Kraft, BCTMP, and TMP Dewatering Behaviour along the Axis of a Screw Press

Bouchaib El idrissi,[a,]* Éric Loranger,[a] Robert Lanouette,[a] Jean Pierre Bousquet,[b] and Mark Martinez [c]

The drainage- and dewatering-controlling mechanisms in a screw press were detailed in this work. Three pulps (kraft pulp, bleached chemi-thermomechanical pulp, and thermomechanical pulp) were studied to compare a wide range of wood fibre types. The dewatering was controlled by the screw press parameters and the pulps' properties. Filtration was found to be the controlling mechanism in the first part of the screw press for the three pulps, and it was less important when the fines content was greater. In the compression zone, the degree of compression was affected by the pulp flexibility and the fibres' tendency to entangle. Filtrate flow rate monitoring along the screw press could be a good indicator of where the transition from filtration to consolidation occurs. The pressure along the screw press did not change much in the filtration zone, and it notably increased near the discharge end. When the drainage was very high, the pulp feed increased, causing the pulp axial velocity in the end part to be greater than the screw's linear advance.

Keywords: Screw press; Dewatering; Wood pulp; Axial distribution; Transition point; Pressure profile

*Contact information: a: Université du Québec à Trois-Rivières, I2E3 – Institut d'Innovations en Écomatériaux, Écoproduits et Écoénergies, à base de biomasse. Trois-Rivières, QC, Canada; b: Valmet, Inc., Duluth, GA, USA; c: University of British Columbia, Pulp and Paper Centre, Vancouver, BC, Canada; *Corresponding author: bouchaib.el.idrissi@uqtr.ca*

INTRODUCTION

Screw presses are used industrially for mechanical separation of solids from liquids. The screw speed and screw configuration are adjustable according to the nature of the product or process (Karunanithy and Muthukumarappan 2013), making them very useful for dewatering. They are used in many industrial fields, such as the pulp and paper industry and the food-processing industry (for oils, juices, *etc*.), and recently they have been widely used in the pretreatment of lignocellulosic biomass (Yan *et al*. 2014). In the pulp and paper industry, dewatering is an important unit operation, and screw presses were introduced in the early 1900s. At first, they were used to remove cooking liquor from chemical pulps, in addition to deliquoring and fiberizing chemically treated wood chips. The screw press's use increased with the development of mechanical pulping processes, especially for reject thickening. Currently, screw presses are used in practically all pulping processes, including mechanical, semi-mechanical, and chemical processes, as well as in the processing of waste paper-based pulps. Despite the screw press's wide use in the pulp and paper industry, it is not well reported in the technical literature. Thus, little is known in the public domain, but there are recent studies investigating the screw press process and trying to model the press. Probably due to geometric complexity, until now, there has been a simplified model that can describe and agreeably predict the data in the screw press.

Dewatering in a screw press depends on many factors; according to the literature, the controlling mechanisms occur in two steps (Seiffert 1969; Shirato *et al*. 1978; Lunev *et al*. 1982; Filippov *et al*. 1983; Shirato *et al*. 1985; Filippov *et al*. 1987; Egenes and Helle 1992, 1994). First, in the inlet, the water in the free-flowing suspension is removed by filtration. As the suspension consistency increases in the screw channel, the fibre network compresses in the screw channel, allowing dewatering of the fibre mat by a combination of expression and shearing of the fibres (Wakeman 2007). Meanwhile, Yan *et al*. 2014 studied the dewatering of lignocellulosic biomass and described the dewatering process as follows: The first step (of three steps) in the screw press process is characterized by compression; air escapes from the cavities without dewatering. The rotating screw shaft causes friction against the biomass, comminuting it. By rotation of the screw shaft and friction on the barrel wall engaging the biomass with each other, a first comminution takes place for the long and tough material. In the second step, with increased pressure, the moisture leaves the biomass and exits the press *via* the strainer barrel. In the third step, after the partial fluid release has been completed, the pressed material is in equilibrium with the applied compression forces.

Dewatering of clay slurries has been described by Shirato *et al*. (1978, 1985) as follows: In the filtration zone, the filter web and the aqueous suspension move along the channel at uniform speed with a gradually increasing filtration pressure. However, they assumed a constant linear movement of the material along the linearly tapered channel, and a pressure profile must be created along the channel to maintain a constant drainage level. Lunev *et al*. (1982) analysed the filtration stage in a screw press. They based their calculations on classical filtration theories while considering a laminar flow in this zone. Their simplifications and the lack of experimental validation of their mathematical model reduce its applicability in this case. Seifert *et al*. (1969) based their modelling on simplified filtration equations without web compaction. They assumed that the web stays fixed to the filtering barrel surface and then is scraped off by the flight of the screw with every flight revolution. Their model is based on direct integration over the screw geometry, considering two cases: one with perfect mixing of the thickened mat with the feed slurry and another with no remixing.

