shop. The second phase in implementation is placing the technology into routine operation with automated responses to adjust charge and blowing parameters.

Research Tools

Estimating the Slopping Intensity — The prediction of slopping is based on the calculated slag height during the blow. The following information is used to calculate the slag height:

Authors

Maxim Shakirov, Senior Project Engineer, Anatoli Boutchenkov, Project Manager, Grigori Galperine, President, and Barry Schrader, Director of Sales, ZapTech Corp., Norcross, Ga. (bschrad@attglobal.net)

- Slag chemistry and metallic phases.
- Physical properties of the slag, such as surface tension, viscosity and density.
- Temperature of the slag and metal.
- Decarburization rate.
- Vessel conditions.
- Blow and flux profiles.

Before the heat is produced, the slag height is predicted. During the heat the instantaneous slag height is calculated. A display screen is shown in Fig. 1. Studying slopping behavior and piloting the technology required the development of five new terms to describe the behavior of slopping and an estimation of its intensity. These terms are:

- Slopping index — the intensity of slopping for a particular short period of time during the blow. The particular time period may be 1/50th, 1/100th or 1/200th of the blow. For this work 1/100th of the blow was chosen.
- Heat slopping rate — the sum of all slopping indices during the blow.
- Maximum slag height — the calculated maximum slag height during the heat.
- Critical slag height — the current height of slag at which slopping should occur. This is an estimate based on actual performance of recent heats.
- Slopping potential — the difference between the maximum slag height and the critical slag height.

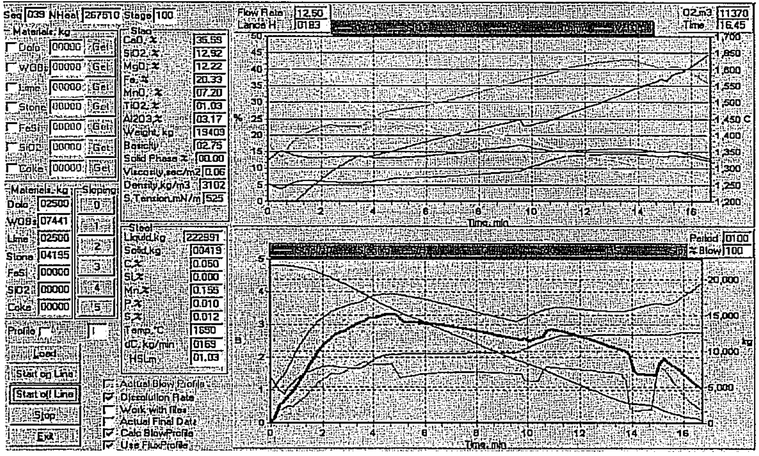
Slopping Indices — The slopping index represents the slopping intensity for a particular period of the blow. Table 1 summarizes the indices. Usually, the blow is divided into 100 equal portions, and the slopping index describes the intensity of slopping for 1/100th of the blow using integers.

Heat Slopping Rate — The slopping indices are summed to create the heat slopping rate. The heat slopping rate combines intensity with duration to give an overall rating for the heat. The heat slopping rate can be divided into five groups, as described in Table 2.

Results

Slopping Classifications — There are many reasons for slopping. Using many years of experience, the classifications for slopping shown in Fig. 2 were created. We believe these classifications show all the basic reasons for slopping and the possible materials or actions that cause them.

Figure 1



Seq 039 NHeat 267510 Stage 100

Materials, kg
☐ Dolo 00000 Get
☐ WOBs 00000 Get
☐ Lime 00000 Get
☐ Stone 00000 Get
☐ FeSi 00000 Get
☐ SiO2 00000 Get
☐ Coke 00000 Get

Slag
CaO, % 36.59
SiO2, % 12.92
MgO, % 12.22
Fe, % 20.33
MnO, % 07.20
TiO2, % 01.03
Al2O3, % 03.17
Weight, kg 19409
Basicity 02.75
Solid Phase, % 00.00
Viscosity, sec/m2 0.06
Density, kg/m3 3102
S.Tension, mN/m 525

