THE MINIMILL OF THE FUTURE

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ABSTRACT

In our globalized world, with issues of global warming and responsible use of natural resources getting more and more attention from the public, the steel industry is bound to develop green technologies. Steel minimills, which are a prime example of recycling industry, cannot be designed exclusively on the base of the traditional metrics, productivity and energy consumption. Irrespective of the geographic location it is time to consider efficient use of raw material, minimization of waste and environmental impact as fundamental parameters which determine the plant design. The minimill of the future will be a resource-efficient, clean factory, and a better working place. Several technologies needed for this are already available today and can be implemented effectively: good examples are the newest, energy-efficient electric arc furnaces and the direct hot-rolling process. Combined, they can reduce the energy consumption per ton of rolled steel by 30%. Remote-controlled equipment and industrial robots relieve humans from many heavy- and hazardous tasks; centralized minimill control is achieved through the implementation of the Operation Control Center, which maximizes information available to the human operators and achieves the most meaningful cooperation of humans and machines. The ability to run sophisticated, real-time mathematical models of the steelmaking process has opened new possibilities for the optimization of production and quality; the expanding digitalization of the steel industry is bound to proceed at rapid pace and will benefit the economics of minimill operation .

INTRODUCTION

Some global trends, like reduction of greenhouse-gas emissions, and the advance of digitalization, are expected to influence the steel industry in the next decade and diffuse progressively from the leading economies to the rest of the world.

How will minimills look in future? According to the vision developed by Primetals Technologies, they will have these fundamental characteristics:

- All the component plants, not only the major consumers, will be optimized for lower energy demand and reduced emissions.
- Smart sensors, data warehouse tools, and optimization algorithms will control production processes in real time, dynamically meeting the optimum operation point according to the varying, actual process conditions.
- Humans will be removed from the more exhausting and risky tasks; human intelligence will be more and more focused on the overall control of the production process, and on the creative interpretation of data to improve plant performances.

These technologies are being developed at present, and some have reached full maturity and start to spread to the global steel industry. For example, most modern electric arc furnaces have reduced their electric consumption by 20-25% compared to traditional ones, while direct hot rolling of billets reduces the total energy consumption (natural gas plus electrical power) of bar rolling by 60%.The Energy Saving Assistant, using smart sensors and computation algorithms, decreases energy demand of fume treatment plants by 15-20%.

This article will give a concise overview of present developments, by following the minimill process flow from the scrap to the rolling mill.

SCRAP YARD OPTIMIZATION

Smart scrap yard

Developments in the scrap area focus on one side on the extension of automated functions beyond the current state of the art, and on the other side on the integration with the process optimization functions of the EAF. The purpose is to make scrap feed to EAF more controlled, constant in quality and to adapt EAF operation to unplanned changes of the scrap mix.

Primetals Technologies has developed a concept called Smart Scrap Yard, which sees use of new sensors, full automation of cranes and vehicles, and data transfer to and from the EAF, to perform:

- Scrap assessment and identification of hazardous substances by means of image analysis
- Full automatization of the bucket loading- and transport processes
- Connection of the scrap supervision with the EAF optimization system (Level 2)

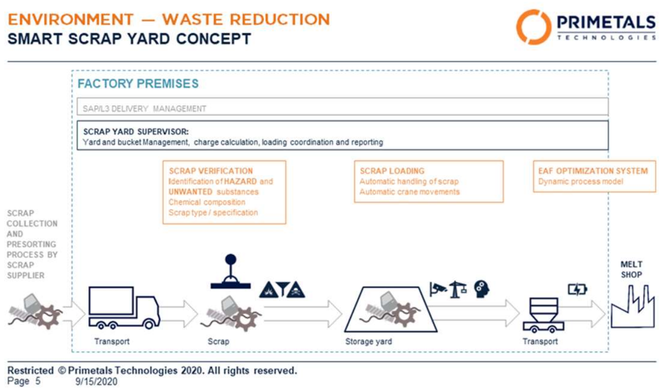

Figure 1 - Smart Scrap Yard

Fully automatic travel of scrap buckets, automatic loading to the EAF Quantum, and fully automatic bucket charging into conventional EAFs, are currently in industrial operation, with references in Asia and Europe respectively. New developments focus on the full automatization of the scrap yard, on the automatic control of the whole scrap logistics and on the co-operation with the EAF optimization system. The expected advantages are greater energy efficiency and productivity of the arc furnace.

