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Experimental hydrocyclone roping models

Kari Heiskanen*

Department of Material Science, Helsinki University of Technology, PO Box 6200, Vuormiehentie 2a, 02015 Espoo, Finland

Abstract

Hydrocyclone roping has not been studied and modeled in true grinding circuits. The paper discusses experiments made with a pilot size closed grinding circuit treating 0.5–1.0 t/h crystalline limestone. The equations found in the literature did not all describe roping very well. The best results were obtained by predicting the underflow solids volume flow. Equations based on underflow particle size did not give good results. Roping had mixed effects on the performance of the grinding circuit depending upon how it was obtained. Experiments were made by initiating roping through increasing mill feed rate or decreasing cyclone apex diameter. Varying responses are discussed in the paper. The estimation given in literature, that a circuit has the optimal operational point close to roping, was also confirmed for this set-up.

Keywords: Hydrocyclone roping; Grinding circuit; Crystalline limestone

1. Introduction

A roping is a phenomenon still not well understood. It has important ramifications in operation because of changes in cut size and flow split. It is even more important as the best separation efficiency is obtained close to the roping discharge regime according to Plitt and Booth [1]. They have modeled separation efficiency response surfaces as functions of classifier orifices and feed rate.

Roping has been studied mostly in stand-alone hydrocyclones. Only limited work has been done in continuous closed grinding circuits. The circuit dynamics have an influence on roping as well as in reverse. It was therefore decided to make a pilot plant study of roping in order to examine the dynamic effects of a full circuit. A rod–mill-ball–mill circuit was chosen. It will be described later in more detail.

2. Experimental

The experimental set-up has been discussed in detail by the author elsewhere [2]. The test material was crystalline limestone from the Parainen quarry of Partek-Nordkalk company.

In the first test series the feed rate to the grinding circuit was kept constant at 0.49 t/h. The final product fineness was in 'normal' operation, i.e. in the spray discharge tests ∼68–70% −45 μm. The experiment was conducted so that the apex orifice was decreased step-wise from 16.5 to 7 mm. Each test was sampled after it had obtained its equilibrium. Equilibrium was followed by the PSI-100 particle size analyzer. Usually it took 1–2 h to gain equilibrium. In the first set the cyclone was operated with a constant pressure of 37 kPa. This needed a sump level control, which was actuated by a water addition to the sump. This meant that the feed pulp density decreased as the circulating load decreased.

During the second set the cyclone had a constant 12-mm apex opening and the new feed capacity was increased until the cyclone went to roping. This happened at 0.8 t/h of new feed.

The third set was controlled so that the feed pump sump level was kept constant. In the test the apex opening was varied from 12 to 7 mm and back to 12 mm.

The fourth set was conducted as the first set but with a pressure of 60 kPa. The last test was performed with a 100-mm cyclone and a slightly higher feed rate of 0.61–0.65 t/h.

3. Roping models

3.1. The Mular and Jull model

The criterion for roping published by Mular and Jull [3] is often employed. They state that as the solids' content of the overflow increases so does the underflow percent solids at which roping will commence. They state that the overflow solids content (w/w) and underflow solids content (w/w)

* Fax: +358-94512795.
E-mail address: kari.heiskanen@hut.fi (K. Heiskanen).

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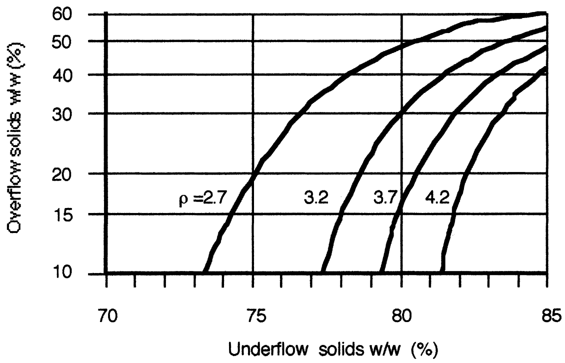

Fig. 1. Roping commencing according to Mular and Jull.

must be related to each other in the manner given in Fig. 1. The curves in Fig. 1 must be regarded with some caution as such variables as particle size and shape do not appear.

