October 2019

Daniel Carvalho
Process Consultant Steel Plant

Ternium

Steelmaking Automation

AIST OSTC Scandinavian Study Tour 2019

Ternium

- Sales: US$ 11,5 bilhões
- Capacity: 13 mio t/year
- Direct Employeess : 20.800 thousand
- Plants: Brazil, México, Argentina, EUA, Colombia and Central America
- Vertically Integrated: from Iron Ore to servisse center
- Focos: High added value products
- New York Stock Exchange (TX)

Techint Group: faturamento anual de US$ 15,2 bilhões e 48.500 funcionários em todo o mundo

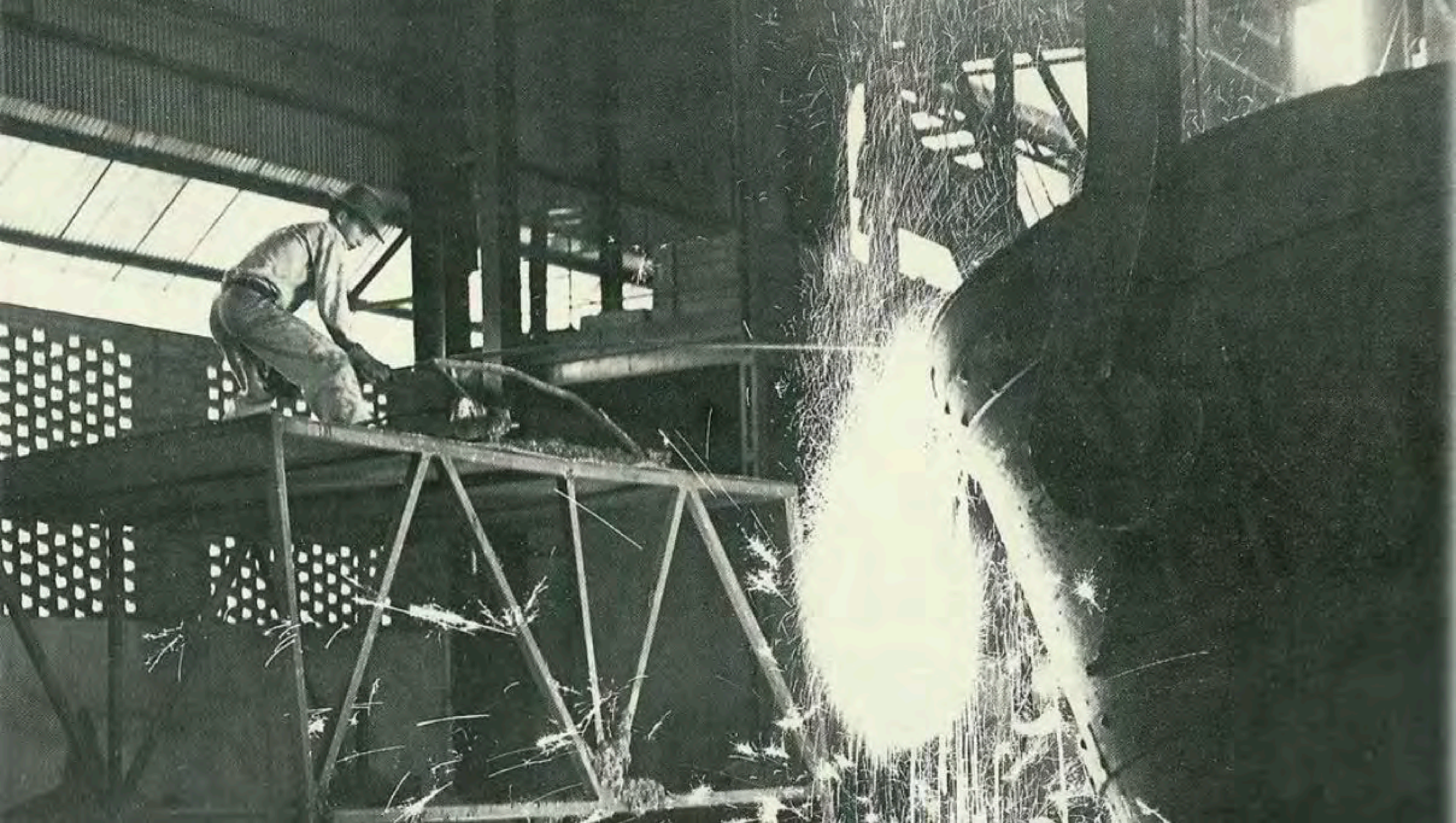
Steel Plant

Ternium - Rio de Janeiro

Average heat size of 342 t steel

2 x Hot Metal Desulfurization plants (HMD)
2 x BOF-TBM vessels
2 x Ladle Treatment Stirring stations (LTS)
1 x Aluminium Heating Facility (AHF)
2 x Vacuum Degassser Plant (RH)
2 x Continuous Casting Machines (CCM)
2 x Strands of twelve segments each one

How People See the Steel Industry?



Innovation and Impact in Labour Conditions

“Any working conditions I would not work in for 8 hours should be eliminated from this company.”

Paolo Rocca – 66 years old

Ternium Chairman

BOF and Steel Plant Models

Summary

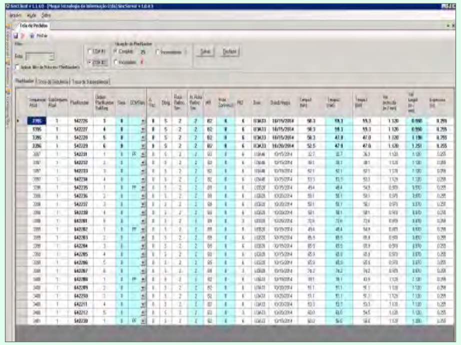
- BOF Process Models
  - Static Model
  - In Blow Correction Model
  - Cyclic Model
  - Dynacon Model
  - Operational Practices
  - Tapping
  - Additional sub-models

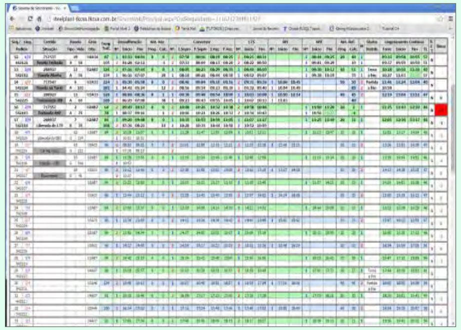
Planning, Scheduling and Thermal Control Model

Level 3 Slab Sequence Design
(based on process orders)

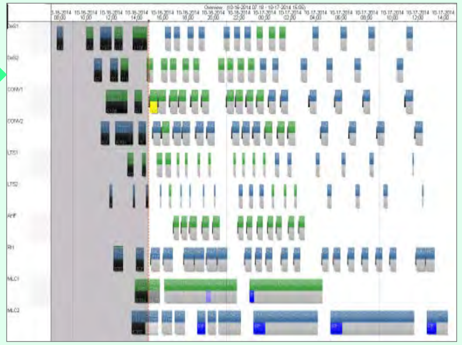
Caster Production Planning

Level 2 – Time Scheduling System

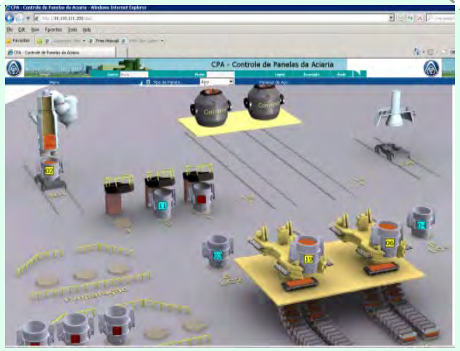




Caster Production Planning, adjusted based on SM condition/priorities



Whole SM facilities' times optimized to produce the Heats.

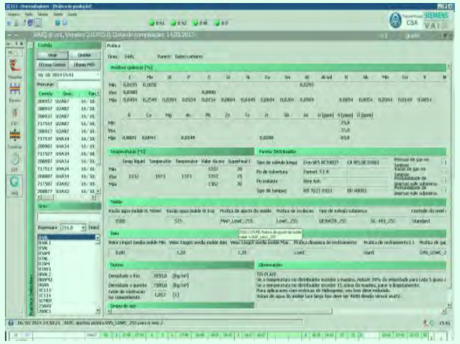


Level2 – Ladle Tracking
(Ladles thermal condition)

Thermal Control Model

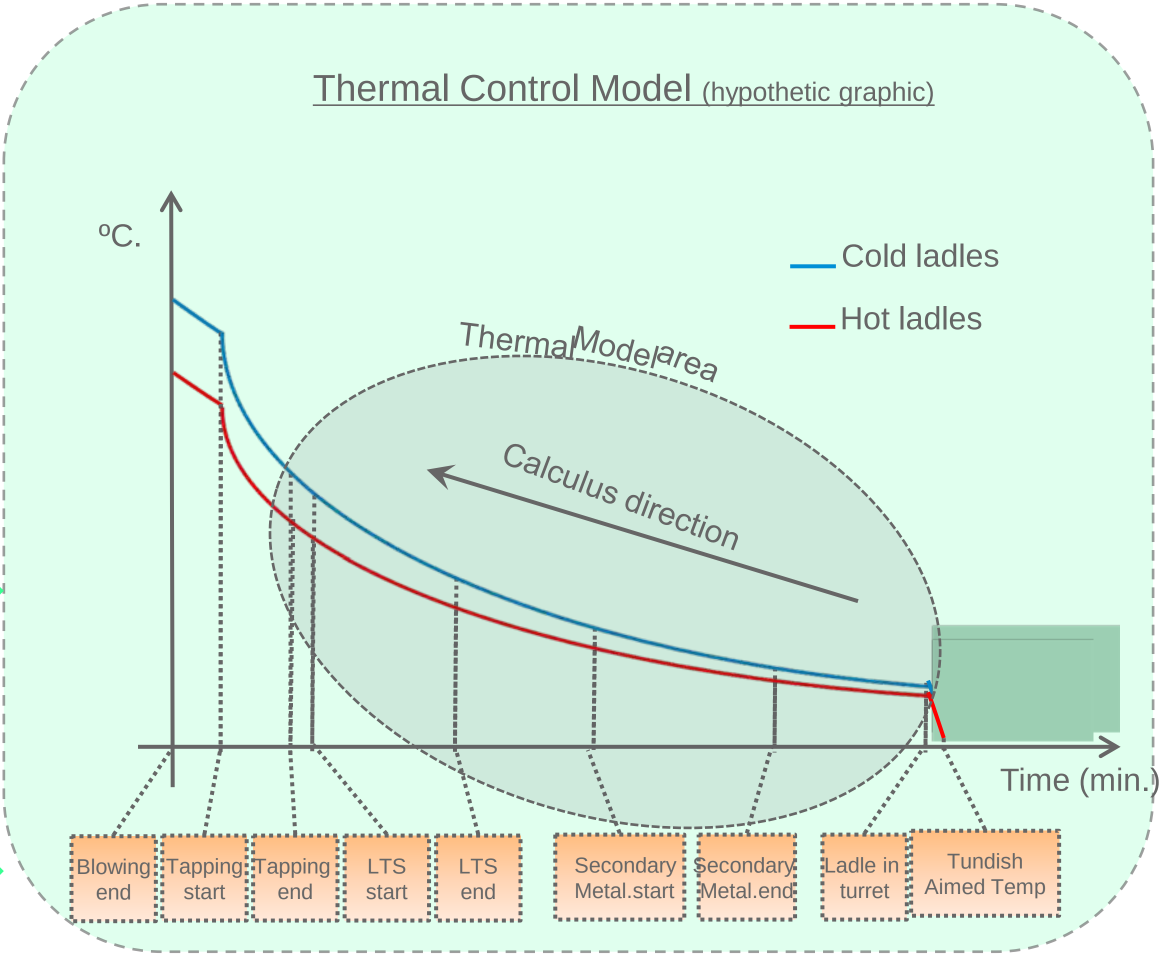
Planning, Scheduling and Thermal Control Model