Scrap processing

According to several market studies, the next two or three decades will see more scrap reaching the market, while the proportion of obsolete scrap will also increase. The quality of scrap will deteriorate progressively, as tramp elements, especially copper, accumulate through successive recycling[1]. There will be more competition for scrap, especially for the higher quality, from the integrated mills, which are looking to reduce their hot-iron production in the effort to curtail CO_2 emissions.

More competition for scrap and gradually worsening quality are a potential threat for the profitability of minimills; and scarcity of good scrap at the right price is already felt today in some areas of the world.

An effective answer to this situation would be to process low-quality scrap on the minimill premises, and we expect to see such solutions gaining more consideration in the future.

Mechanical screening and magnetic separation are able to reduce copper content of heavy-melting and shredded scrap (by 50% in the latter case), and to separate up to 10% of non-iron and non-metallic residue. The cleaner scrap benefits the EAF process with lower electrical- and slagbuilder consumption, higher metallic yield and lower dust emissions.

To achieve full control of the scrap logistics and quality, scrap cleaning plants will be integrated into the Smart Scrap Yard infrastructure.

ENERGY-EFFICIENT ELECTRIC MELTSHOPS

The arc furnace uses about one half of the total energy needed in a minimill, thence it is the first unit to consider in the effort to reduce energy demand of steelmaking.

Minimization of the energy consumption is achieved by means of proper design choices and operating practices meant to maximize the efficiency of energy inputs and minimize the energy losses:

- Increase transformer power and arc voltage to minimize power-on time and enhance energy transfer to the scrap. This strategy can be coupled with single-bucket design to reduce losses and to better enclose the electric arc with scrap
- Recover lost energy by using it for scrap preheating (which in practice puts lost energy back in the system)
- Recover lost energy by use of waste-heat recovery systems

EAF Ultimate

The EAF Ultimate is a single-bucket furnace with a powerful transformer (up to 1.5 MVA/t) to achieve lowest power-on times. In addition, the chemical power package is increased, with post-combustion burners (oxygen injectors) creating additional exothermic energy by converting CO to CO_2 in the upper shell, where a big scrap pile is present.

Short power-on and -off times, and the single-bucket process, effectively reduce energy losses and electric consumption decreases to 350 kWh/t (for 100% scrap charge). At the same time productivity is 15% higher than a conventional EAF of the same size.

A furnace of this type, rated for 220-240 t/h, decreases CO_2 emission by 60,000-70,000 ton annually. Its environmental footprint can be further reduced by combining it with a waste heat recovery system; in this case its CO_2 emission will decrease by more than 80,000 ton annually.

EAF Quantum

In the EAF Quantum the hot off gas is used to preheat the scrap in a vertical shaft. Thanks to the intense contact between the scrap and the gas raising through it, this arrangement is the most efficient, with the scrap reaching high temperatures (600-700 °C depending on time and scrap density)[2].

Electrical consumption values of 290-300 kWh/t have been routinely reached in the operation of EAF Quantum furnaces. These numbers cannot be reached by EAFs with side conveyors for scrap, where the off-gas flows on the top of the scrap and the heat transfer is limited, so that the scrap is not preheated above 200°C, resulting in effective savings around 30 kWh/t unless additional chemical energy (burners) is employed.

Furthermore, the Quantum EAF is operated with 70% hot heel which ensures a continuous flat bath operation, very low electrode consumptions, nearly no flicker and network disturbances and thanks to continuous foaming slag (no open arcing) very low NOx emissions.