Roping is probable with $\rho_s = 2.7$ specific gravity material at 75–78% w/w solids in the underflow and with $\rho_s = 3.2$ from 77 to 81%. Higher material densities allow higher percentages.

Based on earlier work of Tarr (see for example Ref. [4]), Jull [5] refined this method and gave for the underflow capacity.

$$M_{SU} = 0.435 D_u^{2.12} \quad (1)$$

where M_{SU} = solids capacity of the underflow in m^3/h, D_U= apex diameter in cm.

3.2. The SPOC model

Another model widely used is the so-called SPOC model developed by Plitt for the CANMET process simulator SPOC [6]. It was the first attempt to take roping into account in process simulation models. The equation was given as:

$$\phi_L = \phi_{L20} + 0.2\,(\phi_f - 20) \quad (2)$$

where ϕ_L = the % solids by volume in the underflow at which roping is initiated, ϕ_f = the % solids by volume in the feed, ϕ_{L20} = the % solids by volume in the underflow at feed solids concentration of 20% the default of ϕ_{L20} is 56%.

3.3. The Plitt model

Plitt et al. [7] fitted the Jull equation (Eq. (1)) to a new set of data and obtained as new parameters:

$$M_{SU} = 0.35 D_u^{2.35} \quad (3)$$

In the same work, they also developed an equation for the roping condition as functions of median particle size of the underflow:

$$\phi_L = 62.3\left(1 - \exp\left(-\frac{d_u}{60}\right)\right) \quad (4)$$

where ϕ_L = the % solids by volume in the underflow at which roping is initiated, d_u = mass median particle size of the underflow solids.

3.4. The Concha ratio

Concha and his research group have studied the geometrical ratios in a hydrocyclone and their effects on roping [8–10]. They claim that the ratio of diameters of apex orifice D_u and the vortex finder D_o determines the air core. They established that the rope discharge depends on the apex to vortex diameter ratio.

$$\begin{array}{ll} D_u/D_o < 0.34 & \text{rope discharge} \\ 0.34 < D_u/D_o < 0.50 & \text{rope or spray discharge} \\ 0.50 < D_u/D_o & \text{spray discharge} \end{array} \quad (5)$$

This was based on the idea that if the air core inside a hydrocyclone is larger than the apex size with a certain margin, then crowding and rope discharge occur.

4. Results

4.1. The Mular and Jull model

Fig. 2 shows the Mular and Jull [3] prediction (the curve on the right) for solids density of $\rho_s = 2.7$ and experimental points obtained in this study. The relationship between overflow and underflow pulp density does not appear to predict the onset of roping in this case very well. The experimental points are of remarkably lower density than predicted. The prediction seems also to be hampered by the fact that the underflow density remains essentially constant after roping

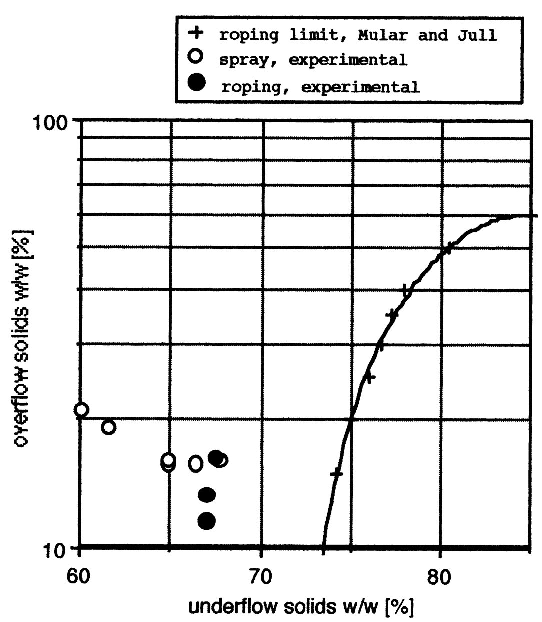

Fig. 2. Overflow pulp density versus underflow pulp density, test series 1.