Filippov *et al*. (1983, 1987) studied the flow-controlling parameters in the consolidation zone of the screw press. They based their study on the filtration theory of consolidation, applied to filtration of the liquid phase through the inter-grain spaces of the product, with respect to the controlling forces and permeability characteristics of the mat. Egenes and Helle (1992, 1994) used a pilot plant screw press to perform experiments and data analysis to understand the dewatering mechanisms. They found that the drainage decreases along the screw press and increases near the discharge end. They also found that the web is constantly removed and compacted, creating two regimes. First, the mat is deposited on the barrel surface and continuously peeled off and pushed by the screw flights. In the second regime, there is a free-flowing suspension moving toward the discharge end at a greater speed than the flights.

The objective of the screw press is to raise consistency in an efficient way. The removed water will, however, contain finely dispersed contaminants, meaning that the screw press may even play an active part in the removal of the contaminants in addition to water removal. They are widely used in deinking or removing resin from mechanical pulps. Horacek (1980) stated that dewatering of waste paper did not have any negative effects or any ink redeposition. On the other hand, Alamo et al. (1991) found that unlike ink, the shearing action of the rotating screw imparted a dispersion action on particles in the stock. Alamo found more resin in the filtrate than in the water surrounding the crude fibre material. It was also found that the screw press treatment can lead to an increase in pore volume and pore surface area, especially in the earlywood fibres.

Therefore, the aim was to increase the understanding of the screw press for other materials and fill the lack of studies for the screw presses manufacturer to modify or manufacture more efficient screw presses, especially in the pulp and paper industry. This study examines the dewatering mechanisms along the screw press and compare three types of wood pulps.

EXPERIMENTAL

Materials

A Thune SP 23 screw press (Voith, Heidenheim, Germany), with a varying pitch, was used. The screw press characteristics are detailed in Fig. 1. Four pressure sensors and fourteen drainage channels were installed along the screw press. Three pulps were studied: kraft pulp, bleached chemi-thermomechanical pulp (BCTMP), and thermomechanical pulp (TMP). Table 1 lists the main properties of the pulps used in this study. Notably, according to the crowding factor values for the three pulps, the suspension entering the screw press was above the gel point (Martinez *et al*. 2001, 2003). The fibre distribution of the pulps also was evaluated, as it is shown in Fig. 2. It is apparent that kraft had the longest fibres, with 35% having a length of less than 1.5 mm, BCTMP with 90% of fibre length less than 1.5 mm, and TMP with 80% less than 1.5 mm.

