NEW TECHNOLOGIES AND APPROACHES TO IMPROVE EFFICIENCY FOR REHEATING FURNACES AND PROCESSING LINES

2016 ASEAN Iron & Steel Sustainability Forum Bangkok
Session #7 – Presentation #3
14 November 2016 - 16 November 2016
Foreword

In this presentation we will focus on several new features to improve efficiency such as:

- New reheating furnace concept,
- Exclusive patented R-TOP 3D reheat furnace mathematical model to improve productivity and to reduce specific consumption thanks to unique real-time 3D calculation of temperature of all products in the furnace and optimization of discharging temperature according to metal composition.
- Demonstration on how new technologies can improve NOF (Non Oxidizing Furnaces) energy efficiency from 50-60% up to 75-85% with regenerative solutions.
- Global efficiency improvement thanks to heat recovery solutions in jet cooling sections of processing lines.
- New features in the well-known patented L-TOP® line process model to increase productivity & reduce specific consumption during transient phases.
Increasing energy efficiency for reheating furnaces: industrial context

- Energy efficiency is a challenge since OPEX of reheat furnace per year has the same order or magnitude than its CAPEX.
- Any improvement concerning energy efficiency is therefore important since it brings competitiveness to the steel makers. This was done in the past mostly by reduction of heat losses and improvement of heating efficiency.
- Furnace is not considered as bringing added value to the products (slabs, blooms or billets) processed, but more than a necessity to feed smoothly hot rolling mill which was considered as the heart of hot rolling process: flexibility is essential.
- Development of new steel grades such as AHSS steels required for automotive has brought new constraints to reheating process: high accuracy of discharging temperature, stringent requirements concerning product homogeneity, specific heating curves.

Efficiency cannot anymore be dissociated from requirements to improve product quality and productivity. This has brought some major changes, not only in furnaces design but also in the way they are controlled.
Increasing energy efficiency for reheating furnaces: technical challenges

Conventional reheat furnaces present two zones: one recuperative section to preheat the products and one active section and present several drawbacks:

- The recuperative and active section lengths are calculated for maximum output. If the output is reduced due to external factors, products stay longer in the furnace and consumption per tons increases together with scale losses.
- In case of mill stoppage, products stay in the furnace at high temperature to limit waiting time to restart the production, increasing consumption per tons and scales formation.
- Product heating heterogeneity due to non even product heating or skids marks is critical. On-time 3D calculation of every point of each product temperature was not possible due required to calculation time.
- Such discharging temperature has to be determined accurately, and depends on the chemical composition of the steel usually calculated from 22 BISRA steel properties v.s. temperatures curves. → not adapted to ULC (Ultra Low Carbon) steels → preventive increase of discharging temperature to be on safe side.
- Finally uncontrolled scale formation and furnace de-scaling campaigns leads to overconsumption and productivity losses.
Increasing energy efficiency for reheating furnaces: new furnace design

- The furnace is divided in 3 zones instead of 2. One recuperative zone, one active zone with a length sized to heat the products at the discharging temperature at the maximum output, and a discharging zone separated by a wall from active zone at the exit of the furnace.
Increasing energy efficiency for reheating furnaces: new furnace design

- Pressure control
- Stoppage management
- Scale reduction

- Variable length depending on output
- Yield maintained for each output

- Better emissions
- Less energy consumption
Increasing energy efficiency for reheating furnaces: combustion system

- Several layers

| Service pressure control | • Air / fuel on smooth regime  
| SIMPLICITY OF CONTROL | • Single set-point |
| Macro-zones | • Ratio air/gas fine control  
| SELF-MAINTENANCE | • Self-corrective system |
| Process zone | • 1 row = 1 zone  
| FLEXIBILITY / ENERGY SAVING | • High flexibility |
| Individual Burner | • Flameless – ultra low NOx  
| QUALITY / ENERGY SAVINGS | • ONOFFSoft optimal control |
Increasing energy efficiency for reheating furnaces: combustion system ONOFFsoft

Each burner is switched ON (100% e.g. optimum and designed value for efficiency) or OFF, one or several times during a sequence, to ensure heating curve while avoiding sudden variation of the general gas flow. This combined with controlled opening and closing of gas and air valves gives the best pressure control in the furnace and the ducts and reduces maintenance and consumption.
Increasing energy efficiency for reheating furnaces: DRB & BFG

BFG has LCV and cannot give good adiabatic flame temperature without air and gas preheating.
Increasing energy efficiency for reheating furnaces: DRB & BFG

Conventional drawbacks of DRB

- Based on Honeycombs regenerators, **Lifetime is limited - 6 to 12 months.**
- The **efficiency decreases with the clogging of the honeycombs** and non-uniform routing of waste gases.
- **High CO content in the fumes** coming from residual gas in the regenerative beds at the cycle change
- The technology “as it is”, does not comply with the European legislation: safety and pollutants.
Increasing energy efficiency for reheating furnaces: DRB & BFG

