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Research Article

Research on Optimum Mass Concentration of Unclassified Tailings Paste based on the Herschel-Bulkley Model

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Abstract: Tailings paste technology is more and more widely applied in underground paste filling, surface paste discharge area. The core of the tailings paste technology is how to prepare qualified paste which has good stability and liquidity. The definitions of qualified paste are divaricated both at home and abroad. Heretofore, there is no uniform definition. In this study, the unclassified tailings of a certain Lead-Zinc mine were configured into slurry at the concentration of 70~78% for the rheological experiment. Based on Herschel-Bulkley model regression, we obtain slurry rheological equation through the flow exponent n to evaluate whether qualified slurry paste. When the flow exponent n = 1, slurry for the Bingham plastic fluid, the qualification concentration of the paste is optimal and the range of 74~76% are the optimal mass concentration. This conclusion is consistent with the reality through a slump experimental validation. This study puts forward with the flow exponent n to determine the optimal quality of paste concentration method is feasible and has great applied value.

Keywords: Herschel-bulkley model, optimum mass concentration, rheology, tailings disposal, unclassified tailings paste

INTRODUCTION

Mining industry provide raw materials for human beings. At the same time, it disturbs and destroys the earth's environment inevitably. According to statistics, China's existing tailings repository 12000, metal mine tailings impoundment reached 80 tons, 6 tons and an annual growth rate of. Tailings paste is disposed to be tailings thickening and dewatering, prepared with good stability, fluidity and plasticity of the toothpaste shaped cemented body, under gravity or under the action of external force to the plunger flow patterns conveying to the goaf filling or stacked. Paste preparation is the key to determine the reasonable rheological parameters and mass concentration, the paste has good stability and liquidity. Foreign usually think that when yield stress is greater than 200Pa namely qualified paste, while the domestic industrial application of tailing paste yield stress are not more than 200Pa. At present the domestic that paste meet Bingham plastic rheological model, namely the flow index n = 1 is qualified paste. Therefore, this study on the basis of experiments by using the theories of rheology analysis of different mass concentration of slurry rheological model and rheological characteristics and through the rheological index n determine full tailing paste suitable concentration range and the slump experiment to determine the paste concentration range verification (Zhai *et al*., 2011).

Total tailings slurry rheological model and its features: a large body of research shows that, total tailings slurry rheological characteristic of complex, in laminar flow, it is a kind of typical non Newtonian, generally yield pseudoplastic body, with the yield stress (Yu, 2009; Hallbom and Norwood, 2007). Used to paste the dynamic rheological model of two parameters Bingham plastic body model, Casson model, Law model and Power Herschel-Bulkley model with three parameters. In view of the three parameter model with two parameters of the model with high precision and wide adaptation range (Nehdi and Rahman, 2004), usually adopts Herschel-Bulkley model analysis under different shear rate slurry flow performance index and then determine the rheological model.

Herschel-Bulkley model formula is as follows:

$$\tau = \mu\gamma = \tau_0 + K\gamma^n \tag{1}$$

Type of:
τ = Shear stress, Pa
μ = Apparent viscosity, Pa•s

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Table 1: Rheological model of tailings pulp

Rheological characteristics parameters				
τ_0	n	Fluid type	Rheological model	Rheological parameters
$\tau_0 = 0$	n = 1	Newtonian fluid	$\tau = \mu(\frac{du}{dy})$	μ: viscosity coefficient
	n>1	Dilatant fluid	$\tau = K(\frac{du}{dy})^n$	
	n<1	Pseudoplastic fluid	$\tau = K(\frac{du}{dy})^n$	K: consistency index n: flow behavior indexes
τ_0>0	n = 1	Bingham plastic fluid	$\tau = \tau_0 + \eta(\frac{du}{dy})$	η: plastic viscosity
	n>1	Yield-dilatant fluid	$\tau = \tau_0 + K(\frac{du}{dy})^n$	
	n<1	Yield-pseudoplastic fluid	$\tau = \tau_0 + K(\frac{du}{dy})^n$	K: consistency index