Materials, kg
Dolo 02500
WOBs 07441
Lime 02500
Stone 04195
FeSi 00000
SiO2 00000
Coke 00000

Steel
Liquid, kg 222991
Solid, kg 00419
C, % 0.050
Si, % 0.000
Mn, % 0.155
P, % 0.010
S, % 0.012
Temp, °C 1650
dC, kg/min 0169
HSlm 01.03

Profile ☐ 1

☐ Actual Blow Profile
☑ Dissolution Rate
☐ Work with files
☐ Actual Final Data
☑ Calc BlowProfile
☑ Use FluxProfile

Flow Rate 12.50
Lance H 0183
O2, m3 11370
Time 16.45
Period 0100
% Blow 100

Screen of the model for slopping control.

Table 1

Slopping Indices

Slopping Index	Description
0	No slopping.
1	Slag is visible on the mouth of the furnace. A small amount of slag falls onto the shell of the furnace.
2	Slag flows in small streams from the mouth of the furnace and drops under the furnace.
3	Large slag stream flows as described above.
4	Heavy slopping of slag and molten metal. Brown smoke also is present.
5	Heavy slopping of slag and molten metal. Brown smoke lowers the visibility around the furnace and typically interrupts the blow.

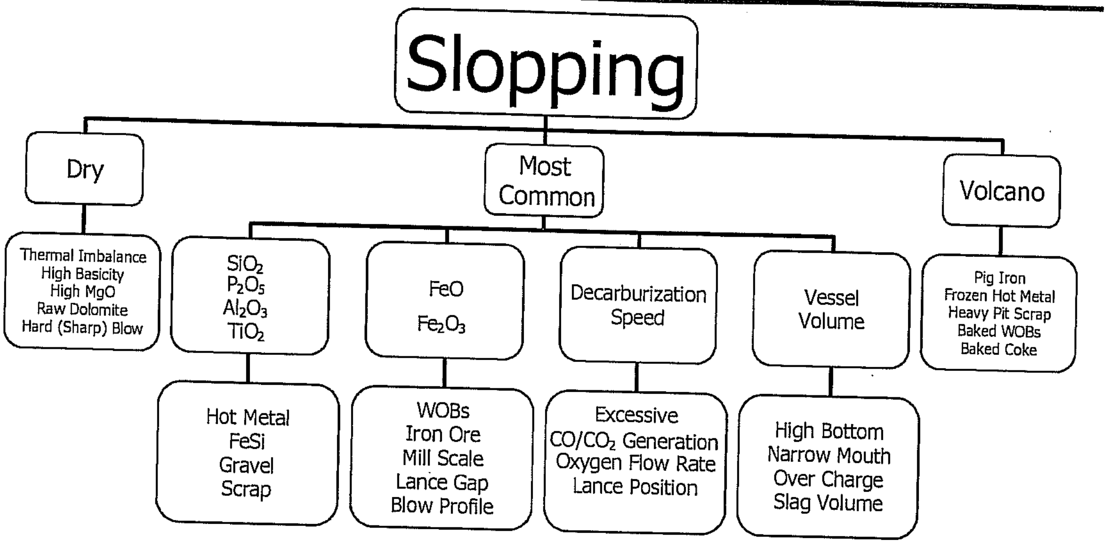
Table 2

Definition of Slopping Rates

Heat Slopping Rate Range	Comments
≤10	Normal process. Slag is on the mouth. Minimal slopping with an index of 1 or less.
10–19	Slight slopping. Predominantly slopping with indices of 1 and 2.
20–29	Mild to heavy slopping. Predominantly slopping with indices of 2 and 3.
30–39	Heavy slopping.
≥40	Heaviest slopping.

