

Characterisation of the pulse wave of an InLine Pressure Jig in a near density application

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Abstract

InLine Pressure Jigs are relatively new in the mineral processing industry. By nature they possess a greater number of control variables than other gravity classifiers. The pulse action is complicated and can alter substantially in nature with just a minor adjustment to one of these variables. Three main aspects of the pulse can be discerned and these are, pulse stroke length (amplitude), pulse frequency (wavelength) and pulse a-symmetry (mode position). In this paper, the pulse is characterized into a single variable and it is correlated, along with other variables, to the efficiency of the unit, in a silica/calcareous-sea-shell classification application.

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1. Introduction

The use of jigging machinery for the classification and beneficiation of ore has a long history, particularly in the coal industry. During the 1980's and before, Harz and Kelsey jigs were popular and in the 1990's, this led to an improved design, which incorporated a centrifugal action (Beniuk et al., 1994). However, recent technological developments have resulted in jigging technology becoming an even more sophisticated tool of classification. The invention of the 'InLine Pressure Jig' (IPJ) has resulted in a more sophisticated classifier that can achieve even higher levels of efficiency, with the entire process occurring in a confined pressurized environment that adds a new dimension of security.

Published detailed-fundamental work on the mechanism of classification in a jigging device has been sparse with only bare basics being debated (Steiner, 1996). The invention and widespread industrial application of the

IPJ has once again necessitated further studies into the jigging mechanism of separation, specifically for the purposes of increased efficiency and ultimately optimisation. This is all the more important as the economic environment is forcing mineral processing operations to enter into more financially marginal mineral beneficiation processes. Processes, such as Ferro-alloy recovery from smelter dump material (Vorster, 1999), or the separation of zircon and rutile from beach-sands (Tomicki, 2004), in which efficient and cost effective gravity separation must play a role.

In the particular duty that examined in this paper i.e., the classification of silica $RD = 2.65$ and calcareous beach shell $RD = 3.00$, the closeness of the densities requires a detailed study of the system variables for the purpose of optimisation. These challenges steered the research group to study and identify a characterisation of the pulse shape and size and to relate this to IPJ efficiency.

2. Theory

Classic jigging units characteristically dilate the particle bed by an upward blast of water, through a screen,

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Nomenclature

U_u	superficial water upward velocity (m s^{-1})	SL_{max}	maximum possible peak height (m)
U_d	superficial water downward velocity (m s^{-1})	A	area under the pulse curve (m^2)
t	time (s)	A_0	area of under standardised pulse curve (m^2)
Y	sum of rates of change of displacement Eq. (2) (m s^{-1})	dz_u/dt	rate of upward displacement of jig bed (m s^{-1})
U	characteristic value describing the behaviour of the pulse relative to the shape of the pulse and not the shape (dimensionless)	dz_d/dt	rate of downward displacement of jig bed (m s^{-1})
NPB	characteristic value describing the behaviour of the pulse relative to the size and shape (dimensionless)	X_1	time taken to reach peak height (s)
		X_2	time taken to reach initial position from peak height (s)

caused by the movement of a remote piston. However, the IPJ moves the screen up and down in a cyclic manner by means of a hydraulically powered servo that is mechanically linked to the screen. The result is a sawtooth pulse with linear displacements (see Fig. 1). This effectively creates the same classic jiggling effect. But also, tantalisingly, allows for better control of both the bed dilation stroke (downward screen movement), as well as the settling stroke (upward screen movement), unlike in the case of a normal jig where the settlement stroke is dictated by the settling velocity of the feed charge. In addition to this improved control, hutch water feed, which results in an independent variable upwards flow of water, can be used to further improve classification.

The important variable in the jiggling process (Galvin et al., 2002; Mishra and Adhikari, 1999) is the water superficial velocity. Assuming that the water superficial velocity in the IPJ, correlates directly to the vertical velocity of the screen, one should be able to deduce water velocity from the ram/servo velocity, directly. The effect of hutch water addition will have to be superimposed onto the servo velocity. Preliminary tests at different velocities for both the up and down stroke tended to indicate that all changes in ram/screen displacement are linear with time and for the up stroke (α) (bed compaction) is a function of hydraulic oil pump speed. The

ram drop velocity (bed dilation) is a strong function of the mass of the screen and is controlled essentially by the aperture setting of the hydraulic oil return valve. Assuming that the hydraulic oil is non-compressible and that the effect of change of pressure head in the moving servo is negligible, this mechanism will lead to linear water velocities during both the up and down strokes, i.e. Eqs. (1a)–(1c). It is also assumed that the addition of hutch water is constant.

$$dU_{u,d} \propto dt \quad (1a)$$

$$\frac{dU_u}{dt} = f \text{ (Screen weight, oil return valve aperture size, and hutch water)} \quad (1b)$$

$$\frac{dU_d}{dt} = f \text{ (Hydraulic pump speed, hutch water addition)} \quad (1c)$$

where U_d is water superficial velocity down (m s^{-1}) and U_u is water superficial velocity up (m s^{-1}).

