SCALE-UP OF A DTM CRYSTALLIZER

Agata Małysiak a, Piotr M. Synowiec a,b

a Silesian University of Technology, Department of Chemical and Process Engineering, ul. ks.M. Strzody 7, 44-100 Gliwice, Poland; b Fertilizer Research Institute, Branch Gliwice, ul. Sowińskiego 11, 44-101 Gliwice, Poland

Abstract. The scale-up problem of crystallization process is a difficult task. The commonly used in mixing tanks criteria of e.g. constant unit power input or tip speed together with geometrical similarity fail. In this paper the relaxation of geometrical similarity of crystallizers by considering different width of gap between the draft tube and the propeller was presented. The Computational Fluid Dynamics was used to investigate four volumes of the tank. The primary circulation time (PCT) was chosen as the representative parameter to describe obtained results. In each scale the optimal width of gap, in which the value of PCT was the smallest, was determined. From kinetic point of view PCT should not change with scale or even it should decrease. Having that in mind the other ways to decrease the PCT value by relaxing geometrical similarity should be investigated.

Keywords: scale-up, DTM crystallizer, fluid dynamics, CFD

1. INTRODUCTION

Crystallization from solution is a very important technology in major sectors of the chemical and other related industries. Produced crystals in various sizes: from few tens of nanometers to several millimeters or more, both as discrete particles and as structured agglomerates. The examples of crystalline products include: common salt, catalysts, fertilizers, pharmaceuticals, pigments etc [1]. Thus the tonnage of such particulate products is enormous and as a consequence the industrial plants become larger and more efficient. Despite the increasing demand the process of crystallization is still relatively not well explored. Especially difficult part of dealing with this process is scale-up. It is not as straightforward as in other unit operations.

While analyzing the scale-up problem of crystallization from solution it is necessary to decide which parameters describing fluid dynamics in the apparatus are the most important. Apart from the unit power input (energy dissipation) influencing nucleation conditions, crystal growth, pumping capacity and crystal size distribution, there is another important parameter, i.e. the primary circulation time (PCT), directly connected to the intensity of circulation \( I_C = 1/\tau_C \) and macro-mixing conditions [2]. The PCT physically may be expressed as the average time for a fluid-element to make a complete circuit around the crystallizer. It is the value which influences the mixing-frequency of crystals with supersaturated solution and transport time of superheated feed to zone of supersaturation generation.

From authors experience and literature data it was noticed that with increasing apparatus volume the primary circulation time becomes longer [2, 3]. This phenomenon is mainly a result of lengthening suspension circulation loop as well as less efficient mixing in a full scale crystallizer as a consequence of scale-up procedure.
2. THEORETICAL BACKGROUND

The primary circulation time \( \tau_c \) is described by the relation:

\[
\tau_c \propto \frac{V_a}{V_p} \left( \frac{D}{d} \right)^3 n^{-1}
\]

(1)

where \( V_a \propto D^3 \) is a volume of an apparatus, \( V_p \propto n^3 d^3 \) is a pumping capacity, \( D \) is a diameter of the crystallizer, \( d \) is an impeller diameter and \( n \) is a propeller’s number of revolutions.

In the physical crystallization executed by cooling, evaporation or vacuum where suspension is circulated, commonly used criterion of scaling up is constant unit power input \( (\varepsilon) \) or, less frequently, tip speed of propeller \( (u_t) \) if apparatus with stirrer is considered [4-6].

From the fluid-dynamics point of view, when geometrical similarity is preserved the relation (1) is simplified to \( \tau_c \propto n^{-1} \). Depending on scale-up criterion the change of primary circulation time may be expressed as:

For \( \varepsilon \) - const

\[
\tau_{c,\text{in}} \propto \left( \frac{d_{\text{in}}}{d_{\text{lab}}} \right)^{2/3} \tau_{c,\text{lab}}
\]

(2)

For \( u_t \) - const

\[
\tau_{c,\text{in}} \propto \left( \frac{d_{\text{in}}}{d_{\text{lab}}} \right) \tau_{c,\text{lab}}
\]

(3)

From equations (2) and (3) one can notice, that the increase in scale while preserving geometrical similarity will increase the value of PCT. This effect is unfavorable. Other scale-up criteria applied together with geometrical similarity will extremely affect unit power input changes. This fact eliminates them from practical use.

From kinetic point of view the PCT should not change with scale or even it should decrease [7]. Implementing standard scale-up procedure (full geometrical similarity and constant tip speed or constant unit power input) results in considerable increase in PCT. To ensure proper performance of a crystallizer those two tendencies should be equalize - PCT should be as short as possible.

There is no simple scale-up rule. In addition commonly applied geometrical similarity is not a recommended method to deal with this problem. One of the method is to partially withdraw full geometrical similarity to seek for less fluid-dynamic efficient apparatus in a lab scale and more fluid-dynamics efficient in a full scale. In this way one may partially equalize PCT in both scales [8].

