EFFECTS OF HOT DISPERSION ON THE PROPERTIES OF DEINKED PULP

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From a literature review, it is apparent that although hot dispersion is an integral unit of the deinking process, there has been no systematic study of the effects of pulp consistency and operational temperature on the physical and optical properties of the resulting paper. In this study, we used a mill-site hot dispersion system to treat computer forms and examined the effects of different operational temperatures and pulp consistencies on resultant handsheet properties. Operational temperatures were controlled at 90, 100, 110, and 115 °C and pulp consistencies at 19%, 32%, 35%, and 36%. The pulp freeness was measured, and the tensile strength, burst index, tear strength, stiffness, brightness, whiteness, opacity, and light scattering coefficient of the handsheets were parameters of interest. Results indicated that when operated at consistencies of >32%, the temperature effects were more significant than the consistency effects. At 110 °C, the highest pulp freeness, handsheet tear strength, whiteness opacity, and light scattering were obtained. When operating at 100 °C, the highest handsheet tensile strength, stiffness, and coefficient of absorption were obtained; at 90 °C, the highest handsheet burst index was produced; and at 115 °C, the highest handsheet brightness was engendered. With regard to consistency, at 35%, the highest handsheet burst index was reached. All other properties examined showed no significant correlation with pulp consistency. In summary, hot dispersion should be operated at temperatures of 100~110 °C, and consistencies of >32%.

Keywords: disperser, consistency, temperature, deinked pulp, physical properties, optical properties

INTRODUCTION

Since the 1980s, hot dispersion systems have been a standard unit of deinking pulp mills. The main purpose of hot dispersion is to impart mechanical treatment at high temperatures (either 40~60 or 90~150 °C) and high consistencies (25%~30%), and through the working of suitable facilities, to transfer energy to the pulp. Hot dispersion cannot remove the ink, toner, and sticky particles entrained in the pulp, but rather the high shear forces diminish the sizes of these particles to smaller dimensions. Simultaneously, high shear forces acting on high-consistency pulp tend to separate unwanted contraries attached to the fibers, which can then be removed at the next operation unit. Under the high-temperature and high-consistency conditions exerted by suitably designed disks, fibers are kneaded together and the hornified layers are peeled away, leading to better fiber activation and disintegration of fiber bundles, which in turn influence the physical and optical properties of paper.[1-11]

The main units of a hot dispersion system include a thickener, a heating screw, and a disperser (refiner), as shown in Fig. 1. A hot dispersion system can operate under atmospheric- and high-pressure conditions. High-pressure conditions are conducive to the dispersion of inks and stickies. A plug screw helps feed pulp from the thickener to the heating screw, while avoiding pressure loss and steam escape.[4] Mechanical actions of high temperature and consistency of a hot dispersion system alter the properties of the pulp and fibers. However, most information in the literature is on reducing contraries or dirt, not altering pulp or fiber properties. Only a few reports mentioned pulp or fiber properties.

Lundberg[12] used a conical high-speed disperser by Sund Defibrator to treat old newsprint pulp/old magazine pulp (ONP/OMP). He noted that the tensile index increased when the pulp was treated at 70 and 90 °C; however, the 120 °C experimental set showed an adverse effect on the tensile index. Zachrisson[13] used a Cellwood disperser to treat deinking laser-printed paper. He noted an increase in the tear strength while the breaking length remained the same. Rangamanner and Silveri[14] used a Beloit disperser to treat white ledger paper and found that along with decreasing pulp freeness, the burst strength, breaking length, tear strength, and wet tensile energy absorption (TEA) increased. Niggl[15] used a Sulzer Escher-Wyss disperser to treat household waste paper, and pulp obtained at a discharge consistency of 5% had a higher breaking length than that obtained at a 30% consistency, but it had lower tear strength. McKinney[16] found that treatment with a hot dispersion system increased the breaking length from 3.80 to 3.93 km, with a concomitant reduction in fiber curls. Huber *et al*.[17] used a pilot-scale disperser to treat wood-free recovered paper and found a detrimental effect on the tensile strength, burst strength, and wet-stretch of pulp from the concentrating effect of the screw press; in contrast, a high-speed disperser provided benefits to the tensile and bursting strengths, and wet-stretch of the resulting pulp.