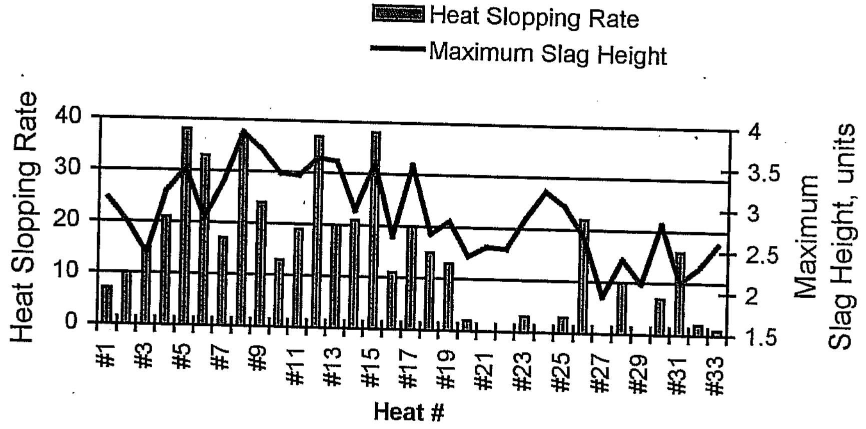
At the extremes of Fig. 2 are two opposite types of slopping — dry slopping and volcano slopping. These types of slopping are related to the charge materials and/or the steelmaking practice used. If the practices are consistent and the culprit is understood, these types of slopping are relatively easy to resolve. Once the cause is eliminated, it should not recur as long as the prescribed practices are followed.

Figure 2



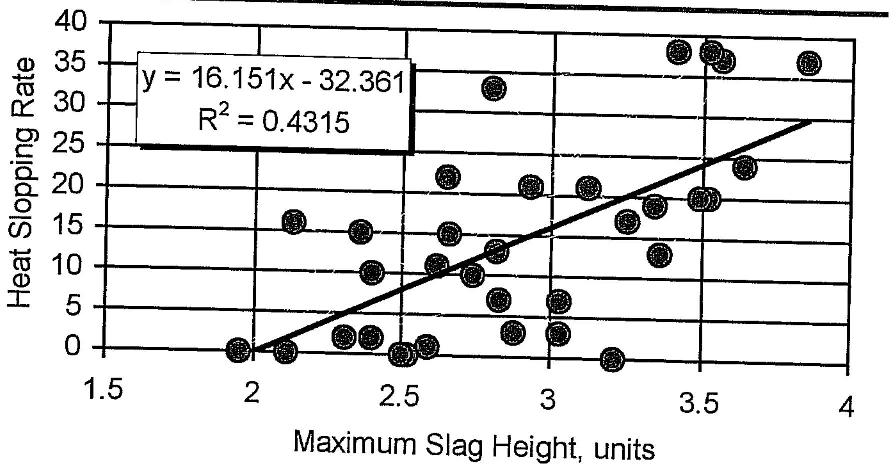
Slopping classifications.

Figure 3



Heat slopping rate compared to the maximum slag height.

Figure 4



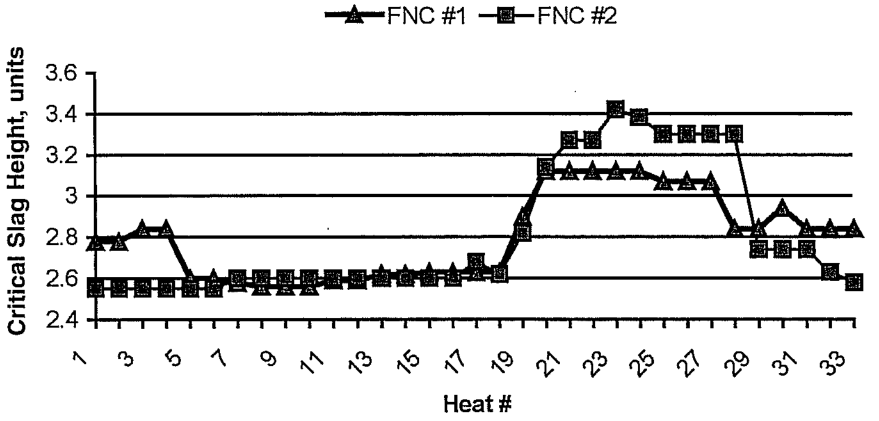
Correlation of maximum slag height and heat slopping rate.

