Cavitation-jet deinking: A new technology for deinking of recovered paper

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ABSTRACT: A new method and in-house device for treating secondary fiber were developed. The method is based on the fluid-jet cavitation technique. In this apparatus, pulp suspension was injected into the reacting vessel by using a high-speed jet that produced cavitation bubbles around the jet. The impact of the collapse of cavitation bubbles detached ink, binder, and other contaminants from fiber surfaces. The effects of the cavitating jet (CV-jet) treatment on deinking of the pulp from mixed office waste (MOW) and old newsprint/old magazines (ONP/OMG) mixture were studied. The basic experiments on cavitation control showed that the intensity and region of cavitation were controlled by the jet velocity and the pressure difference in the reacting vessel. The CV-jet generated broad ultrasound waves; the conventional ultrasonic apparatus generated an intrinsic frequency. The MOW test results showed that CV-jet, even without chemicals and high temperature, decreased dirt speckles and reached almost the same dirt reduction level as the mill kneader. Moreover, the CV-jet minimized fiber damage during the process. This yielded pulp handsheets giving much higher paper strength compared with pulp from the kneader. The ONP/OMG test revealed that CV-jet was superior to mill disperser in terms of ink detachment and stickies dispersion.

Application: This paper gives new insight into paper recycling technology in terms of reducing dirt speckles and stickies in deinked pulp with minimal fiber damage and describes the concept and apparatus.

In recent years, demand for secondary fiber has been growing because its use can lower paper manufacturing costs and save resources. As the market for those paper grades increases, the requisite quality of secondary fiber and recycled paper also becomes higher and higher. Secondary fiber for printing and writing grades must have high brightness and minimal dirt speckles. In general, two kinds of devices are used for ink detachment and decreasing the number of dirt speckles: high-speed dispersers and low-speed kneaders [1].

As for producing such a high-quality deinked pulp, a higher mechanical load is needed to get it. However, increasing mechanical load causes other problems, such as fragmentation of pulp fibers and excess generation of fiber fines [2]. This results in a loss of paper strength and dimensional stability [3], and an increase in manufacturing costs. One solution to this problem is to repeat multiple cycles of deinking processes until the desired pulp quality is obtained, but this approach requires a large capital investment and large amounts of electricity. Another approach is using deinking chemicals specialized for decreasing dirt speckles like toner [4]. This works very well for decreasing the target material but cannot decrease the problems caused by other contaminants, such as stickies and ultraviolet (UV) varnish. In addition, increasing the use rate of recovered paper results in an increase of repeated recycling fibers. These fibers seem to be readily damaged by mechanical force. Thus, it is difficult to obtain high-quality deinking pulp without fiber damage and loss of physical strength of paper by using conventional deinking technology.

Despite the fact that ink particles adhere only to the surface of fibers, conventional devices impose the mechanical load onto the entire fiber. Thus, the authors have investigated the use of cavitating jet (CV-jet) as a selective deinking force, which acts only on the fiber surface, for minimizing fiber damage [5-7].

Cavitation causes severe damages in fluid machinery such as pumps, turbines, valves, and screw propellers. It generates a high impact pressure reaching several gigapascals in a local region on the order of several micrometers when cavitation bubbles collapse [8]. If a lot of cavitation bubbles collapse near the fiber surface at the same time, the impact force arrives at the fiber surface directly and detaches and breaks up adhered ink. The bubbles are very small compared with the fibers so that the impact force is not so strong as to damage the entire fibers. Thus, this method might be used to reduce fiber damage during the ink detachment process if the problem of erosion in machinery could be solved. Recent advances in the studies of CV-jet made it possible to control the region in which cavitation occurs and even the impact force by using hydrodynamic parameters of the jet [9,10]. As a result, the authors expected that the strong energy of cavitation could be used for pulp treatment by controlling the impact force.

Cavitation can be generated using a liquid jet, an ultrasonic transducer, an ultrasonic transducer with horn amplifier, laser irradiation, or mechanical mixing. These methods are divided into two groups: those that generate an intrinsic frequency and those that generate a broad frequency.

Deinking applications using ultrasonic transducers, which generated an intrinsic frequency, have been studied [11]. Turai and Teng [12] and Naimpally [13] used a liquid whistle device to mechanically generate ultrasound (approximately 20 kHz ultrasonic waves). In the liquid whistle generator, a liquid flow induced vibration in the thin steel blade and created acoustic energy. The blade, however, is subject to erosion by the passage of high velocity particulates. Therefore, it does not produce high intensity cavitation.