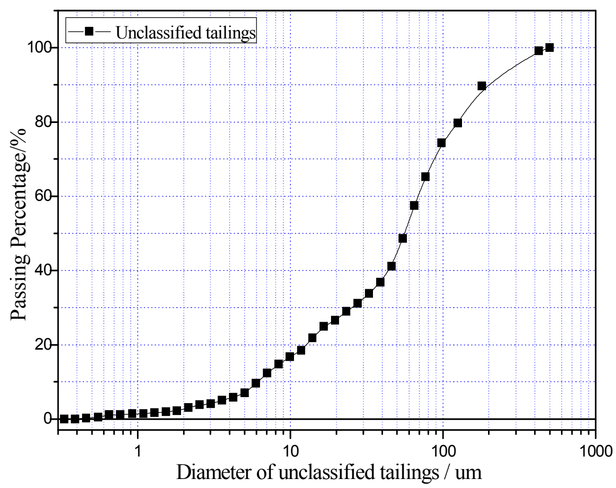

Fig. 1: Grain size curve of unclassified tailings

τ_0 = Yield stress, Pa
K = Consistency index Pa•s
n = Flow behavior indexes, n<1
γ = Shear rate, s^{-1}

When τ_0 = 0, n = 1 Newtonian fluids fluid; τ_0 = 0, n<1 power law fluid; if τ_0>0, n<1 Yield pseudoplastic fluid; When τ_0>0, n = 1 Bingham plastic fluid.

Total tailings slurry rheological model and the relationship between mass concentrations: total tailings slurry rheological model and quality has a direct relationship between the concentrations of. When the mass concentration of slurry is low, the rheological model is a Newtonian fluid. As the concentration increases gradually, the slurry appeared yield stress. Slurry in pipeline transportation process by the shear stress as a function of shear rate change bias to shear rate axis bending, showed pseudoplastic, then the slurry rheological model of yield pseudoplastic fluid. When the mass concentration close to the saturated state, slurry subjected to shear stress as a function of shear rate change tends to be straight, until meet the linear relationship, namely, Bingham plastic, the slurry concentration is the critical concentration of paste. Critical mass concentration is associated with fine particle size and content. Particles finer, rheological model changes more and more complex (Gan and George, 2009). So as long as the analysis of different mass concentration of slurry rheological model, so it can determine the critical concentration of paste.

This study uses Herschel-Bulkley model regression analysis, get the yield stress and flow index, as shown in Table 1 when n = 1, as Bingham plastic fluid, can be concluded that the concentration of slurry for qualified paste.

MATERIALS AND METHODS

Experiment materials: The experiment uses the Guangxi lead-zinc mine tailings, the tail sand level respectively by laser particle size analyzer and manual sieving to obtain, as shown in Fig. 1. Whole tailings accounted for 3.17 t/m^3, 56.3 μm, -20 μm particle content was 26.72%, -74 μm particle content is 64.15%. Through calculation, full tailings' C_U value of 12.98, C_C value of 0.067, according to the engineering experience, tailing grade distribution range, but the tail sand continuous condition.

Table 2: The parameters of R/S + rheometer

Model	Shear rate (s^{-1})	Time (s)
CSR	0-120	120

Fig. 2: R/S + rheometer

Experimental instruments and solutions: experimental measurement instrument is R/S + Rheometer (Fig. 2). The apparatus is suitable for the measurement of rigid suspension and paste. The apparatus and computer program Rhoe3000 connection, computer control. Because of measurement accuracy, in recent years in foreign countries it's use more popular. Compared with traditional capillary viscometer, cross-shaped rotor on the sample structure of minimal damage and can be in low speed measurement of yield stress fluids; and a conventional cylinder rheometer in Fig. 2, the maximal overcomes the cylindrical surface of the slip effect, thus greatly improves the measurement accuracy of (Nguyen *et al*., 2006; Barnes and Nguyen, 2001). Figure 2 the rotor V60-30-3tol, 500 mL beaker, balance etc.

The experiment accords to the mixture ratio preparation of different slurry in a beaker, placing in a rheometer, according to Table 2 parameter settings.

In the experiment, the Guangxi Lead-Zinc Tailing configuration of the concentration of 70~78% slurry rheological parameter test, respectively, on the basis of Herschel-Bulkley model regression the rheological equations, determine the value of yield stress and flow index n and then determine the paste suitable concentration range and the slump experiment validation.

