Hydrocyclone performance comparison under the influence of underflow pumping

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Abstract

A mathematical model is developed to predict the performance of hydrocyclones for solid-liquid separation. This model is based on residence time theory combined with estimation of average vertical velocity according to locus of zero vertical velocity resulted from equilibrium orbit theory for hydrocyclones. The tangential velocity component is also related to that radial distance of inlet particle from the hydrocyclone centerline. This mathematical model is then used to develop the equivalent area factor that indicates the area of a gravity settling time with the same separation performance as in the hydrocyclone. A performance chart is developed from the model and is compared with literature. It is shown that the chart obtained in the current study is in good agreement with experimental data. This performance chart can be used now as a guideline for selecting and design of hydrocyclones. An experimental setup is also designed for validating the model and resulted chart.

Keywords. Particles – hydrocyclone – performance – modelling – equivalent settling area.

INTRODUCTION

Predicting performance of a solid-liquid separation process can help in comparing different separators for selection and design. This can be applied to hydrocyclone technology which is used in industry due to its unique features. For sedimenting centrifugal separators, equivalent area factor (capacity factor) was introduced (Ambler, 1959) by considering a cut size particle sedimenting in a separator. This factor is used for comparing separation performance of the devices. Using this concept, (Lavanchy et al., 1964) proposed a performance chart for comparing centrifugal separators along with hydrocyclones that needs to be evaluated considering changing in technology over the years. In the current research, this is performed for hydrocyclones through modeling the separation performance the results are validated.

MODELING

For a uniform distribution of particles in operation, volume flow rate and gravity settling velocity for centrifuge separators were correlated (Ambler, 1959) and a relation was derived for equivalent area factor Σ (with an area unit) -also termed the theoretical capacity factor- such that:

$$Q = 2v_g\Sigma \quad (1)$$

where Q is flow rate and v_g is settling velocity under gravitational acceleration (Ambler, 1959) for 50% cut size particle. Similarly a relation is developed for predicting equivalent area factor in hydrocyclones based on residence time theory (Rietema, 1961). The vertical velocity component v_z in a hydrocyclone is now estimated by utilizing equilibrium orbit theory and the locus of zero vertical velocity (LZVV) for a none-zero underflow flow rate Q_u. The tangential velocity component is also obtained in term of changing in distance between the particle position in the inlet pipe and hydrocyclone centerline. v_z in a particular section is obtained such that:

$$v_z = \frac{4QR_f}{\pi\left(D_z^2 - D_{equil.}^2\right)} \quad (2)$$

in which Q is feed flow rate, D_z & $D_{equil.}$ are equilibrium diameter at the end of mantle and imaginary equilibrium surface (Bradley, 1959) according to vertical position z. Using this velocity component in developed equation for residence time theory (Svarovsky, 1984), applying $0.7D$ and $0.43D$ (D is hydrocyclone diameter) for D_z & $D_{equil.}$ (Bradley, 1959) and analogues with equation (1) considering that Σ is associated with hydrocyclone overflow, Σ is obtained:

where ΔP is pressure drop across a hydrocyclone, R_f is flow ratio (the ratio of underflow to feed flow rate), D_i & D_o are inlet and overflow diameters, L is hydrocyclone total length, ρ is liquid density, g is gravity acceleration and n is a coefficient in tangential velocity component (Svarovsky, 1984).

$$\Sigma = \frac{0.3\pi n L \Delta P}{(D/D_o)^{2n} - 1}\left(\frac{1}{1 - D_i/D}\right)^{2n+1} \times \frac{(1 - R_f)}{\rho g R_f} \quad (3)$$

RESULTS

The model is evaluated using a given minimum and maximum pressure drop in hydrocyclones that applies less pressure drop to the large hydrocyclones where hydrocyclone diameters changing from 1 to 100 cm for Bradley and Rietema aspect ratios (Svarovsky, 1984). Having the pressure drops and hydrocyclone dimensions, flow rate and equivalent area factor are obtained. The results for flow rate are plotted against $2v_g = Q/\Sigma$ and the resulted graph is bounded to identify the region of hydrocyclones performance. This performance region is shown in Figure 1 and the relevant particle cut size is also shown.

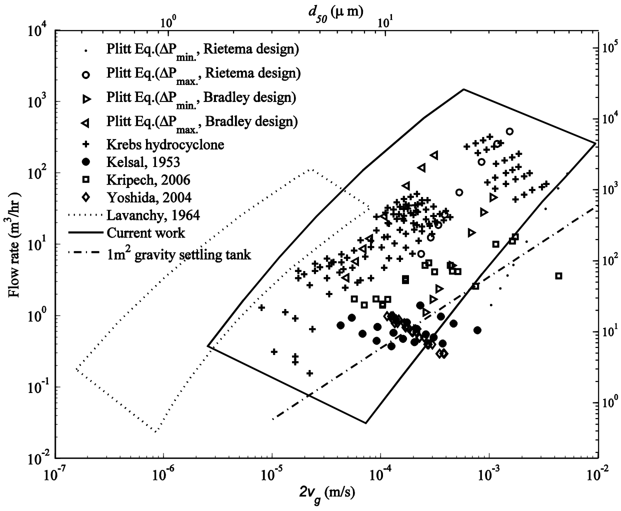

Figure 1. Hydrocyclones performance chart; The top horizontal axis shows separation cut size assuming 1 g/cm^3 density difference between solid and water as liquid.

This chart is compared with the performance of a gravity settling tank that has unit area and also with the chart suggested by (Lavanchy et al., 1964). A significant discrepancy is observed between the current work and the chat from Lavanchy. To evaluate the results, experimental data from literature (Kelsall, 1953; Kraipech et al., 2006; Yoshida et al., 2004) and Krebs hydrocyclone manufacturer's data sheet (Palma, 2013) are employed as shown on Figure 1. Plitt correlation (Svarovsky, 1984) is also used to generate more empirical data. As it can be seen in Figure 1, most of experimental data is in the region developed I the current study from the mathematical model. This indicates that the chart from (Lavanchy et al., 1964) is over predicting the separation performance of hydrocyclones.

An experimental setup is designed for further evaluation of the results particularly where less experimental data is available. In this setup the underflow is attached to a pump that provides the ability of simulating changes in the underflow diameter without clogging in the underflow pipe. The hydrocyclone performance is evaluated using several feed concentration, particle size distribution and operating conditions.

CONCLUSION

Performance of hydrocyclones for solid-liquid separation is evaluated both in theory and practice. A modified residence time theory is developed to predict the hydrocyclones performance. Using the developed model a performance chart is obtained that predicts the performance region for hydrocyclone diameters up to one meter. The chart is evaluated using experimental data from literature and a manufacture data sheet and is compared to the chart from Lavanchy et al. It is indicated that the developed chart and model is in agreement with experimental results. A test rig is also designed and applied to predict more performance regions of the hydrocyclones.

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