Patented DRB concept with purge of beds without N2, mixed balls/honeycomb bed and Fluent modeling

Results fully comply with all European environmental and safety norms, ArcelorMittal Gent has been designed with CMI patented D.R.B. in second phase e.g. capacity extension from 225 tph to 350 tph.
Increasing energy efficiency for reheating furnaces: Global concept

- B.A.T. implemented in ArcelorMittal Gent:
  - Dry tight charging and discharging doors (without water cooling)
  - Automatic de-scaling to guarantee 2 years operation without de-scaling campaign
  - Staggered ridders to minimize skids marks
  - Deflectors designed by numerical modeling to optimize fumes/slabs thermal exchanges
  - Specific fume exhausts designed by Fluent S/W to optimize fumes flows and products temperature homogeneity
Increasing energy efficiency for reheating furnaces: ArcelorMittal Gent

Automatic scale recovery

Staggered ridders

Dry exit door
Increasing energy efficiency for reheating furnaces: A brain R-TOP-3D

- **Exclusive combination of:**
  - NEW 3D modeling of products temperatures
  - NEW Ultra Low Carbon thermal characteristics
  - NEW Steel oxidation model
  - BAT Residence times prediction in the different zones of the furnace
  - BAT On-line calculation of the Optimal Heating Curve based on minimum residence time in the current furnace thermal state
  - NEW Heat demand control with flow control roof temperature checking
  - BAT Thermal inertia in the furnace at each significant variation of the furnace temperature.
Increasing energy efficiency for reheating furnaces: GPUs vs CPUs

- Computation ratio is from 1 to 20 thanks to GPUs (CMI unique method is 20 times faster than classical 3D calculation)
- 3D modeling is achieved at the same speed than conventional 2D modeling with 50 products in a furnace

Interest for slabs: + (great)
Interest pour billets/blooms/tubes/beam blanks: ++ (huge)
Increasing energy efficiency for reheating furnaces: GPUs vs CPUs

Innovative BUT safe approach:
- Our tri-dimensional model for product temperatures tracking all along the furnace has been tested in real time in our offices on actual furnaces (thanks to modem link) comparing with results of 2D model installed and actual results (skid marks for instance)

Results:
- Skid marks are well predicted and may be reduced by applying correct strategies:
  - Optimization of top/bottom firing ratio
  - Heating curve optimization

Reminder: The location of the thermocouples regarding the burners location, and the way they are set in the roof, are very important for the thermal model
Increasing energy efficiency for reheating furnaces: GPUs vs CPUs

- BISRA tables define 22 types of steel.... but not ULC steel (Ultra Low Carbon (below 0.1% C) which has however very different physical characteristics:

Results: Using this ULC code instead of low carbon one from BISRA may lead up to 0.2 GJ/t decrease in consumption
Increasing energy efficiency NOF furnaces: industrial context

- 2 possibilities exits for heating in CGLs & CALs:
  - Non Oxidizing Furnace (NOF) is followed with a radiant tube furnace (RTF) or
  - use of a full radiant tube (ARTF).
- During the past decade, a lot of progresses have been made to reduce gas consumption on RTF. Solutions are now in operation with combustion efficiency of 85% with regenerative solutions.
- A number of references exist with Non Oxidizing Furnace however one of the main drawbacks of the solution is higher gas consumption due to efficiency around 50-60%.
- When developing new technical solutions for a furnace with direct fired burner for a CGL, it is required to respect others constraints such as steel quality and NOx emissions.
Increasing energy efficiency NOF furnaces: Technical challenge

- As of today, CGL and CAL waste gases are conducted to the stack going through a centralized recuperator. This recuperator preheats combustion air to temperatures typically around 450°C feeding the direct-fired furnace burners.

- The global efficiency of such furnace is not more than 50-60%, due to the fact that the waste gases are still above 1000°C at the exit of the furnace, then diluted at around 850°C in the recuperator, as a limit of the material of the bundles.
Increasing energy efficiency NOF furnaces: up to 75-85% efficiency

- The innovation consists in replacing the classical recuperator by rotating regenerator exchangers to preheat combustion air at a much higher temperature than 450°C, typically higher than 850°C.
- This rotating regenerator exchanger is composed of a three-part regenerator with stationary lower and upper part. The central part (honeycomb matrix of ceramic material) is a rotating stored and chambered vessel.
Increasing energy efficiency NOF furnaces: up to 75-85% efficiency
Increasing energy efficiency NOF furnaces: Benefits

- For a galvanizing line 350,000 tpy the yearly consumption gain is 14 GWh/year (ref. strip width 1660 mm and thickness 1mm running at 95 mpm)

