Industrial Scale-up of Fiber Recovery Technology from Mixed Office Waste Fine Screen Rejects

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Industrial-scale testing was performed for fine screen reject recovery technology with a mixed office waste (MOW) pulping line. Results showed that the recovery system removed macrostickies and dirt specks with an efficiency of 95.7% to 98.3% and 51.5% to 76.8%, respectively. These results were not affected by the running consistency (0.26% to 1.44%). The recovery system improved the physical strength of the pulp. Relative to untreated rejects, the tensile index increased 5.1% to 15.2%, the tear index increased 6.6% to 11.4%, and the breaking index increased 6.6% to 25.7%. Running consistency had no obvious effects on tensile strength and tear strength, but bursting strength increased with increasing running consistency (%). The volume energy consumption (y) increased with increasing running consistency (x), and a linear relationship of $y = 0.73x + 4.2191$ ($R^2 = 0.9466$) was observed. The specific energy consumption (y) of the pulp decreased with increasing running consistency (x), and the relationship could be expressed as $y = 499.67x^{-0.906}$ ($R^2 = 0.9959$).

Keywords: Secondary fiber; Fine screen reject; Fiber recovery; Macrostickies; Dirt specks; Physical strength

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INTRODUCTION

Waste paper is an important renewable resource, and its recycling is greatly beneficial to the economy, society, environmental protection, and resource utilization. Due to a desire to reduce paper raw material shortage and forest resource scarcity, the recycling and utilization of waste paper has long been an issue of great concern in China. The amount of recycled waste paper has increased each year. Since 2000, the amount of waste paper used has soared at a rate of over 3 million tons per year (Fan *et al.* 2018; Su *et al.* 2019). By 2016, waste pulp consumption in China reached 63.29 million tons (China Paper Association 2017). Waste paper consumption accounts for 65% of total pulp consumption, which is much higher than that of wood pulp (29%) and non-wood pulp (6%) (China Paper Association 2017). As such, waste paper has become the main raw material of the pulp and paper industry in China. Waste paper products include colored newsprint, high-strength corrugated base paper, carton paper, coated white cardboard, printing paper, and domestic paper.

In 2017, to implement the plan of the China State Council on “the reform of the administration system for the import of solid waste" (General Office of the State Council of the People's Republic of China 2017), the Ministry of Environmental Protection of the People's Republic of China (2017) released a series of policies that aim to increase the use of fiber raw materials. Therefore, it is essential to study methods of improving waste paper utilization efficiency. In waste paper pulping, a large amount of reject is discarded during the purification process, in which fine screen reject accounts for 2% of raw materials. Although most fine screen reject consists of long fibers of high quality, it can only be discharged from the system and utilized to produce low-value products due to its high macrostickies content. This wastes fiber raw materials, adds to solid waste pollution, and increases the cost of solid waste treatment. Much research has been conducted on the properties of waste paper pulping and deinking (Chen 2003; Long and Wen-Ying 2014). Results indicate that high-frequency decontamination can be used in combination with flotation to recover fine screen reject fibers in mixed office waste (MOW) and old newspapers (ONP). The removal rates of macrostickies and dirt specks reached over 90% and 70%, respectively (Su *et al.* 2019). The recovery rate of fibers was about 80%. In addition, paper tensile resistance and breaking resistance can be improved by 20.2% to 23.5% and 29.3% to 32.3%, respectively (Su *et al.* 2018a, 2019). When treating ONP fine screen rejects, the removal rate of macrostickies and dirt specks can reach over 80% and 53.0%, respectively, and the removal rate of residual ink can reach over 25% (Su *et al.* 2018b). Further, the tensile strength, tear-resistance, and breaking resistance increased 95.4%, 16.3%, and 84.3%, respectively (Su *et al.* 2018b).

In this study, the pilot-scale magnified system was used in the MOW line to study the industrial recovery rate of fibers, the removal rate of macrostickies and dirt specks, and the tensile resistance, tear-resistance, and breaking resistance of paper. Samples were taken continuously with different running consistencies, and the impact of running consistency on the removal of macrostickies, the removal of dirt specks, and pulp strength were studied to provide a reference and promote industrial adoption of similar methods.

EXPERIMENTAL

Materials

The fine screen rejects were sampled from the MOW paper mill production line, Dongguan City, Guangdong Province, China, and the physical test results are summarized in Table 1.