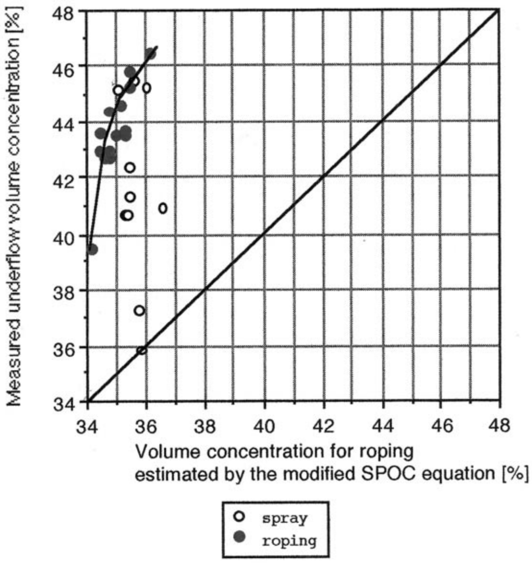

Fig. 3. The prediction of the SPOC equation with the default value for ϕ_{L20}.

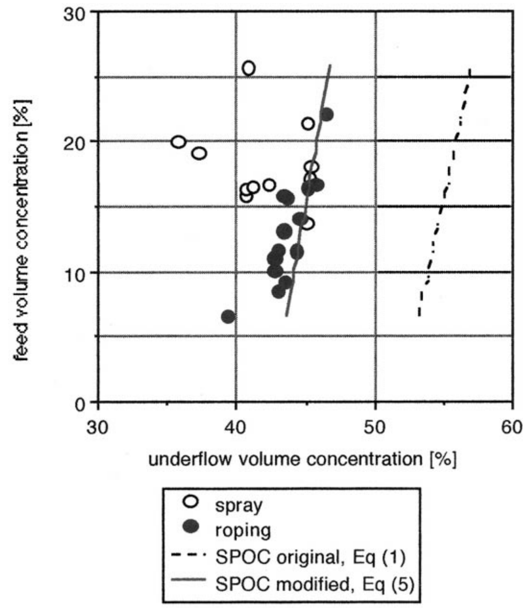

Fig. 4. Relation between feed volume concentration, underflow volume concentration and roping.

commences. As can be seen, there seems to be some limit (?) of underflow solids (w/w) where the roping commences. It seems that the curves given by Mular and Jull need at least calibration before use.

4.2. The SPOC model

Fig. 3 shows the prediction obtained using Eq. (2) with the given [7] default value for ϕ_{L20}. The prediction is not directly acceptable. With the experimental material the prediction does not reproduce the trend of the underflow solids content (v/v) for the roping.

Eq. (2) can be calibrated for the roping conditions. According to experiments the constant ϕ_{L20} was 46% v/v compared to the original of 56% v/v. We get:

$$\phi_{\mathrm{L}} = 0.46 + 0.2\,(\phi_{\mathrm{f}} - 20)$$

When calibrated, it seems to give a slightly better prediction than the Mular and Jull prediction. The equation and the accuracy of the prediction are very sensitive to the given value of ϕ_{L20} as can be seen when comparing Figs. 3 and 4. On the other hand, the equation is insensitive to alteration in feed solids. This can also be seen from Fig. 4.

4.3. The Plitt model

Fig. 5 gives the relationship between the apex opening and underflow volume flow (solids) as given in Eq. (3) for roping conditions. The roping values of the experiments do fit rather well with the predictions. (The values for spray discharge have only been added for the purpose of completeness.) There seems to be no differences between the ways roping had been obtained.

Eq. (4) has been plotted in Fig. 6 together with the experimental points. The prediction of Eq. (4) (dashed line) is not acceptable for this material even after shifting the estimated curve by an arbitrary 25% towards lower pulp densities (v/v) (full line). As can be seen there is no distinction between data points for roping or for spray. No envelope curve for roping can be developed.