From Time Scheduling and Ladle Tracking

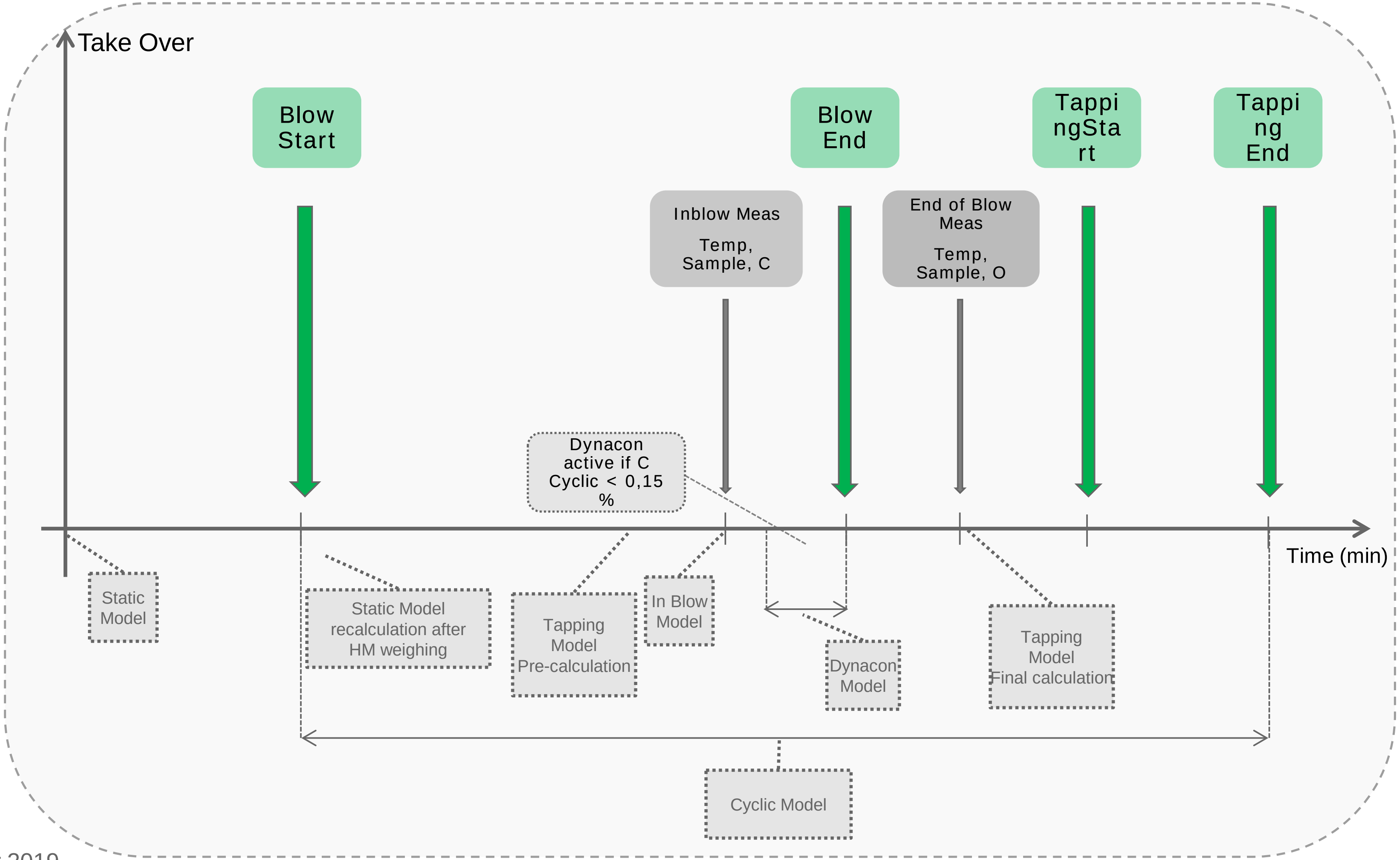


Level2 – Caster System
(Grade casting practices)

Inputs to Thermal Model
Casting Aimed Temperatures;
Facilities production Time;
Steel Grade Practices;
Ladle Thermal Conditions.



BOF Process – L2 Models



BOF Process – Static Model

Hot Metal and Scrap Information

HM temp. and chemical comp.

Hot Metal and Scrap Weight

Scrap type

Thermal Control Model

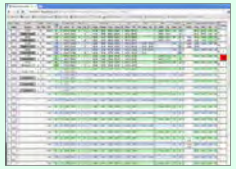
Aim Tapping Temperature

Level2 – Ladle Tracking

Tapping Ladle

Tapping Ladle Condition

Tapping Weight



Level2 – Time Schedule

Steel Grade

Hot Metal Ladle

Level 2 system

Level 2 Take Over

BOF Process – Static Model

Level 2 Take Over

Input

BOF Static Model

- Balance Model
- Slag Former Model
- Tapping Model
  - Alloying Model
  - Deoxidation Model

Model Output

- Heating Agents
- Cooling Agents
- Fluxes
- Alloys
- Gas Volumes

BOF Process – Static Model

▪ Static Model

It runs automatically after the heat charging, and calculates the necessary amount of O2 to be blown and material additions to achieve the aimed steel temperature and chemical composition as well as the slag basicities.

It can also be restarted during the process based on the actual results of the CYCLIC MODEL.

- Mass and Heat Balance Model

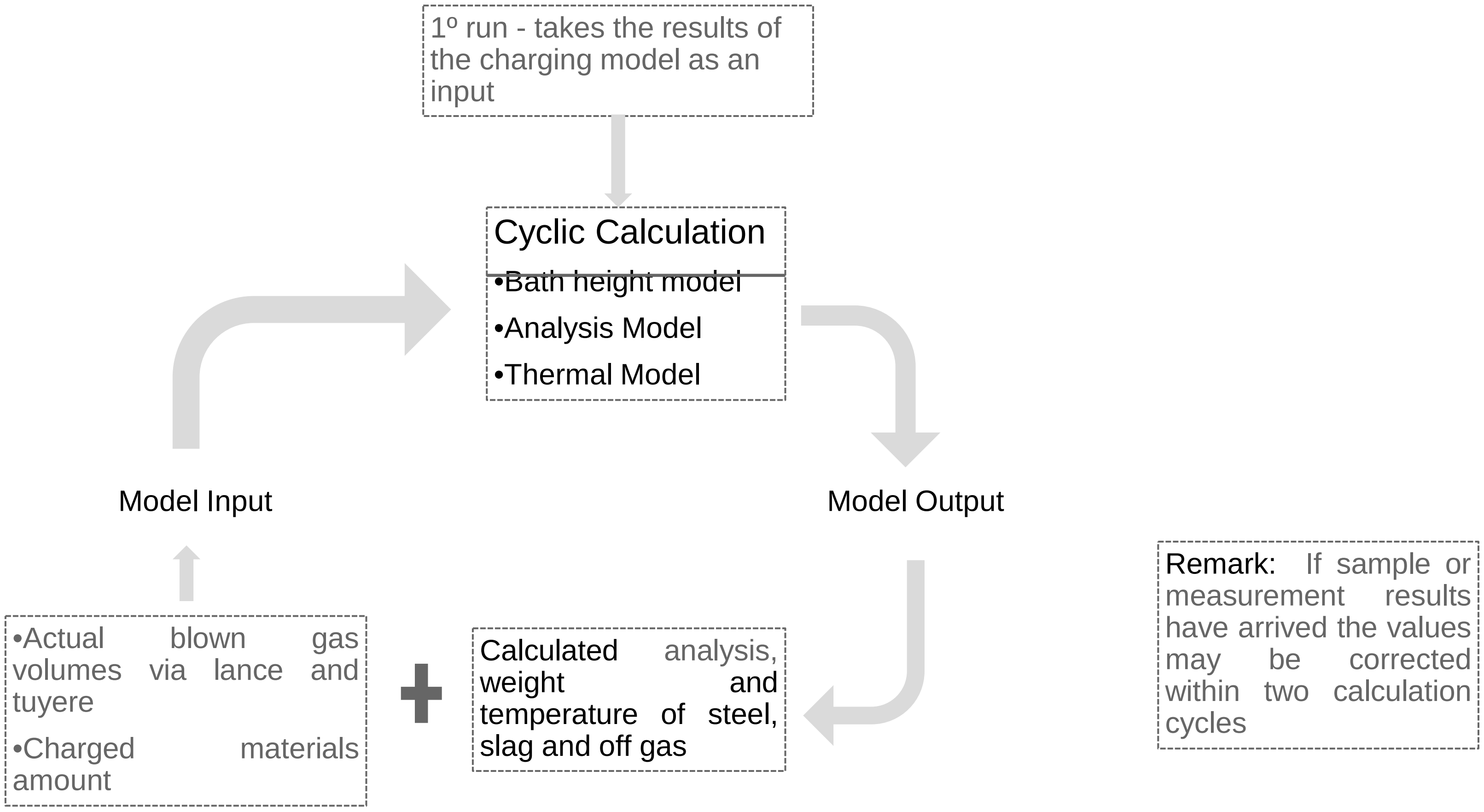
  It is used for the heat and mass balance (calculation of heating or cooling agents) in the BOF converter.

- Slag Former Model

  Calculates the necessary amount of Lime, Dolomite to reach the aim basicities (blowing end at the BOF). If the parameter “OptimizeBasicity” is set to 1 the slag former model can vary the aim basicity in order to adjust the calculated phosphorus content of the steel bath.