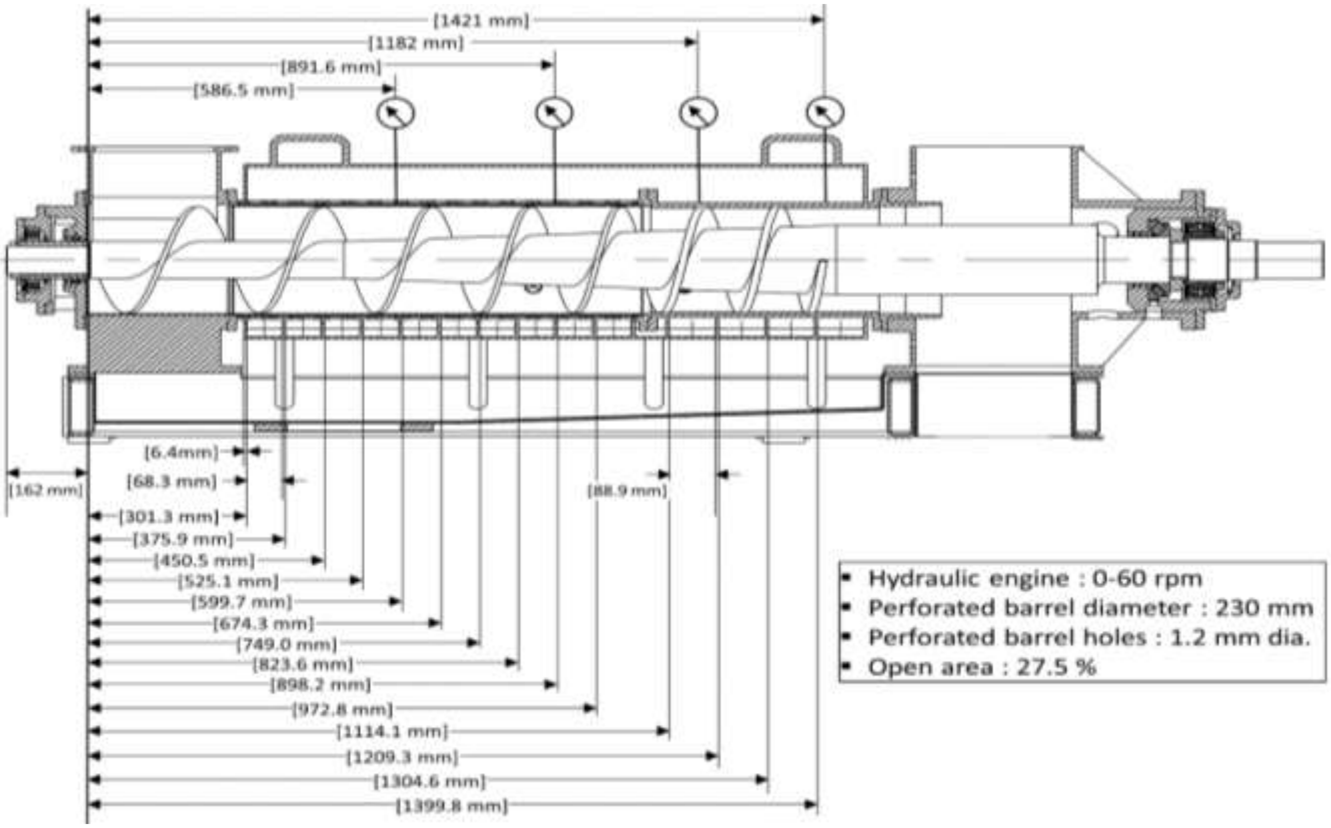

Fig. 1. Schematic of the screw press

Table 1. Pulps' Properties

Property	Kraft	BCTMP	TMP
Type	Softwood (northern bleached softwood kraft)	Hardwood	Softwood
Origin	J. D. Irving, Ltd. (Saint John, NB, Canada)	Rayonier Advanced Materials (Témiscaming, QC, Canada)	Papier Masson Ltd. (Gatineau, QC, Canada)
Fibre length based on length-weighted (lw) (mm)	2.03	0.81	0.91
Fibre width (lw) (µm)	27	28.6	33.9
Fines (lw) (%)	27.5	52.3	60.7
Coarseness (µg/m)	181	167	222
Crowding factor* (Mason 1954)	285	69	54
* The crowding factor (N) represents the number of fibres in a spherical volume of diameter equal to the length of a fibre. It is used to characterize fibre flocculation in an aqueous suspension			