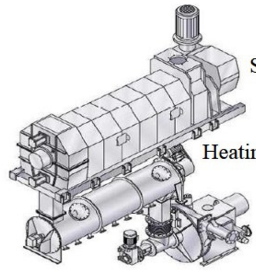

Figure 1: Schematic of a hot dispersion system showing the main units[4]

From a literature review, it is apparent that although hot dispersion is an integral unit of the deinking process, there has been no systematic study of the effects of pulp consistency and operational temperature on the physical and optical properties of the resulting paper. In this study, we used a mill-site hot dispersion system to treat computer forms and examined the effects of different operational temperatures and pulp consistencies on the handsheet properties.

EXPERIMENTAL

The hot dispersion facility utilized in the study was located at the Chubei mill deinking line of Cheng Long Paper (Hsin-Chu, Taiwan). It was a Cellwood KD-450 from Sweden. The wastepaper stock was 100% computer forms. The deinking line process entailed a hydrapulper, followed by high-consistency cleaners, coarse screens, a screw press with added hydrogen peroxide as pre-bleaching, then flotation deinking with the addition of deinking chemicals and sodium hydroxide for pH adjustment and to facilitate separation of ink particles. Afterward, the pulp was treated with low-consistency cleaners, a thickener, a screw press, and finally a hot dispersion unit. The unit was controlled at a disk gap of 0.1 mm, and a back pressure of 1.5 kg/cm^2. By adjusting the discharge pressure of the screw press, the discharge consistency from the disperser could be controlled to 19%, 32%, 35%, and 36%. The steam temperature was controlled to 90, 100, 110, and 115 °C, and the pulp pH was adjusted to 7.95. After dispersing, the pulp freeness was measured in accordance with TAPPI T227 om-99 (Hoel, USA). Handsheets of 60 g/m^2 were prepared according to TAPPI T410 om-98 (Lesson, 306-A, Taiwan). After conditioning at a constant temperature (23±1 °C) and humidity (50%±2% relative humidity) for 24 h, the following physical and optical properties of the handsheets were measured: caliper (TAPPI T411 om-97, Lorentzen & Wettre D2), tensile strength (TAPPI T404 om-97, Lesson 2025D, Taiwan), tear strength (TAPPI T470 om-98, Lesson 3730, Taiwan), burst index (TAPPI T403 om-97, Lorentzen & Wettre 002P), Clark stiffness (TAPPI T451 om-97, Kumagai 8605109, Japan), etc. Handsheet optical properties examined included brightness (TAPPI T452 om-98, Technidyne Micro S-5), whiteness, opacity (TAPPI

T425 om-96, Datacolor Elerpho 450x with Color Tools 3.12 software), etc. Experimental errors were assessed by selecting conditions of a pulp consistency of 32% and a steam temperature of 110 °C for triple replications. The standard deviation (SD) was then calculated with 2 degrees of freedom (d.f.). The total experiment consisted of 16 sets, 1 blank, and 2 additional replicates for a total of 19 sets.

RESULTS AND DISCUSSION

Pulp freeness

The effects of pulp consistency and operational temperature of hot dispersion on the pulp freeness are shown in Fig. 2. The SD of freeness was 5.3 mL CSF with 2 d.f. From the figure, the input pulp had a freeness of 478 mL CSF, whereas the post-dispersion pulp showed decreased freeness, with the temperature effect most notable. Pulp freeness was the highest in the 110 °C group, followed in decreasing order by the 100, 115, and 90 °C groups. As for the consistency effect, the 19% group probably received a smaller kneading effect on the fibers, and the decrease in freeness was minimal. However, for discharging consistencies of >32%, freeness was notably lower probably due to increased rubbing among fibers, which peeled laminae from hornified fibers causing them to have increased bonding potential and reduced fiber bundles or shives. Thus, pulp freeness decreased with increasing consistency. Combining the temperature and consistency effects, hot dispersion was deemed to be optimal operating at temperatures of 100~110 °C and consistencies of >32%.