2.1. Characterisation method I

Assuming that the vertical velocity of the liquid is the most important variable with respect to hindered set-

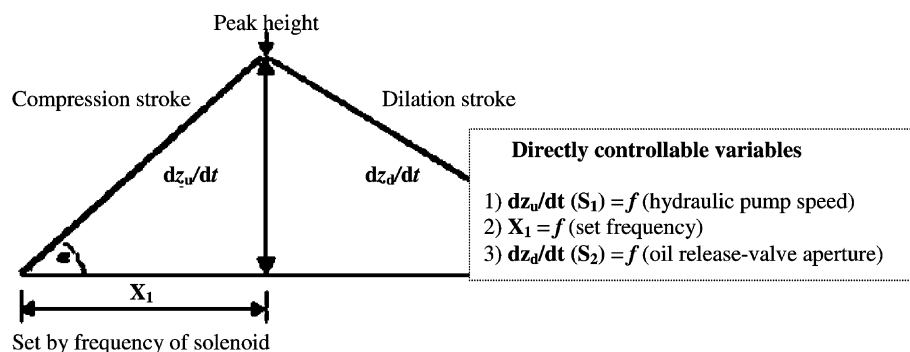


Fig. 1. Schematic of screen movement during one cycle.

ting, the simplest manner to characterise the pulse is by summing the up and down rate/derivative into a single variable with the extremes giving values of negative or positive infinity, i.e. Eq. (2). This value (γ) will be unique for any set of sequential slopes.

$$Y = \frac{dz_u}{dt} + \frac{dz_d}{dt} \quad (2)$$

To temper this variable and make it more realistic a ‘tanh’ function could be employed, i.e. Eq. (3) thus giving us a U factor that now characterises the cyclic fluid displacements;

$$U \text{ factor} = \frac{e^Y - e^{-Y}}{e^Y + e^{-Y}} \quad (3)$$

However, this function will not incorporate a change in frequency that will result in a change in overall size of pulse distribution, a phenomena that is bound to have an effect on the hindered settling of the particles and hence their classification. The solenoid that supplies oil to the servo will, with change in frequency/wavelength (Fig. 7), be open for a different length of time resulting in an change in screen vertical movement while a constant rate of displacement upwards together with a constant return valve setting will leave the U factor unchanged. It will therefore be necessary to characterise the pulse by using both the frequency and U factor. Fig.

2 shows how similar U factors could be achieved for different pulse rates.

2.2. Characterisation method II

Method II (the NPB factor) improves on the shortcoming of Method I by incorporating a dimensionless size factor together with a simplified shape factor. Essentially the shape of the pulse, like in characterisation method I, is located by summing the up stroke rate and absolute value of the down stroke rate. This sum is then made dimensionless by dividing it by the up stroke rate. In an analogous manner, the size of the pulse is characterised by dividing the area under the pulse curve by a standardised area. This standardised area is shown in Fig. 3, which is a symmetrical pulse that has a base, twice the length of the maximum stroke length allowed by the constraints of the equipment. Our final NPB factor is simply the product of this size and shape factors.

The shape factor can be calculated by the following;

$$\text{Shape of pulse} = \frac{\frac{dz_u}{dt} + \left| \frac{dz_d}{dt} \right|}{\frac{dz_u}{dt}} \quad (4)$$

The size factor can be calculated by the following;

$$\text{Size of pulse} = \frac{A}{(SL_{\max})^2} = \frac{A}{A_0} \quad (5)$$

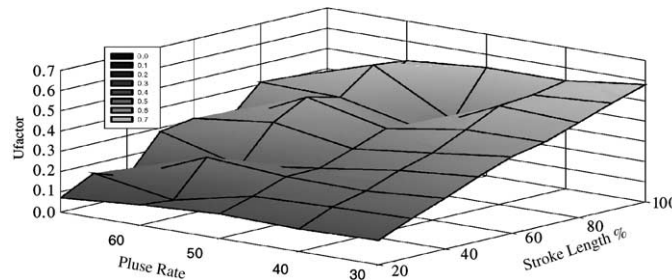


Fig. 2. Characterisation Method I (U factor) of ‘saw-tooth’ pulse produced by an IPJ.

