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Containers (WCC) by Flotation

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Fundamental Aspects of Recycling Waxed Corrugated Containers (WCC) by Flotation

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ABSTRACT

A combination of screen and flotation for removing wax from waxed corrugated containers (WCC) was examined in this study. The mechanism of high fiber loss during flotation of waxed fiber, the distribution of residual wax after flotation, and the effect of residual wax on the fiber and handsheet properties were investigated. As long as wax is separated from the fibers, it can be removed by screen and flotation. The mechanical action during repulping has a significant effect on the removability of wax. Both physical entrainment in foams and fiber hydrophobicity are responsible for the high fiber loss of WCC during flotation. Careful control of flotation conditions could reduce the fiber loss to an acceptable level. The residual wax that was still attached on the fibers after repulping could not be removed by flotation. It was observed that most residual wax was in the form of small particles rather than as a coating or spread form on fiber surfaces. Heating treatment tends to make the residual wax melt and cover more fiber surface and consequently lowers the inter-fiber bonding and fiber wettability.

Key words: Wax, waxed corrugated container, flotation, screening, recycling

INTRODUCTION

About 1.5 million tons of waxed corrugated containers (WCC) are produced by US box makers annually (1). They are mainly used to package moist products, such as fruits, vegetables, frozen fish, chicken, and meat. However, its moisture-resistant nature prohibits repulping. Since wax causes problems in the recycling of waxed paper and in

paper production, WCC is currently not recyclable. Groceries have to add more expense for picking WCC out from the old corrugated container (OCC) stream and sending them to a landfill instead of selling them to recyclers. If new recycling technologies cannot be developed, the waxed box business is seriously threatened by other industries, such as plastic containers.

Wax causes many problems during the production of papers and affects the properties of the products. Wax can reduce the coefficient of friction of the sheet, which has an impact on the productivity of subsequent converting operations. Wax reduces inter-fiber bonding and lowers internal sheet strength. Small amount of residue wax in recycled fibers will dramatically reduce the fiber wettability, which makes it difficult to use recycled fibers for high quality paper products. Paper printability and glueability are also harmed by wax. The wax is also a cause of spots on paper sheets. Furthermore, wax causes operational problems on paper machines when it is deposited on wires, felts, and dryers.

Many efforts have been made to solve the WCC recycling problems, including development of recyclable wax and new recycling processes.

One of the solutions for recycling WCC is to create a dispersible wax. Back and his coworkers (2-7) reported their development of autodispersible wax and pilot plant trials. They modified the wax by adding about 5% stearic acid and 0.5% nonionic surfactant before it was applied to the paper. During the recycling process, the modified wax disperses under alkaline conditions during a hot-dispersion stage. The sodium soap will form a stable wax dispersion in the dilute pulp. The dispersed wax can be then removed in a subsequent washing stage. The wax in the water from the washing stage can be separated by coagulation with a high-molecular-weight polyethylene oxide in the presence of a phenolic resin. This modification shows no effect on the wettability or the water-vapor permeability of the wax film. However, the efficiency of the wax removal by washing is only 60-80% due to the retention of wax particles in the fiber bed during filtration (washing). Furthermore, a strict clarification is needed to remove wax from the

washing water. McEwen and Wang (8) proposed to use so-called “fiber release additives” at low repulping temperatures in order to increase wax flake size and to improve the removal efficiency by cleaning and screening.

Inland Paperboard and Packaging Inc. and Thermo Black Clason Inc. announced jointly the introduction of Xtrax™ (9). The Xtrax process uses a new fiber-cleaning technique called Reverse Screening™ to reduce the wax content to an acceptable level. The operation temperature of the system was maintained above the melting point of wax. One hundred percent waxed boxes with 30% wax by weight were repulped to release the wax from fibers. The fibers were then separated from the wax-laden water by multistage reverse screening. The residual extractable contaminants (wax) in the final pulp produced by the process could be as low as 1% or less. However, no commercial system has been installed yet for recycling the waxed boxes.