RESULTS AND DISCUSSION

Different concentration of slurry rheological characteristic parameter is shown in Table 3. As you can see from Table 3: in addition to the slurry concentration is 78% because of the yield stress is too big, already exceeded the rheological measurement range cannot be measured, other concentration slurry were returned to get more accurate rheological equation, R^2 above 0.9.

Figure 3 different slurry concentration, shear stress, shear rate curves, as you can see from Fig. 3 with the

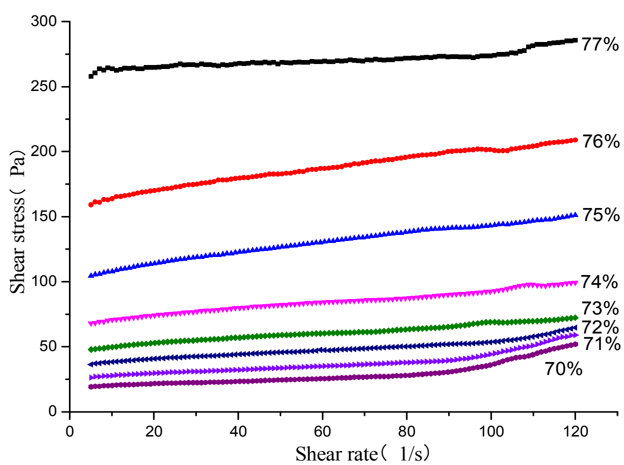

Fig. 3: Plots of shear stress versus shear rate

Table 3: Rheological characteristics parameters of the slurry

Mass concentration (%)	Rheological equation	R^2	Yield stress τ_0	Flow behavior indexes n
78	Beyond the scope of rheometer, not start	-	Too large, not start	-
77	$\tau = 265.09 + 9.54 \times 10^{-5} \times (\gamma)^{2.54}$	0.912	265.09	2.54
76	$\tau = 154.48 + 1.89 \times (\gamma)^{0.7}$	0.996	154.48	0.70
75	$\tau = 98.77 + 1.94 \times (\gamma)^{0.68}$	0.999	98.77	0.68
74	$\tau = 68.05 + 0.38 \times (\gamma)^{0.91}$	0.988	68.05	0.91
73	$\tau = 47.85 + 0.3 \times (\gamma)^{0.91}$	0.991	47.85	0.91
72	$\tau = 38.83 + 0.021 \times (\gamma)^{1.45}$	0.966	38.83	1.45
71	$\tau = 30.24 + 9.07 \times 10^{-6} \times (\gamma)^{3.11}$	0.967	30.24	3.11
70	$\tau = 22.18 + 2.29 \times 10^{-7} \times (\gamma)^{3.9}$	0.984	22.18	3.90

