InsPyro’s Approach to Process Improvement in Metallurgy

Sander Arnout, Els Nagels

Introduction

InsPyro’s knowledge centered approach to process improvement relies on process modelling to understand an industrial reality. It acknowledges that, to successfully operate and improve a metallurgical process, two types of knowledge are required.

The first is experience, or the knowledge how to run a process. This is based on successful mixes or trials in the past, and often takes the form of gut feelings. It is crucial to have a number of people in the plant with this kind of experience, in order to keep the plant running even when a strange situation is observed in the middle of the night. However, as long as this knowledge stays in the heads of these people, it is difficult to verify and difficult to transfer.

The second type of process knowledge is the understanding of the physics or thermodynamics involved. It requires more effort to acquire this type of knowledge, as it needs to be established by experimental proof and modelling based on chemical or physical laws. In the long term, however, this knowledge enables a company to adapt its processes towards new boundary conditions, such as new resources or new environmental restrictions.

We are convinced that combining both types of knowledge allows to increase control over processes and speed up innovation. As the approaches can be quite different and different personalities are involved, it does take some effort to integrate both in a single operating framework. In one direction, it is important to translate process models to concepts and rules of thumb, which are understandable while simple or more complex, process models allow to structure discussions and training, make consistent decisions based on working hypotheses rather than on feelings, and discover opportunities for improvement.

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Process modelling is a crucial tool in order to translate the information from a process into knowledge, and to create a common framework for all involved to understand the mechanisms driving the process. Process data, experimental results, materials characterization provide valuable information, which is difficult to interpret without a reference frame. Additionally, the day-to-day experience from those who run the process needs to be integrated. Whether process data, experimental results, materials characterization provide valuable information, which is difficult to interpret without a reference frame. Additionally, the day-to-day experience from those who run the process needs to be integrated.
still based on scientific principles. In the other direction, it is important to listen to the operators daily problems, which are often indicators of important mechanisms in a furnace, even if those may seem hard to grab in a model at first.

In the following, we will discuss our thermodynamic approach to modelling process, and the advantages of having such a framework when solving problems or making operational decisions.

2 Modelling processes

To investigate the feasibility of a new metallurgical process, the first step is to understand the chemistry, which determines the yields to a large extent. Apart from studying literature, a thermodynamic process model to estimate yields, energy consumptions etc. as a function of process parameters is constructed for this purpose. When the yields, required temperatures and energy consumptions are known, a first feasibility assessment can be made. Only if this is positive, further work on experiments or reactor design will be initiated. Hence, thermodynamics are often the first topic to be investigated for a new process. With this in mind, it is remarkable that many existing processes are running without a model based on the underlying reactions. This may be due to the expectation that models need to be complicated and are often far from reality, whereas a simple model can already clarify several questions and trends, even if not fully quantitatively correct.

Simple equilibrium process models start from an input composition and result in a phase distribution of the elements at a specified temperature. The only requirement is a robust description of the phases in the process. Since thermodynamic calculation software has been developed, databases have been expanded and improved, and these now cover several of the main technologically important materials. Metallic alloys, oxide slags, sulphides and gas phases are covered to a large extent. For non-ferrous processes, it may take some additional effort to establish a solid framework. InsPyro has investigated some critical systems and has built its own data additions or databases, e.g. for lead recycling sulphide matte (see Arnout [1]).

Stepwise equilibrium process models still have a very limited complexity, but can answer questions on expected mechanisms and sequences in the process. The most evident strategy is to model a time aspect (see e.g. Kho [2], Swinbourne [3-4], Arnout [5]), but other mechanisms can also be investigated. For instance, the stepwise addition of a reductant can show the order of the elements to be reduced and the evolution of the slag composition (e.g. Soete [6]), whereas the stepwise addition of heat can detail melting or evaporation phenomena. An example for lead recycling can be seen in Figure 1, for which more details are available in Arnout [1]. Figure 1 gives the evolution of the amounts of lead bullion, slag and matte as a function of carbon additions. It can be seen that at low carbon additions the slag is reduced to form metallic lead which still has a high sulphur concentration. Only at sufficient reducing conditions a matte will be formed which also captures the sulphur. The decrease in the lead amount is mainly the sulphur changing phase from bullion to matte. Comparing this type of model to industrial measurements allows to decide if the reducing conditions (or carbon additions) are sufficient to remove the sulphur from the bullion. Similar analysis can be performed to verify the influence of iron and sodium in the process giving insight in the reaction sequences and process performance.