BOF Process – Cyclic Model

- Every 2 seconds, it calculates the on going chemical reactions, estimating the actual chemical composition, weight and temperature of steel, slag and off gas analysis.



BOF Process – Cyclic Model

- Bath Height Model
  - Calculates the position of the liquid bath surface in the converter after charging of the pre-melt.
  - It uses the LACAM and valid level measurement from the sub-lance to determine the height of steel.

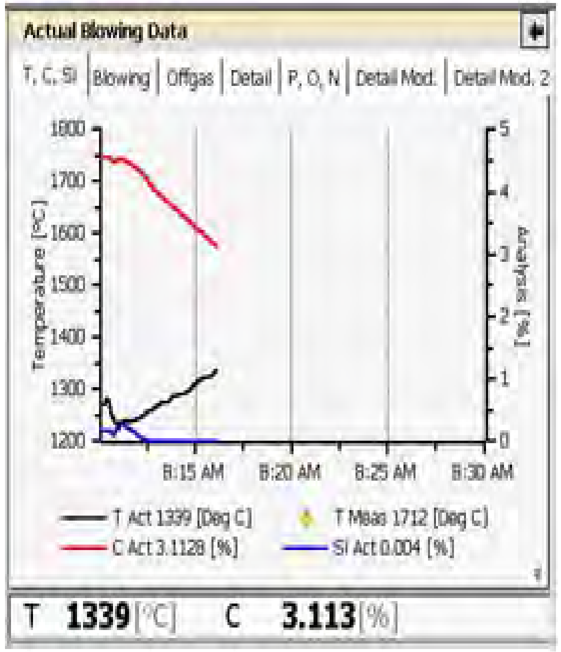
- Analysis Model
  - Continuously calculates the ongoing reactions including the dissolution of additions, oxidation and reduction reactions, the nitrogen, oxygen and hydrogen pickup in the steel bath, the sulphur and phosphorus distribution between steel and slag and the post combustion of CO and H2.

- Thermal Model
  - Cyclically determines the heat and energy balance of the steel bath based on the steel, slag and off gas analysis from the ANALYSIS MODEL in order to calculate the bath temperature.

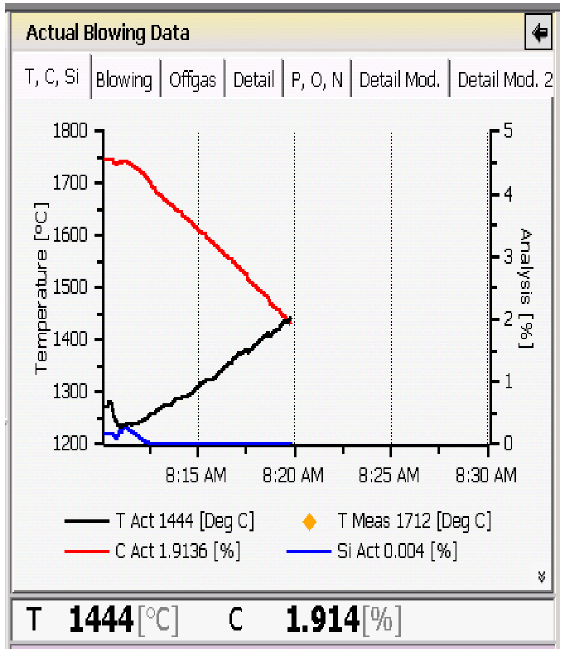
BOF Process – Cyclic Model

- Cyclic C, Si and T evolution prediction:

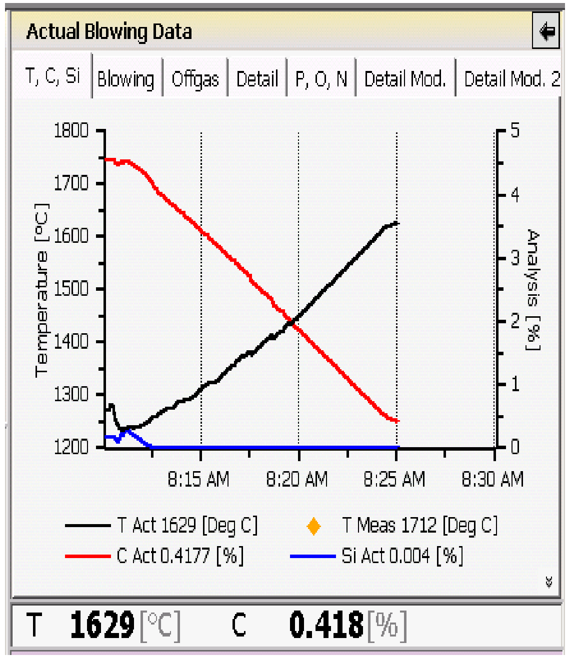
O2 Volume: 29%



O2 Volume: 57%

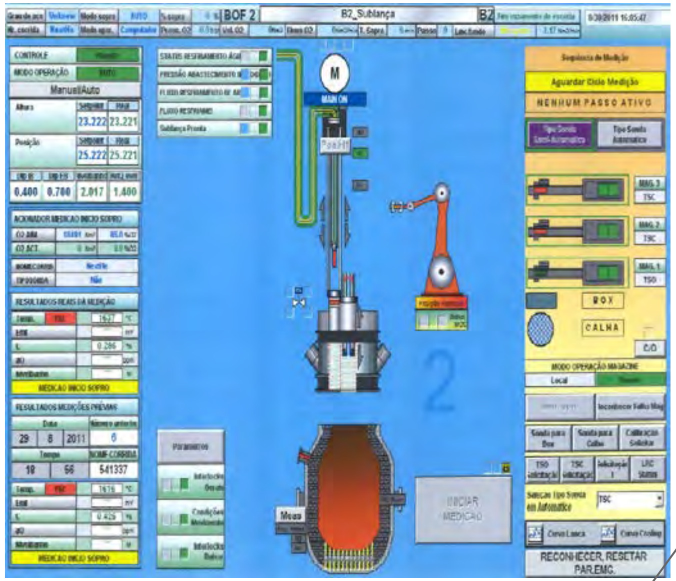


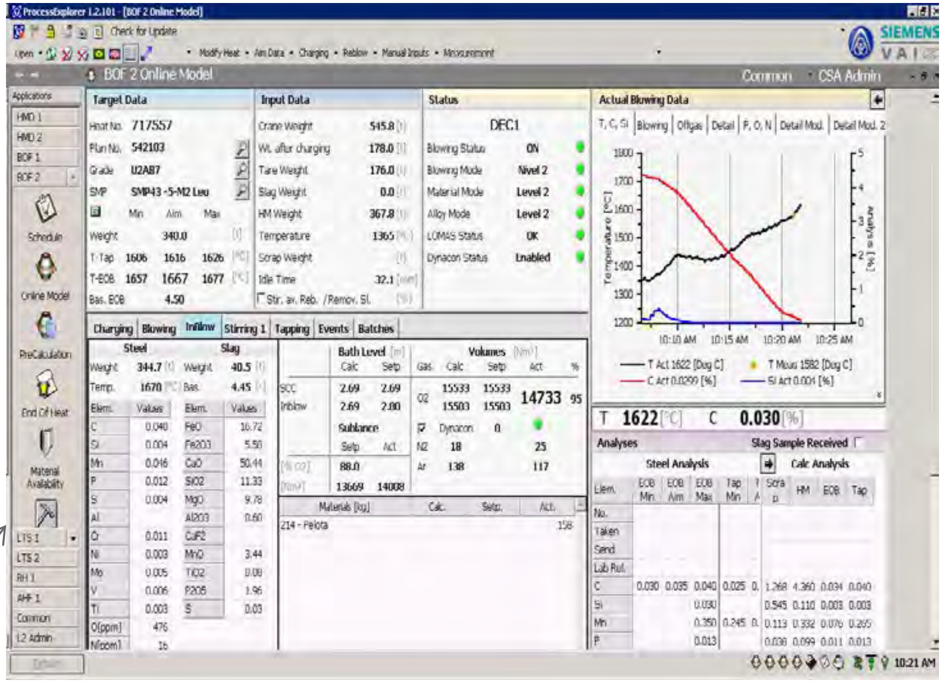
O2 Volume: 90%



BOF Process – In Blow Correction Model

It is automatically executed after In blow sub lance measurement – at 88% of the Oxygen blow.





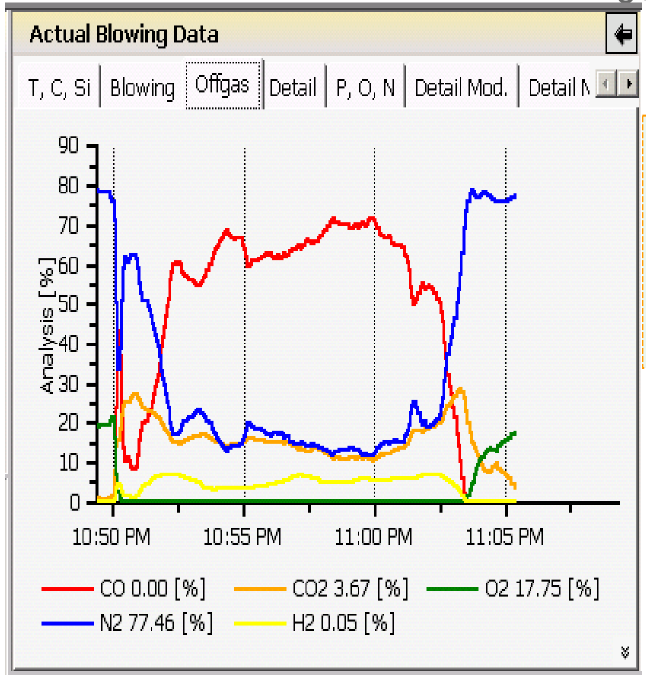
In blow Measurement:

- Actual Steel Temperature
- Actual C content
- Sample taken

- Recalculates the O2 volume and heating/cooling agents, based on the actual measured temperature and C content.

BOF Process – Dynacon Model

- Carbon content prediction at the end of the blowing process based on off gas analysis (CO, N2, O2).
- The prediction is activated:
  - When the actual C content predicted by the Cyclic Model < "CHighLimit" (system parameter = 0,15%).
  - Dynacon considers its prediction plausible (Ex: valid off gas volume and analysis; correct oxygen volume and lance position; CO must be descending; CO2,N2 and O2 must be ascending; etc..)