Tensile strength

The effects of hot dispersion temperature and consistency on the breaking length of the resulting paper are shown in Fig. 3. The SD of the measurement was 0.11 km with 2 d.f. After dispersion treatment, breaking lengths of the pulps all increased with respect to the input pulp (2.58 km) at consistencies of >32%. The temperature effect on the breaking length appeared to be more significant, and the 100 °C group showed the best performance (3.19 km, a 23.6% increase with 32% consistency pulp). Figure 2 shows that at a 110 °C refining temperature, the resulting pulp freeness was generally higher than refining results at 115 and 90 °C. Breaking lengths, however, were similar. These findings suggest that refining at 110 °C produced a better pulp-enhancing effect than at 115 and 90 °C. The results are in agreement with those obtained by Granfeldt *et al.*[18] and Lundberg.[12]

The experimental results thus indicate that when refining at a temperature of 100 °C, an enhanced efficacy of breaking length was obtained. In contrast, when refining at higher or lower temperatures, the reverse was true. From the perspective of the pulp consistency effect, fibers of the 19% consistency group received the least mechanical action during hot dispersion, and hence showed less improvement in breaking length than those with consistencies of >32%. For hot dispersion consistencies of >32%, however, there were insignificant differences among treatments, within the range of the experimental error. It appeared that hot dispersion at 100 °C produced the best breaking length results.

Tear strength

Figure 4 shows the effects of temperature and consistency on the tear index of the resulting pulp. The SD of the tear measurements was 1.9 $mN{\cdot}m^2/g$ with 2 d.f. Tear indices of the post-dispersion pulps were all higher than that of the input pulp (62.2 $mN{\cdot}m^2/g$), with the temperature effect more pronounced. The highest tear index attained was for the pulp treated at 110 °C (80.5 $mN{\cdot}m^2/g$, a 29.4% increase over the blank at a 32% consistency). The performances of the other temperature groups in decreasing order were 115, 100, and 90 °C; and the trend was similar to that of pulp freeness. From a pulp consistency perspective, the 19% group had higher pulp freeness, hence also higher tear indices, followed by 32%, 35%, and 36%, with the latter two consistencies having ranges within the experimental error.

Burst index

The effects of the hot dispersion temperature and pulp consistency on the burst index of treated fibers are shown in Fig. 5. The SD of the burst index was 0.36 $kPa{\cdot}m^2/g$ with 2 d.f. The figure shows that after hot dispersion, deinked pulp showed an improved burst index over the blank (6.85 $kPa{\cdot}m^2/g$), the temperature of the treatment showing more significant effects. The burst index of the pulp was the highest for the 90 °C group (12.50 $kPa{\cdot}m^2/g$, an 82.5% increase over the blank at a 35% consistency). The performances of the other temperature groups in decreasing order were: 100, 110, and 115 °C.

As for the consistency effect, the 32%, 35% and 36% groups produced similar effects on the burst index, and the differences were statistically insignificant and within the experimental errors.

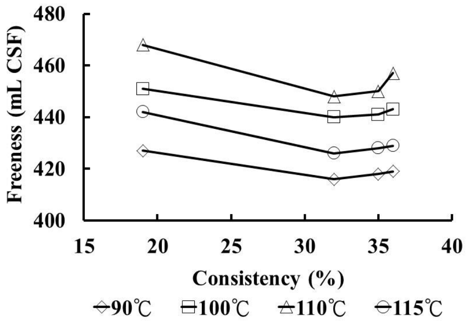

Figure 2: Effects of hot dispersion temperature and consistency on the pulp freeness (input pulp freeness: 478 mL CSF, experimental standard deviation ±5.3 mL CSF)

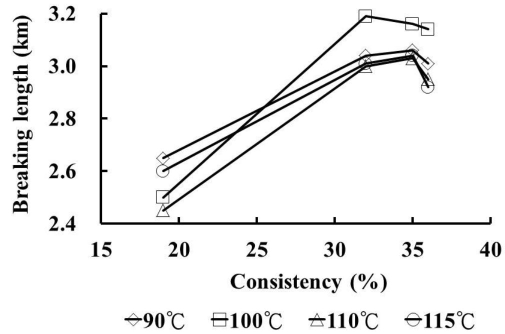

Figure 3: Effects of hot dispersion temperature and consistency on the breaking length of the resulting pulp (input pulp: breaking length of 2.58 km, standard deviation ±0.11 km)