Table 1. Characteristics of Fine Screen Reject

Brightness (%)	ERIC 700 (ppm)	Macrostickies (mm^2/Kg)	Dirt Specks (mm^2/m^2)	Ash (%)	R200 (%)
65.2 to 71.8	93.0 to 98.0	6027 to 23413	1293 to 3640	14.0 to 14.8	86.8 to 91.8

Analytical Methods

Macrostickies were analyzed with a master screen-type instrument (Pulmac Screen MSA-XLQ; Cowan Technologies Inc., Montpelier, VT, USA) and a scanning system Spec*Scan2000 (Apogee, Norwood, MA, USA) according to TAPPI T277 pm-99 (1999). Twenty hand sheets were prepared for dirt speck analysis with an image analysis system according to TAPPI T563 om (2012). For ash content analyses, the filter papers for the consistency measurement were incinerated at 525 °C. Brightness, residual ink, fiber length, and physical strength were analyzed according to ISO 2470 (2016), TAPPI T567 om (2009), TAPPI T233 cm (2006), and TAPPI T220 sp-10 (2010), respectively.

High-frequency dispersion

Dispersion was performed using a magnified-scale high-frequency dispergator 23 (ZRI Haarla Oy, Tampere, Finland), which consisted of a stator and a rotor with a frequency of 300 Hz (18000 rpm). The fine screen reject was dispersed *via* continuous feeding into the center of the stator at a pressure of approximately 1 bar to 2 bars. During dispergator operation, the gap between the stator and rotor was approximately 1 mm. A manual valve was used to control the through flow and the pressure, which was 1 bar. All parameters, such as flow, pressure, concentration, and energy consumption were automatically monitored by the system.

Flotation

An HG continuous flotation cell was used for the flotation of accept pulp from the high-frequency dispergator. The airflow was kept constant for the entire experimental process. No additional chemicals were used, as the samples contained residual flotation chemical agents. Samples of each batch and the removed froth were taken before and after flotation for analysis. The fine screen reject recovery process is shown in Fig. 1.

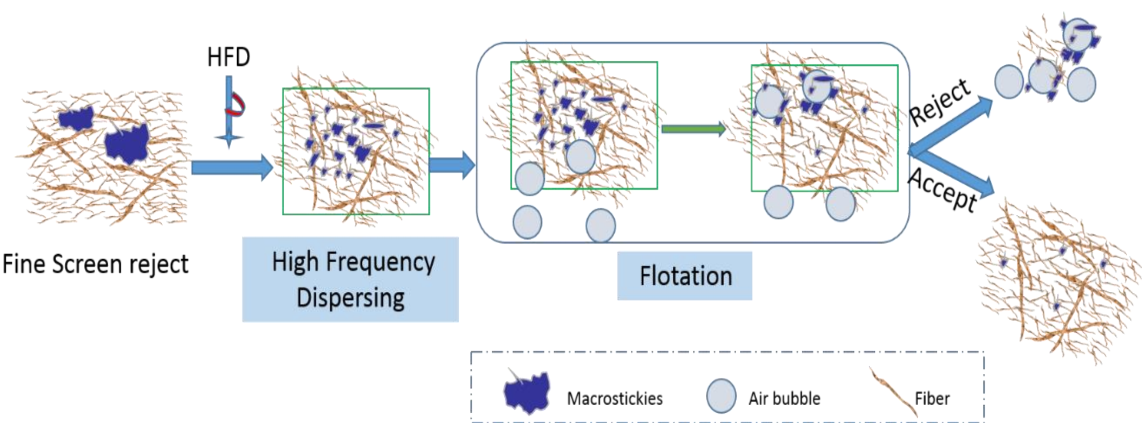


Fig. 1. The Fine Screen Reject recovery process

Handsheet Making

Handsheets of' 60 g/m^2 were made and dried in a RK-3A Rapid-Kothen sheet former (PTI Laboratory Equipment, Vorchdorf, Austria).

RESULTS AND DISCUSSION

Removal of Macrostickies

Macrostickies control is essential during the fine screen reject treatment process, as high macrostickies content is the biggest obstacle to the reuse of fine screen reject. To investigate the effect of fine screen reject recovery system on the removal of macrostickies, several rounds of trials were conducted with different consistencies (0.26%, 0.55%, 0.62%, 1.36%, and 1.44%). Untreated samples, dispersed samples, and dispersed and floated samples were taken for each consistency condition, and their macrostickies contents were analyzed. The content and size distributions are presented in Figs. 2 and 3, respectively.