Flotation is another approach to removing free wax from fibers. As Chou (10) stated, waxes and stickies that are too large for washing and too small for screening can be effectively removed by flotation. Heindel and Hodgson (11) evaluated the removability of model wax particles from a model brown-fiber system consisting of virgin softwood linerboard using a column laboratory flotation cell. They concluded that flotation is very effective for removing their model contaminants. Under their experimental conditions, the overall removal efficiency of model wax particles was 95-97% with a fiber loss of about 8-17%. Galland et al. (12) dewaxed WCC using a sequence of repulping – coarse screening – high density cleaning – fine screening – 2-stage flotation – light-weight cleaning. Introduction of flotation combined with light-weight cleaning led to a pulp with less than 1% of trichlorethylene extract, but the fiber loss was high (15-20%). Doshi et al. (13) examined the application of flotation in an OCC recycling system to remove wax and stickies from OCC containing 1% WCC. The result indicated that the flotation was more effective in removing wax and stickies than through-flow cleaners. The removal efficiency of wax and stickies was up to 90% with an overall flotation loss of 2-5%. Their two mill trials conducted recently confirmed the laboratory results above (14, 15).

Although many reports are available on removal of wax by flotation, as mentioned above, many questions still remain unanswered. One is the possibility of recycling 100% WCC by flotation. So far, most of the publications have been concerned with the introduction of a flotation stage into a typical recycling system to remove wax and stickies in an OCC stream. Further investigation is necessary to know the feasibility and limitations of flotation in the removal of wax from 100% WCC. The second question is the cause of high fiber loss during flotation of waxed fibers. It is well known that flotation of waxed paper usually has an unacceptable fiber loss of 15-20%. However, the cause of high fiber loss remains unclear. The third question is the distribution of residual wax and its effect on fiber properties. It has been believed that residual wax has a negative effect on inter-fiber bonding, physical properties, and coefficient of friction of the paper. However, many aspects of the mechanism are not clear. In this study, we intend to examine how the surface properties of the fibers and operating conditions of flotation affect the fiber loss. The focuses of this study are given to how the residual wax exists on the fibers, how the distribution of the residual wax affects the surface and physical properties of the fibers and the papers, and whether the thermal treatments change the status of the residual wax and consequently affect the fiber properties.

EXPERIMENTAL

Waxed Corrugated Containers (WCC)

WCC used in this study was provided by Mead Container, Atlanta. The container board was curtain-coated using wax with a melting point of 75-85°C produced by Conoco Inc. WCC has a wax content of 16.6% by weight.

Determination of Wax Content

The percentage of wax by weight in WCC and pulps was determined by extraction using 1, 1, 1-trichloroethane as a solvent according to TAPPI T 405 cm-97.

Repulping and Screening

WCC was first torn into small pieces of about and then soaked overnight. Repulping was completed using a LAMORT Repulper at room temperature without any chemical. The repulper can be operated at two speeds (low and high). The repulped slurry was screened using a plate screen with an 8-cut screen to remove large particles (flakes) of wax released during repulping.

Flotation

Two kinds of flotation cells were used in this investigation. One is a 4-L Wemco flotation cell (Sacramento, California), and another is an E-18 Voith flotation cell. TritonTM X-100, henceforth referred to as TX-100, was used as a nonionic surfactant, which is an octyl phenol ethoxylate (9.5 moles EO). Sodium oleate was used in the presence of calcium chloride. Polydiallylmethyl-ammonium chloride (PolyDADMAC) was also investigated as a flotation agent in this study. All chemicals were used as received. Terms and calculation are as follows:

Rejection rate (%) = (Oven-dry solids in reject / Oven-dry solids in feed) × 100

Fiber loss (%) = (Oven-dry fibers in reject / Oven-dry fibers in feed) × 100

Residual wax (%) = (Weight loss during CH₂Cl₂ extraction / Oven-dry pulp) × 100

Preparation of Model Wax Particles

Model wax particles were generated from the wax used for container manufacturing at Mead Container, Atlanta. First, melted wax was dropped into ice water at a high stirring speed in a blender, and congealed into small wax particles. Subsequently, the wax particles were cut into smaller particles in the blender for a further 30 minutes. Then the wax particles were filtrated and air-dried. Finally, the wax particles were fractionated by a 48-mesh screen into two fractions above and through the screen. For the flotation experiments using model wax particles, 10% of wax particles by weight on fiber were added into disintegrated virgin linerboard slurry. The mixture was well mixed with a blender before flotation trials. Flotation trials were performed at 1% consistency for 10 minutes with a Wemco cell.