If [C ≤Caim] and [T ≥ Tmin] and [T ≤ Tmax]
or
If [C ≤ Cmax] and [T ≥ Tmax]
or
If [C ≤ Cmin]

Send SP: Automatic Blow End

Charging | Blowing | InBlow | Stirring 1 | Tapping | **Events** | Batches

Step	Name	Start	End	Additional Information
	CraneWeighing	10-17 16:07:24		GrossWt:
	TappingSPSent	10-17 16:09:31		
10	DEC1	10-17 16:11:07	10-17 16:12:05	
11	DEC1	10-17 16:12:05	10-17 16:13:20	
12	DEC1	10-17 16:13:20	10-17 16:14:19	
	StlSampleTaken	10-17 16:13:59		Type: Steel, Pos: S
	InBlowMeas	10-17 16:13:59		
13	DEC1	10-17 16:14:19	10-17 16:15:38	
	InBlowSPSent	10-17 16:14:24		
	DynaconBlowStop	10-17 16:15:37		O2VolStop: 15527
14	STIR	10-17 16:15:38	10-17 16:18:20	
	MainBlowEnd	10-17 16:15:38		O2VolAct: 15567
	BlowingEnd	10-17 16:15:56		
	TappingStart	10-17 16:18:20		
15	TAP	10-17 16:18:20	10-17 16:23:15	
	SteelSampleReceived	10-17 16:19:30		
	TapSlagStopDetectTime	10-17 16:23:00		
	SteelSampleReceived	10-17 16:23:10		
16	AFTERTAP	10-17 16:23:15	10-17 16:23:15	
	TappingEnd	10-17 16:23:15		
	TreatmentEnd	10-17 16:23:15		
	HeatEnd	10-17 16:23:15		

BOF Process – Tapping Model

- Tapping Model
  - Alloying Model

    Calculates the necessary amount of alloys to achieve the aim tapping composition.

  - Deoxidation Model

    Its results will depend on predefined steel grade configuration:
    - Can calculate the necessary amount of aluminum for completely deoxidize the steel and to reach the target values Al from tapping analysis.
    - Or can calculate pre-deoxidation with carbon, followed by final deoxidation with aluminium.

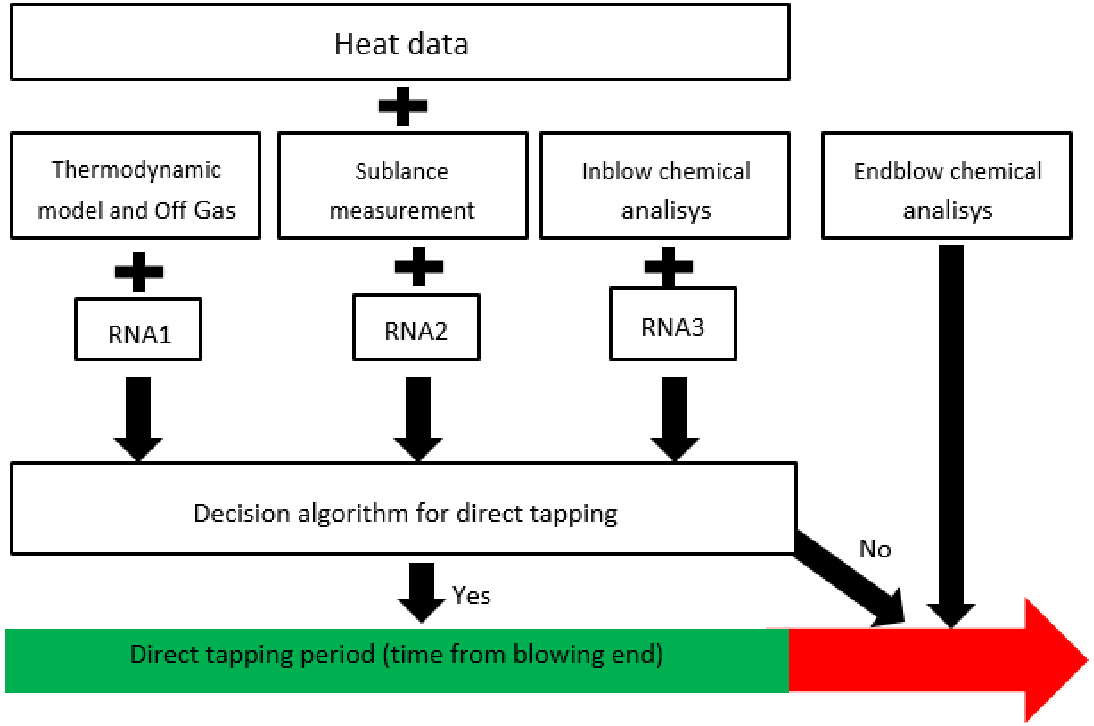
  - Direct Tapping Model

    Predict C, Mn and T, based on process values, calculated or measured without in-blow sub lance results.

Development

DIRECT TAPPING MODEL

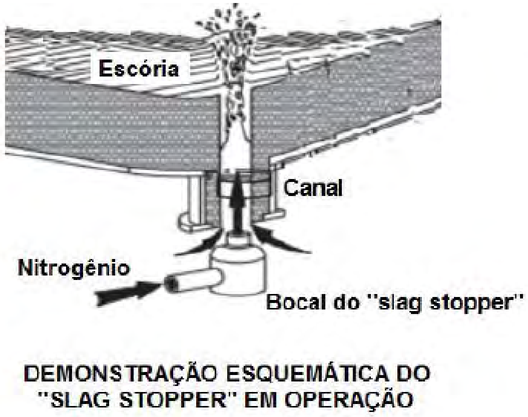
- Industrial process data were used to train **3 x Artificial Neural Network (ANN)** regression models for phosphorus prediction at BOF blowing end.
- Tapping is authorized when the risk of out of range is smaller than 1% (21)



