CHEMICAL ENGINEERING TRANSACTIONS

VOL. 29, 2012

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Hon Loong Lam, Jiří Jaromír Klemeš

ISBN 978-88-95608-20-4; **ISSN** 1974-9791 DOI: 10.3303/CET1229039

Some Benefits of Dynamic Simulation of Energy Systems in an Integrated Steel Mill

Thibault Henrion*[a], Andreas Werner[b]

[a]Austrian Institute of Technology, Department Energy, Giefinggasse 2, 1210 Vienna, Austria
[b]Vienna University of Technology, Institute for Energy Systems and Thermodynamics, Getreidemarkt 9/302, 1060 Vienna, Austria
thibault.henrion@ait.ac.at

In the frame of a research project, the physical behavior of the steam and hot water networks of an integrated steel mill were reproduced using the APROS simulation tool. The analysis of the steam distribution network behavior shows that strong fluctuation of some state variables (pressure, temperature) occur due to batch process productions and variable heat demand.
Classical methods for efficiency improvement, like energy/exergy analysis or pinch/total site analysis, are based on steady-state assumptions. Hence, they do not consider inefficiencies due to the above described transient behavior. This work relies on a method based on dynamic behavior modeling of energy systems in order to assess energy efficiency, fluid quality and flexibility improvements.
This paper describes, through a practical example dealing with a pressure swing problem caused by the interaction between the basic oxygen furnace and the hot rolling mill steam systems, the modelling and improvement procedure of the steam network. Subsequently, the application range of the developed simulation models is discussed.

1. Introduction

The actual need in the industry to further reduce energy use encourages investigating new methods for the analysis and optimization of existing production processes. To answer to this need, a method using physical modeling of the dynamic behavior of energy systems has been developed. It is based on the general procedure of the process synthesis as explained by Tuomaala (2007).Existing optimization methods are usually based on empirical correlations or on thermodynamic correlations. They assume a steady-state operation of the considered units. An improved accuracy of the process parameters estimation can be reached, when the dynamic behavior of the process is taken into account, especially when time dependent physical phenomena play an important role in the involved processes (Henrion, 2012c). Therefore process modeling and especially dynamic simulation of transient operation helps to gain detailed knowledge on the investigated processes and deliver better optimized technical solutions. It helps in the case of existing industrial plants to complete the information from partially missing documentation and/or not available process data. This paper exposes some findings of a study, which used dynamic simulation tools in order to investigate the behavior of an existing Integrated Iron and Steel plant (IISP). It explains how the tool helps improving operations profitability by reducing the energy costs and increasing unit operability. The utilized method is detailed for one specific application example: the discontinuous steam production of the basic oxygen furnace and the hot rolling mill are interacting with each other and produce some pressure peaks in the networks. This leads to steam release through certain safety valves. Solutions to avoid these quality and energy losses were

Please cite this article as: Henrion T. and Werner A., (2012), Some benefits of dynamic simulation of energy systems in an integrated steel mill, Chemical Engineering Transactions, 29, 229-234

investigated with a dynamic model of the steam distribution network; their evaluation is exposed in this paper. Finally the extent of possible findings that can be reached through the used method is shown.

2. Characterization of the investigated energy system

This section describes the behaviours of the steam distribution network main consumers and suppliers, which have been characterized through process data analysis. Relevant control mechanisms of the steam parameters are also explained.