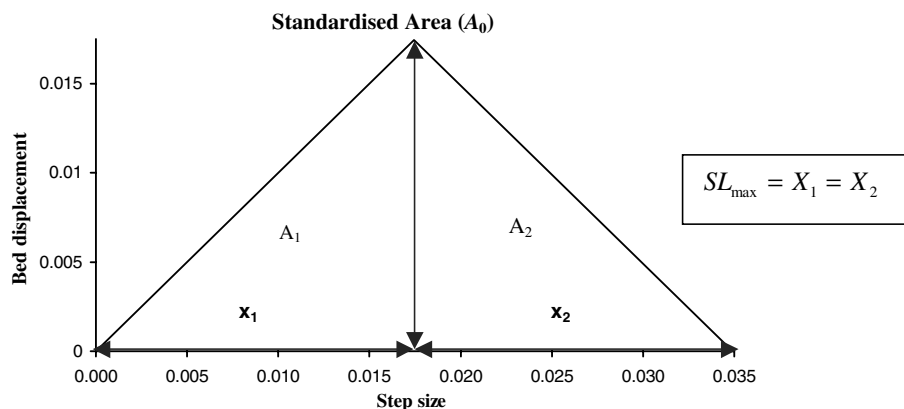


Fig. 3. Standardised pulse from which standardised area is calculated.

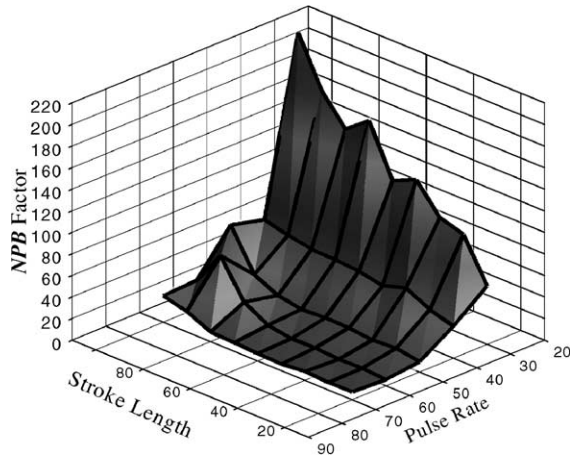


Fig. 4. Characterization Method II (NPB factor) of saw-tooth pulse produced by an IPJ.

where A is the area under the pulse curve (m^2), SL_{max} is the maximum stroke length (m) and A_0 is the standardised area (m^2).

Finally, the characterisation term is the product of the terms defined in Eqs. (4) and (5).

$$NPB = \frac{\frac{dz_u}{dt} + \left| \frac{dz_d}{dt} \right|}{\frac{dz_u}{dt}} \times \frac{A}{(SL_{max})^2} \quad (6)$$

As with all characterisation models it is necessary to test for uniqueness with respect to existing pulse variables and this was achieved by examining a three-dimensional plot of stroke length, frequency against the NPB factor for constant oil return valve setting, Fig. 4.

