USE OF HYBRID MODELS IN METALLURGY WITHIN THE CONCEPT OF INDUSTRY 4.0

Ivo ŠPIČKA [1], Milan HEGER [1], Ondřej ZIMNÝ [1], Tomáš TYKVA [1,2], Dagmar ŠPIČKOVÁ [1]

[1]VSB - Technical University of Ostrava, Faculty of Metallurgy and Material Engineering, Ostrava, Czech Republic, EU

[2] Business Intelligence, Ltd., Ostrava, Czech Republic, EU

Abstract

Vision Industry 4.0 also includes a digital factory. Its core is based on the ideas of cyber-physics systems, models using all available modelling methods, artificial intelligence that includes fuzzy systems, artificial neural networks, expert systems, etc.

This concept is also beneficial to the metallurgical industry, where many systems have been developed, although not under the conception of Industry 4.0, in the past. The article aims to show how the ideas of Industry 4.0 can be used in the blast furnace batch preparation, i.e. in the agglomeration plant.

Keywords: Modelling, control, artificial intelligence, fuzzy logic, metallurgical industry

1. INTRODUCTION

It might be unnecessary to mention here the details of the Industry 4.0 vision. Gradually this vision, as well as its principles and objectives, comes to the attention of not only the professional community but also the laical one. So, for the sake of order, we summarize that this is a trend followed up by many developed countries for several years now; in Germany, where this vision was born, it is called Industrie 4.0, in the Czech Republic the name Industry 4.0 (further as I4.0) is used. Individual elements of this revolution, based on e.g. the Internet of things or the Industrial Internet (in OECD terminology), cyber-physical systems and artificial intelligence, will have real economic and social transformational impacts. Despite the fact that for many experts from practice as well as from academic sphere the information presented here will not be unknown, it is evident that the Czech Republic is not sufficiently prepared for these changes.

At the heart of the fourth industrial revolution there is the combination of the virtual cyber world and the world of physical reality that involves significant interactions of these systems with the whole society; it can be considered as the cyber-physical-social revolution. Therefore, in the Czech Republic the National Initiative Industry 4.0 has been established, which aims to mobilize key sectors and industry representatives to develop detailed action plans in the areas of political, economic and social life. It is also clear that the journey to the 4th Industrial Revolution will be specific in the Czech Republic (as well as in the other countries) and will differ from the original German initiative.

Technological assumptions and visions stress the deep, knowledge-based industrial integration, as the core of Industry 4.0 based on information and cyber technologies. Mass sharing and continuous communication supported by high-quality communication infrastructure (broadband internet) are expected. Other major industry technologies include big data, autonomous robots, sensors, cloud computing and data storages, as well as additive production, widespread reality and, last but not least, the whole discipline of cybernetics and artificial intelligence forming the intellectual and technological core of ongoing industrial revolution.

I4.0 does not seem to be a possible extravagance; it appears that its basic ideas are being applied in the number of industrial sectors. Originally its main feature was the use of automation and robotization - mainly in the automotive industry, resp. in the large-scale engineering production. The heavy industry sphere, i.e. the processing of raw materials into intermediate products and their subsequent processing in the mills, has seemed to be quite inappropriate for the significant I4.0 concept implementation. However, if we realize that the core area is the creation of cyber-physics models and their use, then the metallurgical industry is very suitable for this implementation.

In the following text a brief review of the processes that have been applied in the metallurgical industry, ranging from the processing of primary raw materials (agglomeration plant) through the production of pig iron and the subsequent steel refining to their processing in the form of castings or rolled products, will be made.

2. EXAMPLES OF THE APPLICATION VISION PROCESS I4.0

This chapter deals with the summary of the different types of models that are used for offline and online modelling, such as the cores of control algorithms, resp. as a part of expert systems. These models use a wide range of tools that are suitable for describing and creating of these models, having in mind a classical mathematical description of physical and chemical processes, through the models based on classical management theory, up to the latest trends using means of artificial intelligence, i.e. artificial neural networks, fuzzy logic or genetic algorithms.

Individual procedures complement each other and balance the weaknesses of one type of model with the strengths of the alternative description. Therefore, it can be argued that these are the hybrid models as described in earlier published articles, for example [1].

2.1. Problem I4.0 in the preparation of blast furnace batch

In the publication [3] the model of the agglomeration line, the state of the sintering line grates, the agglomeration mixture composition and the fuel dosage are solved. The model predicts the quality and amount of agglomerate; so, it serves to find the optimal dosing of the mixture, predicts the production, composition and costs for the sinter production, as well as the RDI (Reduction Degradation Index). As a problem has seemed to be the dosage of lime which has improved melting and sintering but has had a negative effect on the granulation of the mixture. At the same time the model can prepare the course of the sintering process and its temperature throughout the whole length of the sintering belt. Appropriate dosing of fuel and lime has resulted in the increase of agglomerate production by 7.5%. The control algorithm based on band mix stabilization has improved the productivity and quality.