Figure 2 shows that the quality of the fine screen reject discharged from the production line in the different periods fluctuated greatly. The original macrostickies content of the samples ranged from 6027 mm^2/kg to 23413 mm^2/kg, but decreases of 48.7% to 80.9% were observed in macrostickies content. Although the original macrostickies contents and the macrostickies removal rate varied greatly due to dispersion, the overall removal rate of macrostickies after flotation with a reject rate of approximately 25% ranged from 95.7% to 98.3%. In addition, the consistency of fine screen reject during dispersion had no remarkable effect on macrostickies removal efficiency. The macrostickies size distribution (0.26%, 0.55%, 0.62%, 1.36%, and 1.44%) shown in Fig. 3 is represented in plots A, B, C, D, and E, respectively. The high-frequency dispersion had a noticeable effect on macrostickies larger than 0.25 mm^2 regardless of running consistency. With running consistencies of 0.26%, 0.55%, 0.62%, 1.36%, and 1.44%, the content of large-sized macrostickies (> 0.25 mm^2) decreased 86.1%, 82.7%, 87.6%, 77.1%, and 92.9%, respectively, during dispersion. For 0.26% running consistency, a decrease from 4323 mm^2/kg to 600 mm^2/kg was observed. For 0.55% running consistency, a decrease from 5315 mm^2/kg to 918 mm^2/kg occurred. For 0.62% running consistency, a decrease from 20781 mm^2/kg to 2587 mm^2/kg was observed. For 1.36% running consistency, a decrease from 5722 mm^2/kg to 1312 mm^2/kg was observed. For 1.44% running consistency, a decrease from 17776 mm^2/kg to 1260 mm^2/kg occurred. However, high-frequency dispersion had no obvious effect on the removal of macrostickies smaller than 0.25 mm^2. The rubbing action that occurs during kneading may modify the shape of macrostickies and cause them to become more spherical, and the high-speed dispersers produce more impacts, which lead to breakup of the particles (Su *et al.* 2018a,b). The results indicate that the dispersion effectively breaks the large contaminants into smaller pieces.

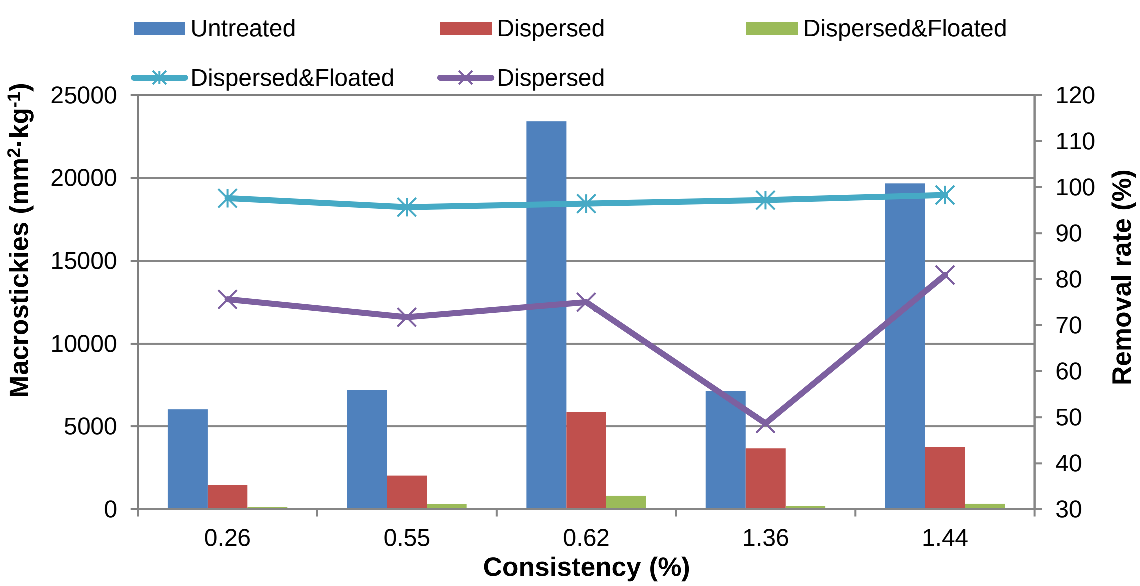
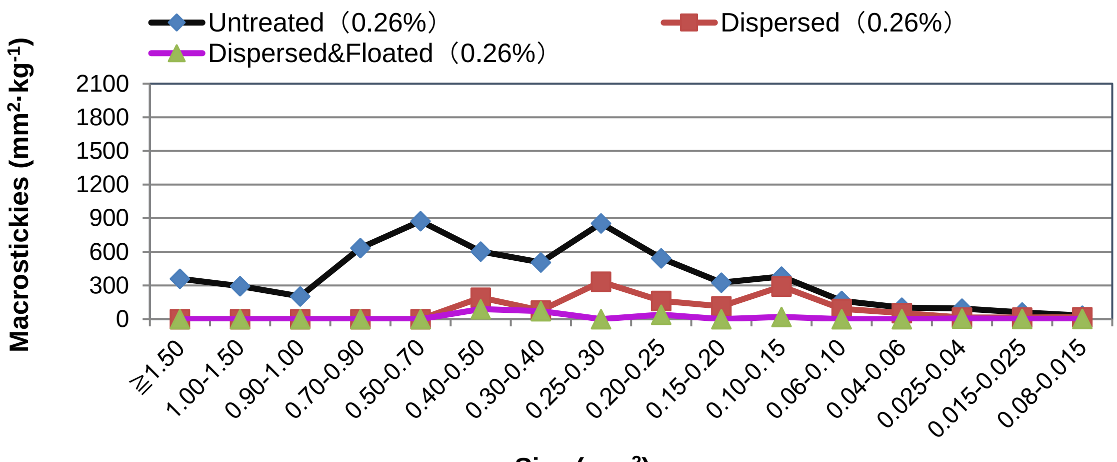
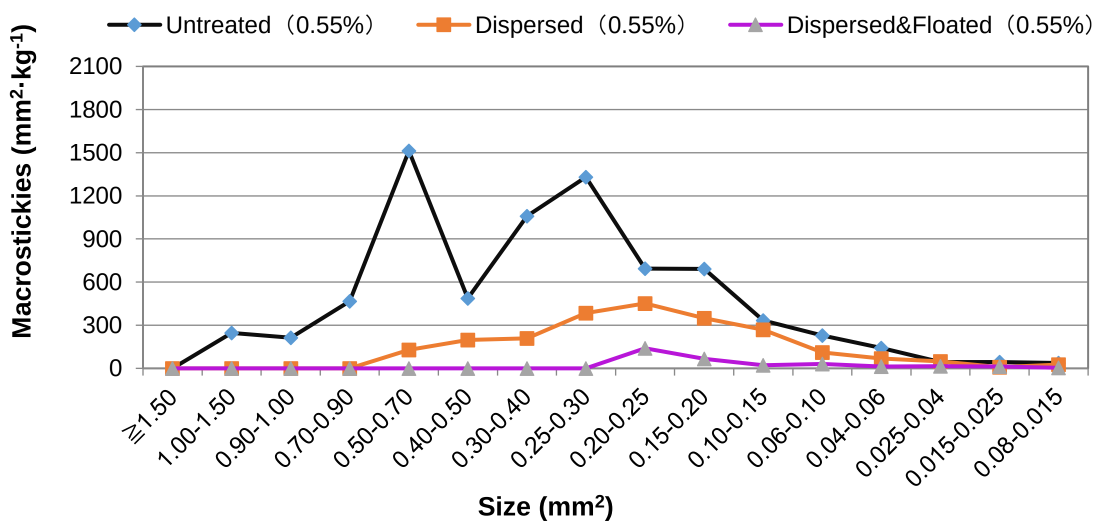


