Model-Based Engineering of a Process Wash Plant using SysML: Case study of beneficiation processes in a phosphate industry

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Abstract

The fourth industrial revolution is being fostered in many countries to make more efficient and flexible plants. Industry 4.0 target is to get a more competitive industry. Under this framework, improvement of mineral processing requires knowledge of previous methods and current technology in order to develop new techniques and approaches. As phosphate deposition decreases, the need for new recovery methods keeps growing. From this perspective, the need for control and optimization of existing processes becomes a necessity. It also includes the development of equipment with more advanced digitized components. The objective of our work is to develop a model of a process plant using SysML. In this paper, we adopted a system engineering-based approach, which consists on modeling and formalizing knowledge collected in the field. A well understanding of phosphate value chain allows both driving and optimizing current processes. In addition, we used this approach to model information flows in which we integrated a specific equipment in the overall process. This model will follow a systems engineering approach. In this paper we present the development of the SysML model of a process plant (Wash plant of phosphate). The model includes the requirements as well as the structure, behaviour and activity

diagrams. A specific type of mining processes were studied with aim of giving feedback on the implementation of system modeling for mineral processing.

Keywords

Phosphate Beneficiation, Mineral Processing, Model Based Engineering, Control, SysML, Optimization.

1.Inroduction

Today we are in what is called the fourth industrial revolution (called Industry 4.0 or Connected Enterprise or Industrial Internet depending on the country or consortium) Kagermann and Wahlster (2013); vans and Anninziata (2012). This revolution is being integrated in many industries, such as mining companies that want to enhance their productivity by the digital transformation. Therefore, they require new strategic models for making their processes smarter, including full integration from sensors to planning. Industrial Internet tackles the challenges of the industry: increased functionality in products, more connectivity, high interdisciplinarity, more product/process complexity, very software intensive, digitalization, needs of simulation and visualization, comply with more demanding regulations, etc.
To achieve the new requirements traceability throughout the entire system lifecycle is needed, traceability from the initial requirements to the final physical product, Eigner et al. (2014); Stark (2011). The concept of Model Based Systems Engineering, Paredis (2012), provides methods to guide the cross-disciplinary, virtual product development process and to achieve the required traceability.
The concept of Model Based Systems Engineering, Paredis (2012), provides methods to guide the cross-disciplinary, virtual product development process and to achieve the required traceability. Model Based Systems Engineering (MBSE) is a multi-disciplinary engineering paradigm propagating the use of models instead of documents to support analysis, specification, design and verification of the system being developed, Gilz (2014).
Using models instead of documents, a new discipline-neutral view of the system specification is created. The resulting system model helps to well understand and to overview the complexity of the developed system. System models are created by application of the Systems Modelling Language (SysML). The Systems Modeling Language (SysML), Friedenthal et al. (2014), is a general-purpose graphical modeling language for specifying, analyzing, designing, and verifying complex systems that may include hardware, software, information, personnel, procedures, and facilities. In particular, the language provides graphical representations with a semantic foundation for modeling system requirements, behavior, structure, and parametrics, which is used to integrate with other engineering analysis models.
The objective of our work is to develop a model of a process plant of phosphate using SysML.
This model will follow a systems engineering approach, starting from the requirements.
In this paper we present the development of the SysML model of a process plant of phosphate (the beneficiation activity of phosphate). The model includes the requirements as well as the structure, behaviour and activity diagrams. In this work a model transformation from SysML to a process simulation language (in this case Excel) is presented. This allows for the analysis and the control of the process in the design and developement phases. The results of the simulation will be fed back to the SysML model for further use.

2. Wash Plant Description

Phosphate ore is a nonrenewable resource, but it is essential for agriculture, as a raw material for fertilizers. Phosphates cannot be really substituted and recycled. Feeding the ever-growing world's population is becoming a challenge and phosphate needs are always bigger (Sis and Chander, 2003).
Siliceous phosphate ores are generally beneficiated by a two-stage flotation technique using amine and fatty acids for silica based gangue and phosphates respectively. The beneficiation of phosphate ores containing carbonaceous gangue is complicated because of the similarities in the chemical behavior of the minerals present (Somasundaran 1975)