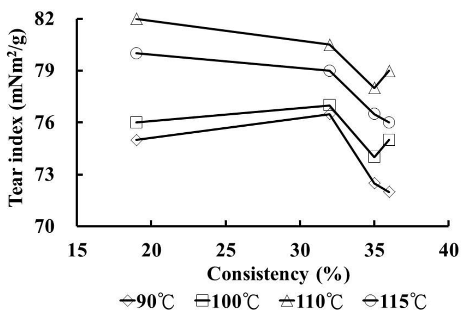

Figure 4: Effects of hot dispersion temperature and consistency on the tear index of the resulting pulp (input pulp tear index 62.2 mN·m^2/g, standard deviation ±1.9 mN·m^2/g)

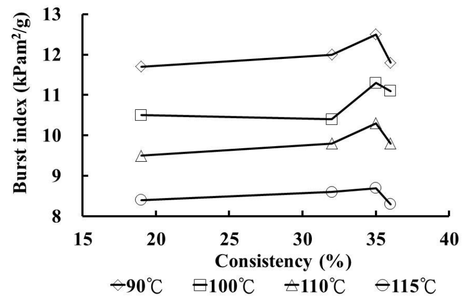

Figure 5: Effects of hot dispersion temperature and consistency on the burst index of the resulting pulp (input pulp: 6.85 kPa·m^2/g, standard deviation ±0.36 kPa·m^2/g)

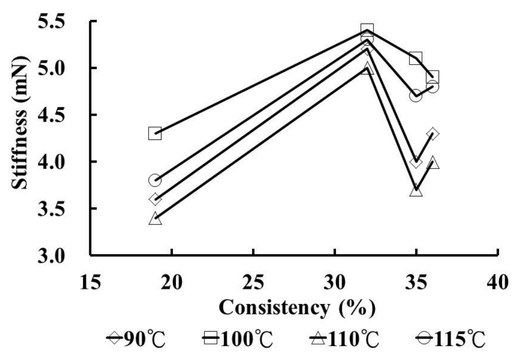

Figure 6: Effects of hot dispersion temperature and pulp consistency on the Clark stiffness of the resulting pulp (input pulp: 3.74 mN, standard deviation ±0.18 mN)

Clark stiffness

The effects of hot dispersion temperature and pulp consistency on the Clark stiffness of the resulting pulp are shown in Fig. 6. The SD of the measurements was 0.18 mN, with 2 d.f. Results indicated that after the hot dispersion treatment, the Clark stiffness of the handsheets made from the pulp all increased with respect to the untreated pulp (3.74 mN). Temperature appeared to exert a more significant effect. The stiffness of the handsheets was the highest for the 100 °C group (5.40 mN, 44.4% higher than the blank, at a 32% consistency). It was followed in decreasing order by the 115, 90, and 110 °C groups. As for the consistency effect, 32% was optimal. Higher and lower consistencies resulted in smaller stiffness improvements.

Optical properties

Brightness and whiteness

Figure 7 shows the effects of hot dispersion temperature and pulp consistency on the brightness and whiteness of the resulting pulp. The SDs for brightness and whiteness were 0.15 and 0.18% ISO, respectively, each with 2 d.f. Results indicated that except for the 115 °C group, all post-dispersion groups had brightness values lower than that of the untreated deinked pulp (83.2% ISO). Conversely, the pulp whiteness gained after dispersion compared to the untreated pulp (91.8% ISO). The effect of temperature was more pronounced, and the lower the dispersion temperature, the lower the pulp brightness became. There was a positive correlation between the two parameters.