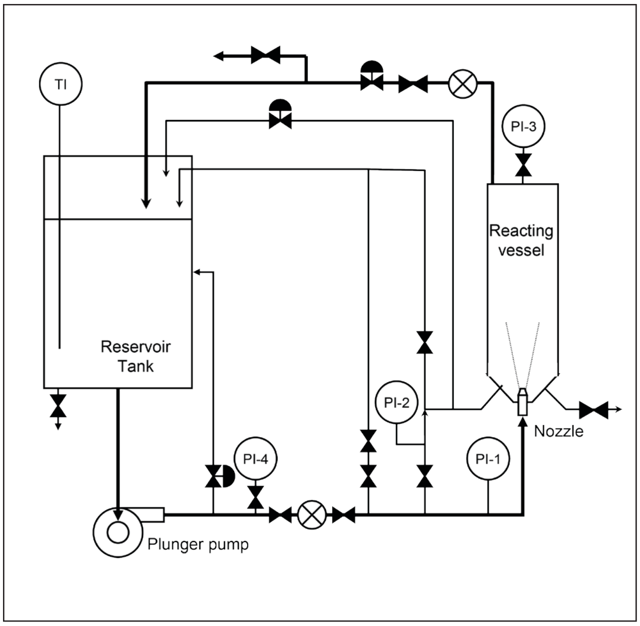
Norman and coauthors [14] used piezoelectric transducers to generate ultrasound (22 kHz ultrasonic waves). In this case, an acoustic vibration created by a piezo crystal was coupled into the treated pulp. Offill and Venditti [15] used 40 kHz ultrasonic waves. Those studies revealed that using ultrasound could decrease dirt speckles. Sell and coauthor [16] reported that the frequency of ultrasound influenced deinking performance of dirt speckles, the lower frequency ultrasound interacts more strongly with the larger particles, and the higher ultrasound frequency interacts with the smaller particles. Gerber and Scott [17] compared the effectiveness on dirt reduction of piezoelectric transducer and ultrasonic whistle. They found that the ultrasonic intensity produced with the liquid whistle was not significant and the optimum pH of that was 4-6. Ramasubramanian and coauthors [18] used an ultrasonic transducer with horn amplifier to enhance cavitation impact. However, these methods based on piezoelectric transducer were difficult to apply in industry because of the difficulty of scale-up and continuous treatment.

Because the size of ink specks varies, the liquid-jet method that generated a broad frequency is superior for deinking. Thus, the authors developed an in-house CV-jet device to generate broad ultrasounds and applied it to deinking. Pulp suspension was directly compressed by this device more than five times than that of the liquid whistle method [12,13]. Because the CV-jet device does not have any blade in the vessel, it can be used for long and continuous treatment of pulp slurry without erosion of the device. The objective of this study was to establish the method for controlling cavitation and to evaluate the effects of CV-jet treatment on deinking of mixed office waste (MOW) and old newsprint/old magazines (ONP/OMG).

EXPERIMENTAL

Materials

Terephthalic acid (TA) was purchased from Wako Pure Chemical Industries, Osaka, Japan. Deinking agent, DI-7027, was donated by Kao Corporation, Tokyo, Japan. Pulp samples were obtained from mill A (MOW) and mills B and C (ONP/OMG) of Nippon Paper Industries.



1. Schematic diagram of cavitating jet device. PI = pressure gauge, TI = temperature sensor. The liquid in the reservoir tank is pressurized to 12-20 MPa and jetted into the reacting vessel through the nozzle (throat diameter = 0.7-2 mm). The downstream pressure in the vessel is controlled from 0 to 0.5 MPa by a valve and monitored by a pressure gauge. The liquid, once through the nozzle, can be collected by a sampling line or circulated many times.

CV-jet device

The CV-jet device used in this study was based on the apparatus for washing metal surfaces and peening metal alloy [19,20]. **Figure 1** shows the schematic diagram of the device. The pulp slurry in the reservoir tank was pressurized with a plunger pump up to around 13 MPa, and jetted in a reacting vessel. The jet was passed through a nozzle (throat diameter = 1.5 mm) and cavitation bubbles were produced around the submerged jet. The flow velocity of the jet was presumed to be around 70 m/s when the upstream pressure was 7 MPa. The region and intensity of the cavitating jet were controlled by pressure difference in the vessel. The main parameter of the cavitating jet was the cavitation number σ, which is a measure of the resistance of the flow to cavitation. The cavitation number is given [19] by Eq. (1):

$$\sigma = \frac{p_2 - p_v}{p_1 - p_2} \tag{1}$$

where p_1, p_2, and p_v are upstream, downstream, and vapor pressures, respectively.

Because $p_1 > p_2 > p_v$, Eq. (1) can then be simplified as Eq. (2):

$$\sigma = \frac{p_2}{p_1} \tag{2}$$

Acoustic analyses of CV-jet

The frequency of ultrasound waves generated in the vessel by CV-jet was measured and analyzed by means of a vibrometer. An accelerometer was set on top of the reacting vessel. The distance between the sensor and the nozzle in the vessel was approximately 50 cm. In this experiment, water filled the CV-jet device, and the power spectra of the sound waves generated by CV-jet were monitored. The influence of upstream and downstream pressures and cavitation number σ on the spectra was verified. The effect of deinking agent on the CV-jet treatment was also evaluated. Static surface tension of water containing certain amounts of deinking agent was measured at 25°C with a tensiometer based on the Wilhelmy plate method.

OH radical measurements

Cavitation phenomena generate radical species, especially hydroxyl (OH) and hydrogen (H) radicals. Because the pH of water was near neutral in this experiment, OH radicals were much more stable compared with H radicals. Thus, the generation of OH radicals during CV-jet treatment was examined by their radiation with TA anion to produce fluorescent hydroxyterephthalete (HTA) ions. TA acted as a free radical scavenger; details of the method are described in the literature [21]. TA was dissolved in water and a certain amount of TA solution was added into the device. The final TA concentration was adjusted to 1 mM and the pH of the water in the vessel was adjusted to 10. CV-jet treatment was conducted with the upstream pressure at 7 MPa and downstream pressure at 0.3 MPa. Samples were taken after treatment for 2, 5, 10, and 20 min and wrapped with aluminum foil to avoid exposure to light. The fluorescence intensity of HTA (excitation = 310 nm, emission = 425 nm) was measured by spectrofluorometer.