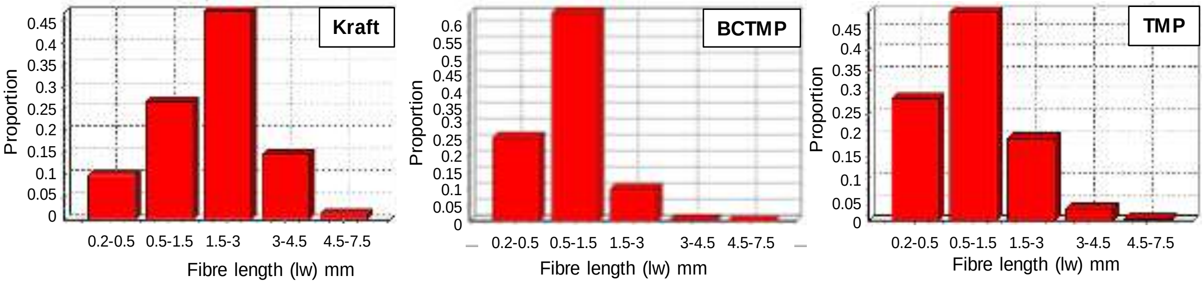

Fig. 2. Fibres length distribution

Methods

Based on literature and the authors' previous work (El Idrissi *et al.* 2019), the main factors to consider for pulp dewatering are the rotational speed, the feed consistency, the pulp freeness, the feed pressure, and the counter-pressure. So, these five parameters were included in the experiment. Table 2 summarizes the operational parameters' ranges. For kraft pulp, a central composite-uniform precision design was used, with six central points. For TMP and BCTMP, a central composite-orthogonal block design was used, with three central points. For kraft pulp, the study involved 32 trials, 27 trials for BCTMP, and 27 trials for TMP. The graphs for all the trials were analysed and by looking at the variation along the screw press. To simplify the presentation in this paper, only two curves were kept for each pulp (the minimum and maximum responses), which can describe the overall variation along the screw press. Therefore, any intermediate conditions will be found in between. It also should be pointed out that the perforated barrel was divided into 14 sections and the data were not showing any ambiguous fluctuation (*e.g.*, Fig. 4), which may affect the choice to consider showing only the maximum and minimum graphs.

The flow rate and the consistency of what has been termed "filtrate" were determined during trials. The pulp was collected at the discharge end to measure the consistency. The average pulp velocity and consistency along the screw press were calculated based on data collected along the screw press.

Table 2. Operational Parameters' Ranges

Pulp	Rotational Speed (rpm)		Consistency (%)		Freeness (mL)		Feed Pressure (kPa*)		Counter-pressure (kPa*)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Kraft	22	44	2	4	176	464	10	30	200	400
BCTMP	9	44	2	3.8	151	328	8	30	200	400
TMP	10	34	2	3.57	137	276	4	18	200	400
* All the measured pressures are expressed as gauge pressure.										

RESULTS AND DISCUSSION

Filtrate Flow Rate

Figure 3 shows the filtrate variation along the screw press for the three pulps studied, and Table 3 shows the operational parameter values for each trial. For low drainage, the three pulps drained the same way. The drainage was almost constant along the screw press. For high drainage, the filtrate flow rate was constant, followed by a noticeable decrease at 1150 mm, followed by an appreciable increase. High drainage was observed with greater rotational speeds and high freeness. When the rotational speed was increased, the pulp moved faster to the discharge end, giving space for the suspension to drain by filtration. Furthermore, the screw flights scraped the pulp mat off the screen basket, allowing for faster drainage. The drainage decreases can be explained by the screw channel filling with the pulp, which starts to consolidate, inhibiting drainage as fines and short fibres are retained inside the mat. At this point, a pressure build-up occurred, and the mat was consolidated, due to the increased pressure from the moving flights and drag forces. The drainage decrease was greater for BCTMP and TMP, which is explained by the pulps' permeabilities.