3. MODELING

The modeled crystallizer was of the DTM (Draft Tube Magma) type and is presented in Fig. 1. The centrally positioned stator was of the height of 0.05 m and the base diameter equal to 0.08 m in the lab scale, respectively. The propeller was of the Lightnin A100 type commonly used in industrial scale crystallizers. Distance between the agitator and the bottom of the vessel was \( h_m = 0.064 \) m in the smallest scale and the ratio of cylindrical part of the draft tube diameter to the diameter of the apparatus - \( d_{tr}/D_f = 0.33 \). The ratio of the stirrer diameter to the crystallizer diameter - \( d/d_f = 0.26 \), and the gap between draft tube and apparatus bottom - \( h_{tr}/d_{tr} = 0.43 \). Four volumes \( i.e.: 11 \cdot 10^{-3}; 88 \cdot 10^{-3}; 1.4; \) and 11 m\(^3\) were investigated. Dimensions in the last three of the above mentioned volumes were enlarged proportionally 2, 5 and 10 times. As a working medium a solution of \((\text{NH}_4)_2\text{SO}_4\) was used.

The crystallizer geometry was drawn in Gambit and the computations were performed using Fluent commercial package. The standard k-\( \varepsilon \) method of turbulence modeling was
applied because of its simplicity, low computational power requirements and satisfying accuracy of results.

![Scheme of industrial DTM crystallizer.](image)

Figure 1. Scheme of industrial DTM crystallizer.

4. RESULTS AND DISCUSSION

From fluid dynamics point of view when geometrical similarity is preserved better scale-up criterion is constant unit power input. But this criterion does not allow to achieve satisfying process conditions - the maximum linear scale-up factor is equal to 5 [8]. In Fig. 2 the comparison of “classic” scale-up criteria ($u_t=\text{const}$, $\varepsilon=\text{const}$) and preserving constant gap between draft tube and propeller is presented. The withdrawal of geometrical similarity resulted in the slowest increase value of primary circulation time in industrial scale in comparison to laboratory scale. The observed tendency allow to assume that there is an optimal width of gap between draft tube and propeller for each apparatus scale when the PCT value would be the smallest.

![Graph showing dependence of relative primary circulation time on scale up factor under various scale up criteria.](image)

Figure 2. Dependence of relative primary circulation time on scale up factor under various scale up criteria: ♦ $\varepsilon=\text{const}$ and $d_{\text{d}}/d_{\text{m}}=\text{const}$, ■ $u_t=\text{const}$ and $d_{\text{d}}/d_{\text{m}}=\text{const}$, ▲ $\varepsilon=\text{const}$ and $(d_{\text{d}}-d_{\text{m}})=\text{const}$.

The relaxation of geometrical similarity was considered as change in the width of a gap between propeller blade and draft tube wall instead of a constant $d_{\text{d}}/d$ ratio. The minimal
Concerned value was consistent with constant width of gap and the maximal value was equal to the gap size resulting from full geometrical similarity. This parameter was checked for linear scale-up factor equal to 2, 5 and 10. The results of computations are presented in Fig. 3, in which the primary circulation time as a function of the width of gap between propeller and draft tube is shown. In each scale there exist a point in which the PCT value is the shortest. The change in primary circulation time is relatively small yet meaningful and thus the optimization of the gap width can influence the overall performance of the crystallizer. Since no unique and comprehensive description of crystallization process is known every step taken in the right direction is important. Further relaxation of geometrical similarity should be investigated in order to minimise the increase of PCT value in such a way, that it will be close to in both industrial and laboratory scale in order to satisfy kinetic requirements of the process.

![Figure 3. Dependence of relative primary circulation time on width of gap between propeller and draft tube for various scales: ♦ $d_{in}/d_{lab} = 2$, ■ $d_{in}/d_{lab} = 5$, ▲ $d_{in}/d_{lab} = 10$.](image)

5. CONCLUSIONS

The performed calculations allow to state the following conclusions:
- The criterion of geometric similarity does not work in scaling-up of crystallization processes.
- The increasing of the primary circulation time during scaling-up procedure can be partially minimized by avoiding geometrical similarity.
- The gap width between the draft tube and the propeller blades strongly affects the PCT value.
- The relaxation of geometrical similarity can be done e.g. by individually finding in each scale the optimum width of gap between the draft tube and the propeller.
- The optimal gap width enables to obtain the smallest PCT value. The further numerical simulations regarding decrease of PCT value will be performed.
6. NOMENCLATURE

\( D \) [m] apparatus diameter
\( D_1 \) [m] apparatus bottom diameter
\( d \) [m] impeller diameter
\( d_{lab} \) [m] lab scale impeller diameter
\( d_{dt} \) [m] draft tube diameter
\( d_{in} \) [m] large scale impeller diameter
\( h_m \) [m] distance between stirrer and apparatus bottom
\( h_r \) [m] distance between draft tube inlet and apparatus bottom
\( I_C \) [s\(^{-1}\)] circulation intensity
\( u_t \) [m/s] tip speed
\( V_a \) [m\(^3\)] volume of apparatus
\( V_p \) [m\(^3\)/s] pumping capacity
\( \varepsilon \) [W/kg] unit power input, energy dissipation rate
\( \tau_c \) [s] primary circulation time
\( \tau_{c,lab} \) [s] lab scale primary circulation
\( \tau_{c,in} \) [s] large scale primary circulation time

7. REFERENCES