Preparation of phosphate starts with the activity of mining, usually by using draglines, the ore is then made into a slurry, and transported to wash plant by pipelines. There are different equipment for washing; trommels, log washers, and sandwich screens (Lawver et al.1978)
The mission of the wash plant is to wet enrich phosphate from the extraction site. Enrichment consists in ridding the ore of its poorest particle size fractions, namely grains larger than 3150/2500 µm and smaller than 40 µm. This enrichment is made using specific treatments to raise its BPL (Bone Phosphate of Lime) content and prepare it for

chemical treatment. Figure 1 shows the simplified flowsheet of the process of phosphate wash plant. The wash plant has three main sections:
- A section of phosphates washing, which consists of a scrubbing, screening and physical classification of the product (according to the size of the cuts);
- A flotation section for enriching of poor slices;
- A sterile sludge storage and water recovery section.

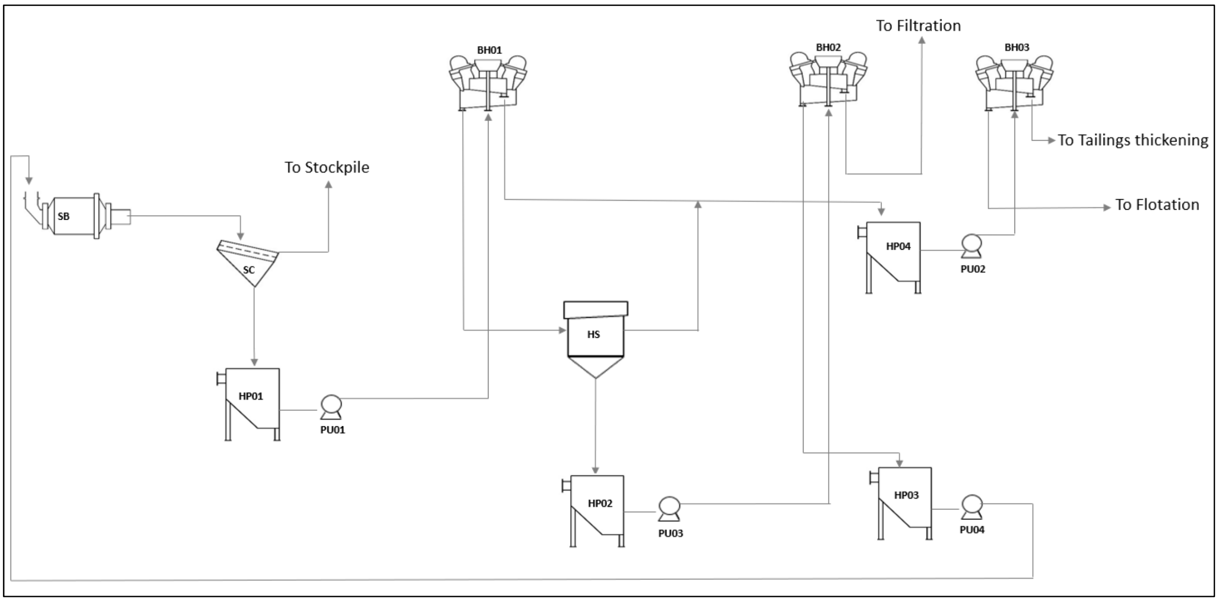

Figure 1:Simple Flowsheet of Phosphate Wash plant

3. SysML Model of the wash plant

We have followed the simplified MBSE method proposed by Friedenthal et al. (2014), to develop the model of the wash plant, which can be applied systematically if we follow a traditional functional analysis method. This method allows to specify the structure and functions of the plant and analyze its performance. SysML provides modelling diagrams and elements to capture the three.

#	Id	Name	Text
1	1	Scrubbing operation	Requirements due to scrubber equipement
2	1.1	Solid rate	Solid rate at the outlet of the scrubber must be 50%
3	1.2	Mixing & attrition	The scrubber must ensure mixing and attrition between the phosphate particles in order to free them from clay limestones
4	2	Screening operation	Requirements due to screen equipement
5	2.1	Screening dimension	Eliminate particles greater than X µm
6	2.2	Irrigation water	The flow of irrigation water must ensure the recovery of the grains attached with the sterile