Ink detachment experiments

Run No. 1

The effect of CV-jet treatment on ink detachment was tested. The model MOW pulp was obtained from the intermediate stage of the deinking process in the pilot plant (Aikawa Iron Works Co. Ltd.; Shizuoka, Japan). The pulp was diluted to 0.3% consistency by weight with tap water and 12 L of the slurry was introduced into the CV-jet device (nozzle diameter = 1.5 mm). To verify the effect of cavitation impulse, the pulp was tested for 5 min with only the pump circulation, only pressurizing upstream pressure, and with both upstream and downstream pressure. The initial temperature of the slurry was 20°C. The turnover period of pulp treatment by CV-jet (i.e., the cycle a fiber passed through the nozzle) was 1.6 minutes when the upstream pressure was 7 MPa. Those samples after treatment were hyper-washed to remove detached ink. Dirt in the handsheets was measured by means of image analyses. The number of dirt speckles in 1 m^2 was obtained from the sum of particles greater than 0.05 mm^2.

Run No. 2

The effect of CV-jet treatment on MOW deinking was compared with a PFI mill as indices of mechanical force for ink detachment. A mixture of 40% toner printed paper, 40% OMG, 10% thermal paper, and 10% carbonless copy paper by weight was disintegrated in a laboratory pulper at 15% consistency, at 40°C for 6 min with 0.2% deinking agent based on o.d. pulp and other deinking chemicals (1% sodium hydroxide, 3% sodium silicate, and 1% hydrogen peroxide). Disintegrated pulp was diluted to 0.9% consistency by weight for the CV-jet treatments and 10% consistency for the PFI mill treatments. CV-jet treatments were conducted with conditions similar to Run No. 1. Samples were taken out after treatment for 2, 5, 10, and 15 min. The pulp was beaten according to TAPPI Standard Method T 248 “Laboratory beating of pulp (PFI mill method),” with clearance at 0.2 mm. The revolution numbers were 1000, 2000, 3000, and 5000.

Those samples, before and after treatment, were hyper-washed to remove detached ink and tested to Canadian Standard Freeness (CSF). The water retention value was determined with TAPPI Useful Method UM 256 “Water retention value (WVR).” The influence on fiber damages was also evaluated by testing fiber length and curl using a FiberLab fiber analysis system (Metso Automation; Helsinki, Finland). The handsheets of these pulps were produced and tested for the residual ink amount as ERIC (effective residual ink concentration) value using a spectrophotometer and tested for ISO brightness using a colorimeter.

CV-jet treatment of MOW

Run No. 3

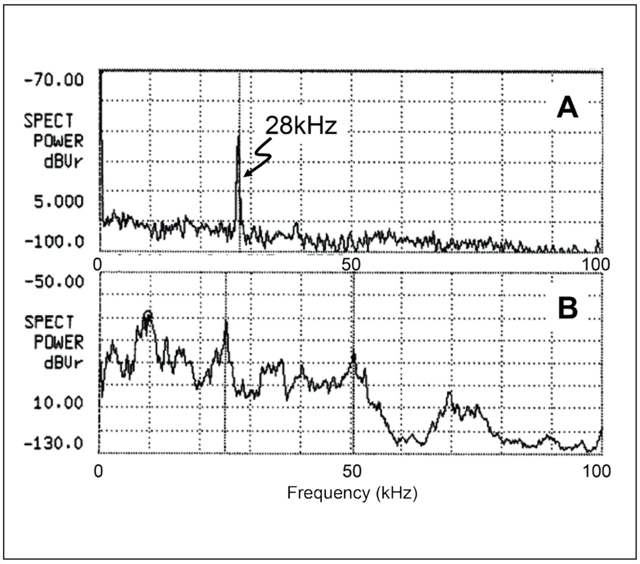
In this experiment, the pulp stock of approximately 30% consistency by weight was obtained from the outlet of an intermediate thickener ahead of a Shinhama kneader in the deinking plant at mill A. This plant manufactured deinking pulp from a mixture of white ledger and sorted MOW. Sodium hydroxide (0.3% by weight), sodium silicate (0.84% by weight), deinking agent (0.15% by weight), and hydrogen peroxide (0.35 % by weight) were added to the pulp at a chemical mixer before the kneader and stood for 3 h in a reactive tank. After kneading, the pulp was used as a comparative reference for CV-jet treatment. The pulp stock was disintegrated with JIS P 8220-1 and diluted to 1.1% (o.d.) consistency with tap water. The diluted pulp was introduced into the CV-jet device. CV-jet treatment was conducted with the upstream pressure set to 7 MPa and the downstream pressure set to 0.3 MPa. The pulp circulated in the device for 2, 5, and 10 min. The initial temperature of the pulp was 22°C and after 10 min was 35°C.

The pulps, before and after treatment, were tested for CSF, and then were hyper-washed on a 150-mesh wire. The properties of fibers and the handsheets made from those fibers were tested with the methods similar to Run No. 2.