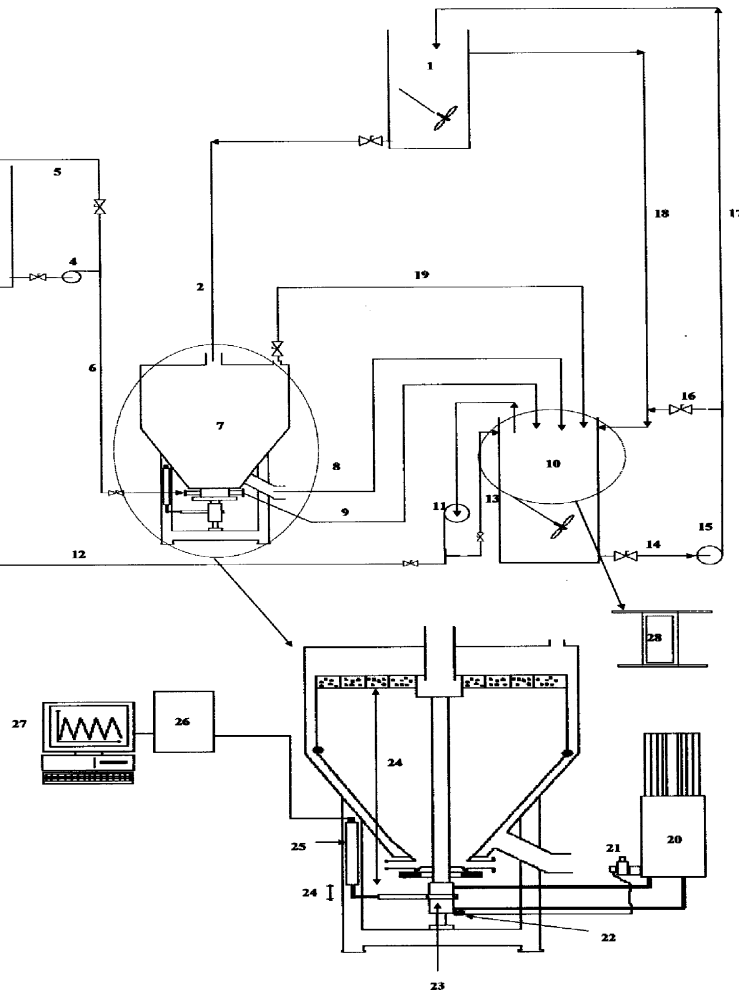


Fig. 5. Schematic representation of pilot plant used for test work. (1) Feed tank, (2) Inlet to IPJ, (3) Hutch water tank, (4) Hutch water pump, (5) Bypass valve, (6) Hutch water addition to IPJ, (7) Inline Pressure Jig (IPJ), (8) Tailings Outlet, (9) Concentrate Outlet, (10) Sump tank, (11) Hutch water return pump, (12) Feed line to hutch water tank, (14) Sump tank outlet, (15) Warman slurry pump, (16) Slurry pump recycle, (17) Feed line to feed tank, (18) Feed tank overflow, (19) IPJ air pressure release valve, (20) Variable speed motor, (21) Solenoid valve, (22) Hydraulic Ram level indicator, (23) Hydraulic Ram, (24) Movement of bed and linear transducer, (25) Variable resistance linear transducer, (26) Data logger, (27) Output of data to desktop computer, (28) Slurry-water separator.

2.3. Efficiency factor

To elucidate the measurement of the effectiveness of the unit at the steady-state variables, the following relationship was used to determine the efficiency of separation.

$$\text{Efficiency} = \frac{\rho_c - \rho_f}{\rho_s - \rho_f} \quad (7)$$

where ρ_s is dry higher density solid, ρ_c is dry density of concentrate and ρ_f is dry density of feed.

3. Test work and pilot plant setup

3.1. Description of pilot plant circuit

The IPJ pilot plant circuit consists of two circuits; one containing suspended solids for classification, and the other solids free, for the addition of hutch water to the

IPJ. The circuit was designed with the intention of preventing loss of material from the system. Steady-state conditions were achieved in a relatively short span of time after startup of the closed circuit preventing energy wastage. A schematic representation of the test circuit is included in Fig. 5.

3.2. Pulse motion data

Two types of data were collected; slurry samples and pulse motion data i.e. the actual displacement of the bed whilst in operation. This displacement data was collected by means of a Gefran linear variable transducer (potentiometer, 0–10 V) (Model number PC-M-0100). The potentiometer sends a continuous differential voltage to a Vanguard Digital data logger (model VGD-200/400/800) and converts the voltage to a digital output signal that is represented on a scale of 0–1000 units. These units were calibrated to the actual vertical position of the bed. The output of the logger is sent to an

