Alternative Models for the Calculation of CAPEX and OPEX for a Hydrometallurgical Plant

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In the case of feasibility assessments or feasibility studies, an important point of discussion is often how to calculate the capital (CAPEX) and operating expenditure (OPEX) of a plant. Generally, there is also the request to know how the CAPEX varies when the size of the plant is increased. Nowadays, many databases give an indication of specific equipment costs in relation to the production rate. These data are based on cost information from equipment suppliers and have to be continuously updated by the owner of the database. The approach presented here is a model which allows sizing of process equipment, for example a leach tank, based on process data in combination with the calculation of mechanical properties. Furthermore, it calculates the CAPEX based on construction material cost and adequate machining surcharges. Thus, a single cost model for a leach tank is adequate for both copper and other hydrometallurgical plants and stays valid with changing construction material prices.

To summarize, the advantage of this model is the more versatile approach and thus the flexibility due to the inclusion of design aspects, process and mechanical engineering aspects and an updatable database. The database, which is in regard to material cost and is the basis for the cost estimation, is easily updatable from commonly accessible data. This model thus approaches the procedures of an engineering company when designing a plant and executing a cost calculation.

INTRODUCTION

Hydrometallurgy nowadays plays an important role in processing of primary and secondary resources. In copper metallurgy, hydrometallurgy accounts for roughly 20 % of worldwide primary production, especially in the case of oxide or low copper-containing ores. Zinc smelters changed their method of production from a pyrometallurgical-dominated concept decades ago to mainly hydrometallurgical routes today. Gold production processes using leaching, especially, have a long history without any development which would not be competitive if not based on hydrometallurgical concepts (Pawlek, 1983; Winnacker-Küchler, 2006).

Apart from the treatment of ores, leaching is becoming increasingly important in the field of recycling. The utilization of secondary resources, such as tailings, slags and dusts, is very often only possible by hydrometallurgical means (Rumpold & Antrekowitsch, 2014). This is due to the fact that the concentrations of valuable elements are so low and effective beneficiation methods are not available, making pyrometallurgical processing impossible from the economic point of view. The opportunity to recover more than only one metal simultaneously makes hydrometallurgy favourable for many cases.

Examples of such developments can be found in the treatment of copper tailings, lead-zinc tailings, platinum recycling or the treatment of special dusts (Steinlechner & Antrekowitsch, 2011, 2013).

The today´s addiction to the development of future processes with low energy consumption also enhances interest in hydrometallurgy. Combined with refining methods such as solvent extraction, it offers a wide field of application, gaining increasing importance in the field of metal production in the future. However, there is the necessity to plan, adapt and build such facilities in an optimized way to be competitive in the market and to utilize the positive aspects of hydrometallurgy in an advantageous way.

In scoping and feasibility studies executed in the past, it was determined that there is a deficiency of tools to estimate the capital expenditure (CAPEX) and operating expenditure (OPEX) of the envisaged plant or plant section. Existing tools give basic price indications for standard equipment. As soon as the construction material or the price of the main construction material changes, the tools are invalid and have to be replaced.

The intention of this investigation was therefore to build more flexible models, allowing the estimates of CAPEX and as well OPEX which are more versatile and easier to adapt by the user.

One of the first models established using this concept is that describing a leach plant. This paper describes the idea and structure, and thus the basis of this model, namely the leach section of a hydrometallurgical plant.

STRUCTURE OF THE MODEL

The model follows the general principles of plant engineering, as shown in Figure 1: the process engineering, followed by the mechanical engineering and the cost calculation.