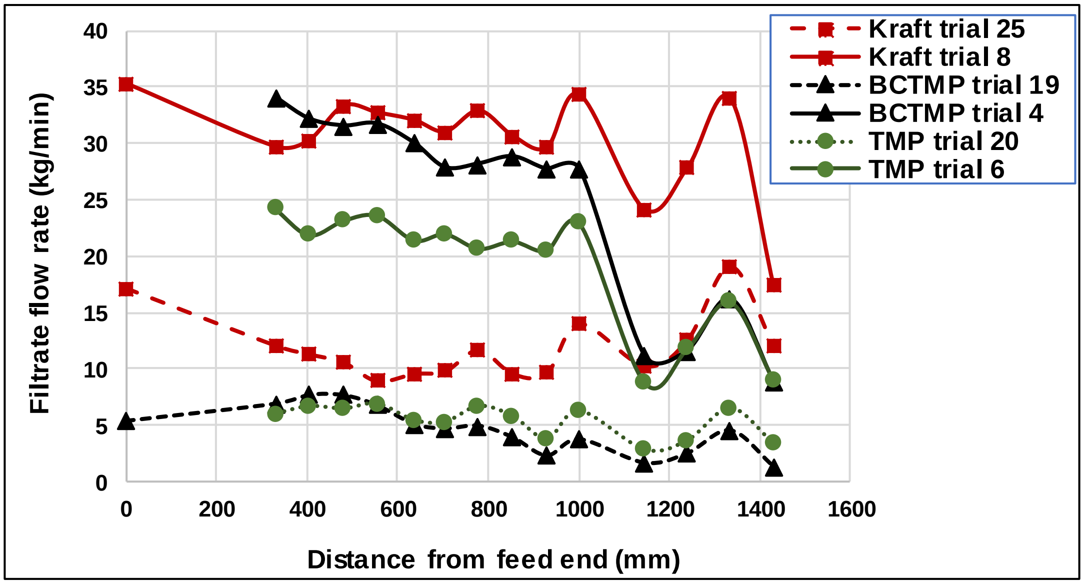

Fig. 3. Filtrate flow rate along the screw press

Kraft pulp is more permeable compared to BCTMP and TMP, due to a much lower fines content, so the water drains more easily. The dewatering process in a screw press is considered to occur in two steps, starting with filtration, followed by consolidation after a point, called the transition point. From Fig. 3, one can presume that the transition point is located somewhere amid the flow rate decrease. Considering that the lowest drainage point, just before it increases again due to the pressure build-up in the screw press, is the point where the filtration is no longer the controlling process and now the dewatering happens by compressing the fibre mat. Notably, when refining the pulp, the fines content increases, thus decreasing the drainage. Fines are generally highly swollen particles (Laivins and Scallan 1996). They fill the spaces between fibres and slow the dewatering (Seth 2003). The secondary fines, generated during refining of chemical pulp, are usually fibrillar (Sirviö and Niskanen 2008), which brings fibres into closer contact and enhances fibre-fibre bonding during pressing.

Table 3. Operational Parameter Values for the Filtrate Flow Rate Extremes

Pulp	Trial	Rotational Speed (rpm)	Consistency (%)	Freeness (mL)	Feed Pressure (kPa)	Counter-pressure (kPa)
Kraft	25	22	4	176	10	400
	8	44	2	464	10	200
BCTMP	19	9	3.8	151	8	200
	4	44	3.18	328	29	300
TMP	20	10	3.57	137	8	200
	6	30	2	276	18	200

Filtrate Consistency

Figure 4 shows the filtrate consistency variation along the screw press. In Table 4, the conditions yielding the extremes of the drainage were not the same for the filtrate consistency, so other trials were chosen to better represent the overall variation. For some operating conditions, the filtrate consistency was very low at the beginning of the dewatering process, and the filtrate consistency did not change much along the screw press. Presumably, not too many fines were pushed through the basket due to the low-drainage conditions. For some others, the filtrate consistency was very high near the feed, with a noticeable decrease in the filtrate consistency along the press, when the pulp consistency inside the press was increasing. The fines and short fibres started to be more efficiently retained by the pulp mat. The filtrate consistency from BCTMP and TMP decreased rapidly, starting from a higher level than the kraft pulp, due to their high fines' contents. Most of the fines and short fibres were removed, yielding a fibre web that was more compact. The remaining fines and short fibres filled the pores, which helped to block more fines and fibres from slipping off the screw press. The kraft pulp did not contain many fines, explaining the almost constant filtrate consistency along the screw press. One should also notice from Figs. 3 and 4 that the filtrate consistency is not significantly affected by the rates at which the filtrate flows through the screen barrel. It is also interesting to compare the filtrate mean fibre length along the screw press (Fig. 5), as it is apparent that the filtrate fibre length is higher when feeding with low consistencies. It also confirms the theory that the screw flights are continuously scrapping off the formed web on the perforated barrel. Operating with high rotational speed pushes rapidly the formed web and reducing the residence time. Thus, making the filtration theory applied in a screw press invalid, at least for dilute suspensions.