Measurement of Paper Physical Properties

The static coefficient of friction of the handsheet was measured with an instrument (Amontons I) of Mu Measurement Inc. according to ISO 15359. The values reported in this study were the average of two sides of the handsheet. The water was measured using the Hercules test according to TAPPI T 530 om-96. The strength property tests of handsheets were performed according to TAPPI T 220 sp-96.

Contact Angle

The contact angles of different surfactant solutions on the wax surface were measured using a dynamic contact angle analyzer (Cahn DCA 312) equipped with a computer with DCA software. An even wax surface was prepared by immersing a thin glass plate (1×1.5") into molten wax. Contact angle of fibers was measured according to the procedure described by Deng and Abazeri (16).

RESULTS AND DISCUSSION

Feasibility of Dewaxing by Flotation

Flotation has been considered a logical choice for removal of wax and stickies from OCC by some researchers (13-15). However, the reported results were either from a model wax system or a mixture of OCC and WCC, and the feasibility of flotation with 100% WCC has not been widely reported. In this section, we try to demonstrate whether it is possible to recycle 100% WCC by flotation.

To investigate the removability of wax by flotation, a model trial was first carried out using model wax particles as described in the Experimental section with virgin linerboard fibers. Heindel and Hodgson (11) confirmed that the removal efficiency of model wax particles by flotation was 95-98%. Since surfactants were involved in the preparation of their model wax particles, surface properties of the wax particles were different from those of actual wax in pulp slurry. In addition, the model wax particles were in the size range of 50-250 (average 113) microns. In fact, it is very difficult to disperse all wax particles into this size range by a common repulper. Many wax flakes

have a size of more than 2 mm as observed in a repulped slurry. In this study, model wax particles with a wider size range were prepared without surfactants and fractionated into two parts with different size distribution by a 48-mesh screen. The fraction above the 48-mesh screen has a size of more than 0.5 mm. Ten percent of the wax on fiber by weight was first well mixed with the fibers and the suspension was subjected to flotation. The results in Table 1 show that most small wax particles were removable by flotation, while the bigger particles had lower removal efficiency. To remove those large wax particles, alternative operations, such as screening, should be used.

To select a suitable flotation agent for WCC, three chemicals were tested to determine their wettability to a wax surface. Figure 1 gives the contact angles of the solutions on a wax surface. PolyDADMAC as a single flotation agent for old newsprint (ONP) was reported in a previous paper (17). As a cationic polymer, polyDADMAC neutralized dissolved anionic substances in slurry to form water-insoluble particles. These particles strongly adsorbed on air-bubble surfaces and functioned as particle foaming agents. The hydrophobic inks dispersed in the suspension could be collected on the bubbles and floated to the surface. Because polyDADMAC has been demonstrated as an effective ink-removal agent for ONP, it is interesting to investigate this chemical as a dewaxing agent in the flotation process. Fig.1 shows that polyDADMAC did not significantly change the contact angle of wax. This is not surprising because polyDADMAC is a water-soluble cationic polymer rather than a surface activity. TX-100 and oleate (nonionic and anionic surfactants, respectively) could sharply drop the contact angle. However, when oleate was combined with CaCl_2 , reduction in contact angle was smaller than that without CaCl_2 due to the formation of calcium soap precipitate. It was also found that an oleate- CaCl_2 system did not produce enough foam for WCC furnish. This system was not expected to be a good agent for flotation dewaxing without other surface-active agents. Based on these results, TX-100, which can form enough foam at a low concentration without excessively reducing the hydrophobicity of wax particles, was chosen as the main flotation agent in this study.