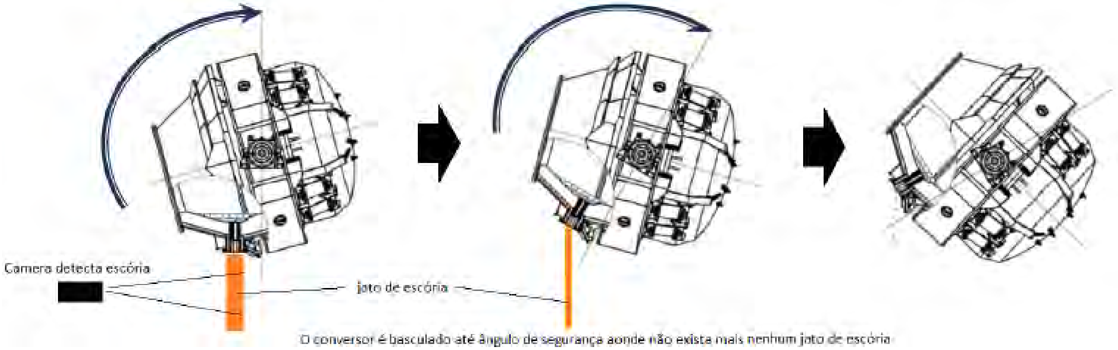
Process Integration, Investments

SLAG CARRY OVER

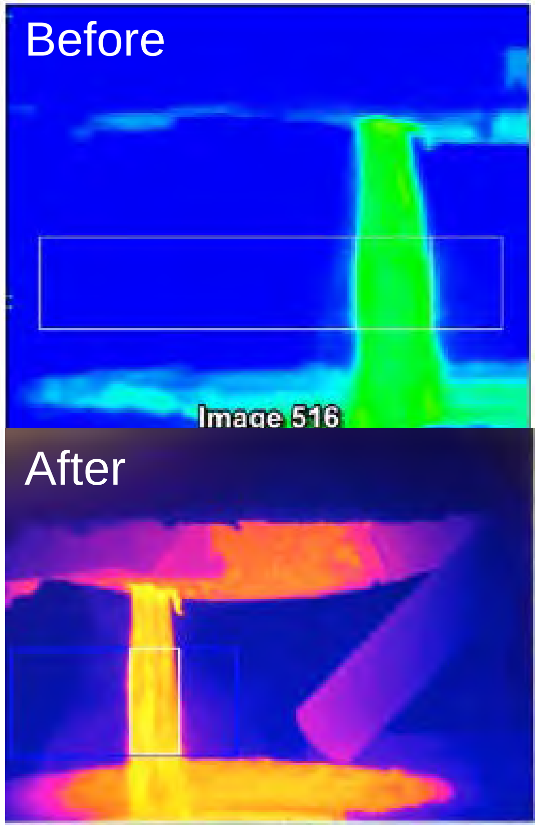
✦Slag Stopper System



✦BOF auto tilting



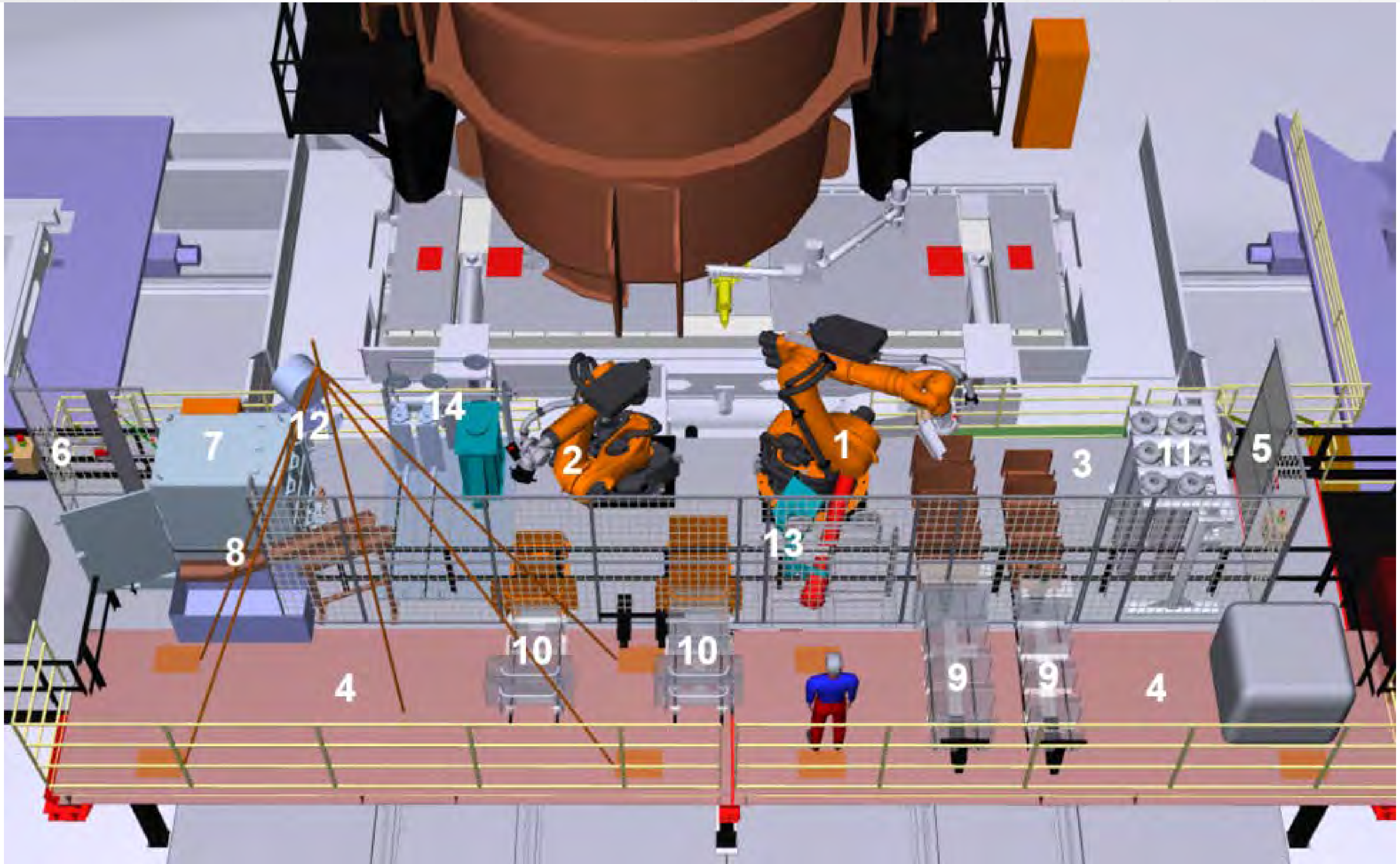
- Slag Detection



Source: Cerchiari, B., Klinger, L., Cruz, F., & Piller, F. (2018). Improvement in Tapping Process to avoid Slag Carry-Over. *49.* Sao Paulo, Brazil: ABM.

New Robots and Innovations

ACIARIA – Lingotamento Contínuo
Robô da Plataforma de Lingotamento



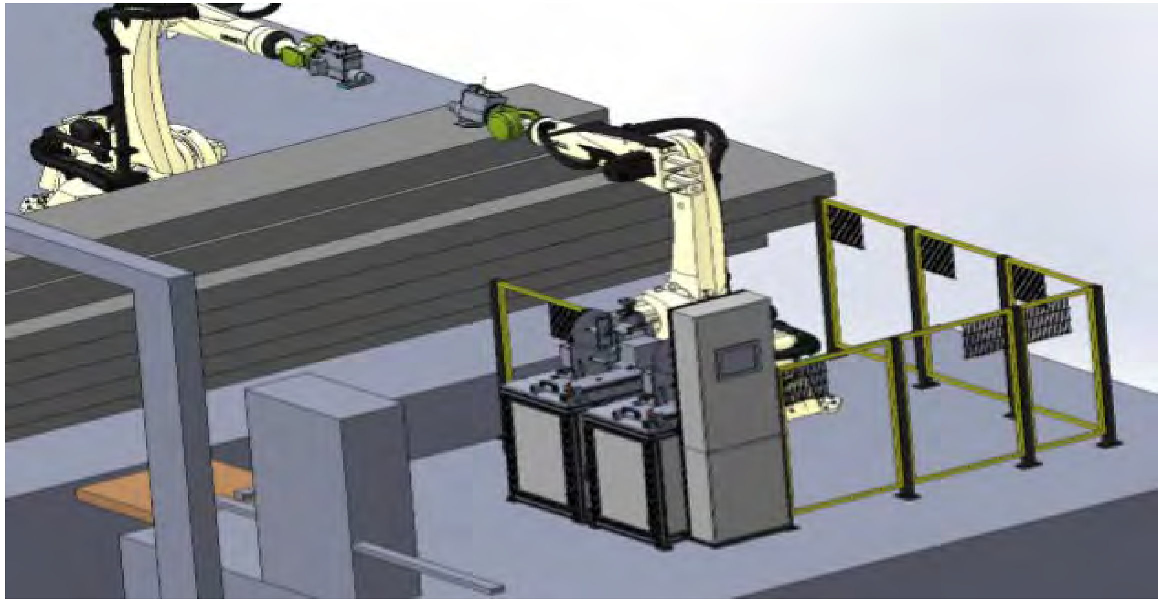
Trends

Robots
Slab Labelling (RFID)

Objetivos

Implantar um sistema de aplicação de tags em automático fazendo uso de robôs capazes de realizar as seguintes funções:

- Limpeza da superfície da área de aplicação do tag
- Aplicação de diversos modelos de tags (vinil, metálica, RFID)
- Integração do sistema de automação do robô com Sistema Ternium Nível 1 do prédio RFID
- Realização do check de aplicação



Robots
Hot Metal Temperature

Objetivos

Medição de temperatura e retirada de amostras em cada um dos quatro canais de corrida.

Robots
Sliding Gate Preparation

Objetivos

Efetuar sete tarefas na área de preparação de panelas, feitas atualmente de forma manual:

- Limpeza da válvula
- Troca da válvula externa
- Abertura do mecanismo
- Substituição das placas refratárias
- Remoção da válvula interna
- Instalação da nova válvula externa
- Fechamento da válvula gaveta

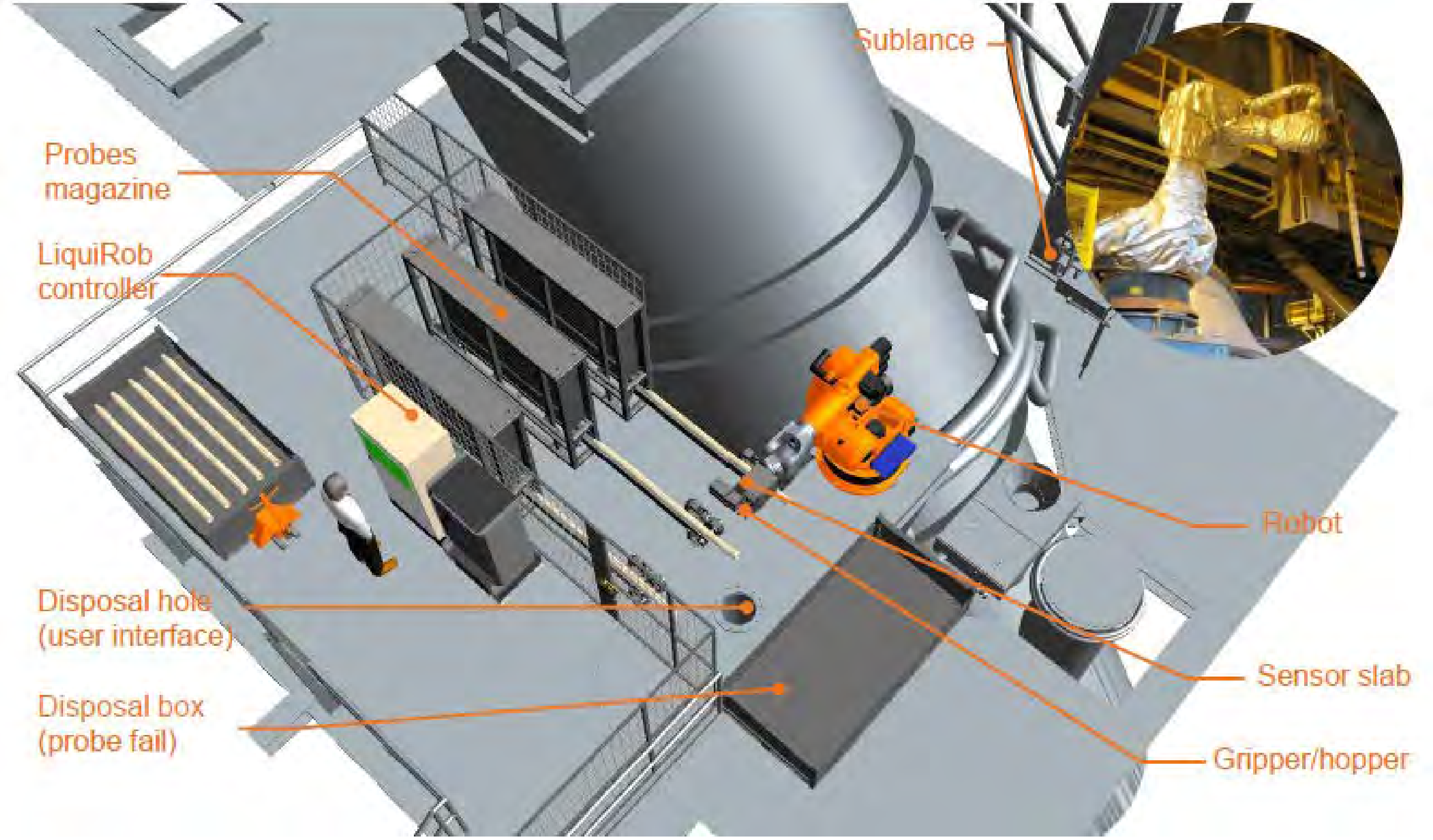
Robots
BOF Sublance Update

Atualmente o sistema é composto de três magazines e um robô para manuseio de cartuchos na sublança dos convertedores.

O conjunto magazine, robô e sublança tem a função de executar basicamente quatro funções:

1. Medição de temperatura
2. Medição de oxigênio
3. Medição de carbono
4. Retirada de amostra

O robô tem o papel de manipular os cartuchos.



Robots
BOF Sublance Update

Objetivos

- Atualização tecnológica do sistema existente (os modelos atuais foram descontinuados pelo fabricante)
- Abastecimento em lote do magazine, em substituição ao atual abastecimento manual
- Implementação de ferramenta no robô para limpeza de cascão na sublança
- Implementação de ferramenta no robô para verificação automática da malha de medição de temperatura, carbono e oxigênio


Limpeza Cascão Sublança


Abastecimento Magazine

Thank you!

Tack själv!

Kiitos!

Dank je!

Merci!

Danke!

Ternium

October 2019

Daniel Carvalho
Process Consultant Steel Plant

Ternium

BOF Phosphorous Control

AIST OSTC Scandinavian Study Tour 2019

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Development

DeP – MACHINE LEARNING

P-partition (L_P), is the capacity to retain phosphorus in form of P_2O_5 stable in the slag phase in contact with the molten steel.