CV-jet treatment of ONP/OMG

Run No. 4

Another pulp stock, 3.1% consistency by weight, was obtained from the outlet of an intermediate washer ahead of a disperser in the deinking plant at mill B. In this case, the pulp was a mixture of ONP and OMG. CV-jet treatment was conducted at the following conditions: consistency 1%, upstream pressure 7 MPa, downstream pressure 0.1 MPa at 15 °C. The pulp passed through the CV-jet device only once. The pulps, before and after treatment and after mill disperser (outlet of final washer), were evaluated by the same method described previously. The amount of macrostickies was also measured by a modified method based on TAPPI Standard Method T 277 pm-99 "Macro stickies content in pulp: the "pick-up" method."



2. Power spectra of sound wave of a conventional ultrasonic washer (A) and the cavitating jet (B) treating water. Ultrasounds refer to sound waves with frequencies greater than 16 kHz.

Run No. 5

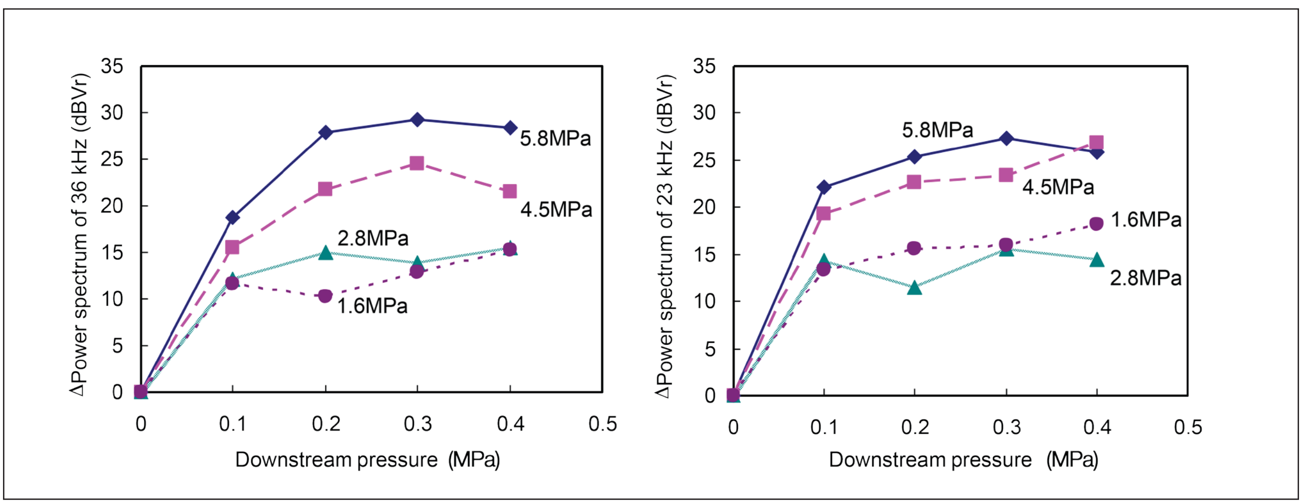
The final deinked pulp from the ONP/OMG deinking process at mill C was diluted to 1.1% and treated with the CV-jet device only once. The upstream treatment pressure was 8 MPa and the downstream pressure was 0.35 MPa. The number of macrostickies before and after treatment was measured. A quartz crystal microbalance with dissipation (QCM-D) monitoring technique was used to measure microstickies deposition. The method of using QCM for estimation of the possibility of microstickies deposition has been described elsewhere [22]. The pulp sample was filtered through a 500-mesh sieve (25 μm opening). The filtrate was injected immediately into the apparatus to monitor the shift of frequency caused by deposition or adsorption onto the sensor surface. Because the surface of the sensor was coated with hydrophobic polystyrene before the measurement, it could measure hydrophobic colloidal materials such as microstickies. The deposits on the sensor surface were observed by a violet laser-scanning microscope.