The middle area in Fig. 2 is where the slopping model is required. These types of slopping are more complicated. No one action is typically considered bad or a mistake. The slopping cause is the combination of many factors. Some of the factors that contribute are high bottom, mouth skulls, high total metallic charge, "dirty" scrap, improper blow, flux profiles, lance gap, incorrect fuel and/or coolant, and slag volume and its properties. As steelmakers attempt to optimize costs and productivity, these causes of slopping can come and go.

Slopping Potential as an Indicator of Slopping — Fig. 3 shows heat-by-heat changes in the maximum slag height and the heat slopping rate. The slopping rate follows the maximum slag height. However, sometimes slopping does not occur even when the maximum slag height indicates that slopping should exist. Also, during other periods the heat slops at a relatively low value for the maximum slag height. These trends took place over periods of time.

Fig. 4 shows a reasonable correlation ($R^2 = 0.43$) for operating data of heat slopping rate versus maximum slag height. However, a better comparison was found using the new term, *critical slag height.* Critical slag height is the current maximum slag height at which slopping begins. Fig. 5 shows the changes in critical slag height observed for two furnaces in the same shop. The critical slag height is not a constant value — it continuously varies. Sometimes the critical slag height for one furnace is higher than that for another. Sometimes they are approximately equal. The critical slag height can be viewed as an empirical measurement of the volume available for slag. This parameter, which indicates the deviation in the real slag volume from the volume available for slag, reflects the situation more accurately.

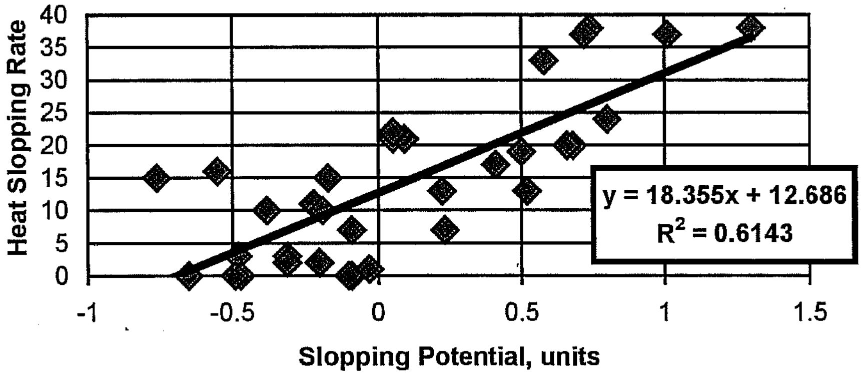
Figure 5



Critical slag height for two different furnaces, heat by heat.

Therefore, the term *slopping potential* is used. The slopping potential, as previously defined, is the difference between the maximum slag height and the critical slag height. This defines the probability and potential intensity of the heat for slopping. Fig. 6 shows the correlation between slopping potential and heat slopping rate.

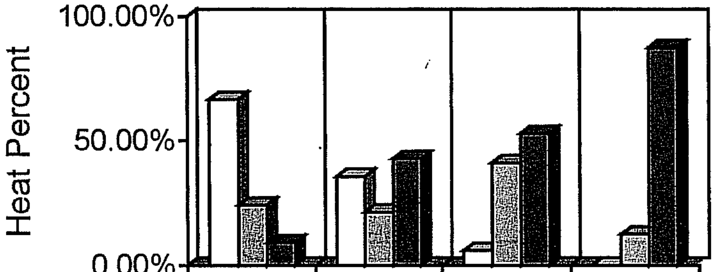
Figure 6



Correlation between heat slopping rate and slopping potential.

With an R^2 greater than 0.6, there exists a better correlation between heat slopping rate and slopping potential than between heat slopping rate and maximum slag height. Fig. 7 shows the probability of slopping rate predictions as a function of slopping potential. The probability of slopping increases with an increase in the slopping potential. For example, if the slopping potential is less than zero, then with a probability equal to about 70%, the heat will not slop (slopping rate ≤10). However, when the slopping potential is greater than 1.0, slopping is predicted with 100% accuracy (slopping rate ≥10).

