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Qualitative and quantitative modelling to build a conceptual framework to identify energy saving options: case study of a wire producing company

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ABSTRACT

Energy management systems are considered as appropriate instruments to identify and realize energy efficiency potentials in industrial plants. Studies point out a largely untapped potential for energy efficiency in industry through the adoption of systematic energy management. We suggest introducing qualitative and quantitative modelling tools into energy management to facilitate a focused process to set priorities and identify effective measures. This paper describes the case of voestalpine Austria Draht GmbH, an Austrian wire rolling mill. voestalpine Austria Draht GmbH at present is implementing a knowledge based energy management system.

Within the work described in this paper, first an overview of energy flows using Sankey diagrams was elaborated. Then a qualitative systems analysis was developed for the plant and a gap analysis done for priority areas. Subsequently physical input–output models for several energy intensive units were prepared. The paper describes the models for the cooling water system and product cooling. This study revealed a significant potential to save electricity by optimizing the control of cooling water pumps along the milling train and to recover heat from the final products. 2 GWh of electricity can be saved annually.

The biggest single energy loss in the mill is the heat from air cooling the products on hook conveyors. These heat flows contain about 30–50 % of the energy input for heating up the billets. Following a theoretical analysis of the potential, a demonstration plant was developed and pilot tests were run to characterize the realistic potential of heat recovery on the hook conveyor. Based on the test results, feasibility studies for large scale plants were carried out. As a result, 0.8 GWh of heat can be recovered annually.

The method was found useful because it helped to structure the existing information with a reasonable effort mostly by the operators themselves in their work and to build a conceptual model of energy flows and energy efficiency of the total plant.

1. Introduction

1.1. Potential for energy saving in the rolling mills

Over 1.3 billion tons of steel are manufactured and used every year globally (World Steel Association, 2014). On average, 1.8 tons of CO_2 are emitted for every ton of steel produced. Iron and steel industry accounts for approximately 6.7% of total world CO_2 emissions. At the same time, in the last 30 years the steel industry has reduced its energy consumption per ton of steel produced by 50%.

In hot rolling the size, shape and metallurgical properties of steel are changed by repeatedly compressing the hot metal with temperatures ranging from 1050 to 1300 °C between electrically powered rollers. The total hot rolled steel output in the EU in 2011 was 151 million tons (excluding Greece, Sweden, Slovakia and Slovenia) (Renda, 2013).

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Hot rolling mills usually comprise the following process steps: conditioning of the input slabs, billets, beam blanks (scarfing, grinding); heating to rolling temperature; descaling; rolling (roughing including width reduction, rolling to final dimension and properties) and finishing (trimming, slitting, cutting).

Surveys have shown that steel processing companies still have potential to reduce their CO_2 emissions (Nolzen, 1984; Johannsson and Söderström, 2011; Rentz et al., 1999):

General measures to reduce energy consumption regarding furnace design or operation and maintenance of the furnaces include: to avoid excess air and heat loss during charging by operational measures (minimum door opening necessary for charging) or structural means (installation of multi-segmented doors for tighter closure); the implementation of automatic furnace control to optimize the firing conditions; the recovery of heat in the waste gas by feedstock pre-heating; the recovery of heat in the waste gas by regenerative or recuperative burner systems; the recovery of heat in the waste gas by waste heat boiler or evaporative skid cooling (where there is a need for steam); the reduction of heat loss in intermediate products; by minimizing the storage time and by insulating the slabs or blooms (heat conservation box or thermal covers) depending on production layout; the change of logistic and intermediate storage to allow for a maximum rate of hot charging; direct charging or direct rolling (the maximum rate depends on production schemes and product quality); and for new plants, near-net-shape casting and thin slab casting, as far as the product to be rolled can be produced by this technique. (Hammer, 1990; Held et al., 1985; Krimmling et al., 1997).

Johannsson and Söderström, 2011 describe the use of biomass as fuel in heating furnaces, heat radiation converted to electricity by thermo photovoltaic technology and the use of Organic Rankine Cycles or Kalina cycles, the generation of hot water from cooling beds, the use of hot water from cooling for district heating as important options to reduce energy intensity.