RESULTS AND DISCUSSION

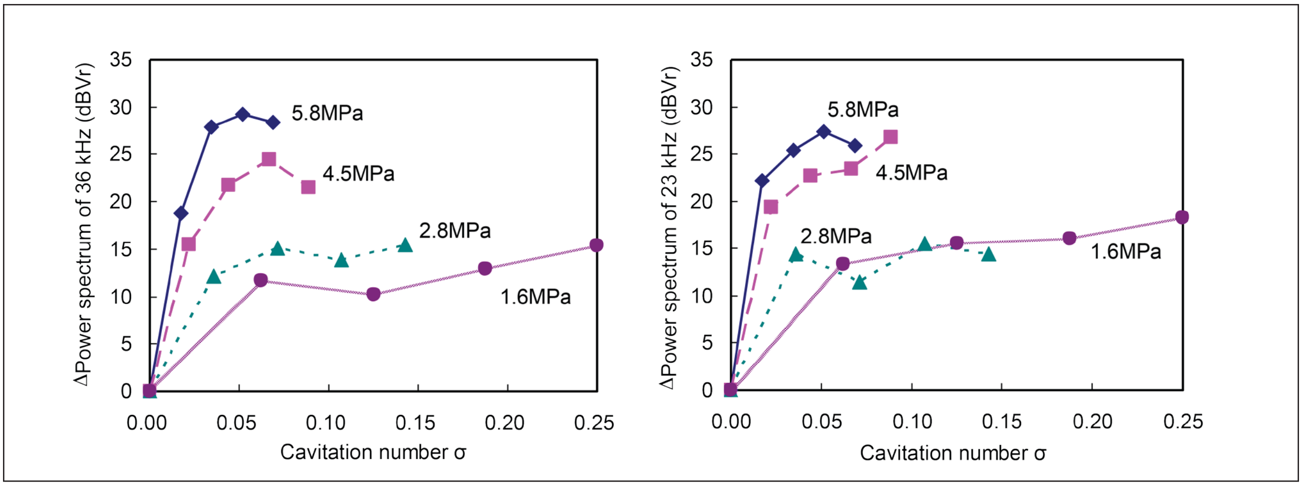
Controlling the CV-jet

Figure 2 shows the power spectra of the sound wave from a conventional ultrasonic washer and the CV-jet device. The ultrasound washer gave an intrinsic frequency (28 kHz). The CV-jet gave a broad range of ultrasound waves, from 16 kHz, the lowest limit of ultrasound, to 80 kHz. With upstream pressure at 7 MPa, the generation of cavitation was hardly observed when the downstream pressure was released. This revealed that increasing downstream pressure compressed the bubbles generated by CV-jet and gave strong cavitation. Increasing upstream pressure in conjunction with adjusting downstream pressure enlarged the intensity of the power spectrum in the range of 16-80 kHz.

The power spectra of frequencies around 23 kHz and 36



3. Increments of power spectra of 36 kHz (left) and 23 kHz (right) ultrasound waves as functions of downstream pressure. The numbers in graphs are upstream pressure of the CV-jet treatment at 1.6, 2.8, 4.5, and 5.8 MPa, respectively.



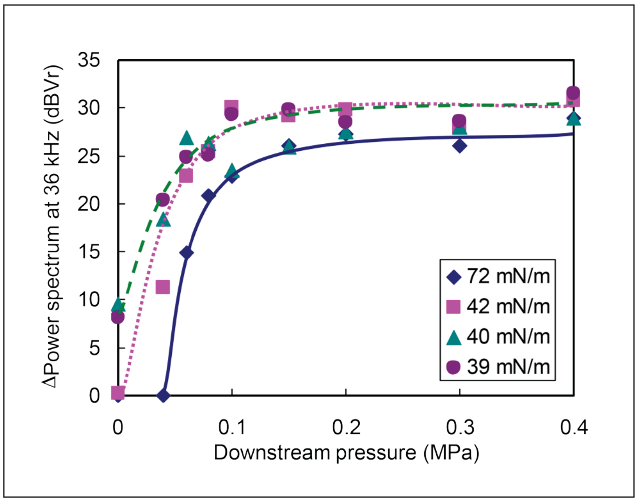
4. Increments of power spectra of 36 kHz (left) and 23 kHz (right) ultrasound waves as functions of cavitation number σ, calculated from downstream and upstream pressures (see Eq. [2]). The numbers in graphs are upstream pressure of the cavitating jet treatment at 1.6, 2.8, 4.5, and 5.8 MPa, respectively.

kHz were significantly increased or decreased by the pressure condition of the device. **Figure 3** shows the spectrum increments as functions of downstream pressure. For both frequencies, the spectrum increased with the rise of the upstream pressure. Increasing the downstream pressure from 0 to 0.1 MPa gave a large increment, whereas the change was small when the downstream pressure increased further.

By plotting the increment of power spectra against the corresponding cavitation number σ, the optimum operation condition of the CV-jet device was obtained. As seen in the results summarized in **Fig. 4**, the optimum cavitation number was getting smaller and smaller when the upstream pressures were increased up to 5.8 MPa. The trends of the changes in power spectra at 36 kHz were almost the same as those of the frequency at 23 kHz. Thus, the treatment condition was adjusted to obtain the optimum σ, ranging from 0.01 to 0.05, with upstream pressure at 1.6 MPa to 12.5 MPa, in the following experiments.

Effect of deinking agent on CV-jet treatment

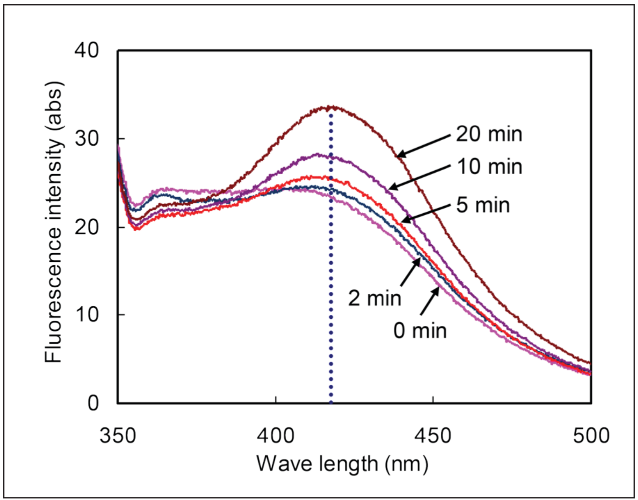
Surfactants can change bubble size by decreasing the surface tension of water. Especially in the deinking process, deinking agents are used to detach ink from fiber. There is a possibility that the intensity of cavitation is changed by the size of bubbles generated. Therefore, the effect of deinking agent on CV-jet treatment was evaluated. **Figure 5** shows the increment of power spectra at 36 kHz as functions of downstream pressure of the device. In these measurements, the surface tension of water changed by the addition of deinking agent from 72 mN/m to 39 mN/m. It was clear that lowering surface tension increased the power spectrum when the downstream pressure was small. Therefore, lowering surface tension led to the same effect as increasing downstream pressure. Both methods caused the size of cavitation bubbles to become smaller.