Figure 7



	<=0.0	0.0/0.5	0.5/1.0	>1.0
☐ <=10	66.67%	35.71%	5.88%	0.00%
▨ 10/20	24.24%	21.43%	41.18%	12.50%
■ 20/30 and more	9.09%	42.86%	52.94%	87.50%

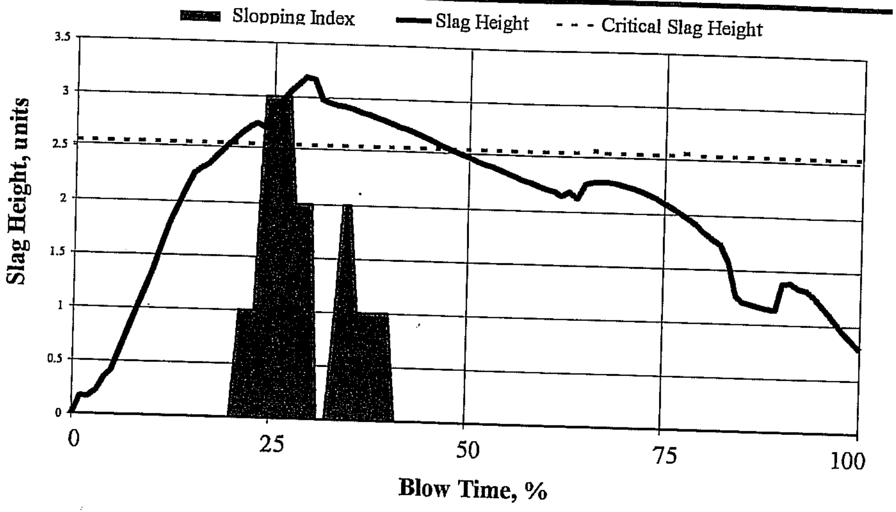
Slopping Potential Range

Probability distribution of slopping rate as a function of slopping potential.

Fig. 7 also shows that when slopping is predicted to not occur (slopping potential ≤0), only 9.1% of the heats slop heavily (slopping rate ≥20) and just 24.2% of heats have light slopping (slopping rate between 10 and 20). However, when heats are predicted to 100% slop (slopping potential >1.0), 87.5% of heats have heavy slopping (slopping rate ≥20) and only 12.5% of the heats have light slopping (slopping rate between 10 and 20). Therefore, it has been shown that these measurements not only predict slopping but, with reasonable accuracy, predict the intensity of the slopping.

The prediction of slopping intensity is important. Light slopping does not have significant adverse affects, while heavy slopping is very costly. According to the observations in Fig. 7, the slopping potential could be classified into four ranges:

Figure 8



Graph of maximum slag height, critical slag height and slopping during a heat.

- If the slopping potential equals 0 or less, no slopping or light slopping occurs. A heat slopping rate of less than 10 is expected.
- If the slopping potential is in the range of 0 to 0.5, mild slopping is expected. The heat slopping rate should be in the range between 10 and 20.
- If the slopping potential is in the range of 0.5 to 1.0, moderate to heavy slopping is expected. The heat slopping rate is, expected to be in the range between 10 and 40.
- If the slopping potential is greater than 1.0, extremely heavy slopping with a heat slopping rate of more than 20 is expected.

