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Enhanced Holland-Batt spline for describing spiral concentrator performance

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ABSTRACT

The Holland-Batt spline is well known when it comes to plotting spiral separation performance. The spline, which consists of a linear curve and power curve, has been successfully used to fit test work data that is presented as cumulative recovery of a valuable mineral versus the cumulative mass yield to valuable mineral concentrate. The benefit of this curve fitting process is that it produces a mathematical expression that is essential for simple mass flow modelling calculations. Although the mathematics is simple, the fitting process can be quite cumbersome. This work enhances the Holland-Batt spline with a few adjustments to improve the fit accuracy and ease the fitting process through (1) smoothing the transition zone between the linear and power law curves, (2) applying the principles to both low and high density particles, (3) use Visual Basic user-defined functions to simplify test work sheets in Excel and (4) use Excel Solver to automate the curve fitting process. These steps are applied to an example test work data set to clearly demonstrate the approach. The enhanced method is easy and simple to apply to spiral concentrator mass flow modelling.

1. Introduction

The spiral concentrator, better known as a spiral, remains a competitive processing technology because it has comparatively low capital cost and high separation efficiency in a well-designed circuit configuration.

Regular assessment of spiral separation performance is important to ensure that the most suitable operational conditions (feed rate, solids concentration, medium viscosity) are applied to maintain high recoveries of valuable mineral for a specific feed material (particle size, density and shape distributions). The most common method for quantifying separation efficiency is to plot cumulative recovery of the valuable mineral versus cumulative mass yield to concentrate containing the valuable mineral. The closer the data points are to ideal recovery (100% recovery at 100% concentrate grade), the higher the separation efficiency. This article discusses fitting of a consistent mathematical relationship of cumulative recovery versus cumulative yield to test work data points. The resulting relationship can then be used to identify data quality problems, as well as to analyse process performance.

Linear and polynomial regression are standard methods to fit empirical models to experimental data. Test work errors can force the fitted relationship into a specific direction, which may result in a model that is not physically meaningful. There are many other equations that can be used to fit series of data points, but these may not be consistent over different test work conditions that are applied in spiral concentrator test work. Its area of applicability may be very small and will require recalibration once the operating area has shifted. This is typical of an empirical model.

The ideal equation is one that realistically describes the physical behaviour of the process under investigation, and that can be fitted accurately and consistently on test work data. This implies a model of a more fundamental nature. Such a relationship needs to be supported by large amounts of test work data and/or fundamental analysis before it can be accepted as an equation suitable to fit test work data.

The technique presented in this article is demonstrated on an example data set of a typical heavy mineral feed material with a grade of 14% by mass that was fed to a rougher spiral.

2. Example test work data

Table 1 provides some data obtained from spiral test work. The spiral product was divided into seven mass fractions with a mouth-organ splitter. The fractions are numbered from the inside of the

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Nomenclature

Symbols

a	gradient of straight line segment, dimensionless
b	exponent of power law segment, dimensionless
c	transition zone half width, mass %
d_j	coefficient for polynomial order j term
r	cumulative high-density material recovery, mass %
r^*	cumulative low-density material recovery, mass %
y	cumulative mass yield to high-density concentrate, mass %
y^*	cumulative mass yield to low-density tailings, mass %

Subscripts

cross	the point where the linear and power-law sections cross
i	spiral split fraction index
lin	linear section
pol	polynomial section
pow	power-law section

spiral (1) to the outside (7). The slimes content (%SLM) of each split fraction was determined by screening on a 45 μm screen. A sink-float technique with tetra-bromo ethane (TBE) at 2.98 g/cm^3 was used on the dried de-slimed sand fraction to determine the total heavy mineral content (%THM, sink fraction) and remaining float fraction (%QRT) of each split fraction. The float fraction consisted mostly of quartz. The head grade of THM, QRT and SLM were calculated with the mass weighted assay of each mass fraction. The right-hand side of Table 1 provides the cumulative figures based on the fractional values on the left-hand side.