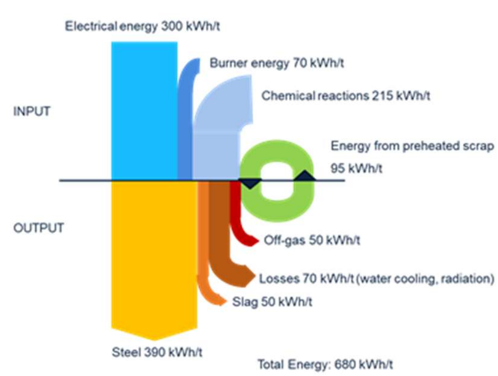

Figure 2 - Energy balance of a Quantum furnace

Waste Heat Recovery for Arc Furnaces

Adding a waste-heat recovery system to an arc furnace saves energy and contributes to reduce CO_2 emissions. In a WHR system, the water-cooled off-gas duct of the EAF is replaced with a pressurized-water duct to produce either hot water or steam, which can be used in different ways:

- Directly, e.g. transferring energy to a district-heating network through a heat exchanger. Such a system runs in Sweden since 2016.
- To generate steam for technological uses. In Italy, Primetals Technologies has delivered an EAF Quantum with WHR, which delivers on average 17 t/h of steam to a pickling line, replacing the existing gas-fired boilers. More than 10 million m³ of natural gas and 20.000 tons of CO_2 can be saved each year.[3]
- To produce electricity in an ORC turbine (Organic Rankine Cycle). A typical 7-MW (electric) turbine saves 15,000 ton CO_2 each year.

When it is possible to use hot water for heating or chilling purposes, or when there is a demand for steam (e.g. for a vacuum degasser with steam ejectors), direct use of these media is economically the most effective solution.

Electric steel plants have only limited demand for steam or heat; therefore, they often aim at a WHR system with power production. This however may require additional investment. A new, interesting approach is to use the recovered energy directly within the dedusting plant. The steam produced in the WHR feeds a simple impulse steam turbine, which in turns drive the main fans of the fume treatment plant.

OPTIMIZATION OF FUME TREATMENT PLANT

Fume treatment plants are often operated in such a way to keep emission control at the cost of energy consumption. On the contrary, advanced control of these plants can improve their energy efficiency; such advanced control is obtained by connecting sensors and optimization functions, thus effectively adding “intelligence” to the plant.

The Energy Saving Assistant is Primetals Technologies’ solution for a smart, energy-efficient fume treatment. Its main components are listed below.

Dynamic Control of Secondary Suction

The secondary circuit is characterized by multiple suction points distributed in the meltshop, with dynamically changing loads depending on the different phases of the production process.

The Dynamic Damper Control is based on a model that calculates the pressure profile in the duct system in real time, according to the actual conditions, and controls the opening of each damper and the set-point for the main fan. In this way, the fume treatment plant always runs at the minimum possible power. Typically, this system results in energy savings of up to15- 20%, as was shown by the first implementation in a German steel plant with one EAF and another 19 different evacuation sources.

In addition, Primetals Technologies has developed a system that monitors suction flow and captation efficiency by means of image processing analysis of video streams taken in selected areas.

Sensor-based maintenance

The Acoustic Expert is a configurable acoustic tool used for the online diagnostic of the pulse-jet valves in the bag filter and of the cleaning performance; which effectively eliminates the need of inspection.

The Bag Break Detection measures dust concentration in the clean gas duct. Statistical methods enable continuous condition monitoring during plant operation

While standard bag filters operate with fixed cleaning cycles, the Bag Filter Control triggers the bag cleaning cycle optimally, by measuring the differential pressure between filter inlet an outlet, and the actual volume flow of the off-gas. The duration of the opening time can be adjusted for each cleaning valve and a reduction of 30% in compressed air can be achieved.

Apart from the reduced energy consumption, a significant advantage of these systems is that, by introducing remote control and eliminating the need for inspection, they contribute to increase the production time and ultimately the plant productivity. Also, these sensors can be connected to a Condition Monitoring System.