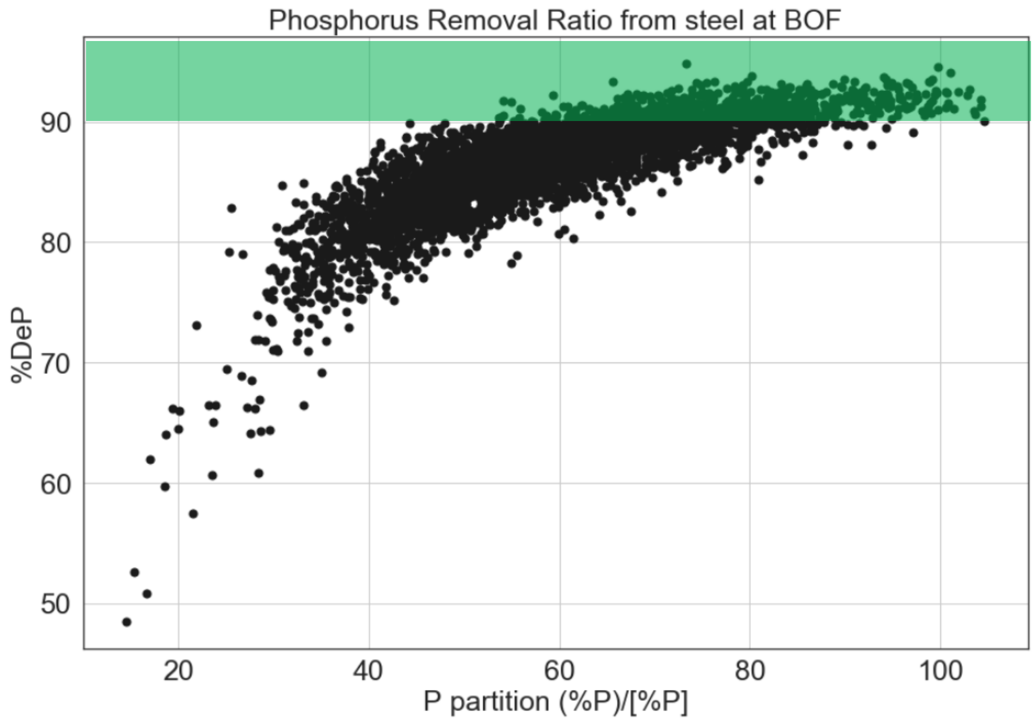
$$L_P = \frac{(\%P)}{[\%P]}$$

Phosphorus removal efficiency (%DeP), is a multivariable problem involving the P-partition, slag mass and dephosphorization kinetics in BOF.

$$\%DeP = \left(\frac{[\%P_{initial}] - [\%P_{end\ blow}]}{[\%P_{initial}]}\right) \times 100$$

Development

DeP – MACHINE LEARNING



- Typical Value:
- Hot Metal = 0.1200 %P
- BOF_EOB = 0.0100 %P

$$\%DeP = \left(\frac{0,1200 - 0,0100}{0,1200}\right) \times 100 = 91,6\%$$

$$L_P = \frac{(\%P)}{[\%P]}$$

$$\%DeP = \left(\frac{[\%P_{initial}] - [\%P_{end\ blow}]}{[\%P_{initial}]}\right) \times 100$$

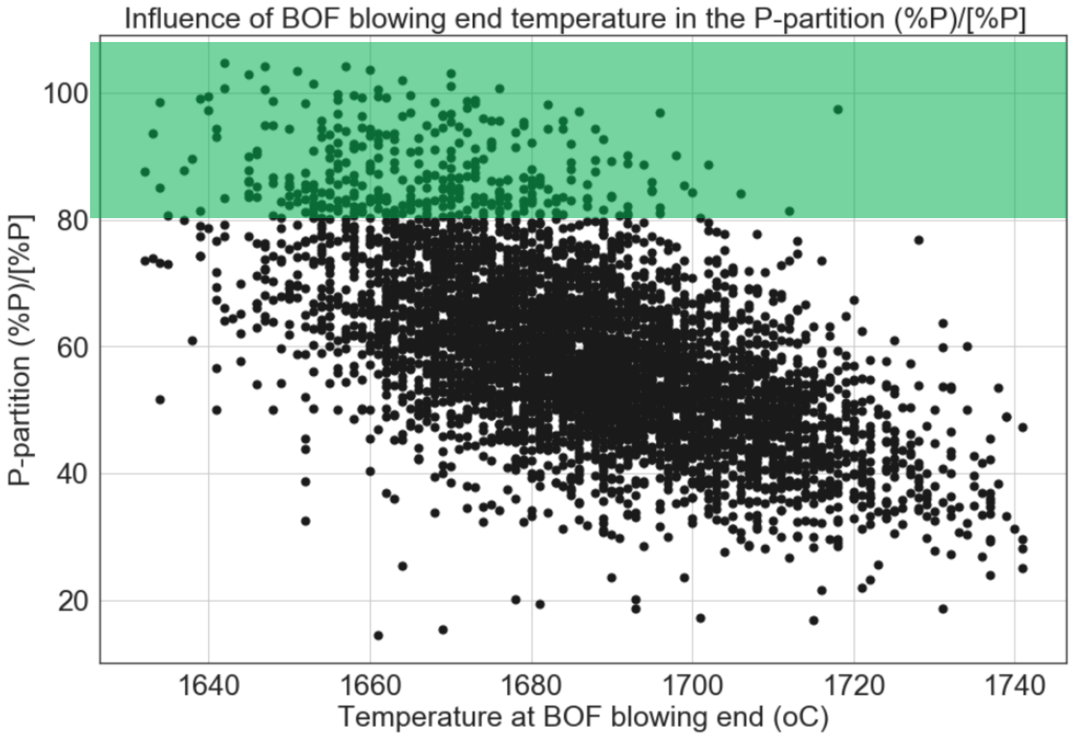
Development

DeP – MACHINE LEARNING

- ✦This work in based on theoretical and empirical approach to achieve the maximum %DeP removal efficiency.
- ✦The theoretical part involves the study of slag dissolution, slag saturation, blowing pattern optimization
- ✦Empirical approach involves the application of state of the art “machine learning” techniques for definition of optimal condition based on “learning from historical data” approach.

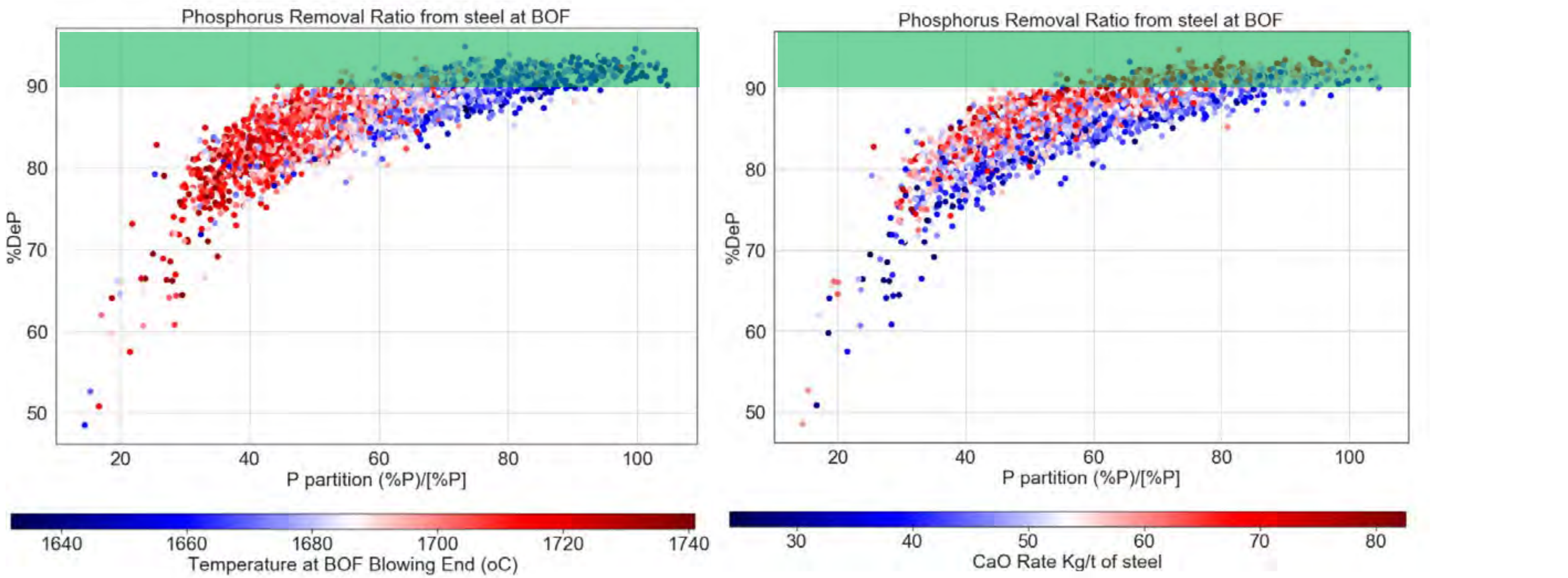
Development

DeP – MACHINE LEARNING



$$L_P = \frac{(\%P)}{[\%P]}$$

Development
DeP – MACHINE LEARNING



$$L_P = \frac{(\%P)}{[\%P]}$$

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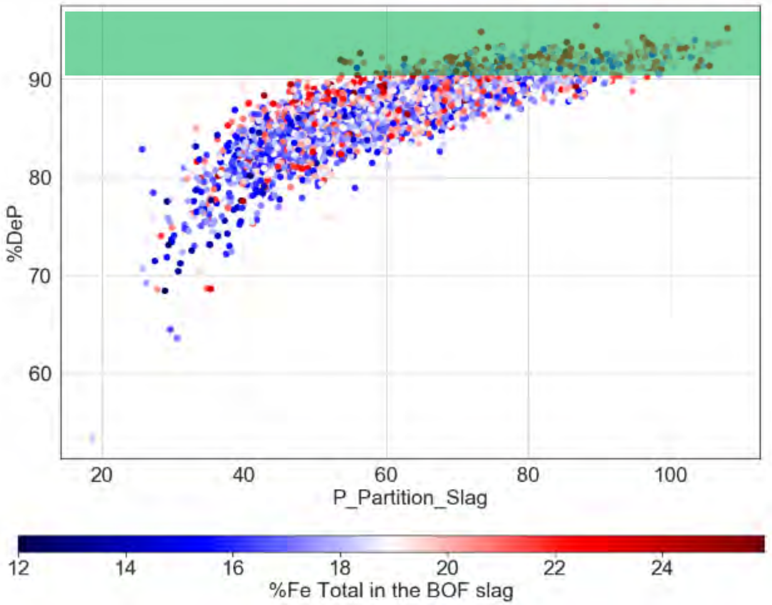
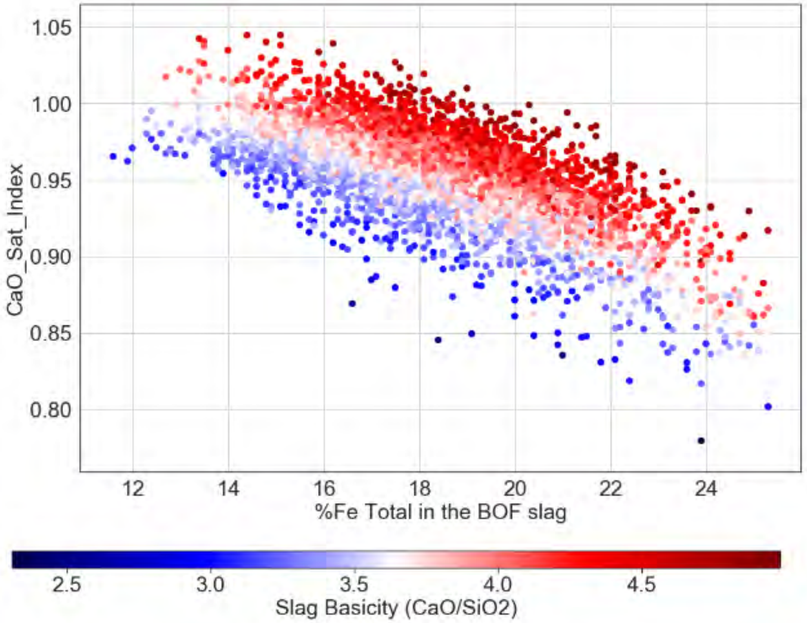
Development