High-temperature flotation

Wax tends to melt on heating. Therefore, it might be easier to separate wax from fibers at a melting state than at a solid state. Based on this assumption, high-temperature flotation was tried. High-temperature flotation in this study means that the whole process from repulping to flotation was operated above the melting point of the wax (90°C was chosen in this study). WCC was first repulped by a blender at 2% consistency and then the slurry was heated to 90°C with stirring. After maintaining a temperature of 90°C for 20 min with or without chemicals, the flotation was carried out at the same temperature. Although the high-temperature flotation can remove the majority of the wax, the reject rates were too high to accept. As discussed later, molten wax spread and coated more easily over the fiber surface at a high temperature. This made the fibers more hydrophobic and easier to adsorb on the air bubbles, which might be responsible for the high fiber loss. On the other hand, hot flotation requires additional energy to maintain the operation above the melting point of wax, which threatens the feasibility of the hot-flotation process. Another problem is that the melting wax readily deposits on the wall of the container or equipment if the temperature is lower than the melting temperature of wax. Because of these problems, wax removal at high temperature is very difficult in common paper recycle practice, although the removal efficiency could be high.

Flotation after screening

Because flotation cannot remove big wax flakes, a combination of screening and flotation was used, and the results are shown in Figure 2. It was found that the wax removal efficiency was very low, and many large wax flakes were still visible in the pulp after flotation if the pulp was not screened before flotation. However, if the large wax particles were screened out using a plate screen with an 8-cut screen before flotation, the efficiency of flotation was meaningfully improved. The most significant change was that fiber loss was remarkably reduced. For example, at a surfactant concentration of 10 ppm, the fiber loss was only 2.2%, compared with 20.8% without screening if other conditions remained the same. Even if the fiber loss during screening (Table 2) was included, the total fiber loss after screening was still much lower than that without screening. The reason for much higher fiber loss for unscreened furnish is not clear, but the significant

difference in the foam stability for screened and unscreened furnishes were found during the experiments. It was also found that high surfactant concentration did not benefit the removal of wax, but resulted in an unacceptably high fiber loss when the surfactant concentration was over 10 ppm. This is reasonable because fiber loss in flotation is mainly caused by physical entrapment of fibers in the froth (18). The high surfactant concentration commonly creates more foam, which results in more fibers to be entrapped and removed from the system.

Because the wax-fiber separation strongly depends on the fiber consistency and repulping speed, the repulping conditions should have a significant effect on subsequent screening and flotation efficiency. Table 2 clearly shows that the residual wax in the pulp furnish after screening and flotation was low for the samples repulped at high consistency and high speed. On the other hand, low consistency and low speed did not provide enough force to release wax from the fibers and resulted in a higher residual wax after flotation. In addition, high shear force at low consistency made the wax particles too small to remove by screen and left a heavy burden for flotation. Fiber loss in the screen stage was shown to be greatly dependent on repulping conditions too. It can be concluded from above discussion that repulping showed a significant influence on the release of wax from fibers, particle size of released wax, fiber loss in the screen stage, and the removability of wax by subsequent flotation.

Fiber Loss during Flotation

It has been believed that high fiber loss is one of the reasons why flotation has not been used in recycling of WCC. Many authors (11, 12) have reported unacceptably high fiber loss in flotation of WCC. However, the fundamentals of the high fiber loss of WCC compared to other waste papers have not been well investigated. Is the high fiber loss due to the natural characteristics of WCC or due to the improper control of process conditions? The answer is uncertain. Deng (18) pointed out that the fiber loss in the flotation process is attributed to two different mechanisms: fiber-bubble adhesion and froth entrainment, but the fiber adhesion is less important than the physical entrainment.

In this study, we want to examine the effect of flotation conditions and fiber hydrophobicity on fiber loss.

As shown in Figure 2, the fiber loss was significantly higher at high surfactant concentration than at low concentration. It is common knowledge that as surfactant concentration increases, more foam will be formed. As a result, more fibers were entrapped in the foams and led to a higher fiber loss. Figure 3 shows that at the same surfactant concentration, the increase either in air-flow rate or in flotation time resulted in excessive foams and consequently an enhanced fiber loss. It is also known that the increase in surfactant concentration will significantly increase foam stability, but reduce the hydrophobicity of fibers (reduce the absorption of fibers on air bubbles) (16). In fact, it can be seen from Figure 2 that fiber loss increases dramatically with surfactant concentration. This implies that the high fiber loss is significantly affected by physical entrapment. These results indicated that the physical entrapment of fiber in foams plays a very important role in fiber loss although hydrophobicity of wood fibers may also contribute to the fiber loss. To reduce the fiber loss, the foams should be properly controlled to a reasonable level, which is enough for flotation but insufficient for an undesirable fiber entrapment.