The heavy mineral material, or sink fraction, is referred to as 'high-density material' in this text; and the light minerals, or float fraction, as 'low-density material'.

3. Holland-Batt recovery curve

Holland-Batt (1990) proposed a combination of two simple equations to fit spiral recovery data. A straight line (Eq. (1)) and a power law (Eq. (2)) are combined to describe cumulative valuable mineral recovery as a function of cumulative mass yield to concentrate (Fig. 1). In industry, this function is commonly known as a double-spline (Eq. (3)). Symbols are defined in the nomenclature section towards the end of this article.

$$r_{\mathrm{lin}} = ay \tag{1}$$

$$r_{\mathrm{pow}} = 100\left(\frac{y}{100}\right)^{b} \tag{2}$$

$$r = \min(r_{\mathrm{lin}}, r_{\mathrm{pow}}) = \min\left(ay, 100\left(\frac{y}{100}\right)^{b}\right) \tag{3}$$

The yield-recovery curve can be divided into three zones, namely the grade zone, the transition zone and the decay zone (Fig. 2a). The grade zone is primarily determined by the number of high-density particles that are concentrated at the inner side of the spiral trough, and is described by the straight line section.

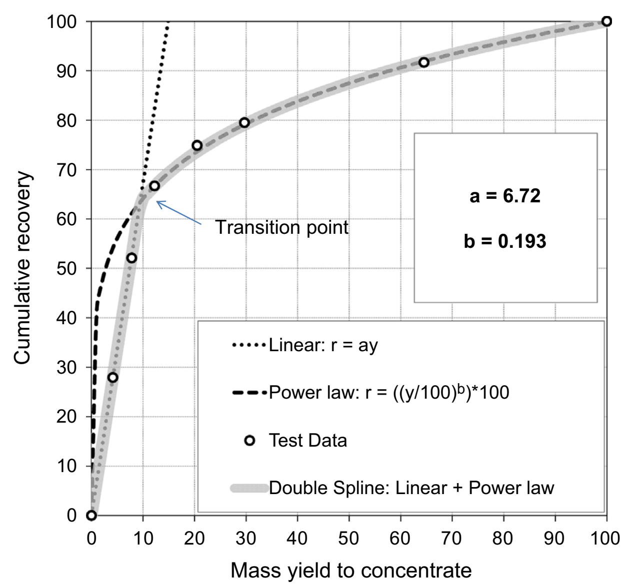

Fig. 1. Holland-Batt double-spline recovery curve fitted to test-work data.

An increase in the number of high-density particles would result in a decrease in the gradient of the straight line, and a larger portion of the spline would be represented by the linear section.

The decay zone, described by the power law, is the result of high-density particles remaining in the bulk of low-density particles, demonstrating a steady decrease in concentration. The decay zone is influenced by the sum of all the factors that could inhibit movement of high-density particles into the grade zone. Such factors may include increased throughput, increased solids concentration, increased viscosity (slimes content) and increased medium-density particle concentration.

Table 1
Example of test work data obtained from a spiral test with mouth-organ splitter. (Slimes is defined as particles smaller than 45 μm.)

Split fraction no.	Fractional mass (%)	THM content (%)	QRT content (%)	Slimes content (%)	Cum. mass (%)	Cum. THM recovery (%)	Cum. QRT recovery (%)	Cum. slimes recovery (%)
1	4.16	92.34	7.27	0.38	0.00	0.00	0.00	0.00
2	3.65	90.91	8.65	0.44	4.16	27.95	0.36	0.60
3	4.43	45.17	54.29	0.54	7.81	52.12	0.74	1.21
4	8.27	13.59	86.18	0.23	12.25	66.69	3.62	2.11
5	9.17	6.93	92.63	0.45	20.52	74.87	12.14	2.85
6	34.83	4.81	93.81	1.38	29.69	79.49	22.30	4.40
7	35.48	3.23	91.00	5.77	64.52	91.67	61.38	22.56
Head/total	100.00	13.74	83.61	2.64	100.00	100.00	100.00	100.00