Krenn et al. (2009) did a study in Austria on the technical and economic feasibility of the application of Organic Rankine Cycles to use the energy content of exhaust gases of walking beam furnaces to generate electricity in hot rolling mills.

Moya and Pardo (2013) extrapolated the application of best available technology in energy efficiency and CO_2 emissions in the EU27 iron and steel industry: The paper suggests that if all measures with a payback time of two years or less are implemented, carbon emissions until 2020 can be reduced by about 5% using 2010 as base line, without technologies based on direct reduced iron. Until 2030, these measures have the potential to reduce specific carbon emissions by about 20%. In the longer term (until 2030) and allowing payback times around 10 years, carbon emissions can be reduced by 60%.

Thollander and Ottosson found (2010) however, that even in energy intensive industries, energy management does not seem to be fully a priority. The wide range application of energy management seems to be a large untapped potential.

The authors learned from discussing with management in several mills in Austria that for a retrofitting project a payback time of 1–3 years is requested to qualify for implementation. Management found it difficult to systematically identify the options with the best return on investment.

Bunse et al. (2011) conclude from their research, that the needs of industry in the area of energy management in production are different from approaches to energy management described in literature. Industry needs energy efficiency metrics at process and plant level, benchmarks for individual process units, knowledge-based systems on the basis of real-time data, a conceptual framework for the evaluation and assessment of data, and tools for simulation and visualization of energy efficiency.

1.2. The hot rolling mill of voestalpine Austria Draht GmbH

In the hot rolling mill of voestalpine Austria Draht GmbH, annually about 500,000 tons of rolled wire with a diameter of 5.0–32.0 mm are produced. Billets with a cross section of 130 × 130 mm up to 12 m long are heated in a walking beam furnace to rolling temperature, descaled and rolled in a two-core roughing mill. After a shear group there are two single core lines with 10 roll stands. Two loops can be used for thermo mechanic rolling. 10 roll stands can be used for finishing. The final rolling speed is 85 m/s with a diameter of 5.5 mm. After water cooling the wire is laid onto the loop cooling conveyor by the loop laying head and formed to coils in the coil forming chamber. There are different options for surface treatment (pickling, phosphatizing, polymer coating) and heat treatment (soft annealing). The pickling plant has a capacity of 140,000 t/a, the annealing plant a capacity of 70,000 t/a.

At the moment, about 4000 points of measurements are installed. Their location was selected to facilitate operational control, not to provide data for energy management. voestalpine Austria Draht GmbH has worked for many years systematically to optimize energy consumption. As a first step, an overview of energy flows of the mill was elaborated. Potentials for improvement were identified in the following areas: heat recovery from a dryer to preheat wire coils before pickling, minimization of heat losses of steam pipes by better insulation, efficient lighting, optimisation of the hydraulic system of cooling water supply.

Step by step, a number of options were implemented. voestalpine Austria Draht GmbH is motivated by pending legal requirements and because of increasing energy prices to further increase energy efficiency in processes, machines and components.

A number of potentials can be identified at components like motors, pumps, fan with better efficiency, optimized control, optimized heat transfer, heat recovery, control strategies, automation. Consequently these need to be evaluated, ranked, realized and the results of implementation controlled. All the individual losses can be reduced with manageable efforts. However it takes more to reach optimum energy efficiency over the whole production system.

In the mill of voestalpine Austria Draht GmbH the relevant impacts on energy consumption are:

- Production of a variety of products in different steps in rolling, heat treatment and surface treatment in changing quantities, temperatures and mechanical strength
- Mode of operation (load, set up, maintenance)
- Unit specific losses (heat losses, efficiencies, friction, transformation)
- Waste heat from product cooling (hot air at the hook conveyor, cooling water from cooling rolling stands and exhaust gas from furnaces)
- load of machines and units,
- Variation and quantity of ordered batches of different products
- Optimization of process organization, maintenance, change overs
- Increase in energy need because of higher pressure and forming resistance in the production of advanced high value products.

The following problems need to be solved from an organisational perspective: Where to start the analysis? Which units should