DeP – MACHINE LEARNING





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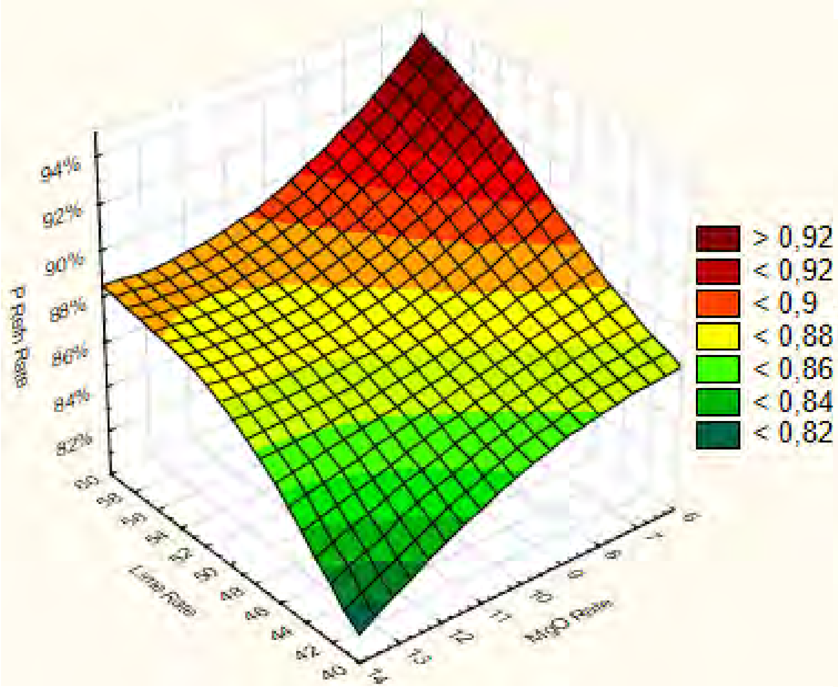
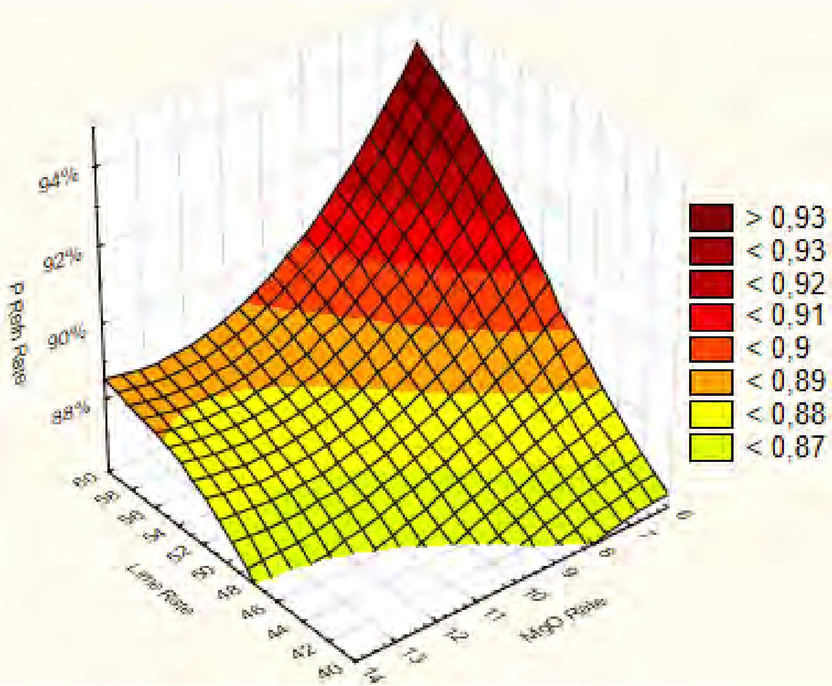
Development

DeP – MACHINE LEARNING





$$L_P = \frac{(\%P)}{[\%P]}$$

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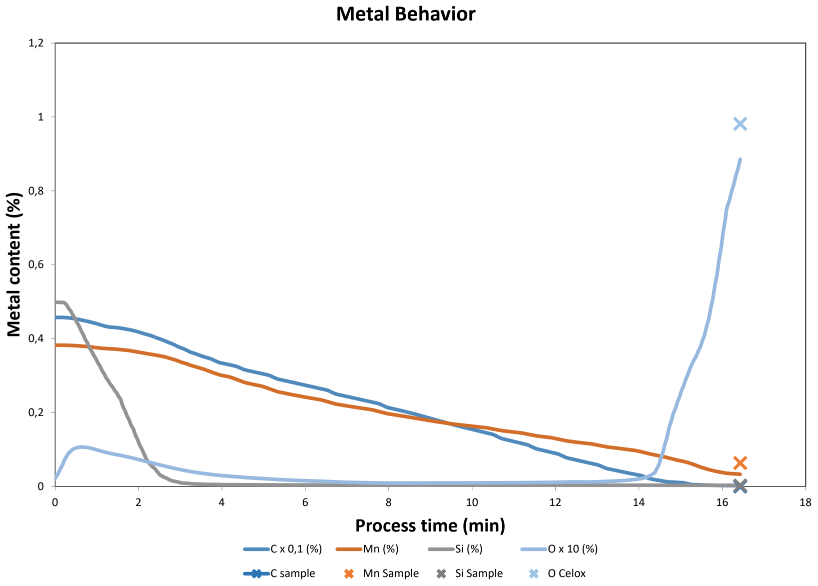
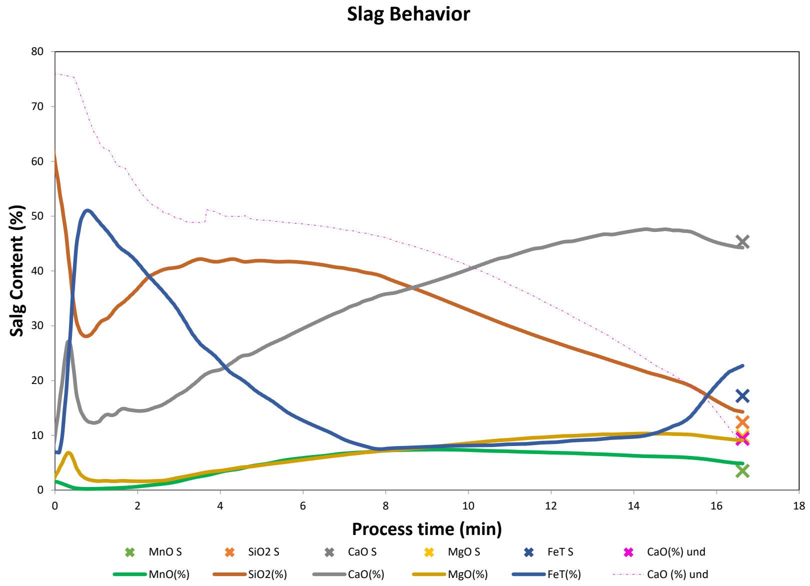
Development

