Data-Based Performance Modelling of Hydrocyclone for Processing Iron Ore Fines

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Abstract

In this study, a data driven performance characterization model of hydrocyclone has been developed using multiple experimental data set collected from the published literature pertaining to processing of iron ore fines. The cut size, d_{50}, has been determined for a given cyclone operating conditions using Lagrangian interpolation technique. A reduced efficiency curve has been constructed to map the performance and the functional behaviour has been modeled employing three typical distribution functions, namely, Rosin-Rammler, Exponential and Logistic. All pertinent model parameters have been estimated in accordance with the experimental data sets. It has been observed that all these functions fairly mimic the performance of cyclone for processing iron ore in the particle size range 25-300 μm. Rosin-Rammler distribution found to be a better function for fitting the experimental data set in comparison to Exponential and Logistic functions to characterize the performance.

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1. Introduction

Iron ore is the primary raw material in the production of pig iron and subsequently steel. Reduction in the consumption of iron ore, coal and fluxes is at the core of technological research for optimizing iron making processes. For economic reasons, quality iron ore is not only required for stable blast furnace operation, but also for emerging iron-making technologies such as smelting-reduction and direct reduction. In order to enhance the efficiency of blast furnace operation, some of the critical issues related to iron ore which encompass composition of iron ore with low Fe and high Al-Si ratio, low strength, lower reducibility, low temperature softening and melting tendency needs to be addressed effectively. Therefore, it becomes imperative to beneficiate relatively low grade ores to make them amenable for blast furnace operation using appropriate mineral processing systems.

Over the years, hydrocyclone has been used as one of the most efficient mineral processing unit operations to beneficiate iron ore fines to meet the stringent quality requirements. It is perhaps one of the most widely used separation device to be found in mineral industry. It owes its popularity to the low manufacturing and maintenance costs brought about by its simple design. Depending on the characteristics of the feed particle size, it can separate different sizes of particles by appropriate selection of operating and design parameters. Combined with moderate pressure drop and a range of throughputs, these advantages have made the cyclone one of the most attractive unit operations for a variety of separation processes. Hydrocyclone as a classifier has found wide applications in mineral industry for efficient separation of coarse and fine particles. Various studies of cyclone separators used for iron ore cleaning have been widely reported in the literature [1-3]. Though the design of the cyclone is relatively simple, however, the characterization of performance for processing minerals is relatively complex because it is a function of design and operating parameters.

In the present study, semi-empirical performance models have been employed to characterize the performance of hydrocyclone using published experimental data set for processing of iron ore fines. The cut size, d_{50}, has been determined for a given cyclone operating conditions in conjunction with size classification data using Lagrangian interpolation technique. Further, a reduced efficiency curve has been generated using size classification analysis. Attempts have been made to describe the functionality of reduced efficiency curve by employing Rosin-Rammler, Exponential and Logistic distribution functions to characterize the performance of the cyclone. A simplistic approach has been proposed to estimate the cyclone performance model parameters.

2. Performance modelling of the hydrocyclone

To quantify hydrocyclone operation various attempts have been made to develop theoretical and empirical models. Although, a number of investigations have been carried out to study the flow field and dispersed phase particle behaviour in the hydrocyclones, their separation phenomena are still not fully understood. The selection and design of hydrocyclone are still empirical and experience based; although first principle based computational fluid dynamic (CFD) analysis has also been reported in the literature [4-6]. Development of high speed computers has been facilitated the numerical solution of fluid dynamical equations. But such solutions are computationally intensive and time consuming.

Thus, there is a need to have a reliable hydrocyclone models for processing iron ore fines which can predict and characterize the performance with a reasonable degree of realism. Empirical cyclone models are based on the observation that the probability of a particle reporting to one of the product streams is dependant upon the particle settling characteristics like size and specific gravity. The classification action of the cyclone is determined by the net effect of the two competing forces that act on every particle – the outward centrifugal force and the inward drag force. On the basis of equilibrium orbit hypothesis [7] any particle that experiences equilibrium between the drag and centrifugal forces inside the cyclone will have an equal chance to exit through either the underflow or the overflow. This is because they will tend to circulate on a circular orbit inside the cyclone until impact with other particles randomly.