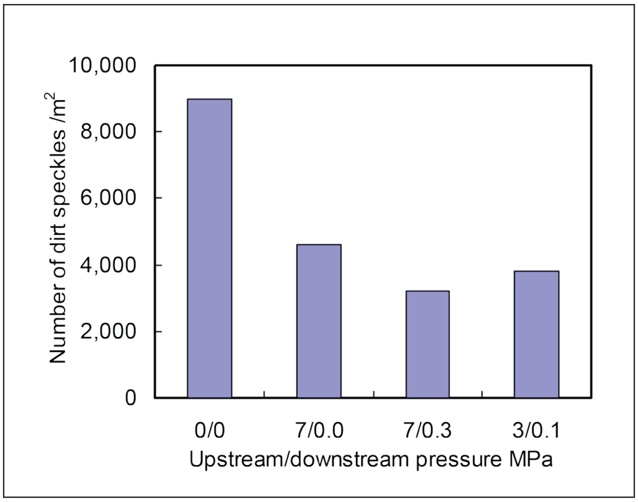
5. Changes in power spectra of 36 kHz ultrasound wave as function of downstream pressure. The numbers in graphs are the surface tension of water in the reservoir tank.

Radical generation in CV-jet treatment

TA, a radical scavenger, was used in the attempt to examine radical generation by CV-jet treatment. TA is a non-fluorescent material, whereas hydroxyterephthalate (HTA) is a fluorescent material created by the reaction with free radicals. The wavelength of emission is around 425 nm. **Figure 6** summarizes the results of fluorescence measurements on the water containing TA after the treatment. The fluorescence intensity of around 430 nm increased when the treatment time became longer. This suggested that CV-jet generated radicals during the treatment and a long treatment time was necessary to get strong radiation in this experimental condition. However, this implied that the CV-jet treatment produced OH radicals that could make the surface of contaminants more hydrophilic.



6. Fluorescence intensity of the water containing 1 mM terephthalic acid (TA) after CV-jet treatment. The upstream and downstream pressures were 7 MPa and 0.3 MPa, respectively. Hydroxyterephthalate (HTA) that is generated from the reaction of TA and free radical gives fluorescence at the wave length 425 nm.



7. Effect of upstream and downstream pressure on dirt after hyper-washing. The upstream/downstream pressures and conditions were as follows: 0/0 = only the pump circulation, 7MPa/0 = only pressurizing upstream pressure, 7 MPa/0.3 MPa and 3 MPa/0.1 MPa = pressurizing both upstream and downstream pressure.

Effect of CV-jet treatment on ink detachment

Figure 7 summarizes the results of Run No. 1. Increasing the upstream pressure to 7 MPa decreased the number of dirt speckles by half of pump only circulation, and increasing the downstream pressure decreased them further. The result from the 7 MPa/0 upstream/downstream pressure, even though cavitation hardly occurred at this condition, revealed that the force generated by the CV-jet device was composed of hydrodynamic shearing force at the nozzle and cavitation phenomenon. As shown in the results from the 7 MPa/0 and 3 MPa/0.1 MPa pressures, controlling the downstream pressure (i.e., generating cavitation) was important to obtain good deinking performance. Thus, the nature of the CV-jet in this study was a cavitating jet that included shearing force.

Table I shows the results of Run No. 2. The model MOW was treated with the CV-jet or the PFI mill, and then the pulp before and after treatment was hyper-washed and its properties tested. The performance of ink detachment by the CV-jet was compared with that of the PFI mill, as a reference of mechanical force for ink detachment. The PFI mill is the method for minimizing fiber damages during pulp beating. In comparison with blank (i.e., before treatment), both treatments decreased the pulp freeness and length-weighted fiber length and increased the water retention value. However, the CV-jet treatment gave a higher brightness of the handsheets and the PFI mill treatment gave a lower brightness. This suggested that CV-jet treatment facilitated ink dispersion without penetration of minute ink particles into fiber lumens. It was also clear that the treatment remarkably decreased the number of dirt speckles. Although the clearance of the PFI mill was 0.2 mm, the increment of dirt reduction by the PFI mill was inferior to the CV-jet. Thus, it was considered that the CV-jet treatment gave

Treatment		CSF, ml	WRV, %	Fiber Length, mm	Brightness, %	ERIC, ppm	Number of Dirt Speckles counts/m²
Blank		289	111	1.18	72.6	93	185,000
CV	2 min	227	116	1.12	76.5	50	22,000
	5 min	208	113	1.07	77.7	35	7,400
	10 min	180	120	1.07	78.8	25	1,000
	15 min	156	124	1.11	79.0	22	920
PFI	1000 rev	220	123	1.15	73.7	82	110,000
	2000 rev	198	124	1.10	72.6	74	70,000
	3000 rev	177	128	0.99	72.1	73	49,000
	5000 rev	150	126	0.97	69.8	71	24,000

I. The results of ink detachment experiment Run No. 2. CV: cavitating jet treatment for 2-15 min and PFI: PFI mill treatment with 1000-5000 revolutions.