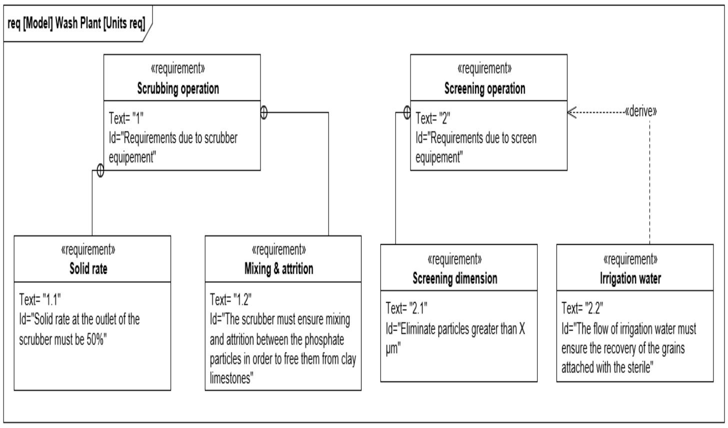

Figure 2:Different diagrams allow to capture the requirements of the Wash Plant in SysML

Wash Plant Requirements: Foremost the plant requirement were established to capture the mission of the plant. Requirements are commonly used to formalize system prerequisites, resulting in features or conditions that should be satisfied by the System, depending on any priorities associated with the requirements. Requirements engineering is an essential part of systems engineering. Indeed, understanding the need facilitates designing the solution. Every requirement should be S.M.A.R. T: Specific, Measurable, Achievable, Relevant and Traceable (White book). One of the main advantages of SysML is that it allows to model the requirements of the system and derive from them the design, maintaining traceability. Different representations are possible: tabular, diagram, matrixes, to convey their organization, as shown in Figure 2.

Behaviour Modeling of the Wash Plant: The refinement of the requirements results in the definition of the plant behaviour. Elaborating the overall behavior is the first step, it is refined in paralel to the design of the wash plant structure, where funtions in the behaviour are allocated. Figure 3 indicates the fundamental functions that occur in the wash plant as SysML activities.

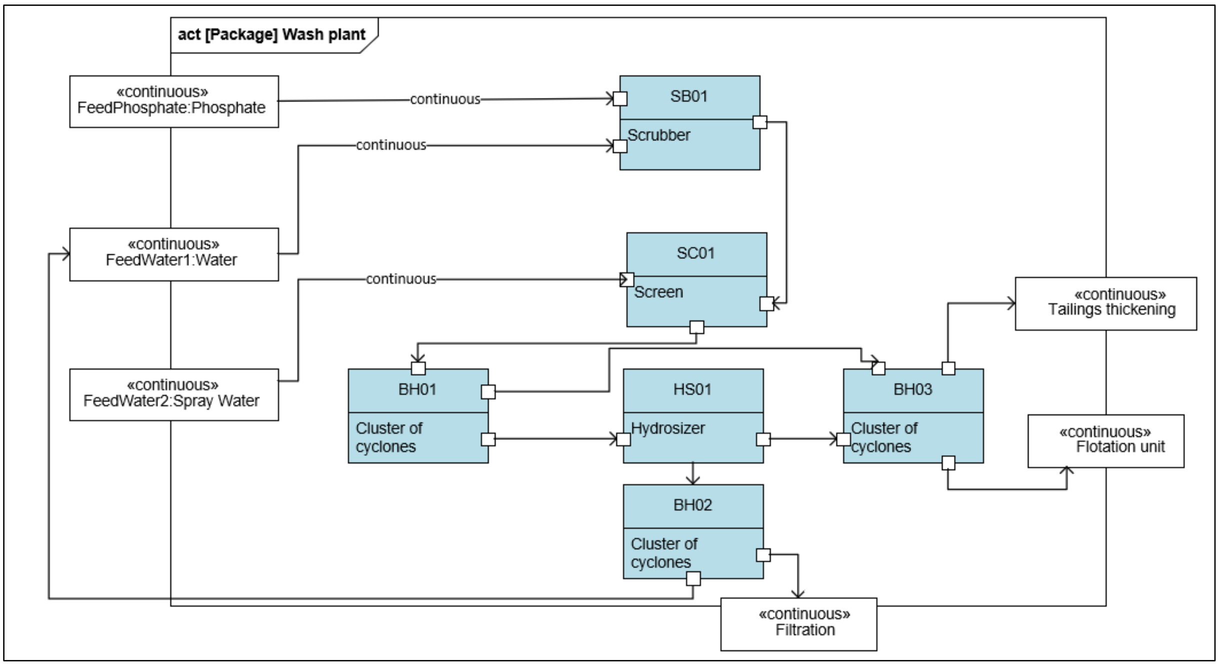

Figure 3:Overall activity diagram of the wash Plant

Structure Modeling of the Wash Plant: The wash plant is modelled as an overarching block that contains blocks. In SysML structure is modeled with blocks as main elements. we discuss the system implementation. We adopt a decomposition approach of the system into subsystems to model its configuration. In this decomposition, we must begin by defining the system on which we will work. Then we must go into the granularity of the process.