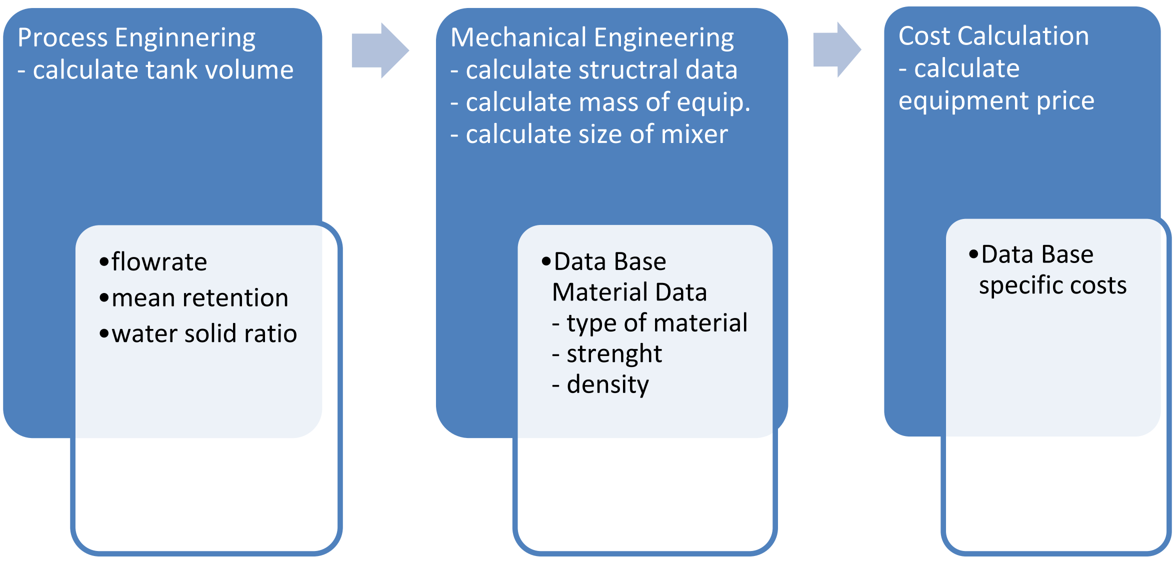

Figure 1. Scheme of the proposed model.

As shown in Figure 2, the model is divided into four different "chapters" or sub-models: the process model, the mechanical engineering model, the cost model and the database.
The first part of this model sizes the process equipment or part of process plant according to the process parameters. For the case of a leach tank or leach tank cascade, this would be the retention time

and the mass flows, which result in the required equipment size—for a leach tank or leach tank cascade, this is the required tank volume.

The second part of the model is the mechanical engineering model. This model selects the material in relation to the process conditions. This starts with specifications, such as acid, chlorine content, etc., and helps the user to select the adequate steel and/or coating material. Taking the strength of the selected material into account, the model calculates the minimum mechanical design parameters.

The third part connects the data from the previous two models and calculates the CAPEX and OPEX from the material and utility costs in the database.

The database contains the relevant material data, material cost and utility costs. This common database includes the costs for different types of construction steel, coating materials and the cost for the relevant utilities (e.g., power, reagents, etc.). Since all the models relate to the database, just one database has to be updated with costs to keep the model up to date.

Sub-model process engineering	Sub-model mechanical engineering	Sub-model cost calculation
Input from User: - mass of solids to be treated - water to solid ratio - density solids	Input from sub-model Process - size of tank - pulp volume per tank - height of pulp in tank - density of pulp	Input - data from process engineering model - data from mechanical engineering model - cost factors from data base
Variables: - height to diameter ratio - number of tanks in line	Variables: - construction material - tank lining - tank coating	
Output: - pulp flowrate - size of tank - pulp volume per tank - height of pulp in tank - density of pulp	Output: - wall thickness of tank - surface area of tank - weights of materials - weight of content - size of mixer	Output: - cost of equipment - cost for surface treatment - CAPEX - OPEX

Figure 2. Scheme of data flow in model.

Sub-Model Process

The step preceding the plant design is a set of metallurgical testwork. The result is generally the water-to-solid ratio and the mean residence time. These data, plus the requested tons of solid to be treated, are the inputs to the first sub-model. The model calculates the pulp volume from the tons of solid and the water-to-solid ratio. The next step is the calculation of the theoretical tank volume based on mean residence time and pulp flow. The following, generally known Equations 1 and 2 form the basis:

$$V = \frac{M * w * (\rho_{ore} - 1)}{\rho_{ore} * (\rho_{pulp} - 1)} \qquad [1]$$

M	mass of pulp (t)	ρ_{ore}	relative density of ore	w	volume of 1 ton of liquid phase (m^3)
V	volume of pulp (m^3)	ρ_{pulp}	relative density of pulp		

$$V = \frac{dV}{dt} * t_{retention}$$

[2]

V	theoretical tank volume	$\frac{dV}{dt}$	pulp flowrate
$t_{retention}$	mean retention time		

As a leach tank cascade under continuous operation is discussed, the number of vessels has an influence on the actual number and volume of vessels compared with the theoretical calculated tank volume. This is based on the residence time distribution of a particle in a leach tank. One tank has a wide residence time distribution; use of a higher number of tanks approaches the residence time distribution of a plug-flow reactor. Therefore, the theoretical volume is corrected with a correction factor for the expected number of tanks to give the actual tank volume.