	After Thickener	CV-Jet Treatment			After Kneader
		2 min	5 min	10 min	
Deinking and bleaching chemicals	No	No	No	No	Yes
Temperature, °C	40	22	29	35	60
CSF, ml	625	630	614	554	663
Fiber length, mm	0.92	0.90	0.90	0.89	0.76
Fiber curl, %	15.9	14.9	14.6	14.0	25.3
Number of dirt speckles, counts/m^2	18,000	500	300	280	360
Density, g/cm^3	0.54	0.55	0.55	0.56	0.55
Breaking length, km	3.3	3.7	3.9	4.4	2.3
Tear index, mNm^2/g	9.1	9.0	9.4	9.0	6.6

II. The results of cavitating jet treatment of mixed office waste. Both "after thickener" and "after kneader" were the outlet of intermediate thickener ahead of the kneader, and the outlet of the kneader, respectively.

	After Washer	After CV-Jet	After Disperser
Number of stickies, counts/kg	146	98	140
Average size of stickies, mm^2	0.46	0.30	0.47
Number of dirt speckles, counts/m^2	2,400	1,400	2,100
Area of hairy ink, mm^2/g	4.06	2.18	3.32
Brightness, %	61.1	61.4	60.2
ERIC, ppm	114	98	109

III. The results of cavitating jet treatment of old newsprint/old magazines. The "after washer" and "after disperser" were the outlet of the intermediate washer ahead of the thickener and disperser, and the outlet of the disperser, respectively.

much higher dirt breakage and ink detachment than the PFI mill treatment. The damage of fibers during CV-jet treatment was equal to that of the PFI mill. In other words, CV-jet treatment has the beating effect along with the deinking effect.

CV-jet treatment of MOW

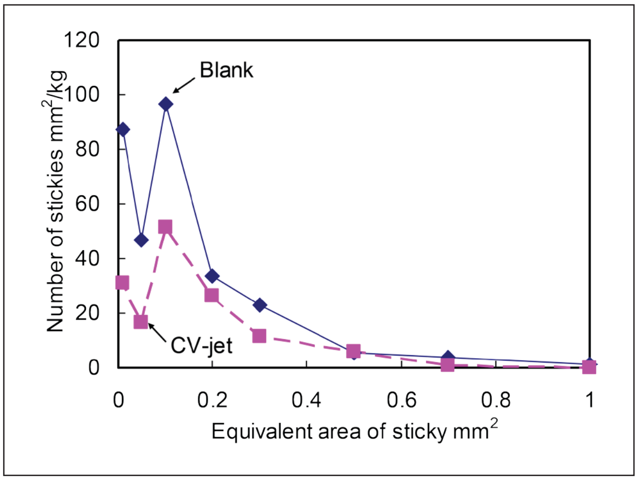
The effect of CV-jet treatment was evaluated by using the pulp from the inlet of the kneader in the MOW deinking plant at mill A. The extent of deinking effect of CV-jet treatment was compared with the mill's kneader (about 60 kW•h/ton). **Table II** shows the results of Run No. 3.

The CV-jet treatment was different from the kneading processes in the following points: no deinking chemicals, low pulp consistency, and low treatment temperature. The CSFs of hyper-washed pulp after CV-jet treatment and after mill kneader were almost the same, except for CV-jet treatment for 10 min. The fibers after kneading increased fiber curl and in some cases shortened the fibers. By contrast, CV-jet treatment hardly changed the fiber length and reduced the curl. The results of the measurements of handsheets made from hyper-washed pulp showed that CV-jet treatment remarkably decreased the number of dirt speckles and reached almost the same level of the mill's kneader. The treatment enhanced ink detachment and increased the brightness of handsheets without bleaching chemicals. Because the treatment minimized fiber damage, the handsheets from CV-jet fibers gave much higher breaking length and tear index than those from the kneader, at almost the same sheet density. Increasing treatment time of the CV-jet gave dense sheets that brought an increase of paper strength and smoothness. Thus, it was considered that the treatment includes a fiber refining effect.

CV-jet treatment of ONP/OMG

The effect of CV-jet treatment for stickies was compared with the conical-type disperser in the deinking process of ONP/OMG at mill B. **Table III** shows the results of stickies in the pulp and the properties of handsheets from the experiment, Run No. 4. It was clear that CV-jet treatment decreased the number of macrostickies to two-thirds of that before treatment. In contrast, the disperser did not affect the number of macrostickies. It should be noted that the load of the disperser was about 20 kW•h/ton, and that could explain this result. However, the performance of the disperser for stickies treatment was verified in other experiments, and the best result of the disperser treatment was 20% in reduction of stickies. The CV-jet treatment also decreased dirt speckles and residual ink in the handsheets.