4.4. The Concha ratio

The rules of Concha's group also seem to give some guidelines for roping with fine limestone and small hydro-

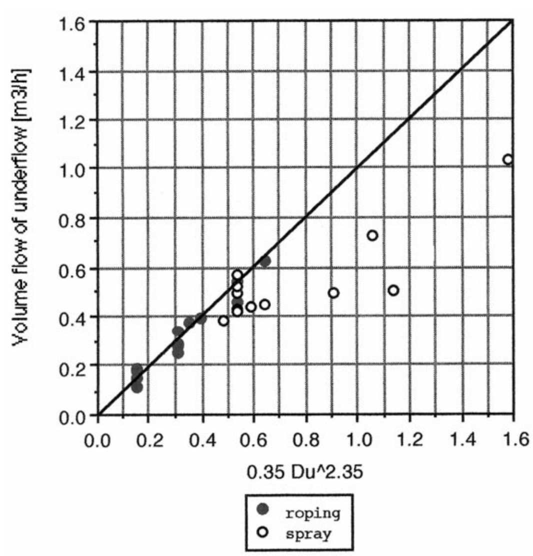

Fig. 5. Apex volume flow predictions.

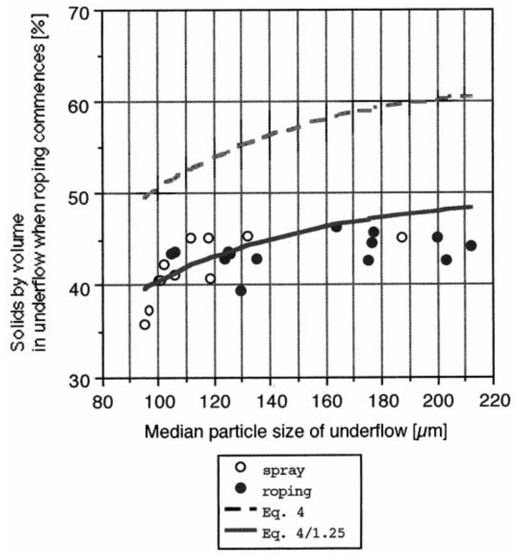

Fig. 6. Roping prediction by Eq. (4).

cyclones. As can be seen from Fig. 7, roping started at the upper ratio regime indicated by them. As the exact definition in roping was slightly elusive with a small cyclone and fine slurry, one can say that roping probably can start at ratios above 0.5. The influence of the closed loop must be taken into consideration. It will cause low D_u/D_o ratios to have different feed characteristics.

4.5. Further development

A simple curve fitting gives for the roping points the following correlation between the critical solids volume concentration:

$$\phi_L = 33.8 + \phi_f^{0.098}$$

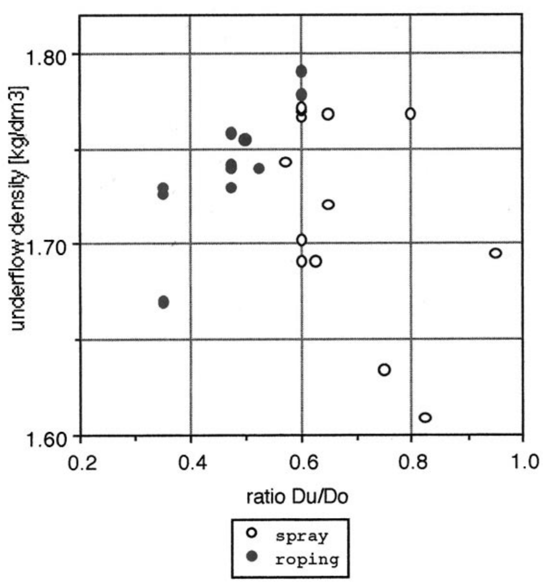

Fig. 7. Pulp density of the underflow as a functions of the ratio D_o/D_u.