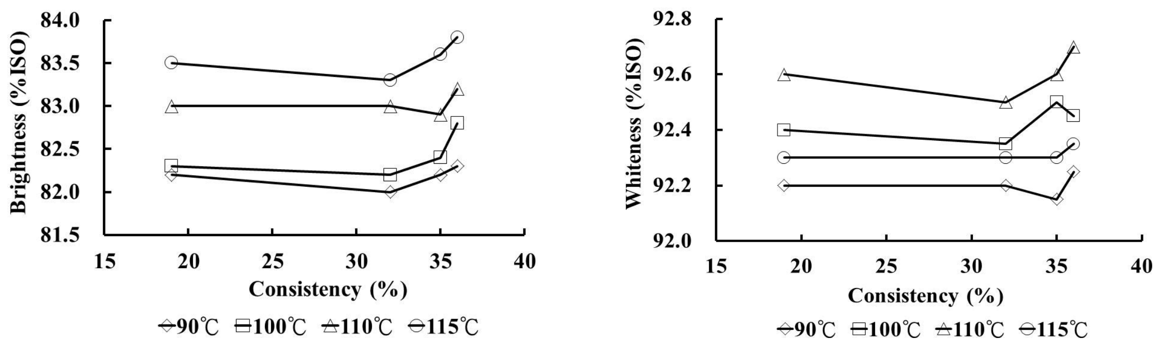

Figure 7: Effects of hot dispersion temperature and pulp consistency on the brightness and whiteness of the resulting pulp (input pulp brightness 83.2%, whiteness 91.8% ISO; standard deviations: brightness ± 0.15%, whiteness ± 0.18% ISO)

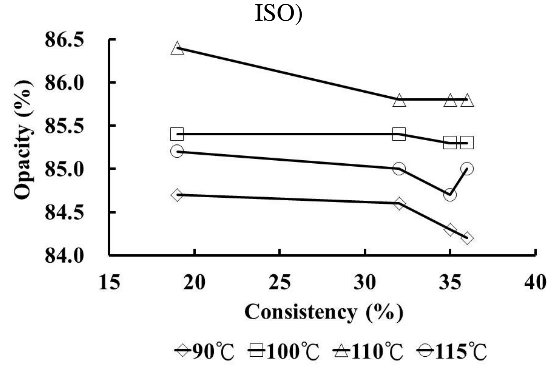

Figure 8: Effects of hot dispersion temperature and pulp consistency on the opacity of the resulting pulp (input pulp: 86.3% opacity; standard deviation ± 0.21%)

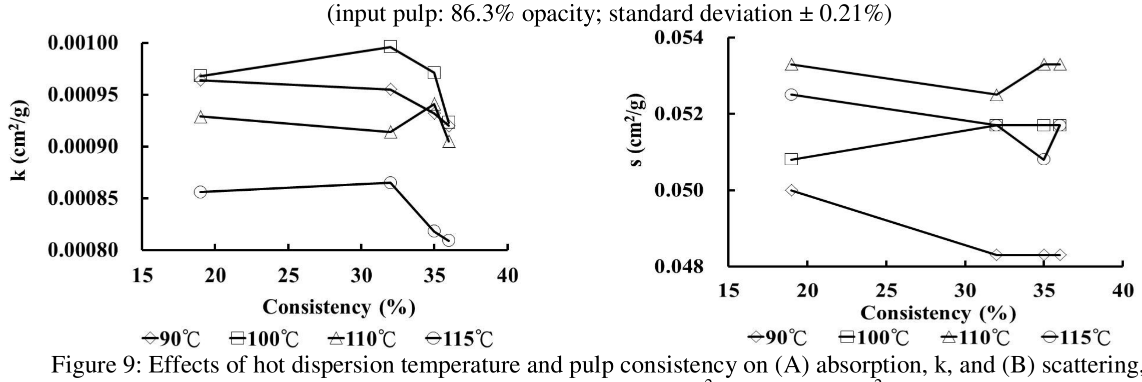

Figure 9: Effects of hot dispersion temperature and pulp consistency on (A) absorption, k, and (B) scattering, s, coefficients (input pulp k: 0.000961 cm^2/g; s: 0.0567 cm^2/g)

As for pulp whiteness, however, 110 °C excelled (92.7% ISO, increased 1 point over the blank, at a 36% consistency). It was followed in decreasing order by the 100, 115, and 90 °C groups. From a pulp consistency perspective, the higher the consistency, the higher the brightness or whiteness became. There were also positive correlations among the parameters.