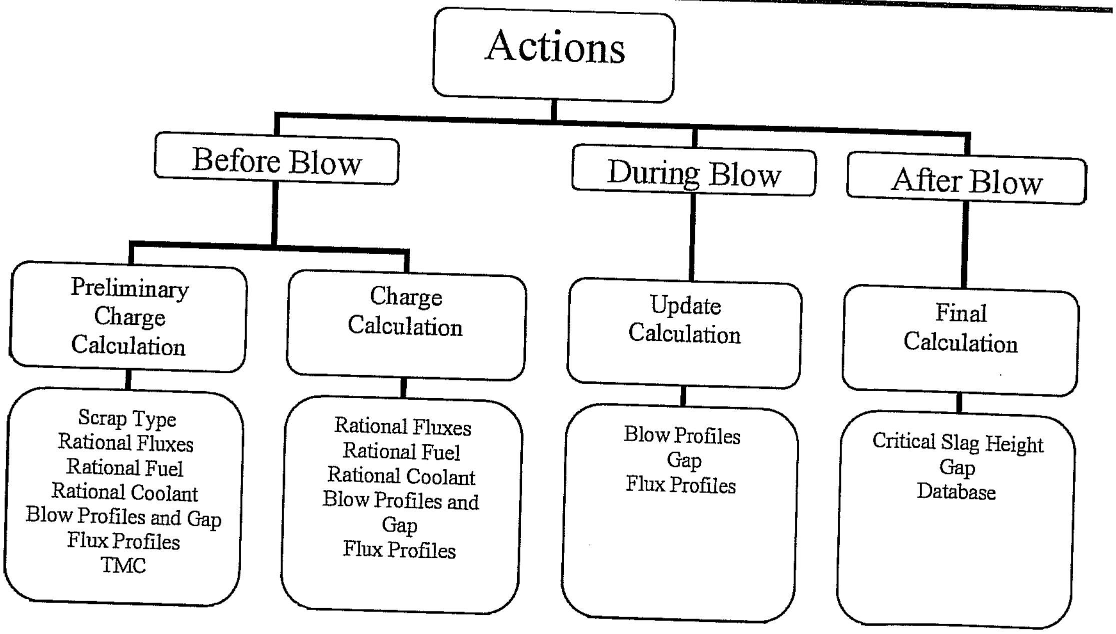
Actions to Prevent Slopping

Fig. 8 graphically displays slag height from beginning to end of a particular heat. This was an observation and was not controlled by the technology. Fig. 8 also shows that the heat did, in fact, slop.

The heat in Fig. 8 began to slop when the slag height reached the critical slag height. Slopping continued to increase as the slag height increased. Slopping disappeared temporarily when the oxygen flowrate was decreased as a reactionary measure. As seen in Fig. 8, slag height was reduced in response to the cutback in oxygen, but it was still high at that time. Consequently, slopping began again after a short time. However, the intensity of slopping was reduced owing to the lower oxygen flowrate, and the slag height reflected this influence. Slopping disappeared for the duration of the blow when the actual slag height decreased below the critical slag height.

The technology used to prevent slopping proposes actions at all stages of heat preparation and production. Each time the model is provided with data, the model calculates the slopping potential. Raw material changes are suggested before the blow. Flux weight and timing, as well as blow parameters, are suggested during the blow. All actions are directed to control the slag height. The slag height during the blow should not exceed critical

Figure 9

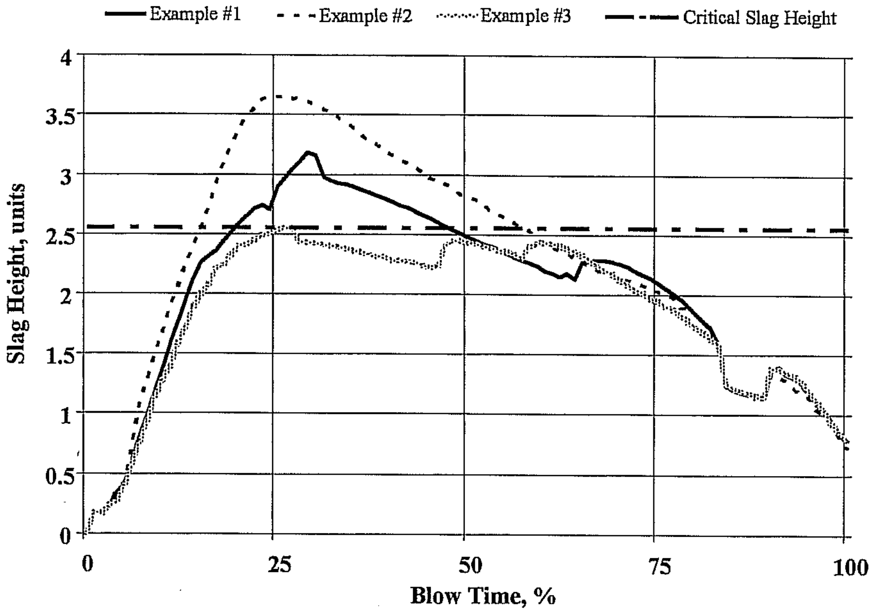


Summary of actions to control slopping.

slag height. Maximum slag height is controlled by optimizing the quantity of each scrap type, fluxes, fuels and coolants, while considering the aim parameters for nitrogen, sulfur and phosphorous. Blow profile, flux profile, and gap are also optimized. Fig. 9 summarizes the actions that are controlled.