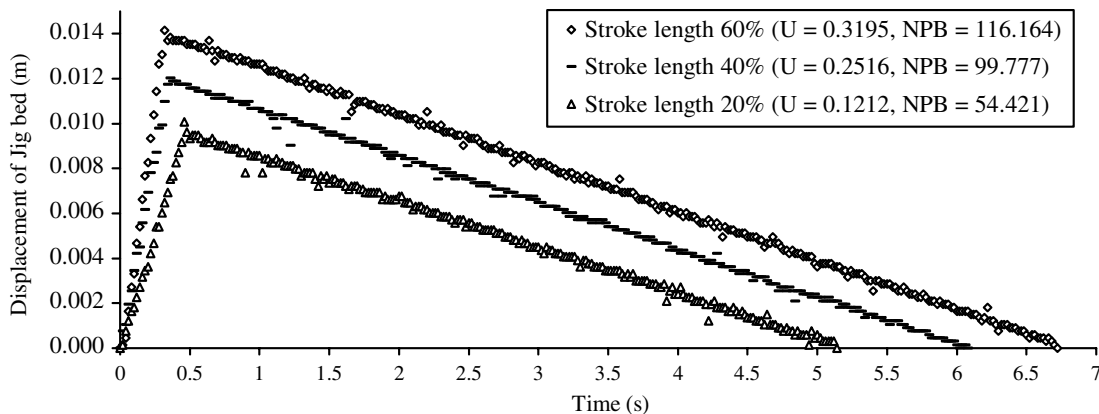


Fig. 6. Effect of Stroke length on the jigging cycle at a constant pulse of 30 and oil return aperture size 12% open.

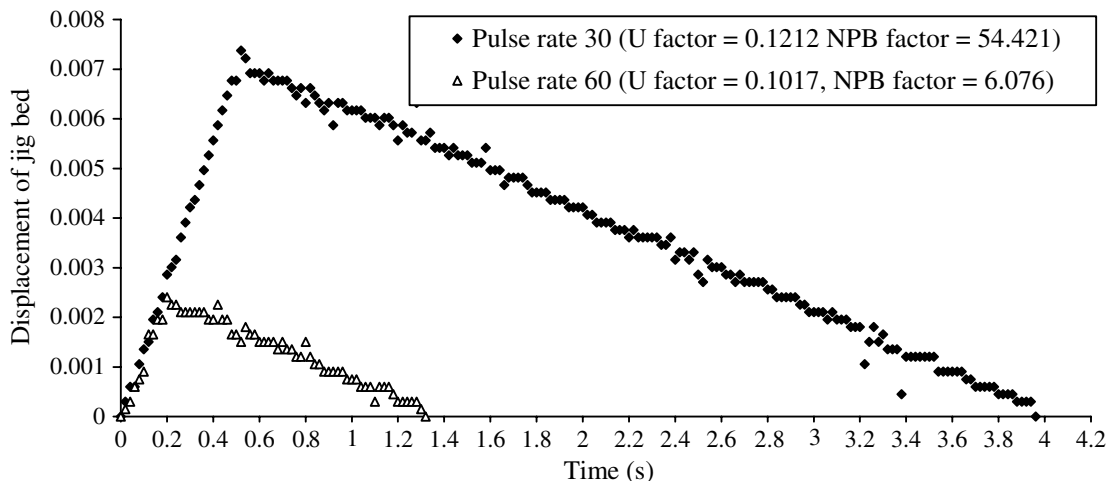


Fig. 7. Effect of pulse rate on jigging cycle with stroke length constant at 20% and oil return aperture size 12% open.

IBM compatible computer through an RS-232 cable, while the data collected can then be analysed through a basic spreadsheet program. Sample frequency could be varied from 20 to 120 Hz.

Slurry samples were taken from the concentrate and tailings outlets of the IPJ at different pulse settings. Smaller, representative samples were selected from these initial samples and their densities were measured accurately by means of a Micrometrics Helium Pycnometer (AccuPyc 1330). The densities were used to calculate the efficiency of the IPJ at different settings.

4. Results

4.1. Characterisation factors

The effect of stroke length, i.e. the hydraulic pump speed, was investigated and it was noted (Fig. 6) that the up-stroke-rate changed with a change in stroke-length-setting proving that the up-stroke-rate of the IPJ is entirely controllable, therefore improving the pos-

sibility of optimisation. In addition, it was noted in Fig. 6 that the down-stroke-rate can be controlled, by the oil return valve setting. It was notable that both the U and NPB factors effectively returned plausible values that would appear to reflect alterations in the nature of the pulse. The effect of pulse rate was investigated and it can be shown in Fig. 7 that a change in the pulse rate does not change the up- and down-stroke-rates, but actually changes the stroke length to accommodate the change in frequency. This statement proves that a change in pulse-rate effectively changes the size of the pulse. By contrast, Fig. 7 displays the effect of increasing frequency while maintaining a constant hydraulic motor speed and oil return valve setting. Clearly, the change in U factor with substantial change in the nature of the pulse is far less than the change in NPB factor.