Opacity

The effects of the hot dispersion temperature and pulp consistency on the opacity of the resulting pulp are shown in Fig. 8. The SD of opacity was 0.21%, with 2 d.f. Results indicated that after hot dispersion, the deinked pulp tended to have decreased opacity compared to the input pulp (86.3%). Temperature effects were more notable. The highest opacity (85.8%, a decrease of 0.6 points) was obtained at 110 °C. It was followed in decreasing order by the 100, 115, and 90 °C groups. The trend was similar to that of brightness. As for the consistency effects, its influence was less pronounced, and its range was within the experimental error.

Absorption coefficient and scattering coefficient

According to the Kubelka-Munk equation, knowing brightness and opacity (TAPPI opacity) allows the absorption coefficient (k) and scattering coefficient (s) to be calculated.[19] In order to understand the effects of the hot dispersion system on the absorption and scattering coefficients of the pulp, these values were calculated and are shown in Fig. 9. Results indicated that except for the 100 °C group, all absorption coefficients of the treated pulps were lower than the input pulp (0.000961 cm^2/g). The effect of temperature was more pronounced, and was the highest for the 100 °C group at 0.000971 cm^2/g. It was followed in decreasing order by the 90, 110, and 115 °C groups. The scattering coefficients of the hot dispersed pulps were all lower than that of the input pulp (0.0567 cm^2/g). The temperature effect was more pronounced as well, the scattering coefficient of the 110 °C group being the highest at 0.0533 cm^2/g. It was followed in decreasing order by the 115, 100, and 90 °C groups. The higher the pulp consistency, the lower the absorption coefficient became, while there was no apparent influence of the consistency on the scattering coefficients.

A hypothetic mechanism

Hot dispersion conceivably functions by exerting kneading and rubbing actions on the fibers under high consistency and operational temperature. Such mechanical actions tend to detach, but not to remove ink particles, and shear forces cause them to diminish in size. Thus, one of the major intended purposes of hot dispersion is to render ink specks invisible and not cause residual specks, which reduce the perceived value of the pulp. It is noteworthy, however, from the present and other studies[20] that hot dispersion also serves to modify the fiber quality, leading to generally better pulp performances. For deinked pulp made from bleached kraft fibers, recycling means that the fibers become hornified, with collapsed cell walls, reattached fibrils, and the fibers consequently lose their bonding potential. The mechanical and thermal actions of a hot dispersion unit impart ameliorating effects on pulp fibers probably because 1) the kneading forces possibly peel away the inactive encrusting layer on the fiber surface, making it more amenable to hydrogen bonding with neighboring fibers; and 2) although the amount of residual lignin in bleached kraft pulp is small, it still exerts a substantial influence on fiber properties. Under the high operational temperature of a hot dispersion unit, it is conceivable that the lignin in fibers will soften and become fluid, allowing the fibers to deform with the mechanical energy. Also, particularly under high-temperature hydration conditions, fibers will swell, allowing shear forces to delaminate the fiber cell wall layers (internal fibrillation), thus contributing to an improved fiber bonding potential and pulp properties.

CONCLUSION

The effects of using an operational mill hot dispersion system to treat deinked computer form pulp on the resulting handsheet properties were investigated. The operational temperature and pulp consistency were found to affect the pulp properties after the treatment and there were obvious optimal ranges for both. At pulp consistencies of >32%, temperature exerted more pronounced effects than consistency did. At an operational temperature of 110 °C, the highest pulp freeness, tear index, whiteness, opacity, and scattering coefficient were obtained. At an operational temperature of 100 °C, however, the best tensile breaking length, stiffness, and absorption coefficient were obtained. A 90 °C operational temperature engendered the highest burst index, and a 115 °C temperature produced the highest pulp whiteness. With respect to pulp consistency, at 32%, the best tear strength and stiffness were observed; at 35%, the best burst index was obtained. All other properties appeared to have weak associations with pulp consistency. Combining the effects of temperature and consistency, hot dispersion operating at 100~110 °C with a consistency of >32% appeared to be optimal.

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