Because the CV-jet treatment decreased the number of



8. Results of size distribution of stickies before and after cavitating jet treatment of the final deinked pulp from mill C.

macrostickies, it was thought that the amount of microstickies increased. Thus, an additional experiment, Run No. 5, was performed to verify the effect of the treatment on macrostickies and microstickies. The final deinked pulp from the deinking process of ONP/OMG at mill C was treated by CV-jet and the macrostickies in the pulp were measured. **Figure 8** shows the size distribution of macrostickies before and after treatment. It was clear that the treatment decreased the number of stickies in the whole range. This meant that the macrostickies became small and those sub-macrostickies could pass through a 0.15 mm slit.

The possibility of microstickies deposition was estimated by means of QCM-D measurement as the frequency change of the sensor (Δf). Because the surface of the sensor was coated with hydrophobic polystyrene before the measurement, it could measure hydrophobic colloidal materials such as microstickies. The results in **Table IV** show that CV-jet treatment slightly increased the weight on the polystyrene-coated sensor. This difference of the frequency shift caused by the treatment was much smaller than the difference that appeared on macrostickies. It was suggested that the stickies after CV-jet treatment did not adhere to the hydrophobic sensor surface easily.

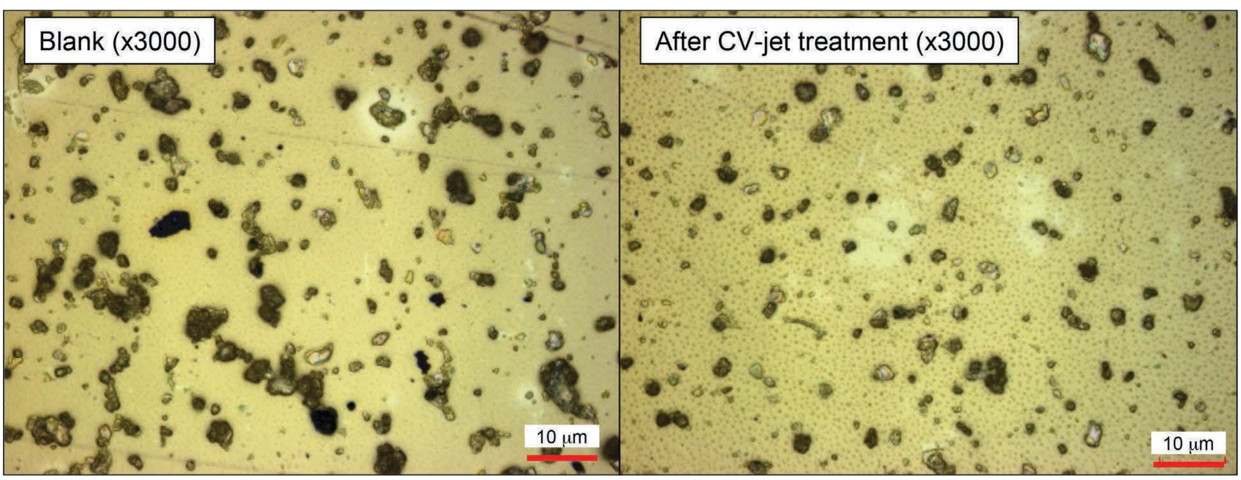
		Blank	CV-Jet Treatment
Macrostickies	counts/kg	350	165
	mm²/kg	47.0	24.2
QCM-D $\lvert\Delta f\rvert$	Hz	59.3	62.5

IV. Results of macrostickies and QCM-D measurements before and after cavitating jet treatment of the final deinked pulp from mill C.

Figure 9 shows photomicrographs of the QCM-D sensor surface before and after CV-jet treatment. In comparison with the blank, the size of deposits on the sensor after the treatment decreased significantly. Thus, the treatment can disperse hydrophobic materials such as microstickies. These results implied that CV-jet could modify the nature of fines and colloidal materials. Further investigation was needed to make sure of the effect of the treatment on microstickies.

CONCLUSIONS

A new deinking method and device using a cavitating jet was developed. This method was able to control cavitation phenomena that acted as impact power for ink detachment and dirt fragmentation. Treatment using this method (i.e., the CV-jet treatment) decreased dirt speckles without deinking chemicals and high temperature. Moreover, the treatment minimized fiber damages during the process, and this resulted in an improvement of the paper strength made from the treated fibers. The number of macrostickies in the deinked



9. The photomicrographs of deposits before cavitating jet (CV-jet) treatment (left) and after CV-jet treatment (right) on the surface of polystyrene-coated QCM-D sensor.

pulp was also decreased by the treatment. Because it can detach ink and decrease dirt speckles without thickening the consistency of pulp, the new CV-jet method has the potential to simplify deinking processes. **TJ**

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ABOUT THE AUTHORS

We conducted this research because we needed a new technology that can solve the contradiction between optical quality and paper strength of secondary fiber.

Although conventional deinking technology uses mechanical force for ink detachment and breakage, we applied cavitation bubbles that acted as a surface-selective force.

The most difficult aspect of this research was improvement of the performance of the cavitation jet (CV-jet) device. We have designed and developed an original, pilot-scale device to increase the treatment consistency.

This technology has the potential to simplify the deinking process. We found that CV-jet treatment decreased the number of macrostickies and the tackiness of microstickies. Our next step is developing the practical scale CV-jet device.

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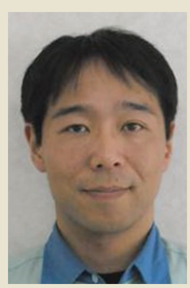

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