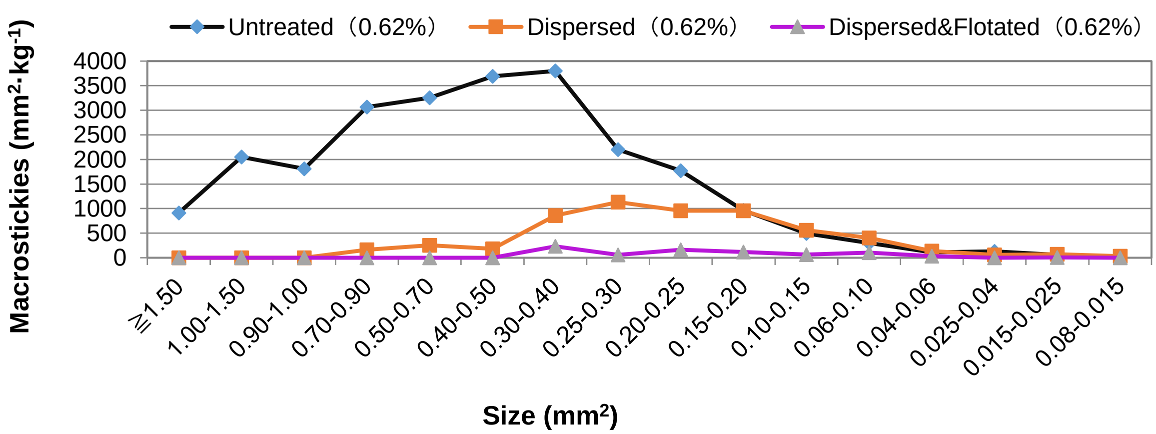
Fig. 2. The macrostickies contents under different consistencies in the screen reject recovery process