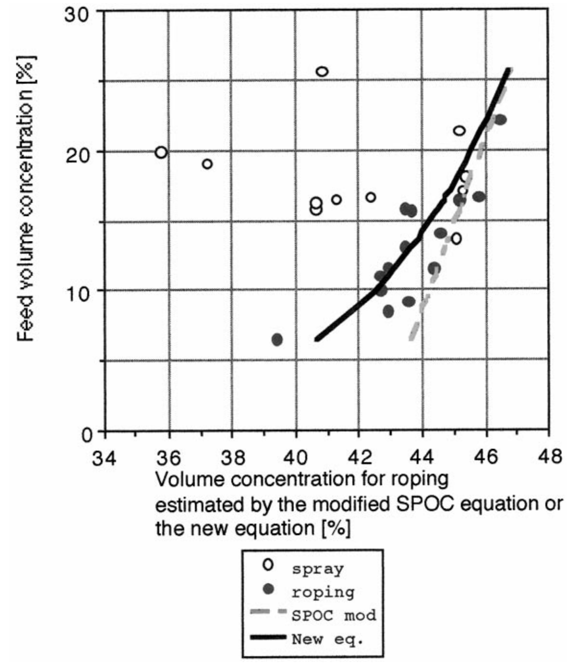

Fig. 8. The prediction of the SPOC equation (Eq. (1)) with the calibrated value for ϕ_{L20} and the new Eq. (5).

This is depicted in Fig. 8 showing a better fit than the SPOC equation even in the calibrated form.

The effect of the feed pulp solids volume concentration on roping is not very marked. A much stronger relationship can be seen between the volume flow through the apex and roping.

The experimental results show only a minor effect from the particle size. It must be concluded that median particle

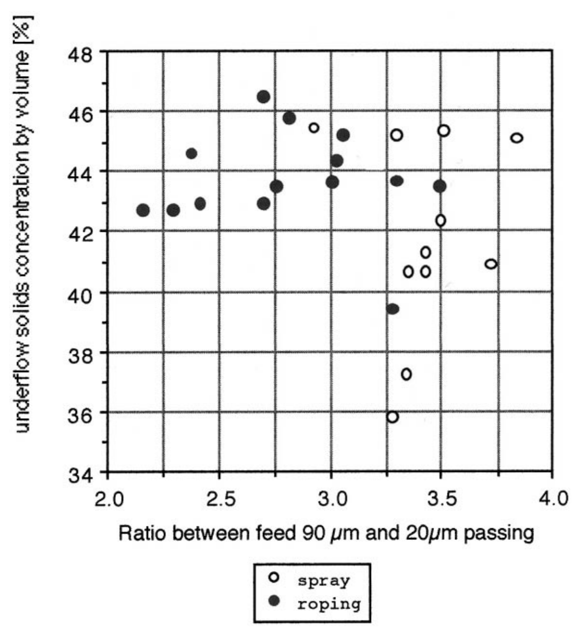

Fig. 9. Effects of feed particle size distribution on roping tendency.

size is not always the decisive size distribution property that affects roping.

There is a relationship between roping tendency and the width of particle size distribution. Fig. 9 shows the roping tendency against the ratio d_{90}/d_{20}. The experimental ratio above 3 obtained higher pulp densities before roping started than narrower distributions. For wide distributions even 45% pulp solids (v/v) could be obtained without roping while with narrow distributions 43% caused roping. The number of points is not sufficient to say if the difference is statistically significant.

According to the results the circuit produces less fines when roping. This is in accordance with the results predicted by Plitt and Booth [1]. Energy consumption (kWh/t for new −45 μm) of the circuit is at its minimum just at the roping limit [2].

5. Conclusions

The commencing of roping seems to be difficult to estimate. The only found criterion is the solids volume flow through apex. It has a power law dependency on the apex diameter. The power seems to be higher than the expected power of 2. The other relation that seems to have some validity is the geometric relation of apex and overflow orifices. If D_o/D_u ratio is less than 0.5 there seems to be a big probability that the cyclone is in roping. Overflow and underflow densities are difficult to use as indicators for roping. Particle size distribution steepness of the feed seems to bear some effects on roping.

The effects on the circuit circulating load were surprisingly rather linear and no step-wise decreases in circulating load were found.

These conclusions cannot be generalized to coarser grinds, which will be researched separately. The different equations studied must be used with caution, as none of them is very accurate to predict roping in simulation or in control.

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