Sub-Model Mechanical Engineering

In this sub-model, the mechanical design parameters are calculated. In case of a leach tank, the most important parameter is the necessary wall thickness for the leach tank, described by Equation 3. The wall thickness depends on the material in use, the size of the tank (height and diameter) and the amount of pulp in the tank. The hydrostatic pressure created by the pulp exerts a force on the walls of the tank. Thus, the maximum force on the walls is the hydrostatic pressure at the bottom of the tank, described by Equation 4. Therefore, the following equations are necessary for calculating the wall thickness:

$$T = \frac{D_a * p_e}{2\frac{K}{S}v + p_e} + c_1 + c_2$$

[3]

$$p_e = h * \rho * g$$

[4]

D_a	outer diameter of tank	
p_e	maximum pressure in vessel/hydrostatic pressure	
K	strength parameter of material	(e.g., 320 N/mm^2 for steel)
S	safety factor	1.5
c_1	supplement for shortfall in wall thickness	0.4 mm
c_2	supplement for wear	(e.g., 5 mm for high wear)
v	load factor weld seam	1
T	requested wall thickness	
h	maximum height of pulp in tank	
ρ	pulp density	

A key number used to estimate the agitation power consumption for mechanical agitated tanks is 0.098 kW per ton of solids in suspension. This key number is used to size the mixer.

Sub-Model Cost Calculation

The cost calculation is based on the data received from the preceding models. Tank volume (thus size of tank) and the wall thickness of the tank give the mass of material (e.g., steel) required for the tank multiplied by the current material price and a fabrication factor (F), described by Equation 5, gives the basic price for a tank.

$$F = \frac{K_M + \sum K_F}{K_M}$$

[5]

K_M = total cost of material, K_F = fabrication cost (e.g., cutting and welding of steel plates)

This makes the estimation of the fabrication cost for a steel tank easier because the welding cost is related to the length of the welding seam.

Additionally, the cost of different surface treatments of the tank is included, as there are paint coatings and/or rubber linings that can be added, and thus, a price is added according to the relevant surface area of the tank and the specific coating cost.

The step from equipment cost to plant cost is achieved by adding costs for assembly, concrete foundation, electrical, instrumentation and engineering, building and structural. These are added with factors which are generally accepted for basic cost calculations. Since this is regarded as a standard procedure (Ruhmer, 1991), it is not explained in detail, but still part of the cost calculation model.

The OPEX cost of a leach cascade is related to power consumption of the mixers. Therefore, these costs are calculated for the installed power of the mixers in the sub-model mechanical engineering and the specific price for electricity.

Sub-Model Data Base

The database summarizes the data used in the different sub-models. These data tables are adaptable and expandable by the user. These tables contain the following listed information:

- different construction materials and the related physical strength of the material and the material cost used in the mechanical engineering and cost calculation model;
- the fabrication factor for different materials and the cost for welding;
- different coating materials and the related costs used in the cost calculation model.

An Outlook for Further Use and Development

The basic structure of the model can be seen as a general approach to build up models for different metallurgical plants or plant sections.

The presented specific model, because it calculates and specifies tanks, can be easily altered in further models for hydrometallurgy based on "tanks" or "tank cascades". After the decision on the necessary volume is made, the subsequent steps involving tank structure, the mechanical engineering and cost calculation are the same. Thus, we have already used the structure of this model to develop a model for a flotation plant and a solvent-extraction plant. This model was also the basis to quickly build a model for a sulphuric acid tank farm.

Advantages and Disadvantages of the Model

The promoted model(s) show various advantages, but of course some disadvantages should not be hidden.

The advantage of this model is the versatility. It can be easily adapted by the user to a new market situation. Only the current prices for the selected raw construction material have to be added or updated. It presents a better specification document which is a more appropriate document for the subsequent detailed engineering. The versatility of the model for different metallurgical processes also has to be seen as an advantage.

A disadvantage of the model is that such a detailed specification document is produced that the user can be misled into concluding that all engineering is done and he can directly order the equipment. The user can also be given the impression that the model is so accurate that it forms the basis for a bankable feasibility study. Therefore, it has to be stated and kept in mind, not to fall into the trap of these disadvantages—that the model produces figures of the accuracy needed in scoping and prefeasibility stages and that it makes engineering of a plant unnecessary.

REFERENCE OF USE OF MODEL

The model was used in different projects and is currently being used in a copper leaching project. In a study on PGM recycling of catalyst (Steinlechner & Antrekowitsch, 2013), it demonstrated a difference of 10% for the CAPEX compared with the offer of the relevant engineering company. Presently, the model is being used to estimate the cost for a copper leaching plant, where the model has to compete with the CAPEX estimation of the engineering company involved. Results are not yet available at the time of publication.

CONCLUSIONS

The importance of hydrometallurgy for future metal production goes hand-in-hand with the necessity of developing effective engineering models. The presented calculation model follows the accepted steps of engineering a plant: the process engineering, the mechanical engineering and the cost calculation. As the model allows variation of important parameters at the different steps, it is more flexible and more accurate than tools presently in use. It takes the material strengths of different construction materials into account and thus allows a comparison of cost effects when selecting a higher grade of construction material for the equipment.

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