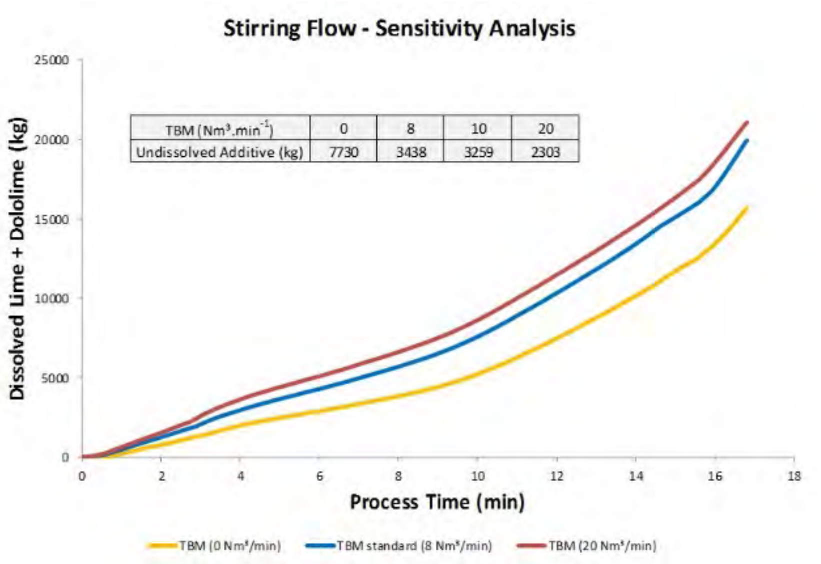
DeP - ADDITIVES DISSOLUTION MODEL

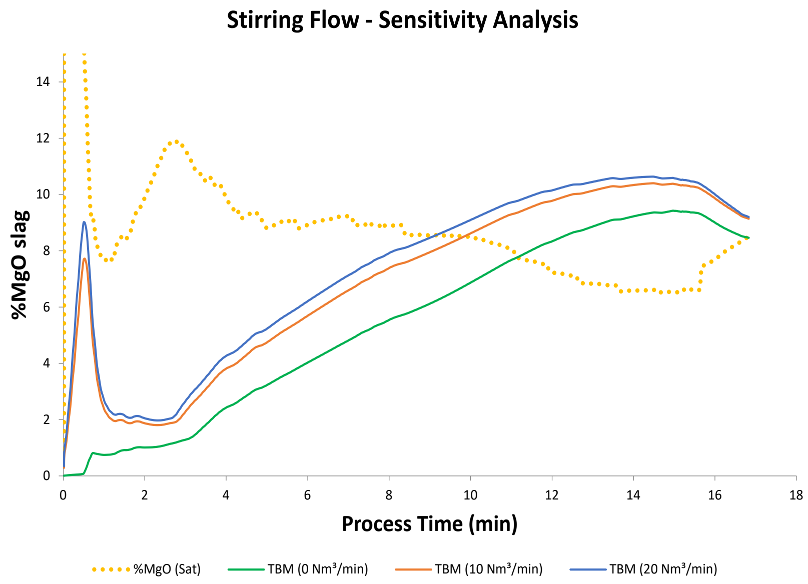




Development

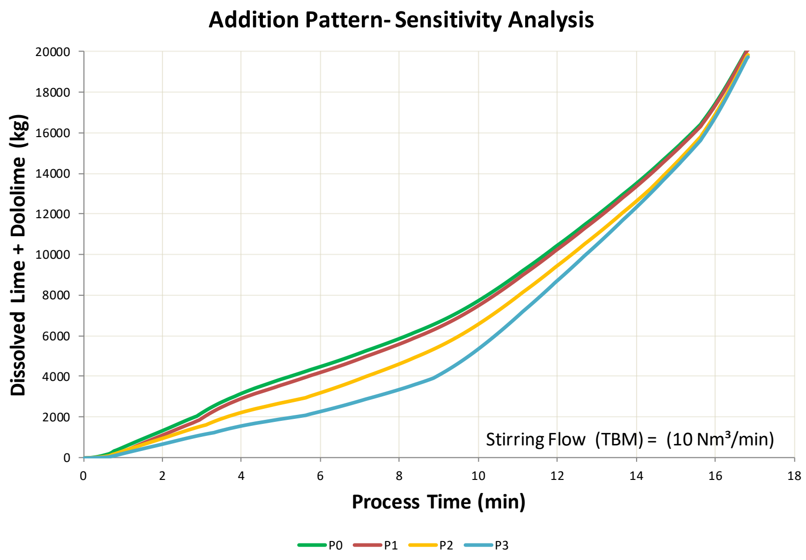
DeP - ADDITIVES DISSOLUTION MODEL

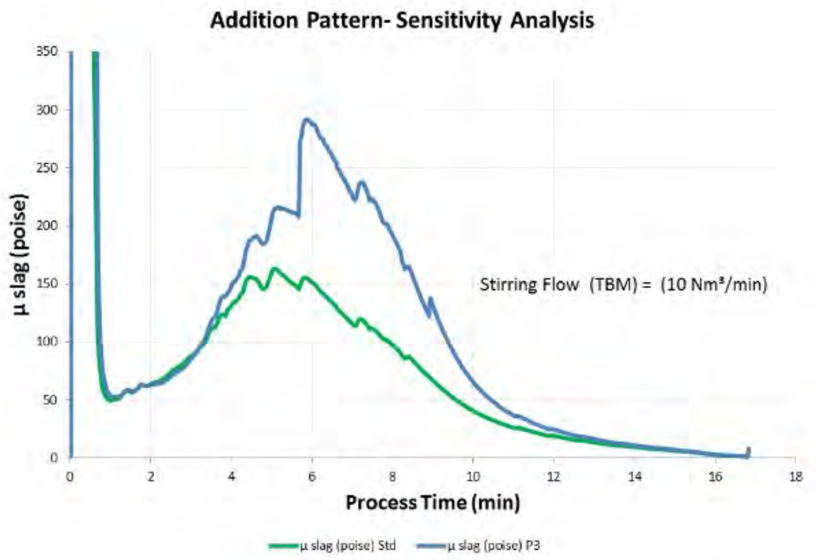




Development

DeP - ADDITIVES DISSOLUTION MODEL





Development

BLOWING PATTERN DEVELOPMENT

- Cold Modelling
- Oxygen Lance “Step-less”
- Single Blowing Pattern (main DeC);
- Constant oxygen flowrate;
- High addition of Iron Ore Pellets (up to 33 t / heat);

Laboratory experiments at LaSiP

LaSiP plexiglas converter (scale 1:10)

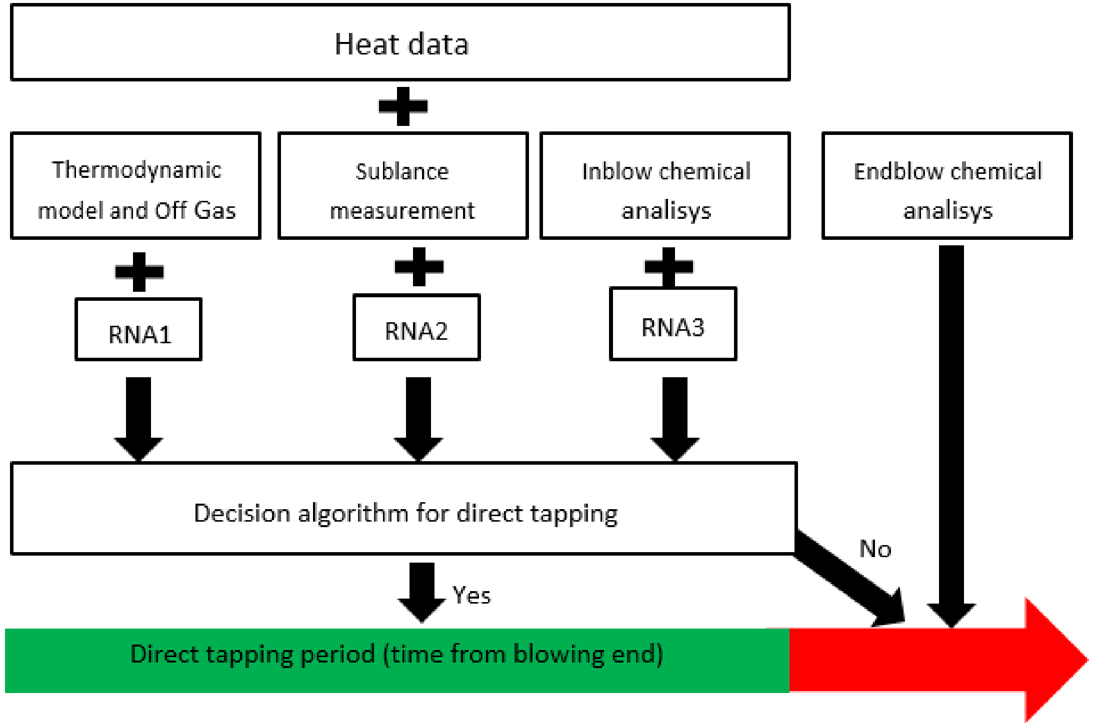
Industrial experiments at Ternium BR

Ternium BR converter (330 ton)

Development

DIRECT TAPPING MODEL

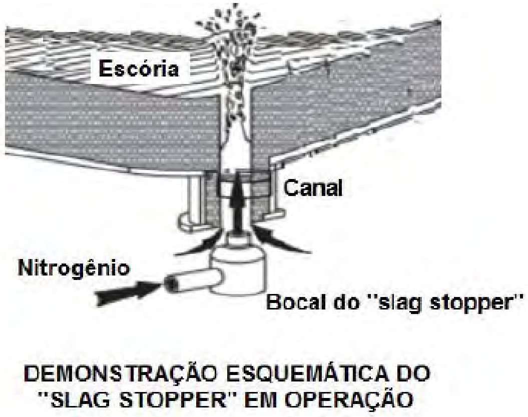
- Industrial process data were used to train **3 x Artificial Neural Network (ANN)** regression models for phosphorus prediction at BOF blowing end.
- Tapping is authorized when the risk of out of range is smaller than 1% (21)



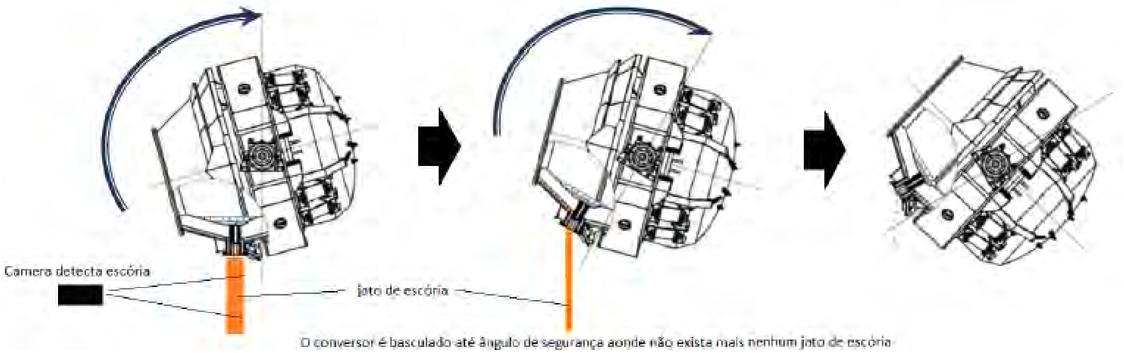
Process Integration, Investments

SLAG CARRY OVER

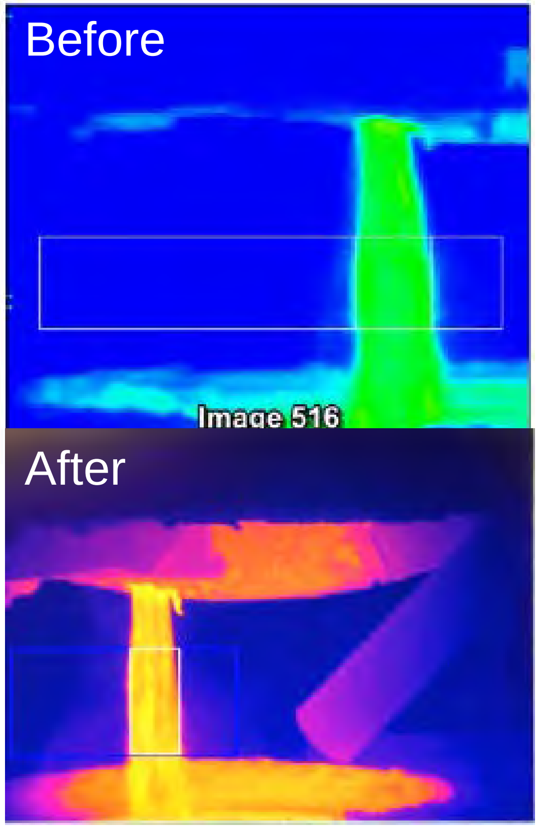
✦Slag Stopper System



✦BOF auto tilting



▪ Slag Detection



Source: Cerchiari, B., Klinger, L., Cruz, F., & Piller, F. (2018). Improvement in Tapping Process to avoid Slag Carry-Over. *49.* Sao Paulo, Brazil: ABM.

Thank you!
Tack själv!
Kiitos!
Dank je!
Merci!
Danke!

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Daniel Carvalho
Process Consultant Steel Plant

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