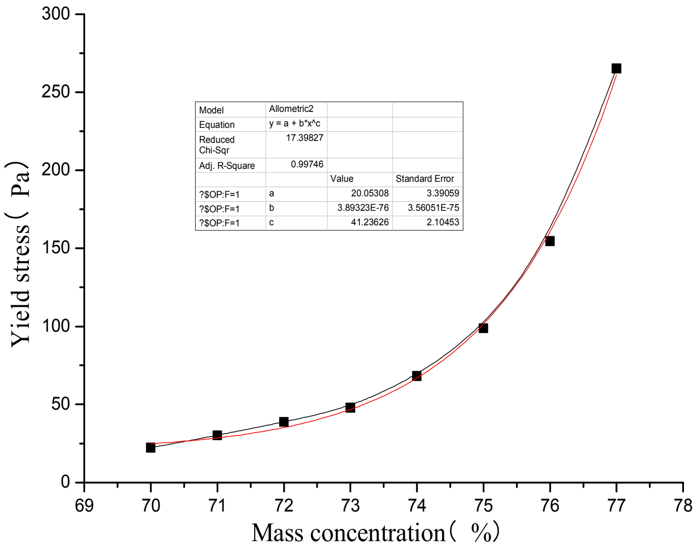

Fig. 4: Plots of yield stress versus mass concentration

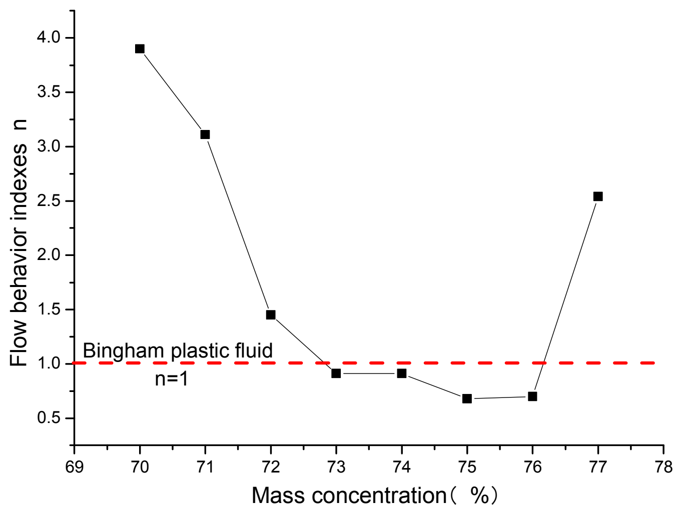

Fig. 5: Plots of flow behavior indexes versus mass concentration

increase of the concentration of slurry, the shear stress increases ceaselessly. In the slurry concentration is greater than 73%, the shear stress with the slurry concentration increased dramatically increases. When the concentration was 78%, the slurry shear stress is too large, more than rheometer measuring range.

Figure 4 for the slurry concentration, yield stress curves. As you can see from Fig. 4, with the slurry concentration increased the yield stress of exponentially increasing. The slurry concentration in the range of 73~75%, mutation interval, i.e., when the concentration exceeds this interval is increased dramatically, liquidity of slurry decreased dramatically.

Figure 5 for the slurry concentration-flow index n curve. As you can see from Fig. 5, with the slurry concentration increases, the flow exponent n presents the first decreased and then increased trend. From the yield- expansion plastic body, plastic body, yield-pseudoplastic to yield-expansion plastic body, forms a concave curve. When n = 1 for the Bingham plastic body and the ideal paste is Bingham plastic body. As shown in Fig. 5, the curve and the N equal to 1 straight two point; nodal mass concentrations were 72.8 and 76.2%. It can therefore be considered concentration was 72.8 and 76.2% when the slurry for the Bingham plastic body. In the preparation of paste process, in ensuring

Table 4: Experimental results of slump

Mass concentration (%)	Slump (cm)	Slump flow (cm)
76	25.1	47
75	26.3	59
74	27.2	72

Fig. 6: Picture of slump on mass concentration 76%

Fig. 7: Picture of slump on mass concentration 75%

Fig. 8: Picture of slump on mass concentration 74%

the study performance of the premise, should try to improve the quality of concentration, reducing the rate of moisture. Therefore, through the flow exponent can be a mine tailing paste concentration should reach 76.2%.

Slump test: From rheological experiment shows, slurry concentration in 76.2% can be considered as a Bingham plastic, to meet the requirements of qualified paste. This part of the experiment was to slump experiment on rheological experimental results. The rheological results basis, the slurry concentration of 76, 75, 74%, respectively slump experiment (Table 4).

From the collapse of experiments can be seen in the 74~76%, concentration of slurry with suitable slump value and extension value. With the mass concentration decreases, expansion degree increase significantly, from 76% when the concentration of 47 cm increased to 74% when the concentration of 72 cm. The photo is shown in Fig. 6 to 8.

Through the slump test shows, rheological experimental results with the slump test results, the slurry concentration in the 74~76% can obtain good fluidity.

CONCLUSION

By varying the concentration of slurry rheological characteristic parameters of experiment can be obtained, the slurry concentration is 78%, the yield stress is too large and beyond the rheometer range cannot be measured. When the concentration is approaching 77% obtained experimental results; concentration in 73~75%, yield stress occurring mutations, amplitude big; through the flow index to identify qualified paste concentration of 76.2%; due to concentration from 76 to 77%, the yield stress amplitude is very big. In the actual production if the paste concentration is 76.2%, if the paste preparation errors, will make the paste properties of qualitative change, it is recommended in the production of the paste mass concentration in the range of 74~76%, try to make paste concentration reached 76%; through the establishment of full tailing paste Herschel-Bulkley model, then with the flow exponent n to determine the optimal concentration of full tailing paste method is feasible, as qualified paste is provided by determining a new method.

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