A NIR device has been used for the continuous monitoring of the mixture chemical composition. Accuracy of measurement was suitable for humidity measurement but was not sufficient for the control of the coke and lime dosing. The moisture control system utilizing NIR data has stabilized and improved the device operation. Grate temperature measurement has provided valuable additional information about the thermal state of the sintering process. The model for the wind boxes temperature profile and for determining the position and temperature of the burning and sintering point has been developed. The model has been integrated into a process stabilization control system that has been very effective in stabilizing quality parameters within the target range, increasing productivity and reducing fuel dosing.

Table 1 represents overview of possible inputs/outputs of blending advisory tool to obtain representative data it is needed to work with at least 1000 data. These data must be related to each other, inputs and outputs, at each time point. Representativeness is given by the confusion matrix, which indicates the number of data that algorithm classified properly, has to reach values of over 97 %. The output values are to be classified according to the criteria of industrial plants that they consider; high, medium and low for any parameter. The values shown in **Figure 1** have been as an example, one can choose, for input and output, any parameter of the industrial sintering process.

Pot grate tests and analyses of operational data determined influences of special sinter mix components such as BF dust, mill scale and anthracite on process efficiency. A blending support tool was developed to find the optimal flux addition and to predict sinter production, composition and costs as well as the RDI index. Coke and limestone coating was shown to improve melting, but the granulability of coke and lime particles was poor.

An on-strand characterization method to monitor the flame front was developed and linked with variations in bed segregation. Pot tests revealed that coke breeze segregation during charging can create optimum holding time at high temperature and limestone segregation can increase productivity by 7.5 %. A charging control system based on a stabilization of the BTP profile across the strand improved productivity and quality. An NIR device was installed for the industrial online chemical analysis of sinter raw mix. The accuracy was reasonable for measuring moisture content, but not sufficient for control of coke and lime. A moisture control system was established based on the NIR data which stabilized and improved the plant operation. A pallet grate temperature measurement delivered valuable additional information about the thermal status of the sinter process. A prediction model was developed for the wind box temperature profile and the burn-through point position and temperature. The model is integrated into a process stabilization control system that was very effective in stabilizing the quality parameters inside the target ranges, increasing productivity and reducing fuel dosing.

Table 1 The overview of possible inputs/outputs for the analysis. In this case the data from 1500 measurements have been evaluated. Source: authors.

INPUTS	OUTPUTS
Coke breeze/ Anthracite	U.S. (production (ton/hour)
Return Fines	U.S. final cost
Basicity Index	RDI (reduction degradation index)
Total Fe content & cost	FeO
Fe (II)	Softening Temp.
Fe (III)	" Tumbler (> 6,3 mm)
Moisture	Average size (mm)
Total Fuel consume	
Speed at sinter strand	
Temp in last 3 boxes	
Gas in the ignition	