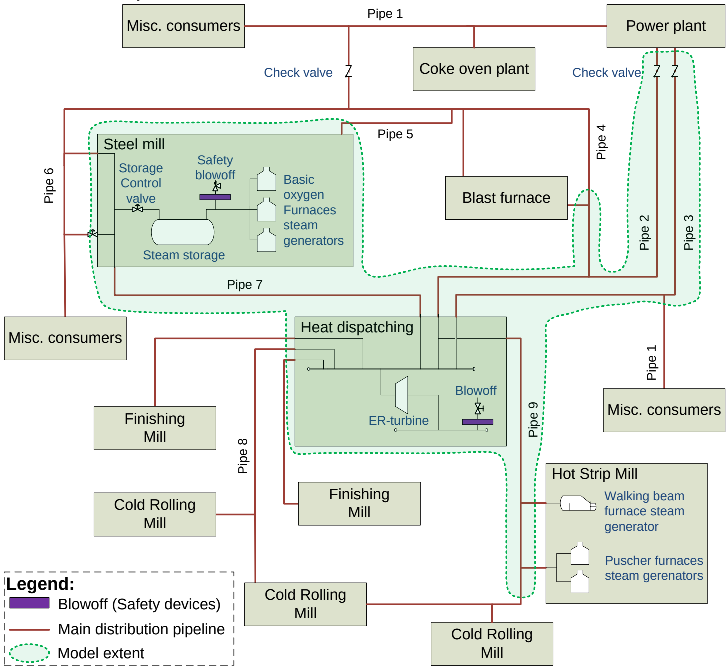

Figure 1: Schema of the steam distribution system

In the considered network, which is schematically represented in Figure 1, the transportation pipes are operated at a pressure of approximately 18 bars gauge (barg), and a temperature varying from 320 °C to the condensing temperature of about 210 °C. Process data analysis shows that most of the steam consumers have a relative constant consumption during the day. A consumption increase is observed seasonally in winter, as heat tracing is used for different purposes. However the consumers in the steel mill are characterized by large and rapid fluctuations of their daily steam demand. These variations are triggered by the vacuum pumps of the secondary metallurgy processes and by the water spray cooling of converter gas. These consumers require some large quantities of steam within few minutes for periods of about 15 to 20 min. The power plant is the main steam supplier. It exports superheated steam (with approximately 300 °C) and regulates therewith the network pressure at the delivery points (Pipes 1, 2 and 3 on Figure 1).

About one third of the total annual process steam demand is supplied by waste heat steam producers. The analysed network counts three major waste heat steam producers:

- The “basic oxygen furnace steam generators” are the largest waste heat steam suppliers. The latent heat of the raw converter gas is used to produce saturated steam in the steel mill. As oxygen blowing in the converter is a batch process, steam is produced in large quantities during short time periods (15-20 min).
  This unsteady production is buffered by a steam storage system (Ruth’s accumulator type). A control valve at the outlet of the storage reduces steam pressure from the storage to the network level. It controls the pressure level in the steam generators and in the storage tanks, which can vary between 18 and 30 barg. Safety valves release steam from the steam generator

drums to the atmosphere to avoid that the operating pressure exceeds 31 barg. If the steel mill internal steam production exceeds the process demand, then saturated steam is exported through pipe 7 to the “heat dispatching” plant.

- The pusher furnaces in the hot strip mill are also equipped with waste heat recovery steam generators. Their production depends on the load of the reheating furnaces. Within half an hour, their steam throughput can vary from half to full load. They deliver superheated steam directly to the steam network.
- The walking beam furnace evaporation cooling system provides the steam network with saturated steam at rather constant mass flow.

The steam network is additionally equipped with two further safety mechanisms in order to prevent pressure peaks:

- a manually operated blow-off valve located in the heat dispatching area.
- a flue gas by-pass of the pusher furnace steam generators, which allows to blow-off hot flue gas in order to limit the steam production.

A detailed process data analysis for the whole system reveals that pressure peaks occur in the network. Those peaks appear during situations where the delivered flows from pipe 1 and 2 are low and the production of the pusher furnace is high. This is due to a local steam excess in part “steel mill, heat dispatching plant, hot strip mill” of the network. The steam network model should be able to reproduce the described phenomenon in order to investigate improvement measures on this issue.

3. The simulation program APROS

APROS (2011) is a simulation tool which is focused on dynamic simulation of thermal and nuclear power plants. It allows the modeling of 2-phase flow considering each phase separately - hypothesis for this model are listed by Hänninen and Ylijoki (2007). A one dimensional discretization method of the pipes is used to solve the governing equations of fluid mechanics. The discretization method for APROS is documented by Hänninen and Ylijoki (2008). Boiling crisis can be taken into account. The possibilities of varying the models boundary conditions and modeling elaborated control systems make this program quite appropriate for the purposes of this work. GRADES is the graphical interface of APROS and allows a process flow diagram representation (Henrion et al., 2012a). The program has been chosen because it can simulate condensation phenomena inside steam pipes as well as in tanks (application for the steam storage). It allows an accurate simulation of vaporization in the steam storage vessels and the steam generators (Henrion et al., 2012b).