More complex models can be constructed to deviate from equilibrium, where sufficient evidence or indications for a certain hypothesis is available. The blast furnace is a typical example, in which the gas phase exits the process at low temperatures, without reaching equilibrium with the incoming charge in the shaft. At higher temperatures in the hearth, however, chemical conditions can be well predicted by equilibrium. A process model in its simplest form would consist of an equilibrium reactor for the hearth, and a heat exchanger without reactions between gas and condensed phases for the shaft (Figure 2). Obviously, more complex-

![Fig. 1: Example of stepwise equilibrium process model: addition of carbon to soda ash lead recycling](image_url)
ity would need to be added to cover raceway temperatures, burden descent speed, or furnace inefficiencies. To cover more complexity, however, takes a quickly increasing amount of effort, up to the use of very detailed techniques such as CFD or dedicated pilot studies. Therefore, we believe in getting the maximum out of relatively simple and understandable models, building a common framework for all those involved. This framework will also be needed if it is worthwhile to cover more complex issues remaining after the first steps.

In existing processes, a large advantage is the availability of process data. Compared to new processes, this allows for simpler checking and optimizing the process description without the need to run lab experiments. However, this advantage should not be overestimated, as the abundantly available information does not necessarily lead to knowledge. Because of the inevitable noise on production numbers and the similarity of operation conditions over time, mostly only a limited number of discrete working points can be distilled from the vast amount of data collected at a process facility. Therefore, the theoretical framework is still of great importance to be able to extrapolate outside known working areas and to define targeted industrial experiments.

Additionally, lab experiments can be very valuable. They should, however, not be confused with pilot or industrial scale experiments, and should be focused on very specific questions rather than on obtaining process information. Topics that can perfectly be studied in lab scale include:

- solubility of a certain element in slag,
- melting point of a raw material or by-product,
- reductive power of carbon materialism,
- maximum separation efficiency of a dross,
- evaporation losses upon holding at high T for certain time.

When needing more process information, exceptional sampling or measurements on the process may be used more effectively to clarify certain issues and test hypotheses. In the next section, we will describe how these results can have a larger impact when used in conjunction with process modelling, and vice versa.

3 Practical value of model based understanding

A first example case can be the build-up of hard accretions in an off-gas or boiler system. In such situations it is obvious that samples of the material need to be taken and investigated with appropriate characterization techniques such as XRF, XRD, SEM-EDX or EPMA. Using the process model, it is then possible to estimate the composition of the gases leaving the reactor at high temperature, information which is difficult if not impossible to obtain in practice. Additionally, carry-over of raw materials can be assumed. From the hot gases, solid and liquid phases are expected to precipitate as the temperature decreases. The results of these calculations indicate which phases are below or close to the melting point, and lead to a hypothesis for the strongly sintered accretion formation mechanism. With this assumed mechanism, finally a solution for the problem can be sought. Can the compounds be avoided by changing the process conditions (temperature, atmosphere, additions)? Or is the accretion inevitable with the current charge mix, but linked to certain raw materials or elements, which could be avoided by blending?

Another example is the feasibility of processing new raw materials in an existing plant. There, the main questions are which yield can be expected, and if these materials can be treated similarly as known materials or need special care. Again, first, a complete characterization is needed, not only in terms of composition but also clarifying the phase structure. Feeding the phases into a process model can then provide a number of differences in reactions or heat effects which need to be taken into account. Together with possible literature results, this provides a basis for assessing feasibility and designing industrial experiments with heavily reduced risks.

As a final example, we discuss a lead refining process. These processes have often been in use since decades if not since a century. Over the years they have been modified and improved with trial and error. Often, the basic working mechanism is known, but quantitative calculations have never been made. Using thermodynamic modelling, the theoretical maximum separation, optimal addition ratio, and ideal temperature can be calculated. Comparing this with actual results, in combination with characterization of the drosses – especially to make the difference between physical and chemical lead losses – opens up possibilities for either process performance improvement or for time-saving simplifications with minimal impact.

4 Knowledge transfer

In all cases, after establishing the process model, the gained knowledge has to be translated to an as wide as possible audience to gain maximal impact. This can be achieved in several ways, depending on the situation:

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Fig. 2: Simple blast furnace model
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- definition of simple rules of thumb based on known mechanisms for basic control,
- transfer of the actual process model for complex interactions,
- creation of explicit summaries, concepts, and hypotheses with clear drawings,
- include the model framework in the training program.

The main idea is to create tools which are more tangible than feelings, and can be validated over time. Also, these can provide a basis for decision making, as well as experimenting. Finally, explicit knowledge is easier to use in the education of operators and new employees.

5 Conclusion

InsPyro’s approach to process improvement in metallurgy relies on a continuous build-up of explicit process knowledge. A combination of process experience and thermodynamics leads to a comprehensive model, providing insight in the mechanisms controlling the metallurgical process. Once a model is in place, it can be used to explain the conditions leading to unwanted phenomena or to study new possible avenues of operation.

References


Dr.-Ing. Sander Arnout
Dr.-Ing. Els Nagels
Both:
InsPyro
Kapeldreef 60
3001 Heverlee
Belgium
Els.Nagels@inspyro.be
Sander.Arnout@inspyro.be