4. SysML Model for Excel simulation

Excel simulation models allow the unification of the information in a single model, it allows the analysis of properties and performance through simulation. In this simulation, the integration of advantages of MBSE allows a well understanding of the wash plant, this would optimize the engineering processes and the collaboration between the different engineering departments in the process.

The preparation of the Excel material balance was made from the particle size distribution obtained at the laboratory scale. The results found make it possible to calculate the mass flow rate of solid (ton/h), the water flow (m^3/h), the solid rate (%), the density (ton/m^3) and the volume flow rate of the pulp (m^3 / h) at the output of each equipment. (Figure 4)

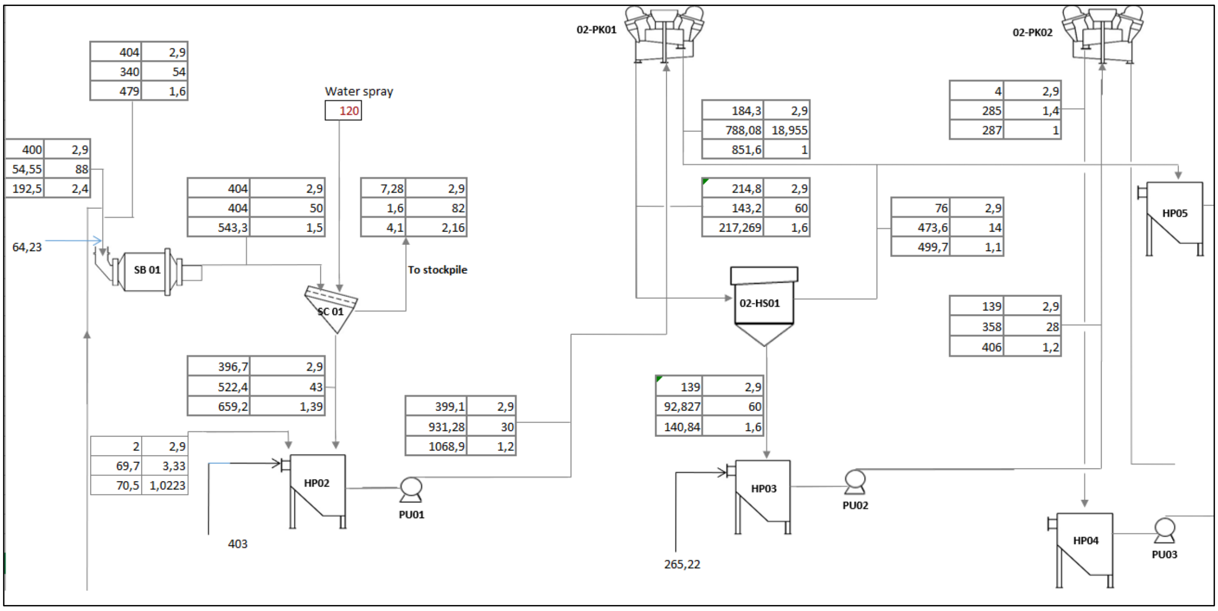

Figure 4:Generation of an Excel simulation based on material balance

5. Conclusions

Model-Based Engineering is necessary for the engineering of the industry 4.0 systems. In this paper we have developed a SysML model of a process Wash Plant of phosphates. This model can be used for the design of the plant and for all the engineering activities through the plant life cycle. Our adopted approach summarizes various modeling tools working with a well-known industrial partner in Phosphate valorization. Using these approaches, we will guarantee efficient beneficiation processes by optimizing their operating parameters. Simulation through Excel allows the analysis of properties and performance of each equipment.
In future works, we will investigate the possibility to generate Excel simulation from any SysML model by defining a map from SysML to Excel elements.

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