4.2. U and NPB factor versus efficiency

In Figs. 8 and 9 the efficiency of the unit is plotted against the U and the NPB factors respectively. These figures show the spread of IPJ efficiency against the U

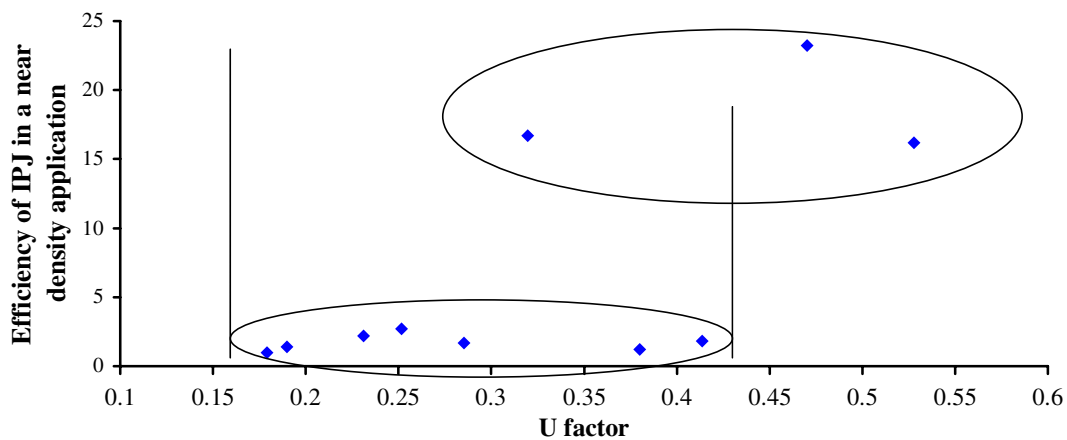


Fig. 8. Plot of efficiency of IPJ versus the U factor in a specific duty.

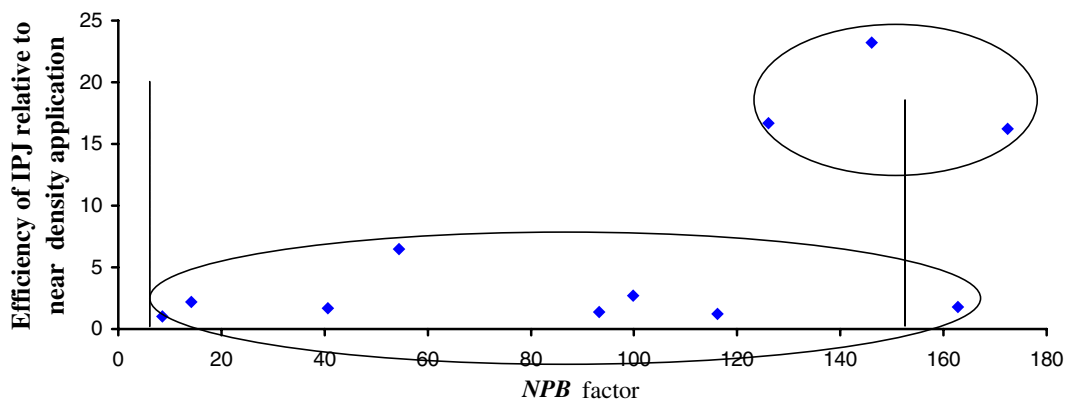


Fig. 9. The correlation of the efficiency of the IPJ versus the NPB factor.

and NPB factors and each can clearly be divided into two groupings of high and low efficiencies. However, in the case of the U , the centroid of these two groupings are much closer together than in the case of the NPB factor. This clearly indicates that the NPB factor will give a distinctive measurement of pulse nature.

5. Conclusions

It was found that all the settings in the IPJ had a major effect on its performance and therefore need to be correctly adjusted, particularly in the classification of close density species. These include other variables such as the hutch water addition, size and density of ragging, ragging bed depth and screen aperture size.

The necessity of having a universal factor that comprises the nature of the pulse of an IPJ is apparent and could be used, along with other jig variables to capture the system settings at steady-state and compare these to the efficiency of the unit for optimisation purposes. In addition it is apparent that the nature of the pulse curve is a complicated function of the three variables of the hydraulic circuit, namely; pump speed,

frequency and oil return valve setting, with every possible combination of these variables returning an original characterisation value in the case of the NPB factor.

The work done in this paper provides a cornerstone for future work and acts as a starting block for further investigation into the efficiency of an IPJ.

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