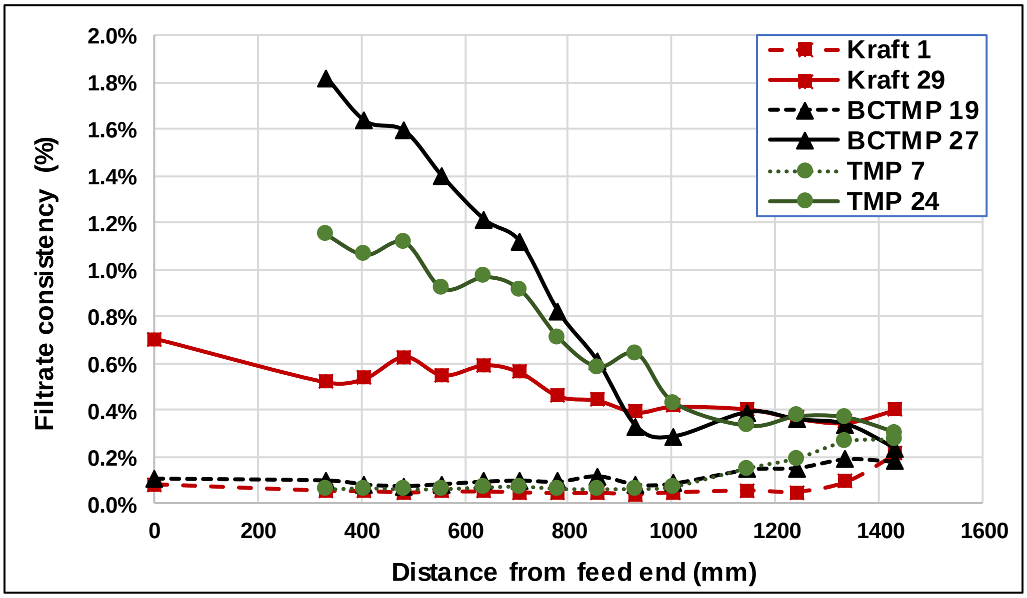

Fig. 4. Filtrate consistency along the screw press

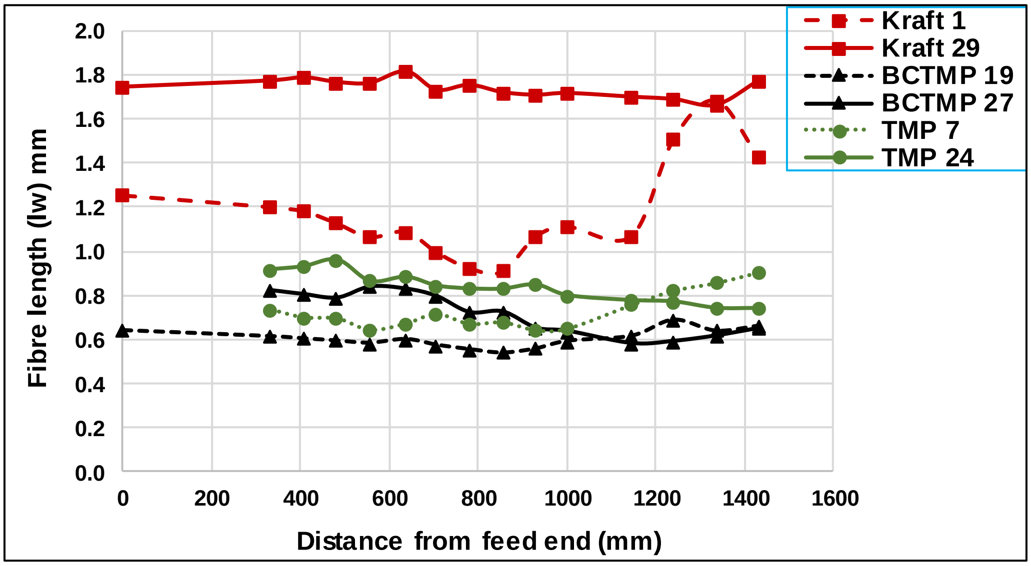

Fig. 5. Filtrate mean fibre length (lw) along the screw press

Table 4 indicates that increasing the rotational speed and the feed pressure increased the filtrate consistency. When increasing the rotational speed and the pressure, the feeding pump is feeding the pulp rapidly to the screw press as it was demonstrated in our study on the screw press parameters (El Idrissi *et al*. 2019). Thus, the fibre mat is rapidly moving towards the discharge end, and the fast-rotating flights are scraping off the web, allowing a clear perforated barrel. Thus, the fines and short fibres freely slip off the screw press. Meanwhile, the filtrate consistency is expected to be inversely dependent on the freeness. Reducing the freeness increases the fines content in the suspension, yielding a greater more important filtrate consistency.

Table 4. Operational Parameter Values for the Filtrate Consistency Extremes

Pulp	Trial	Rotational Speed (rpm)	Consistency (%)	Freeness (mL)	Feed Pressure (kPa)	Counter-pressure (kPa)
Kraft	1	22	4	464	10	200
	29	44	2	176	30	200
BCTMP	19	9	3.8	151	8	200
	27	22	2.44	151	16	300
TMP	7	10	2	276	8	200
	24	10	2	137	8	300

Water Removal

Figure 6 shows the cumulative water removal along the screw press. The same process was performed for the water removal as was done for the filtrate. From all water removal graphs, those yielding the maximum and minimum higher and lower water removal were selected. The conditions for the extreme values are summarized in Table 5. The water removal represents the fraction of the water volume entering the press that has been removed in each section of the press. Most of drainage occurred up to 1000 mm in the screw press, followed by the remaining water's slow removal due to the increased pressure in the screw press.