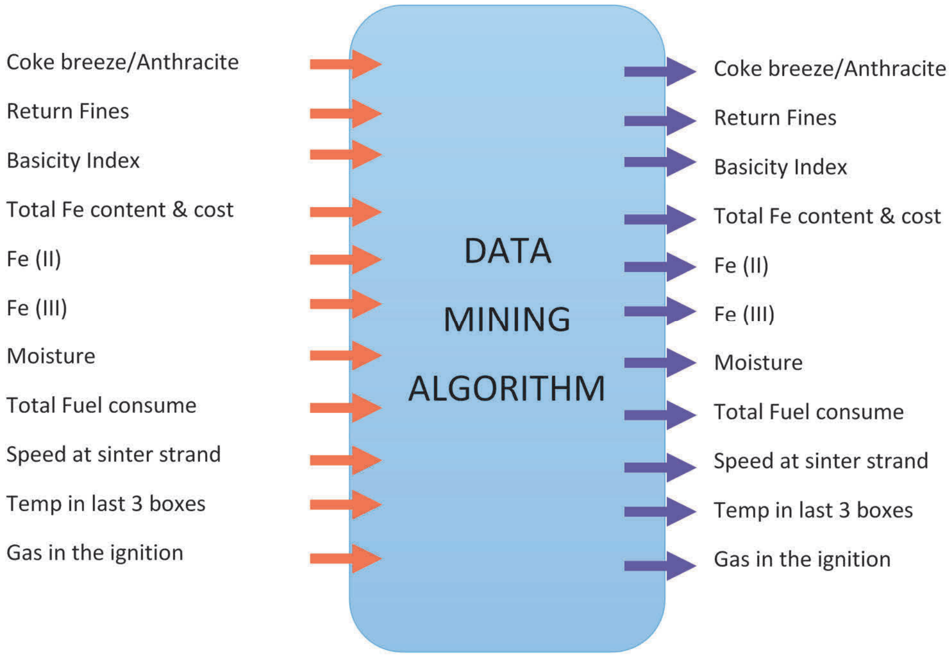

Figure 1 Example with a group of input/output

2.2. Further ways to make agglomeration more efficient

Another project to improve the agglomeration process is described in [3]. The optimum operation of blast furnaces, among other things, ensures the delivery of a high-quality agglomerate. More precise control of the sintering process is required in order to achieve high productivity, stable operation and high quality of the resulting agglomerate. The performance of the sintering line is essentially depending on two types of conditions:

- the selection of all set operating conditions (including agglomeration composition) and
- control of the sintering process.

The main benefits of the mentioned publication relate to:

- the relationship between the composition of the mixture and all parameters affecting productivity,
- the presentation of the Irsid Flame Front model as a research tool describing sintering mechanisms and predicting trends after operating conditions changes,
- the determination of the most important parameters when dosing the agglomeration mixture,
- the description of chemical reactions that occur during the sintering process,
- the typical fuel burning heat pattern along a height and
- the relationship between the operating conditions / temperatures / properties of the agglomerate.

By the author the major contribution has consisted in the development of the model of the heat field movement along the height and width of the sintering belt. The main result is the availability of these new measurements, both in terms of comparison with existing measurements and their sensitivity to the volontary modifications of operating conditions. The last part of the project concerns the use of advanced techniques for the development of models that allow timely forecasting of the agglomerate properties that could provide the control strategies to the operators. At the end of the research two models that have been evaluated by the off-line simulation were available.

2.3. Optimization of existing agglomeration control systems

The project described in the publication [4] five separate activities related to the production and quality of the agglomerate have been solved. Within the project all activities have focused on process management issues and have included the assessments and improvements of the existing systems, the development of new control strategies and of closed loop controllers. This project has led to the improved operational procedures and the better understanding of the input mechanisms required for the effective output and quality control. New control strategies that have been developed along with the established equipment have improved the management of agglomeration facilities involved in the project. Controlling of the sintering process transversely and longitudinally with respect to the sintering belt, permeability control, automation of the coke additives dosing and the application of advanced control strategies were considered as individual working modules being solved by various partners [7,8].

The techniques used to develop the supervision and overall sintering process control were both fuzzy logic tools and traditional types. The Matlab/Simulink environment has been used for modelling. Software applications to assist operators in making decisions have also been developed. New measuring techniques have also been introduced at the agglomeration facility. The most remarkable measurements are strand permeability measurements, mix cold permeability, BRP (burn-rising point - see figure below) along and across the strand, bed height, IR (infra red) analysis of the mix moisture, Ramsey Coil output to measure FeO content of the sintered bed and image analysis of the bed cross-section.