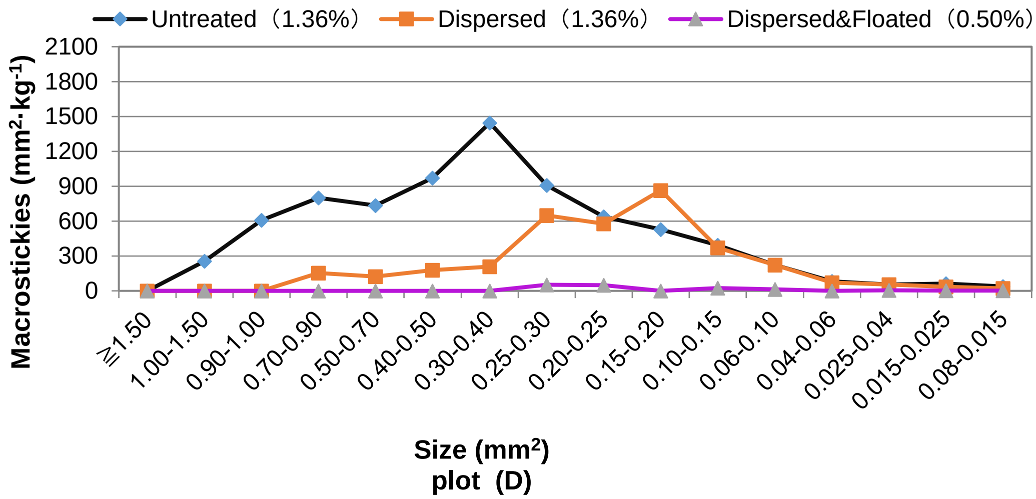
plot (A)



plot (B)



plot (C)



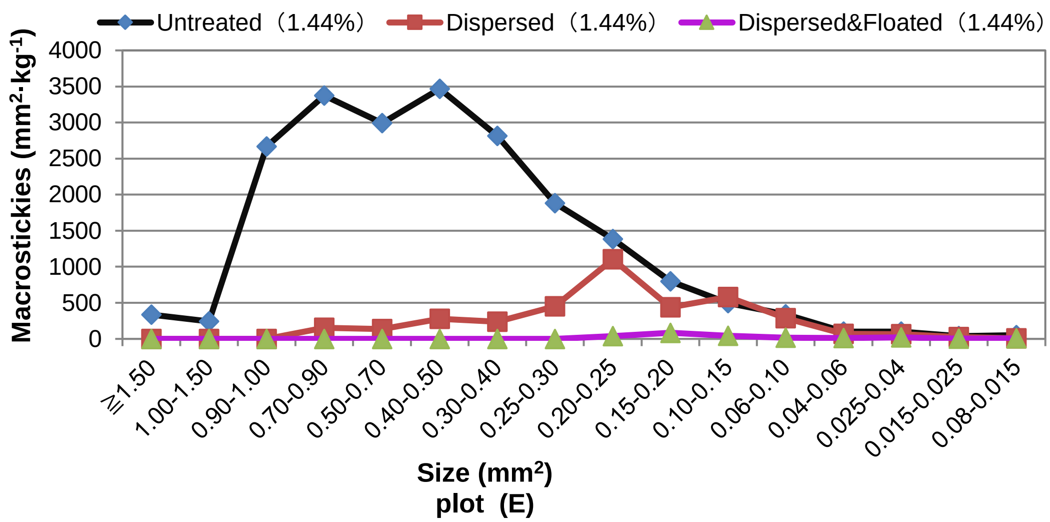


Fig. 3. Plots A, B, C, D, and E describe macrostickies size distributions under different consistencies (0.26%, 0.55%, 0.62%, 1.36%, and 1.44%), respectively

Stickies became attached to air bubbles and rose to the surface of the flotation cell with the bubbles, which allowed their removal from the system. This study suggested that the improved removal of large contaminants in flotation may have been due to the newly formed or cleaned surface produced by dispersion (Su *et al.* 2018a,b). In addition to size reduction, high-frequency dispersion may have also cleaned and activated the surfaces of the contaminants, which improved their adhesion to the bubble surfaces and their ability to float. For all running consistencies, the removal rate of macrostickies larger than 0.25 mm^2 was over 96.2%, and the removal rate of macrostickies smaller than 0.25 mm^2 was above 86.3%. Over 75% of the fine screen reject treated by the fiber recovery system could be recycled.

Removal of Dirt Specks

Dirt specks are also a problem in the recycling of fine screen rejects. The dirt specks of the samples from the inlet and outlet of the high-frequency dispergator and floatation cells under different running consistencies were analyzed to evaluate the effect of the process on dirt speck removal. The results are presented in Fig. 4.