The performance of hydrocyclone is characterized by a partition curve, which relates the weight fraction, or percentage, of each particle size in the feed which reports to the apex, or underflow, to the particle size. The cut point, d_{50}, or separation size, of the cyclone is defined as that point on the partition curve for which 50% of particles in the feed of that size report to the underflow, i.e. particles of this size have an equal chance of going either with the overflow or underflow. The sharpness of the cut depends on the slope of the central section of the partition curve, the closer to vertical is the slope the higher is the efficiency [8]. A reduced efficiency curve can be generated by plotting the weight percent of feed reporting to underflow, against the geometric mean size of the size fraction normalized by the separation size (d_{50}). The reduced efficiency curve is invariant with design and operating variables and dependent on the cyclone size and the nature of the feed material only [9].

A number of useful empirical distribution functions are available to represent the reduced efficiency curve. The most commonly used are Rosin-Rammler, Exponential Sum and Logistic functions [7].

1. Rosin-Rammler

$$y = 100[1 - \exp(-\alpha x^{\beta})] \tag{1}$$

2. Exponential Sum

$$y = 100\left[\frac{\exp(\beta x) - 1}{\exp(\beta x) + \exp(\beta) - 2}\right] \tag{2}$$

3. Logistic

$$y = 100\left[\frac{1}{1 + x^{-\beta}}\right] \tag{3}$$

where, x is the ratio of d/d_{50} and y is the corresponding performance indicator. α and β are the adjustable model parameters which can be estimated and tuned from the experimental results. β is a measure of the sharpness of separation.

2.1 Parameter estimation methodology

Fitting of experimental data to the model equations of reduced efficiency curve necessitates estimation of α and β for the process. Least square method can be applied to determine the parameters α and β after some simplification of the model equations.

Substituting $y' = \frac{y}{100}$ and subsequent simplification of eqns (1-3) yields

$$\ln\left[\ln\left\{\frac{1}{(1-y')}\right\}\right] = \ln\alpha + \beta\ln x \tag{4}$$

Similarly equations (2) and (3) can be linearized as follows:

$$\ln\left(\frac{y'}{1-y'}\right) = \ln\left[\frac{\exp(\beta x)-1}{\exp(\beta)-1}\right] \tag{5}$$

$$\ln\left(\frac{1-y'}{y'}\right) = -\beta\ln x \tag{6}$$

3.0 Experimental data

The experimental data for iron ore fines has been collected from published literature [3]. This data set pertains to 50 mm diameter cyclone with 14.3 mm vortex finder, 3 mm spigot diameter, 17.2×10^4 Pascal, with and without dispersant (1 gm/kg). Percentage of solids in the feed is 11.6.

4.0 Results and Discussions

Equations (4-6) yield a linear relationship between the logarithm of the efficiency and the reduced particle size. The least square linear fitting of the experimental data using equations (4-6) provides initial values for α and β (Figs.1-3). The particle size of separation (d_{50}) has been calculated using a Lagrange interpolating polynomial to the experimental data. Figs (4-5) show the goodness of fit of the Rosin-Rammler, Exponential and Logistic distribution with regard to the current data set. Experimental data sets [3] are indicated by discrete points and the continuous and broken lines show the model based predictions. From this figure, it may be observed that the performance of cyclone represented by the reduced efficiency curve is embodied by these distribution functions for size classification. The d_{50} predictions are successfully validated with the published experimental data [3]. Further, model based predictions of the reduced efficiency curve and adjustable model parameters (α and β) are found to be in close agreement with the literature [9].