To investigate the effect of hydrophobicity of fiber on fiber loss, the following experiments were conducted. The WCC after flotation treatment (2.63% residual wax) was collected and air dried. The air-dried fibers were divided into three parts. One was kept as it was (Original). The second was extracted by trichloroethane to remove the residual wax (Extracted). The third was heated in an oven for one hour to make the wax melt and spread over the fiber surface (Heated). The hydrophobicity of three samples increased in order of Extracted, Original, and Heated. The three types of fibers were then subjected to a second stage of flotation treatment to determine fiber loss under the same conditions (1% consistency, 10 ppm TX-100, 10 L/min air, and 5 min). Hydrophobicity of fiber had a great effect on fiber loss during flotation as shown in Table 4. Compared to wax-free fibers (Extracted), wax-containing fibers (Original) had a higher fiber loss. If the wax-containing fibers were heated to melt the scattered wax spots and cover more

fiber surface, in other words, to increase the hydrophobicity of the fibers, a much higher fiber loss was observed. These results indicated that hydrophobic fiber was much easier to remove by flotation. It is believed that the fiber loss of 2.18% of Extracted resulted mainly from the physical entrainment of fiber by the bubbles (16). However, the wax-containing fibers (Original and Heated) may not only be physically entrapped in foams, but also adhere to air bubbles because of their higher hydrophobicity, resulting in a higher fiber loss.

Distribution of Residual Wax and Its Effect on Properties of Fiber and Handsheet

It is well known that residual wax significantly affects fiber properties, such as interfiber bonding, wettability, and coefficient of friction. However, it is unknown whether the residual wax remains as small particles in pulp or spreads on fibers as a coated wax layer.

After staining the residual wax in a floated pulp with Sudan-IV, we observed the distribution of the residual wax under a microscope. Residual wax was found to exist as scattered small spots on the fiber surface. The wax did not cover or coat the fiber uniformly as expected. It was found that there were very few wax particles in the fiber suspensions, which indicated that residual wax in flotation-treated fibers is in the form of small particles, and these small particles stick on the fiber surface rather than in a free form. Based on this observation, it could be concluded that the wax in WCC was easily broken and most of it was peeled off from the fibers due to the mechanical action of repulping. The wax fragments released could be subsequently removed either by screening or by flotation. The residual wax spots scattered on the fibers were those that failed to be peeled off from the fibers.

Based on the discussion above, we tried to remove the residual wax spots from the fiber surface by further mechanical treatment. Table 4 shows the treatment by a PFI mill of a floated pulp with 3.0% residual wax. The results indicate that further mechanical treatment is truly able to peel off the residual wax from fibers, and then the released wax

can be removed by a subsequent flotation. This confirms that the wax can be effectively removed by flotation as long as it is free from the fibers. After the treatment, the residual wax can be reduced to below 1%. Residual wax of less than 1% has been accepted as a level that does not cause operation difficulties on paper machines and shows no significant effect on product properties (9).

Residual wax significantly affects the physical properties of handsheets as shown in Table 5. The pulp with 2.5% residual wax (UEP) was used in the test, and wax-free pulp (EP) was prepared by extracting UEP with trichloroethane. UEP and EP were beaten by a PFI mill and made into handsheets to examine their physical properties. To investigate the behavior of residual wax during different drying procedures of the handsheets, half of the handsheets from UEP were dried on a steam dryer (these handsheets are called UEP-H in Table 5), and the rest were air dried on drying rings as described in the TAPPI standard. The results showed that the removal of wax enhanced tear, burst, and tensile strength due to the improvement of fiber bonding. On the other hand, if the handsheets were dried on a steam dryer instead of being air dried, the scattered wax spots melted, spread, and covered more fiber surface. Because contact or bonding area between fibers was reduced if wax spreads on fibers, all strength properties were weakened, and the density of handsheets decreased to 0.44 g/cm^3 from 0.60 g/cm^3 . Furthermore, the residual wax also significantly reduced the coefficient of friction. The changes in fiber contact angles reflected the influence of residual wax on the wettability of fibers. The wax, especially when melted and spread over the fiber surface, impressively increased the sizing; in other words, it dropped the wettability.