As shown in Fig. 9, there exists a wider spectrum of possible actions that can be taken before the oxygen blow begins. After each operation is completed in the preparation of the heat, the spectrum of possible improvements to the heat begins to narrow. It becomes especially narrow after the beginning of the oxygen blow. For example, if the fluxes are already in the weigh hopper, the only changes that can be made are the blow profile and gap. Therefore, without early corrections to the charge, the prevention of slopping can be a difficult task.

Figure 10

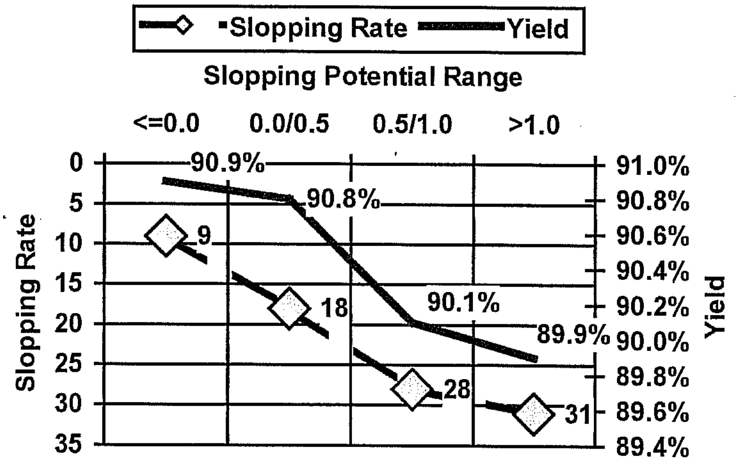


Slag height variations depending on blow profiles.

The slopping prediction model can help evaluate past events, but, far more importantly, the model can predict the upcoming blow situations and prevent slopping by actively changing the composition of the charge.

Fig. 10. shows the slag height for an observed heat as it progresses through the heat cycle. The actual slag height exceeds the critical slag height (plot of Example No. 1). Slopping occurred. If the flux and blow profiles are improperly changed, the heat slops with greater intensity (plot of Example No. 2). However, the plot for Example No. 3 shows the slag height after preventive technological actions recommended through output from the model are taken.

Figure 11



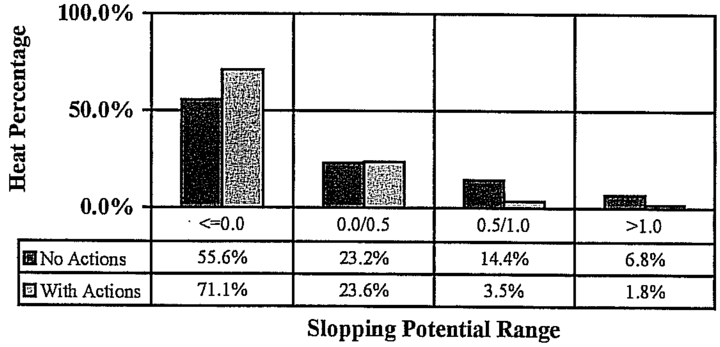
Comparison of slopping potential, slopping rate and yields.

Benefits From the Use of Technology for Preventing Slopping

It is widely acknowledged that slopping reduces yields. Experimental results have shown that the indices, which are used to predict and restrict slopping, do indeed reflect actual conditions. The data in Fig. 11 clearly show that heavy slopping rates affect yields the most. Therefore, if the process eliminates heats that have a slopping potential of more than 0.5, yields are consequently improved by 0.7–0.9% (Fig. 11).