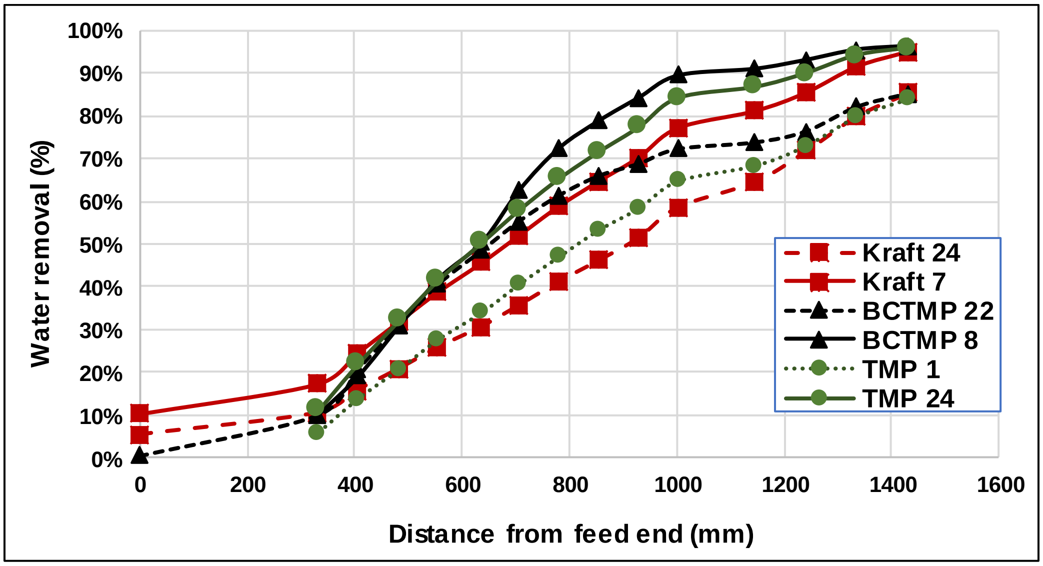

Fig. 6. Water removal along the screw press

Comparing the three pulps, no difference was noticeable in how the water was removed. The graphs had the same shape, and the water removal percentage difference was related to the screw parameters and the pulp properties. For all three pulps and the wide range of operations and pulp properties, one could expect a water removal from 85% to 95%. As one may expect, the water removal could be higher when operating with low rotational speed and feed pressure as it was demonstrated in the authors' previous work (El Idrissi *et al.* 2019). It was affected, of course, by the fines content and the pulp freeness.

When TMP, containing relatively more fines and a bit longer fibre (Fig. 2), was pressed, the fines seal the web pores rapidly, thus reducing the dewaterability of the web. This explains the lower water removal of TMP compared to BCTMP (Fig. 5). Moreover, BCTMP consists of hardwood fibres, which are more rigid, and they remain very few collapsed during dewatering so the pore structure is more open compared to TMP. Thus, there was enough space for fines and water to be pushed through the barrel perforation.

Table 5. Operational Parameter Values for the Water Removal Extremes

Pulp	Trial	Rotational Speed (rpm)	Consistency (%)	Freeness (mL)	Feed Pressure (kPa)	Counter-pressure (kPa)
Kraft	24	44	4	176	10	200
	7	22	2	464	10	400
BCTMP	22	30	3.8	151	8	300
	8	22	2	328	30	300
TMP	1	34	3.57	276	8	200
	24	10	2	137	18	200

Pressure Variation

The screw press was operated with four pressure sensors. The position of each sensor is shown in Fig. 1. Figure 7 shows the pressure extremes, and Table 6 lists the operational parameters values leading to the pressure extremes. The pressure in the first sections of the press was almost constant. A notable pressure increase occurred only at the discharge end. In the first sections of the press, the dominating process was filtration. Most of the drainage happened before the discharge end, as shown in Fig. 6.