<table>
<thead>
<tr>
<th>Estimated annual gain</th>
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<tbody>
<tr>
<td>Specific consumption gain kWh/ton</td>
<td>40</td>
<td></td>
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<tr>
<td>Yearly production tonnes</td>
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<td>Energy gain GWh</td>
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<td>Energy gas price EUR / MWh</td>
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<tr>
<td>Energy savings EUR</td>
<td>490,000</td>
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Heat recovery from jet cooling section: industrial context & technical challenge

- In a typical C.G.L. or C.A.L. The heat extracted from the strip via the jet cool section is generally lost: around 10 MWth for a typical CGL of 350,000 t/y.
- Typically, a jet cooling section is composed of a sequence of cooling boxes where a mixture of cold hydrogen-nitrogen gas is blown onto the steel strip through nozzles – CMI develops and integrates jet cooling systems through the patented Blowstab® technology which optimize cooling efficiency while reducing strip vibrations.
- Since the hot HNx gas coming out of the cooling section is then cooled down by a heat exchanger with cold water in closed circuit coming from cooling towers, all the energy extracted from the strip is invariably lost.
Heat recovery from jet cooling section: power creation by ORC

- A working fluid is used to transfer the energy. The selection of the working fluid for this application must comply respectively with thermo-physical, environmental and security criteria.
Heat recovery from jet cooling section: power creation by ORC: Benefits

- The high grade energy from jet cooling sections of a typical galvanizing/annealing processing line is capable of delivering 1 MWe on an adapted ORC cycle with one regenerator and an one-stage turbine.

- This innovation that enables steel manufacturers to produce electricity from the jet cooling sections targets the hundreds of worldwide existing processing lines of this kind for a total estimated installed electric capacity of more than 1 TWh.

The authors gratefully acknowledge partial financial support from ADEME – French Environment and Energy Management Agency according to the contract 11-81-C0069.
Improving line fce consumption via real time transient management

- The innovation deals with the transient management on a furnace for processing line. The main constraints on an operational point of view are quality constrains and minimization of gas consumption: a maximum of quality for minimal OPEX.
- Transients situation corresponds to the production phases when these constrains are the most complicated to manage in the same times.
- Mathematical model as the well-know patented L-TOP® model is an answer to such objectives.
Improving line fce consumption via real time transient management

- It is necessary to calculate the impact of a line speed change when the weld is inside the furnace to increase performances during transient situations.

- A non stationary model is used as well as new transient situations strategies to improve their management. Main functionalities are:
  - Continuous strip, roll and wall temperature tracking everywhere,
  - Transient situations with less thermal tolerances

- Determination of hot roll profiles for each roll at any time and in any transient situation thanks accurate physical models allows heat buckle risks calculation and prevention
Improving line fce consumption via real time transient management

ArcelorMittal Basse-indre tin plate CAL, competitor model upgrade
- Production increased > 7%, in replacement of an optimizing model
- Heat buckles reducted (infrequent)
- Hydrogen consumption decreased in jet cooling section (up to 70% in hydrogen rate)

ArcelorMittal Mardyck (Automotive CGL), competitor model upgrade
- Production increased > 9% on galvanizing
- Heat buckles reducted (infrequent)
- Specific consumption decreased by 3.0%
- < 0.6% out of tolerance

ArcelorMittal Florange Automotive CAL (competitor model upgrade)

US Steel Kosice Automotive CGL (competitor model upgrade):

Réussite de la chaufée pour la TOLE [%]

Average value with previous technology (Drever)
OK at +/- 5°C on whole strip length: 35%

Average value with L-TOP
OK at +/- 5°C on whole strip length: 65%
Improving line fce consumption via real time transient management

Consumption reduced by 3%

not enough for short ROI but

Quality:
✓ 10 times less risk of heat buckles than with operator or other models
✓ Mistracking problems are well reduced
✓ Thermal Quality is improved: Material reject due to bad quality are reduced (Lower than 0.2% of out tolerances)

Production
✓ Production is increased (> 4% and up to 20%) typically between 5 to 10% for automotive CGLs

Operation
✓ All chambers are under L-TOP® management
✓ L-TOP® manage automatically all operating condition (operators can focus on other tasks)
✓ No line stop to implement

3 months < ROI < 6 months
Conclusion

- Some innovative solutions to optimize the use of energy in reheating furnaces and processing lines are presented in this paper.
- Those solutions are available for new furnaces or to upgrade existing lines.
- As a global concept for processing lines (similarly to the one described for reheating furnaces), they are added to the toolbox of existing well-know solutions:
  - Self regenerative burners for radiant tubes (more than 700 hundreds installed by CMI),
  - ONOFFSoft to well manage the combustion at the burner level,
  - Heat recovery from fumes transferred to hot water circuit or steam production,
  - Optimized cooling concept as the Blowstab® solution and presented in Session6 Paper 3