Figs. 12 and 13 show results from the first two months of using the technology for slopping prevention at Trinecke Zelezarny. Fig. 12 shows that incidences of medium and heavy slopping were reduced by four times (from 21.2 to 5.3%). Incidences of light slopping were kept at the same level. The quantity of

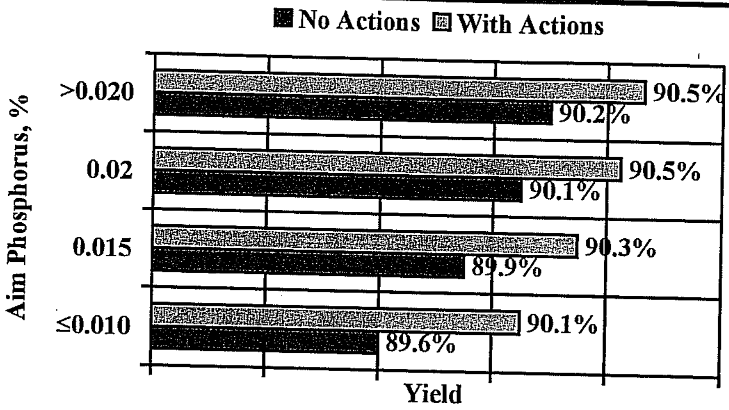
Figure 12



	<=0.0	0.0/0.5	0.5/1.0	>1.0
■ No Actions	55.6%	23.2%	14.4%	6.8%
▨ With Actions	71.1%	23.6%	3.5%	1.8%

Reduction in slopping at Trinecke Zelezarny using slopping prediction technology.

Figure 13



Yield improvements at Trinecke Zelezarny for various phosphorus ranges.

heats without slopping increased by 15.5%. Fig. 13 shows how yields were increased as a result of reduced slopping.

Summary

Historically, many parameters that can effect slopping from BOF vessels were ignored and were not taken into account in steelmaking practices. Examples are:

- Scrap types that are chosen, depending on their availability.
- Fuels and coolants used solely for thermal balance.
- Blow profiles solely as a function of hot metal silicon. The quantity of blow profiles depends on how many data ranges are used.
- Flux addition profiles developed by rote, with most using one or two profiles.

ZapTech, however, has developed a new approach that modifies the charge and blowing practices to minimize slopping. Almost all materials and technological steps are oriented to prevent slopping. Blowing and charge practices depend on the expected slopping potential. Variables that can affect slopping have been characterized. Slopping is controlled by calculating of the slopping potential for each heat and then adjusting variables (see Table 3) to ensure that the heat has the least likelihood to slop.

Key variables are:

- Blow and flux profiles.
- Lance gap.
- Total metallic charge.
- Scrap types and quantity.
- Ratio between fuel and coolant types.

The blowing and fluxing profiles depend on the calculated slag height for the particular heat and are configured automatically for each heat.

Use of slopping control technology and its associated computer support will lead to:

- Higher yield.
- Less fugitive emissions.
- Lower materials consumption.
- Lower production costs.
- Lower maintenance expenses.
- Longer equipment life.

Acknowledgments

The authors are very grateful for the opportunity and help received from Jeffrey Grattan, Section Manager of BOF Steelmaking at No. 4 BOF at Ispat Inland, and his team for allowing the first test of the slopping control technology. The authors are also very grateful to Zbigniev Piegza, Technical Manager at Trinecke Zelezarny, and the team at Trinecke Zelezarny. Without them the success of testing and full implementation of the technology at Trinecke Zelezarny would not have been possible.

✦

Table 3

Comparison of Slopping Prevention Technologies

Items	Old	New
Slag height determination	Nothing or sonic	Self-tuning modeling
Blow profiles	Function of hot metal silicon or its equivalent	Function of slopping potential
Gap	Nothing or manual	Function of slopping potential
Ratio between scrap types and the total metallic charge	Nothing	Function of slopping potential
Flux profiles	Single	Function of hot metal mode and slopping potential
Ratio between fuels when using two or more types of fuel	Fixed consumption of one type of fuel	Function of slopping potential
Ratio between coolants when using two or more types of coolants	Fixed consumption of one type of coolant	Function of slopping potential