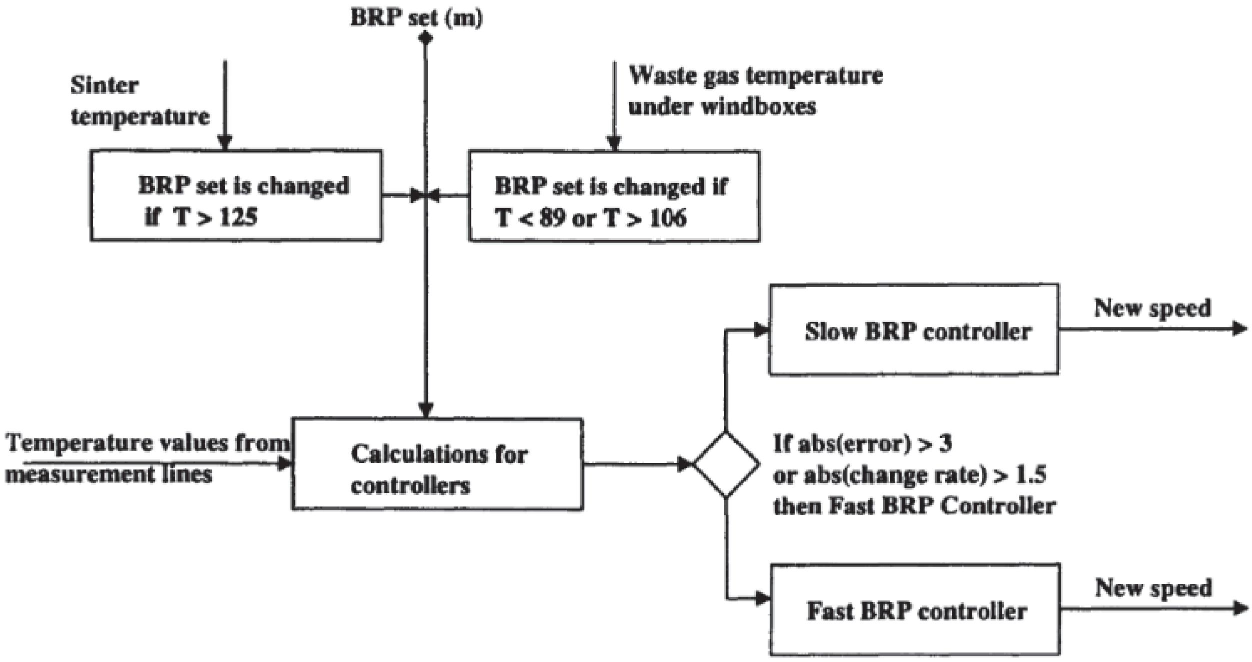

Figure 2 Fuzzy control sintering machine burn-through management. Source: [5]

3. CONCLUSION

The previous text shows some possible aspects of the use of modern process control tools in the field of batch preparation for blast furnaces, i.e. in agglomeration plant. This sector was chosen mainly because of the complex stabilization of the production process along with a long transport delay, and moreover, the agglomeration process is a complicated process in which different physical and chemical patterns act against each other. For this reason, models of physical procedures, chemical processes, thermodynamics and temperature fields etc. can be applied.

Similar procedures and hybrid models can be also found in other metallurgical plants, starting with blast furnaces, through steel processing or steel casting up to the subsequent heat treatment or rolling.

With the whole area being highly energy-demanding and at the same time leading to a high environmental burden, these systems control optimizing is very important [6].

ACKNOWLEDGEMENTS

This article was supported by the specific university researches No. SP2017/38 and No. SP2017/63.

REFERENCES

[1] HEGER, M., ŠPIČKA, I., BOGAR, M., STRÁŇAVOVÁ, M. and FRANZ, J. Simulation of Technological Processes Using Hybrid Technique Exploring Mathematical-Physical Models and Artificial Neural Networks. In: Metal 2011: 20th Aniversary International Conference on Metallurgy and Materials. Ostrava: TANGER, 2011, pp. 324-329.

[2] HAUCK, Thorsten. and RESEARCH FUND FOR COAL AND STEEL. New measurement and control techniques for total control in iron ore sinter plants (Tosico) final report [online]. Luxembourg: Publications Office of the European Union, 2014 [viewed 2018-05-09]. ISBN 978-92-79-38541-4. Available from: http://bookshop.europa.eu/en/new-measurement-and-control-techniques-for-total-control-in-iron-ore-sinter-plants-tosico--pbKINA26683/.

[3] LEROY, J. Improvement of the yield of strand and the regularity of sinter by control of charging conditions and monitoring of flame front propagation: final report. Luxembourg: Off. for Official Publ. of the European Communities, 2002. EUR, 20171. ISBN 978-92-894-3161-3.

[4] HEINÄNEN, K. Improved process control of a sinter plant: final report. Luxembourg: Office for Official Publications of the European Communities, 2003. ISBN 978-92-894-4769-0.

[5] LEIVISKÄ, Kauko. Industrial Applications of Soft Computing: Paper, Mineral and Metal Processing Industries. Berlin: Springer-Verlag, 2001. ISBN 978-3-7908-2488-9.

[6] MADILL, J. D. and EUROPEAN COMMISSION. The use of artificial intelligence to control secondary steelmaking practices: final report. Luxembourg: Off. for Off. Publ. of the Europ. Communities, 2002. ISBN 978-92-894-3170-5.

[7] POMYKALSKI, Przemysław, BAKALARCZYK, Sebastian and SAMOLEJOVA, Andrea. Benchmarking polish basic metal manufacturing companies. *Metalurgija*, 2014. vol. 53, no. 1, pp. 139-141.

[8] SANIUK, Anna, JASIULEWICZ-KACZMAREK, Malgorzata, SAMOLEJOVA, Andrea, SANIUK, Sebastian and LENORT, Radim. Environmental favourable foundries through maintenance activities. *Metalurgija*. 2015, vol 54, no. 4, pp. 725-728.