Figure 4 shows that the original dirt speck contents of fine screen reject varied from 1293 mm^2/m^2 to 3640 mm^2/m^2 on the MOW fiber line. Running consistency and original dirt speck content had no noticeable effects on the dirt speck removal efficiency of the fiber recovery system. Dirt speck removal rates of 41.0% to 50.8% were observed after high-frequency dispersion. High-frequency dispersion had a marked effect on large dirt specks (> 0.1 mm^2), and the removal rate reached 49.0% to 62.8%. In addition, flotation had a dirt speck removal rate of 7.7% to 26.2% without obvious selectivity for dirt speck size, which was consistent with the results of Su *et al*. (2018b). These results indicated that dirt specks, particularly those large in size, were fragmented into smaller particles, and dispersion caused some of the dirt specks to fail to be measured. Further, some of dirt specks were removed with the flotation rejects by subsequent floatation.

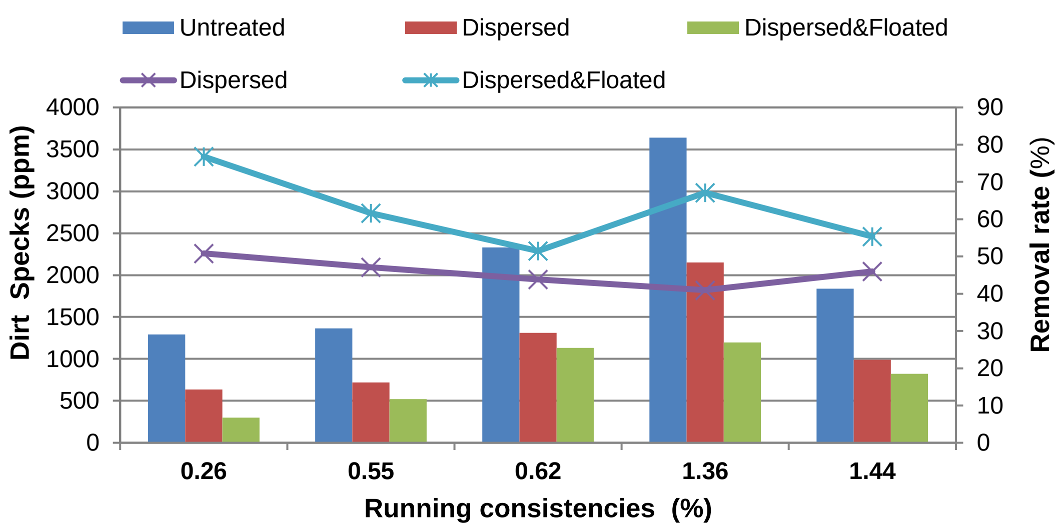


Fig. 4. The dirt speck contents with different running consistencies (0.26%, 0.55%, 0.62%, 1.36%, and 1.44%)

Effects on Pulp Strength

The physical properties of the different samples during the recovery process were tested under standard atmospheric conditions (50 ± 2% relative humidity and a temperature of 23 ± 1 °C) to investigate the effect of high-frequency dispersion and flotation on the quality of recovered pulp. The results are presented in Figs. 5, 6, and 7.

Figure 5 shows that the tensile strength of the samples increased 5.3% to 19.5% from 24.2 $N\cdot m\cdot g^{-1}$ to 27.6 $N\cdot m\cdot g^{-1}$ to 28.0 $N\cdot m\cdot g^{-1}$ to 31.6$\cdot m\cdot g^{-1}$, relative to paper made from the unmodified fine screen rejects, after high-frequency dispersion with different running consistencies, but the influence of floatation on tensile strength was not clear. Figure 6 shows that the average improvement in samples was over 12% after high-frequency dispersion and flotation, which showed no noticeable correlation with running consistency. Figure 7 shows that the burst strength of the samples increased 6.6% to 25.7% after high-frequency dispersion and flotation, and burst strength was found to increase with increased running consistency. This result indicated that high-frequency dispersion acted on the macrostickies and dirt specks and had a mechanical effect on the fibers, which allowed bonding between fibers with more exposed hydrogen bonds. This finding was supported by the increased beating degree of the samples of approximately 2 °SR. The removal of impurities by flotation enhanced the combination of fiber and fiber. However, the removal of fines decreased the strength of the samples. These interactions resulted in fluctuation in tensile strength, burst strength, and tear strength after flotation. In summary, the industrial-scale test results supported the findings of other literature (Su *et al.* 2018b). High-frequency dispersion and flotation recovery of pulp fiber from MOW fine screen reject improved tensile strength, tear strength, and burst strength.