4. Physical modelling and model validation

APROS is used to model the unsteady behavior of the steam network during a complete day of operation. The developed model is validated thanks to registered process data from the existing unit.

4.1 Model build-up

The modeled parts of the steam network are represented inside the dotted line on Figure 1. Three factors influence the choice of the extent of the model:

1. the questions that have to be answered by the simulation (in the present case, a.o. analyze the pressure peaks in the area steel mill, dispatching plant, and hot strip mill),
2. the availability of process data to validate the modeled behavior,
3. the availability of equipment documentation.

In order to recreate the dynamic system behavior, the geometrical and material properties of each component are modeled accurately: this includes piping (incl. pressure losses and insulation), valves, steam trap, steam generators, steam storage tanks, heat exchangers, turbines… Variable mass flow boundary conditions are used to model the mass flows of steam production and consumption, except for the power plant, which is regulating the pressure at the beginning of the connected pipes. In this case the steam inlet to pipe 2 and 3 is modeled for both pipes with separate variable temperature and pressure boundary conditions. These boundaries equalize the measured process data. The role of the unit, which in reality compensates the difference between steam production and consumption, can be well reproduced in that way. In the steel mill, the complex control loop of the steam storage control valve regulates the mass flow leaving the storage tanks (see Figure 2). The control algorithm can be modeled accurately thanks to the components available in the process control library of APROS. The valve position is calculated from the storage pressure, the steam network pressure, the exported steam flow and the actual valve position itself. The operator can modify the “basis valve position”, which defines the position set point, when the actual measured pressure is within a definite range. For maintenance reasons, the valve position is discrete and its action remains limited. The valve incremental action as well as the hold-off period during which the valve is blocked can also be modified (Schimon and Henrion, 2010).

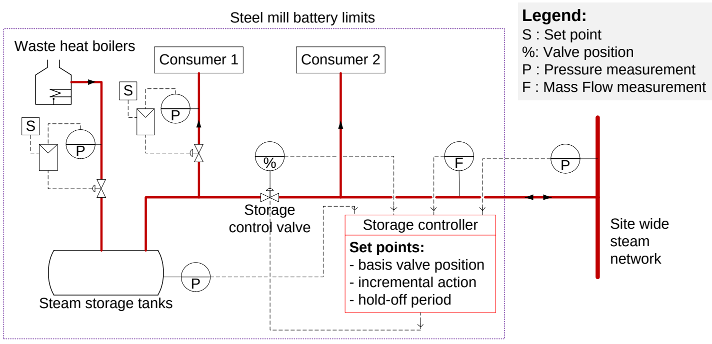

Figure 2: Modeling of the steel mill and its control loops

4.2 Model validation

The validation phase consists in an iterative adjustment of the model parameters (pressure loss coefficients, heat transfer coefficients, boundary conditions…) to approach the simulation results (pressures, temperatures, mass flows) from the measured process data of the simulated operation day. The validation of the storage parameter in Figure 3 shows that the real behavior is recreated by the model relatively accurately. The steam storage pressure profile (left on Figure 3) confirms good quality of modeling of the storage control system. The mass flow out of the steam storage (right on Figure 3) shows a good accuracy of the mass balance in the steel mill.

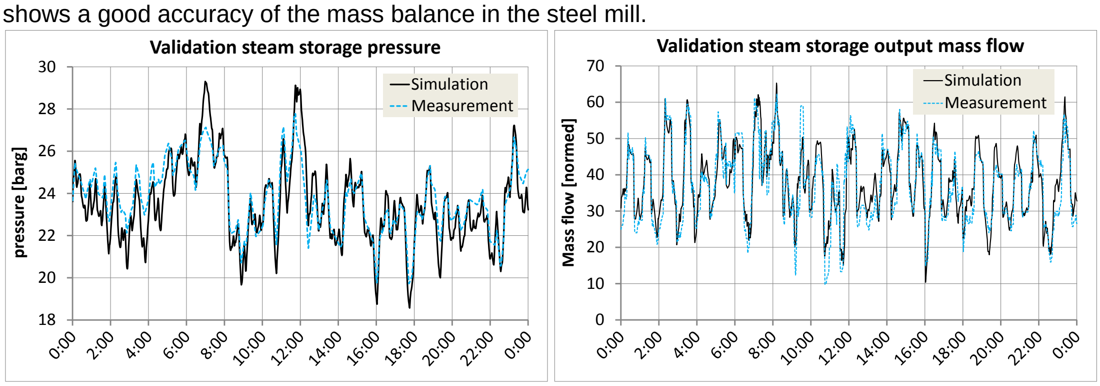

Figure 3: Validation of the steam storage system

Further validations are done for:

- the mass flows delivered by the power plant (pipe 2 and 3): they are particularly significant for the exactness of the model as they close the steam balance of the IISP. The validation shows good approximation of the model even if few differences remain;
- the pressure level in the heat dispatching: here higher pressure peaks are observed in the model. This is due to the reduced model extent. The smaller network volume, that is taken into consideration in the model, is the reason why the modeled pressure peak amplitude is higher;
- the temperature in the heat dispatching: it shows relative good reliability of the model.

The validation results demonstrate that the model is able to give good prediction on most of the network parameters. Model deviations on the pressure peaks amplitude have to be taken into account for the interpretation of the investigation results.

5. Simulation findings

This section describes in detail the analysis of the pressure peaks issue in the steam network. Further results are briefly exposed to give an overview of the application range of the dynamic simulation tool.

5.1 Pressure peaks reduction

In order to reduce the pressure peaks triggered by a steam excess in a part of the network, the effects of two modifications have been investigated with the model. In case 1 the control parameters of the storage valve are modified: the hold-off period is reduced from 300 to 10 seconds and the incremental action from 5 to 1 %. This measure enhances the reaction speed of the control system in case of pressure peaks. In case 2 a steam storage system with a volume two times larger than the original one is simulated.
Both cases are modifications of the validation case (case 0), which constitutes the base case.

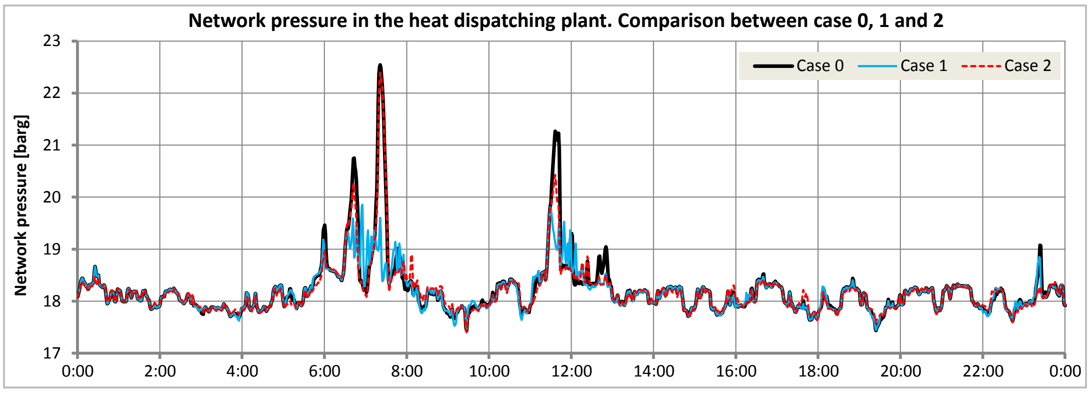

Figure 4: Pressure peaks case study results

The simulations results in Figure 4 show the pressure profiles for each case in a central point of the network. In case 2 steam venting due to safety equipment is reduced by 43 %. Furthermore from Figure 4 can be observed that the amplitude of some pressure peaks is reduced (at 6h45 and 11h30), but the main peak at 7h15 remains still high. In case 1, the modified control parameters allow to keep the pressure at all times below 20 barg, so all peaks could be reduced. Losses due to blow off of steam is reduced by 55 %. In both cases the calculated condensation losses remain unchanged, and the steam delivery from the power plant is slightly lower due to the reduction of the steam blow-off. Thanks to these measures an additional reduction of the waste heat losses at the pusher furnace can be expected. We can conclude that thanks to a simple modification of the steam storage control parameters, the steam pressure quality can be improved without any investment. Steam blow-off and waste heat losses are reduced.