ENDLESS AND SEMI-ENDLESS ROLLING

Direct charge of billets from caster to rolling mill is an established technology which, eliminating the reheating furnace (usually gas-fired) cuts gas consumption by 20-30 Nm^3/t and saves 60% of the total energy demand of rolling, compared to cold charging. Total CO_2 emissions for the minimill (from scrap to rolled bar) decrease by 10%.

This concept has been developed to the extreme with the endless rolling. However, it is easy to see that, considering the main benefits claimed, namely:

- Energy savings
- Higher yield of casting and rolling
- Lower operating costs (especially personnel cost)
- Lower investment costs and inventory costs

endless rolling shows an advantage only regarding the yield (see Figure 3). In fact, 60% of the savings on operation cost can be attributed to the elimination of the preheating furnace, which is common to both processes. A prudent estimate for these savings is approximately 11 €/ton, however this value may change considerably according to local prices of labor and energy.

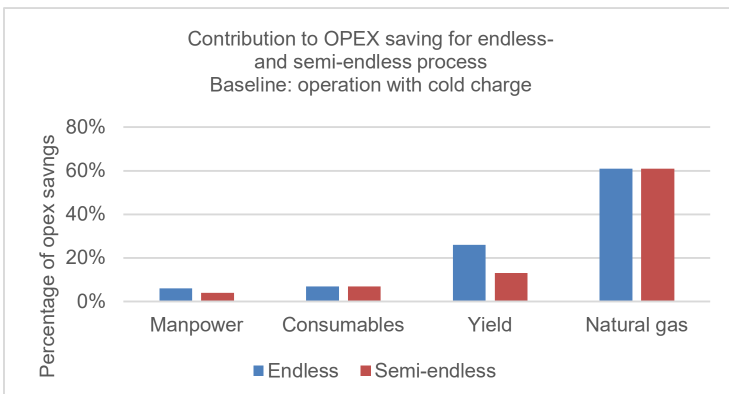

Figure 3 - Comparison of OPEX reduction for endless and semi-endless rolling. Data ere expressed in percentage of the savings achieved by endless rolling.

Therefore, a semi-endless process, which combines a multi-strand caster, quick billet transfer, and a continuous rolling mill, provides at least 85% of the cost benefits of an endless mill, with the advantage of greater flexibility and ease of operation. The strong points of semi-endless plants are:

- Energy savings. High-speed casting and quick transfer devices cooperate to deliver billets at temperatures between 900 and 1000 °C, which is comparable or even better than endless rolling. This billet temperature allows direct rolling without induction heating. An induction heater can be omitted altogether, or a low-power inductor can be kept to compensate temperature variations during transient times (e.g.at the start of each casting sequence).
- Low operation cost and production flexibility. By using a multi-strand billet caster that casts at high but reasonable speed (e.g. just below 5 m/min) the caster design can be kept simple, and this makes both maintenance and cleaning cheaper and faster. The plant is easily scalable to higher production and retains the flexibility to add strands for future expansions.
- Plant utilization. Any rolling mill needs to perform size changes and to replace rolls / grooves when the latter are worn and might impact the surface finish of bars. With increasing hourly productivity, these interruptions become more frequent and cannot be handled reasonably with an endless process, causing too many interruptions and transient times which lower plant utilization. Semi-endless plants are more suited to compensate short rolling interruptions,

minimizing production losses. Achieving uninterrupted production is the most effective way to lower the operation cost.

Starting from around 500,000 ton/year, the limitations of endless plants, in terms of mill interruptions and synchronization with the EAF, start to be significant and make of the endless design the better choice for larger plants. In fact, semi-endless plants with productivities of 100 to 200 t/h are already in operation or will start operation soon.