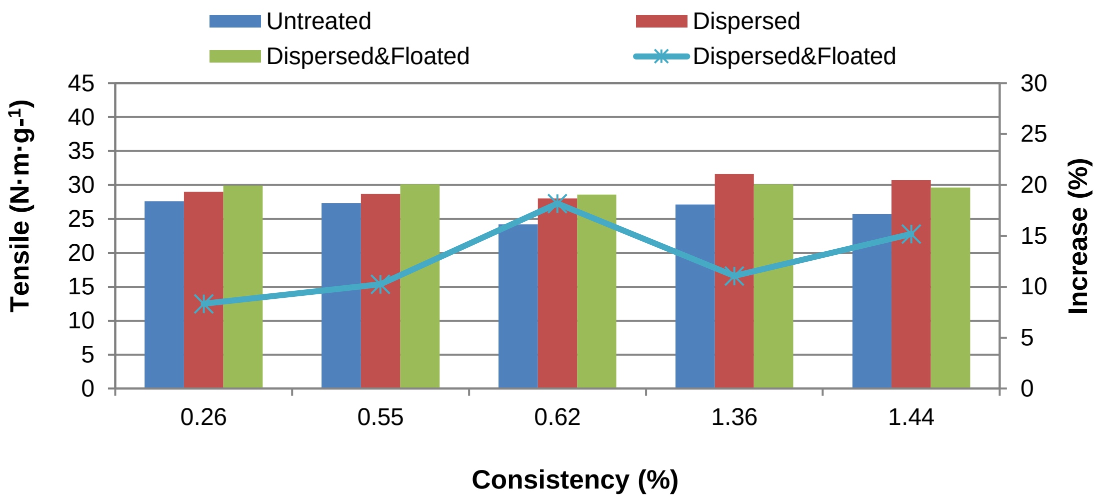


Fig. 5. The tensile strength of samples with different running consistencies (0.26%, 0.55%, 0.62%, 1.36%, and 1.44%)

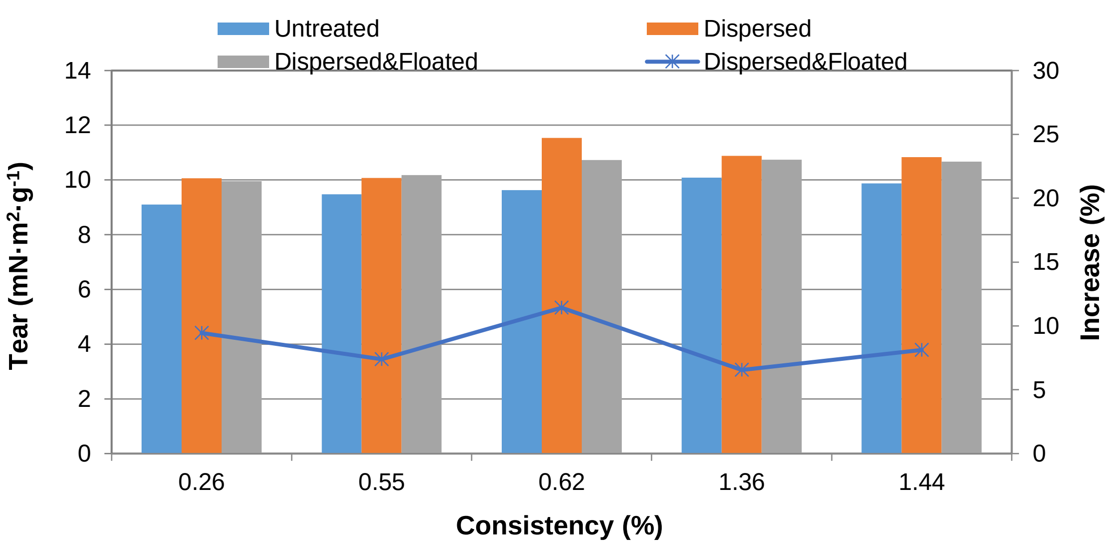


Fig. 6. The tear strength of samples with different consistencies (0.26%, 0.55%, 0.62%, 1.36%, and 1.44%)