5.2 Further findings from different other investigations

Other investigations made, thanks to the steam network model, allowed to improve the quality of steam (temperature and water mass fraction) which is delivered to an energy recovery turbine, thus reducing its maintenance costs and steam condensation in the network. The development of a detailed model of a steam transportation pipeline helped to understand its behaviour during start and stop operations. The reduction of the annual pipe energy losses (through shorter operating time) as well as the increase of the pipe operability (faster start and stop phases) could be investigated. Another model, which simulates the hot water network of the IISP, is used to investigate different measures in order to increase the net heat delivery capacity. By reducing the pressure losses in the network, water mass flow can be increased and so a higher mass flow can be transported. The implementation of a new by-pass with a specific control sequence promises a significant reduction of pressure losses. The model was also used to optimize the heat recovery from a waste heat source.

6. Conclusions and outlook

Through one specific application example, this paper showed how dynamic physical models can be used to improve energy efficiency and operability of complex energy systems. Thanks to the developed model, the effect of different improvement measures on pressure peaks can be predicted, utilizing larger storage tanks or improved control parameters. The better option from the operative point of view can be identified in that way. The developed analysis method is based on the APROS simulation software. An analysis based on process data is necessary to understand the interactions between consumers and producers, which characterize the network behavior. The developed model can be validated accurately, thanks to the process data available for an existing unit. Such a dynamic simulation can be used for instance to assess the effects of improvement measures on the energy demand and operation quality parameters of the considered energy system. In this way all time dependent phenomena like pressure, heat flow and temperature fluctuations are considered. This method can be applied to existing units like in the present example but also for grassroots design of innovative energy systems like done by Henrion et al. (2012a), Paananen and Henttonen (2009), Heim et al. (2010) or Schlagenhaufer (2011). The investigation and evaluation of thermal storage components in complex energy systems constitutes a further relevant application for dynamic models.
The use of such models opens also application perspectives for the development and implementation of complex control systems as explained by Schimon (2011). The use of predictive control algorithms can be inquired by the developed tool in order to realize a real time optimization of the considered energy systems. Further models can also be used for the training of unit operators. It helps minimizing product-, exergy- and heat-losses during shut-down and start-up operations, but also in emergency situations (Henrion et al., 2012b).

References

Hänninen M., Ylijoki J., 2007, The constitutive equation of the APROS six-equation model, APROS documentation.

Hänninen M., Ylijoki J., 2008, The one-dimensional separate two-phase flow model of APROS, VTT research Notes 2443, Helsinki, Finland.

Heim M., Ferrand T., Kluger F., 2010, Simulation der Dynamik von Steinkohledampferzeugern beim Anfahren, im Lastbetrieb und bei Betriebsstörungen, Sichere und nachhaltige Energieversorgung.

Henrion T., Ponweiser K., Band D., Telgen T., 2012a, Dynamic simulation of a solar power plant steam generation system, Simulation Modelling Practice and Theory, DOI: 10.1016/j.simpat.2011.12.009.

Henrion T., Werner A., Kitzberger R., Haider M., 2012b, Dynamic simulation as a tool to improve the efficiency of energy systems - Applications in the steel industry, E2C conference, Maastricht, The Netherlands.

Henrion T., 2012c, Dynamische Simulation als Tool zur Verbesserung der Effizienz von Energiesystemen“, Doctoral Thesis ed. Vienna: Vienna University of Technolog, Austria

Paananen M., Henttonen T., 2009, Investigations of a Long-Distance 1000 MW Heat transport System with APROS Simulation Software, in 20th International Conference on Structural Mechanics in Reactor Technology, Espoo.

Schimon R., Henrion T., 2010, Methoden zur Verbesserung der Energieeffizienz mittels dynamischer Simulation am Beispiel eines integrierten Hüttenwerks, in ASIM Fachgruppentreffen, Ulm, Germany

Schimon R., 2011, Analyse des dynamischen Verhaltens gasförmiger Energieträger in multiverzweigten Rohrnetzwerken, Doctoral Thesis ed.: Vienna University of Technology, Austria

Schlagenhaufer M. M., 2011, Simulation des Dampf-Wasserkreislaufs und der Sicherheitssysteme eines High Performance Light Water Reactors, KIT Scientific Reports 7582.

Tuomaala M., 2007, Conceptual approach to process integration efficiency, Doctoral Dissertation ed. Helsinki: Helsinki University of Technology, Finland

APROS,2011, www.apros.fi, accessed 01/08/2012.