AUTOMATION AND PROCESS OPTIMIZATION

"*Modern automation systems, based on dynamic process models and continuous measurement of process data, are essential to the energy and resource-efficient operation of EAF plants*" [4]

Vision

Primetals Technologies' vision of digitalization is an extended integration of sensors, automation and IT systems, both vertically (across the traditional automation levels) and horizontally (along the production chain)[5]. The result is the Digital Unity concept, which sees the interconnection of a production management system, a "through-process" quality control and optimization, and a central maintenance management system.

The implementation of such systems in the steel industry will be gradual, with some of the mentioned systems being already available and some others under development. A crucial task for the developers is to ensure modularity and connectivity of any new systems, to make them open for future expansions. This is especially important for minimills, which need to contain digitalization expenditures within acceptable limits. There will be no ready-made solution, and each steel maker will configure its path to digitalization according to their business model.

Robotic systems

The installation of industrial robots in meltshop and rolling mill has the purpose to improve health and safety conditions, at the same time reducing the interruptions of production and therefore contributing to increase plant availability.

Several robotic applications are under development at Primetals Technologies. Examples are the LiquiRob, which performs fully automatic temperature measurement and sampling in the EAF and LF, and the RollRob, which performs the replacement of worn rolling rings in the no-twist mill.

The RollRob reduces roll change time by 40% compared to manual operation. When applied in a Winlink mill, it decreases stoppage time and reduces the number of billets discharged off-line during roll change.

Operation Control Center

The integrated control center provides centralized operation and monitoring. Operators are removed from potentially hazardous areas and their activities are relocated to the air-conditioned control center. Manual tasks are automatized, and all the important control functions are mirrored in the control center, where HMI terminals and console elements allow the operator to execute key tasks and safety functions.

Figure 4 - Operation Control Center, China

Smart operation

There are many new plants where increased intelligence and connectivity are implemented. Common to these plants is a tiered architecture in which several "smart" elements are present.

Smart sensors (like dynamic size- and speed measure in rolling mills, vision systems) are integrated in the process control. Till now their use is not widespread across the whole minimill because of the harsh environmental conditions and different levels of impact on the operating cost. However, their development continues rapidly. Level 2 systems make use of mathematical models running in real time, to provide process optimization for each functional unit. The development in this field aims at harmonizing level 2 systems along the production line and improve the communication between different systems. Condition monitoring systems are starting to be used in some plant areas and will need some more time to be extended to the whole minimill.

Increasingly attention is given to the development of modular systems, which are capable of wider interoperability and connectivity, and to the analysis of large amounts of data, which re made available by the progress in network and software technology, at reasonable cost. The systems available for minimills collect and analyze large quantity of quality- and process-relevant data, to derive key performance indicators and compare them against set targets. On this base, plant operation can be constantly monitored and improved. Remote assistance from the plant manufacturers and experts is also provided by systems like the m.connect of Primetals Technologies.

The future will see the progressive expansion of technologies like the use of digital twins and the through-process optimization.

Digital twins, combining real-time field data with process models, provide a virtual representation of the actual plant and of the production process. They are very powerful tools to improve the user's understanding of the process and to assist with the optimization of production.

Through-process optimization (TPO) targets the accumulation of know-how along the entire steel production chain. The basis of this solution is the through-process quality control (TPQC) system which creates a central database by receiving quality- and process-relevant production data from all production units via the basic and process automation systems, as well as laboratory measurements.

CONCLUSION

Work on the minimill of the future is well under way, with developments in the field of equipment and automation which today grant a 30% reduction of the energy demand and 35% of CO_2 emissions compared to the previous generation of plants.

Considering the current developments in the fields of smart sensors, robots, control algorithms, and big data, we can deduce the characteristics of the smart minimills of the next generation, which will see more automated functions replacing direct human control of operation, more integration along the production line, and data analytic tools enhancing human understanding and control of the process.

The interconnection of process equipment and control systems will accentuate the importance of process know-how and disclose the possibility to integrate more knowledge into minimill operation. In turn, the emphasis on knowledge will help the diffusion of knowledge-based services provided by equipment manufacturers.

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