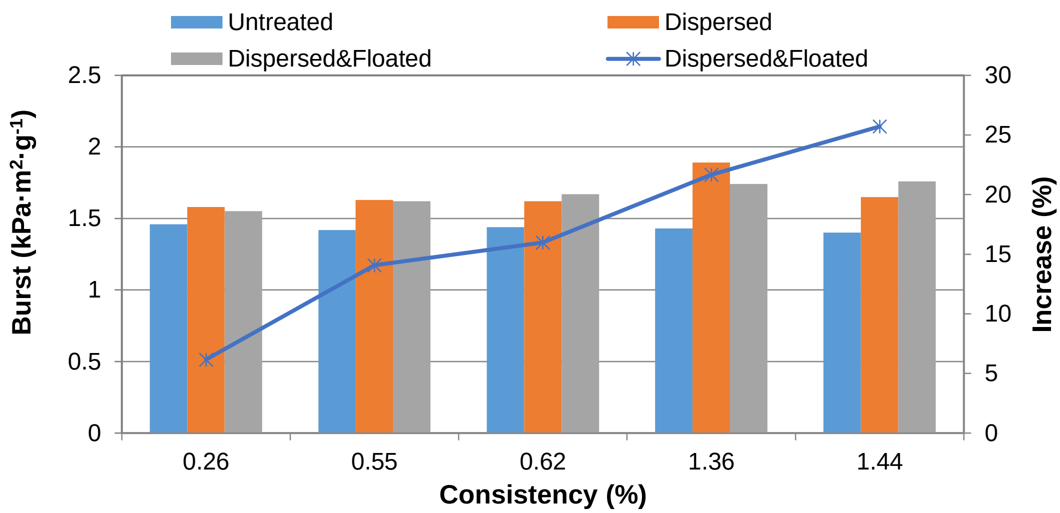


Fig. 7. The burst strength of samples with different consistencies (0.26%, 0.55%, 0.62%, 1.36%, and 1.44%)

Energy Consumption

Energy consumption is the main operating cost of the fine screen rejects recovery system, and it directly determines the economic feasibility of the technology. The energy consumption of the system was measured separately during testing. The energy consumption of the slurry pulp at different concentrations and per ton of pulp (as BDT) is shown in Fig. 8.

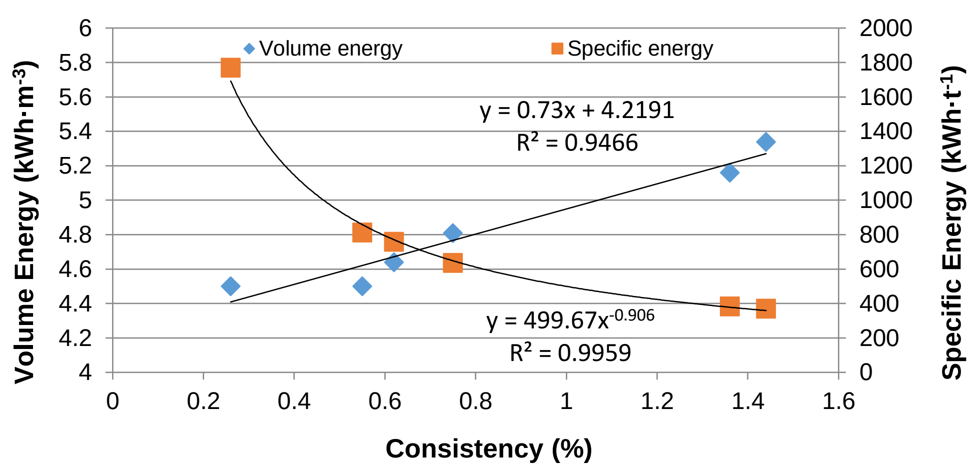


Fig. 8. Volume energy and specific energy correlations with different consistencies (0.26%, 0.55%, 0.62%, 1.36%, and 1.44%)

Figure 8 shows that the volume energy consumption (y) of the fine screen reject treatment system increased with increased operating concentration (x), and a good linear relationship was observed: $y = 0.73x + 4.2191$ ($R^2 = 0.9466$). The energy consumption per ton of dry pulp (y) decreased with increasing operating concentration (x), and energy consumption per ton dry pulp and operating concentration had a power function relationship: $y = 499.67x^{-0.906}$ ($R^2 = 0.9959$).

CONCLUSIONS

1. The industrial-scale test results of the fine screen reject recovery system were consistent with those in the literature, as the system effectively removed large macrostickies and dirt specks from the fine screen reject, and the removal efficiency of macrostickies and dirt specks reached 95.7% to 98.3% and 51.5% to 76.8%, respectively. High-frequency dispersion had a remarkable effect on the removal of large macrostickies and dirt specks regardless of operating concentration from 0.26% to 1.44%.
2. The fine screen reject recovery system improved the physical strength of the pulp. The tensile index increased 5.1%, the tear index increased 6.6%, the tear index increased 11.4%, and the tear resistance index increased 6.6% to 25.7%.
3. The volume energy consumption (y) of the fine screen reject treatment system increased with increasing concentration (x), and a good linear relationship was observed: y = 0.73 x 4.2191 (R^2 = 0.9466). Specific energy consumption (y) decreased with increasing concentration (x), and a power function relationship was observed: $y = 499.67x^{-0.906}$ (R^2 = 0.9959).

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