To compare the effect of different hot-treating procedures on the fiber properties, the following experiments were done. After being air dried, the fibers after flotation with a residual wax of 2.63% were divided into three parts. One was boiled in water for one hour (Boil), and another was heated at 105°C in oven for one hour (Heat). Untreated pulp was termed Original. After the pulps were beaten 3000 revolutions at 0.2 mm clearance by a PFI mill, handsheets were prepared to determine physical properties. Handsheets were also made from the fibers without PFI beating to show the effect of PFI treatment

on wax distribution. The results are given in Table 6. Since heat treatment could change the distribution of residual wax on fibers and weaken interfiber bonding, the fibers after heat treatment should have a lower strength. However, no significant differences were observed in physical properties among the three samples as shown in Table 6. This unexpected result may be explained in the following way: PFI beating peeled off the wax layer that formed when the residual wax particles melted during the heat treatment, resulting in exposure of new bonding surfaces of the fibers. This refining effect counteracted the negative result caused by the heat treatment. This assumption could be confirmed by the sizing test of handsheets. When the pulp was boiled in water, Hercules sizing of the handsheets increased from 3 seconds to 43 seconds, indicating that the wax was melting and spreading over the fibers during the treatment. If the boiled fibers were beaten by a PFI mill, Hercules sizing fell to 3 seconds again, implying that the wax layer was broken by the mechanical treatment. Furthermore, the fact that Hercules sizing of the handsheets dried on the steam dryer is much higher than that of the air-dried handsheets indicated that the wax still existed in the handsheet. In other words, PFI beating only peeled the wax off the fibers, but did not remove the wax from the slurry. When the handsheets were dried on the steam dryer, the wax melted again and sized the fibers once more.

CONCLUSIONS

Based on the results obtained in this investigation, the following conclusions could be drawn. Flotation is a feasible way to remove wax particles from fiber slurry so long as they are peeled off from the fibers and dispersed as desired particles. Removability of wax from WCC by flotation greatly depends on mechanical action during repulping. Both physical entrainment in foams and fiber hydrophobicity are responsible for the fiber loss during flotation of waxed fibers. Careful control of foams by adjusting operating conditions could reduce the fiber loss to an acceptable level. The residual wax attached on the fibers cannot be removed by flotation, but it can be peeled off the fibers by a second repulping treatment and then removed by another flotation stage. It was observed that the residual wax was scattered as spots on the fiber surface instead of as a uniform

coating over the fibers. Heating tends to make the residual wax melt and cover more fiber surface, so any hot treatment of waxed fibers will lower the interfiber bonding and fiber wettability.

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Table 1. Flotation test of model wax particles

Test No.	M-0	M-2	M-3	M-4
Wax, % on fibers	0	10	10	10
Size of wax particles, mesh	--	>48	<48	<48
Residual wax in pulp after flotation, %	--	1.3	0.7	0.4
Removal efficiency of wax, %	--	91.2	95.3	97.2

Note: (1). Flotation conditions: 1% oleate and 2% CaCl₂ on fiber by weight, 20 ppm TX-100, 1% consistency, flotation for 10 min, air rate 15 Lpm.

(2). M-4: flotation time 30 min. (3). Wemco cell.

Table 2. Effect of repulping condition on wax removal

Repulping consistency, %	Speed of repulper	Reject rate of screening, %	Fiber loss, %	Wax content of screened pulp, %	Wax content after flotation, %
8	High	--	--	4.25	1.59
5	Low	14.5	5.8	7.67	3.79
5	High	9.0	2.9	10.62	2.97

Table 3. Effect of fiber hydrophobicity on fiber loss

	Extracted	Original	Heated
Reject rate, %	2.18	7.42	17.72
Fiber loss, %	2.18	5.99	15.82
Wax content in fibers, %	--	1.16	0.38
Wax content in reject, %	--	2.85	3.55

Flotation conditions: 1% consistency, 10 ppm TX-100, 10 L/min air, 5 min, E-18 Vioth cell.