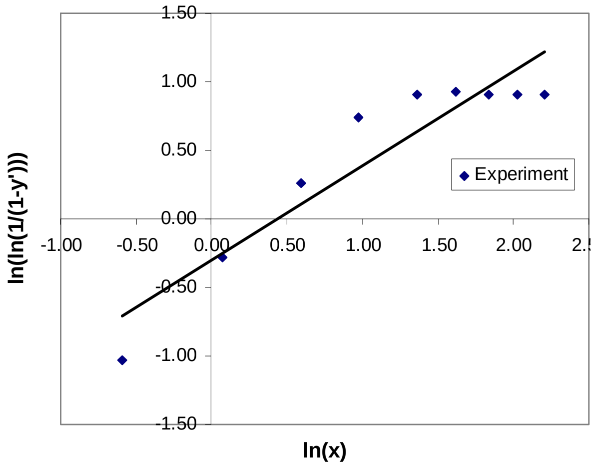

Fig 1: Estimation of model parameters
for Rosin-Rammler distribution function

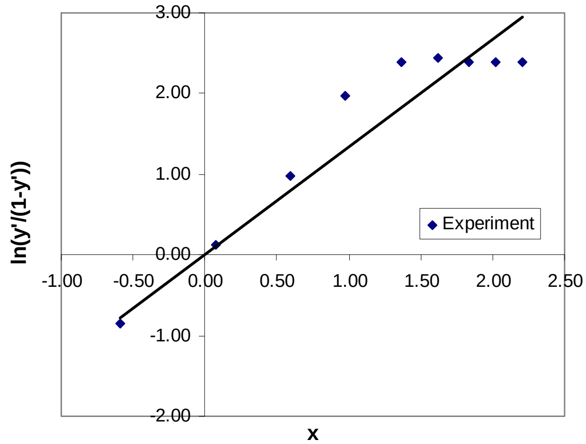

Fig 2: Estimation of model parameters
for Exponential distribution function

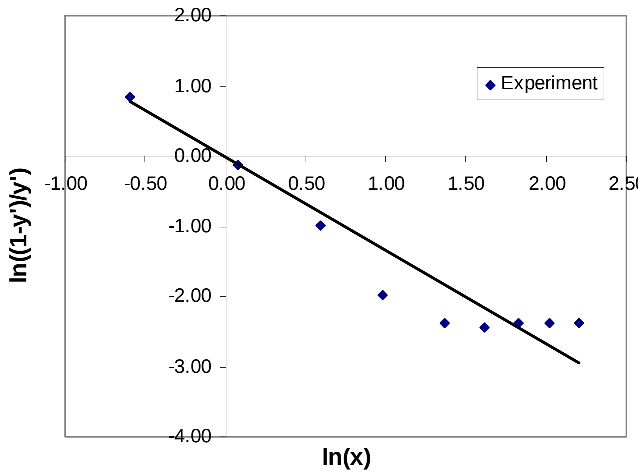

Fig 3: Estimation of model parameters for Logistic distribution function

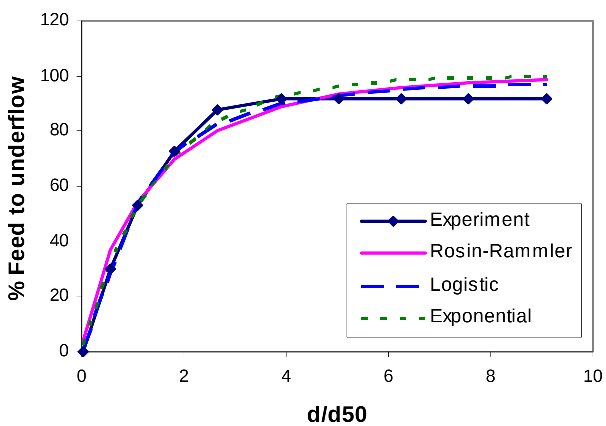

Fig 4: Experimental and predicted reduced
efficiency curve for the dataset with dispersant

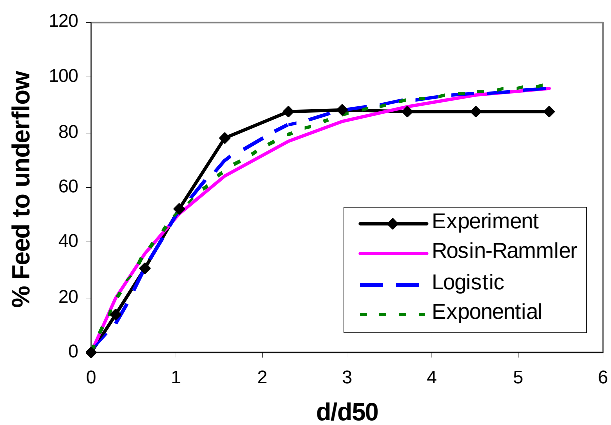

Fig 5: Experimental and predicted reduced
efficiency curve for the dataset without dispersant

5. Conclusions

Performance of hydrocyclone for processing iron ore fines has been attempted using modelling of experimental data. The model parameters have been calculated by transforming the governing model equations in equivalent logarithmic form and subsequently least square technique has been applied. With the estimation of model parameters the performance of the cyclone under different operating conditions can be quantified. It is observed that the Rosin-Rammler, Exponential and Logistic distribution functions can be employed to reasonably mimic the performance of cyclone for size classification. Rosin-Rammler distribution appears to be a relatively better fitting function to capture the performance of hydrocyclone for processing iron ore fines.

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