Table 4. Removability of residual wax after PFI mill treatment

No.	PFI conditions	Wax content after flotation, %
Blank	Without PFI mill treatment	3.0
Test I	8% cons., 0.4 mm clearance, 4000 Rev.	0.9
Test II	12% cons., 0.3 mm clearance, 4000 Rev.	0.9

Flotation conditions: 0.7% consistency, 30 ppm TX-100, 10 L/min air, 5 min, Wemco cell.

Table 5. Effect of residual wax on physical properties of handsheet

	UEP	UEP-H	EP
Density, g/cm ³	0.60	0.44	0.60
Fold endurance, time	160	100	150
Tear index, mN·m ² /g	11.6	10.3	12.1
Burst index, kPa·m ² /g	3.15	3.18	3.39
Tensile index, N·m/g	53.1	48.3	56.4
Hercules sizing, S	2	1110	0
Static coefficient of friction	0.515	0.564	0.823
Fiber contact angle, degree	58.3	68.4	48.6

EP: extracted pulp with CH₂Cl₂, handsheet air dried

UEP: unextracted pulp, handsheet air dried

UEP-H: unextracted pulp, handsheet dried on steam dryer

Table 6. Effect of heating treatment on physical properties of handsheet

	Original	Boil	Heat
Density, g/cm ³	0.46	0.44	0.47
Fold endurance, time	60	70	50
Tear index, mN·m ² /g	13.5	13.4	13.7
Burst index, kPa·m ² /g	2.68	2.60	2.61
Tensile index, N·m/g	39.8	39.7	39.8
Hercules sizing, S			
Handsheets air dried	3	43	--
unbeaten	4	3	5
Handsheets air dried	4070	2330	1130
Handsheets dried on steam dryer			

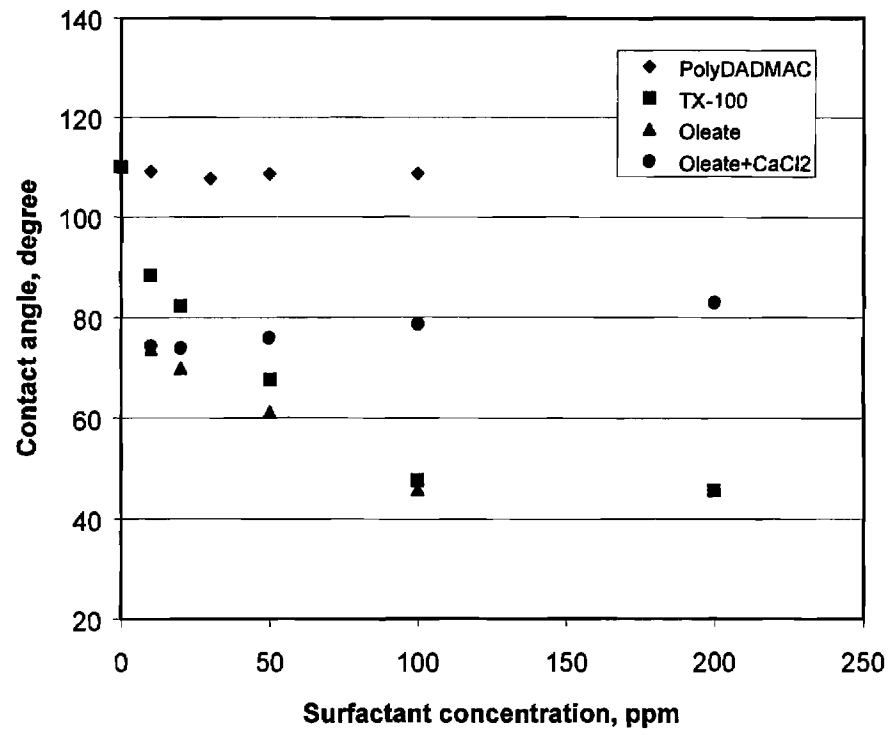


Fig. 1. Advance contact angle of wax surface with surfactant solutions

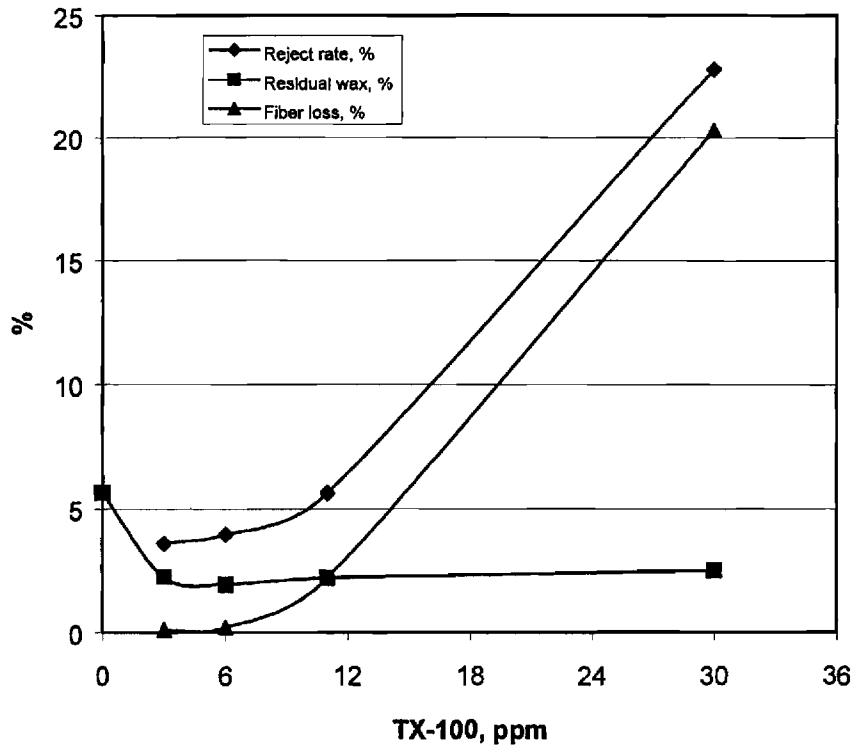


Fig. 2. Result of flotation after screening
Flotation conditions: 1% consistency, 10 L/min air, 5 min, E-18 Vioth cell

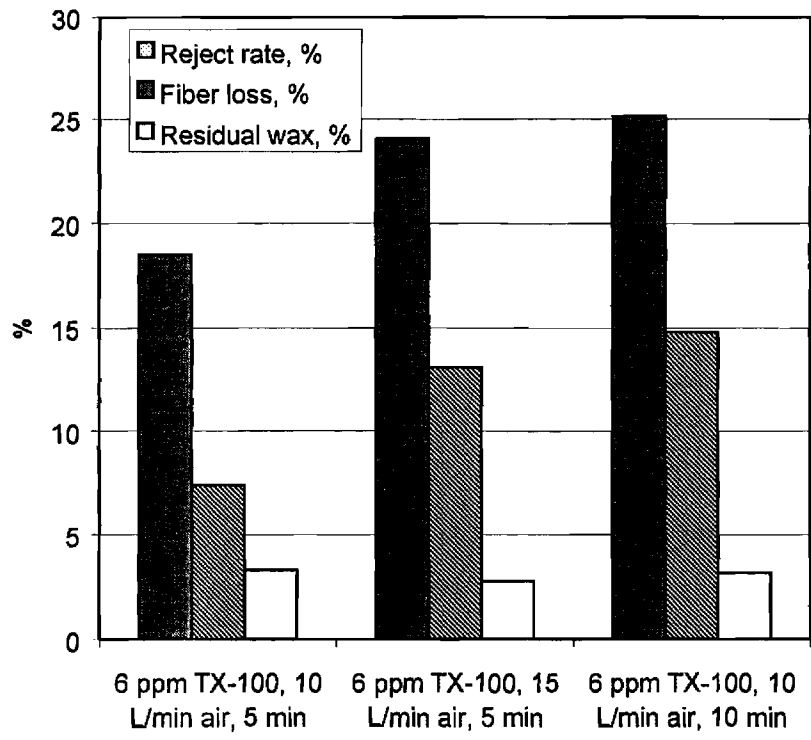


Fig. 3. Effect of operation conditions on fiber loss
1% consistency, E-18 Viorth cell