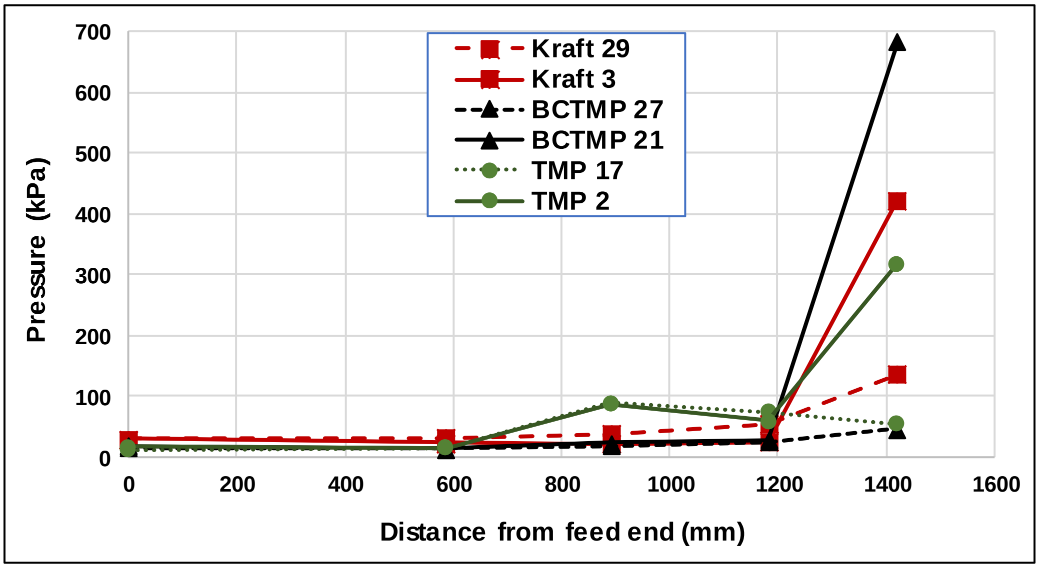

Fig. 7. Pressure variation along the screw press

The remaining water was removed by compression, which explains the pressure increase at the discharge end. The kraft pulp and TMP were both softwood and thus more flexible than the BCTMP, which was a hardwood and thus could develop greater pressure. When the suspension feed flow rate was low, and the fibre mat had enough time to dewater by filtration. By the time it reached the discharge end, the web had the properties of a compressible solid, creating a larger pressure rise near the discharge end. In contrast, when feeding the suspension with a high flow rate, the pressure applied near the feed end pushed the fibre mat rapidly to the discharge end, preventing the web from creating a pressure build-up.

Table 6. Operational Parameter Values for the Pressure Extremes

Pulp	Trial	Rotational Speed (rpm)	Consistency (%)	Freeness (mL)	Feed Pressure (kPa)	Counter-pressure (kPa)
Kraft	29	44	2	176	30	200
	3	22	4	464	30	400
BCTMP	27	22	2.44	151	16	300
	21	9	3.8	151	18	300
TMP	17	34	2.77	197	13	400
	2	10	3.57	276	18	200

Pulp Consistency

Using a mass balance along the screw press, the pulp consistency along the screw press was calculated. Figure 8 shows the extremes, and Table 7 gives the operational parameters values leading to those extremes. The pulp consistency increased more in the second part of the press. As soon as the suspension entered the screw press, the water was removed by the filtration process, which seems to be a slow process, yielding a slow pulp consistency increase. When most of the fines and short fibres were removed, the pulp was thicker, and the pressure increased (Fig. 8). The pressure increase was responsible for the removal of the remaining water, rapidly increasing the pulp consistency in the screw press. The kraft pulp contained very few fines compared to the BCTMP and TMP, which explains the little difference between the two extreme graphs for the kraft pulp. It was possible to reach a maximum outlet consistency of 44.7%, 41.5% and 39.2% for BCTMP, TMP and kraft pulp respectively. It should noticed that the maximum outlet consistency that can reached in a screw press is related to the Water Retention Value (WRV) of the treated pulp (Egenes and Helle 1992), as listed in Table 8. From the results, we reached a higher outlet consistency for BCTMP, which has higher WRV. In our article about the operational parameters (El Idrissi 2019), we found that the counter pressure affects only a little the final consistency of kraft pulp but has no effect on TMP and BCTMP. We would assume that the counter pressure becomes marginal at some pressure level. From the feed end to the point where the counter pressure starts taking effect, the free water between the fibres and even in fibres was removed. The remaining water can be considered as “bonded”. Parts of it exist as swell water and parts remaining in very small pores requiring high pressure to be expelled. Probably by using the consistency corresponding to the water retention value as a practical upper limit for the discharge consistency. It was demonstrated by Egenes (1990) that the maximal discharge consistency corresponded very closely to the solids content achieved by the WRV test. It is a well-known fact that it is possible to remove more water by compression (*e.g.*, in a paper machine) than that corresponding to the WRV test (Ellis *et al.* 1984). However, the pressure required appears to be much higher than those established in screw presses.

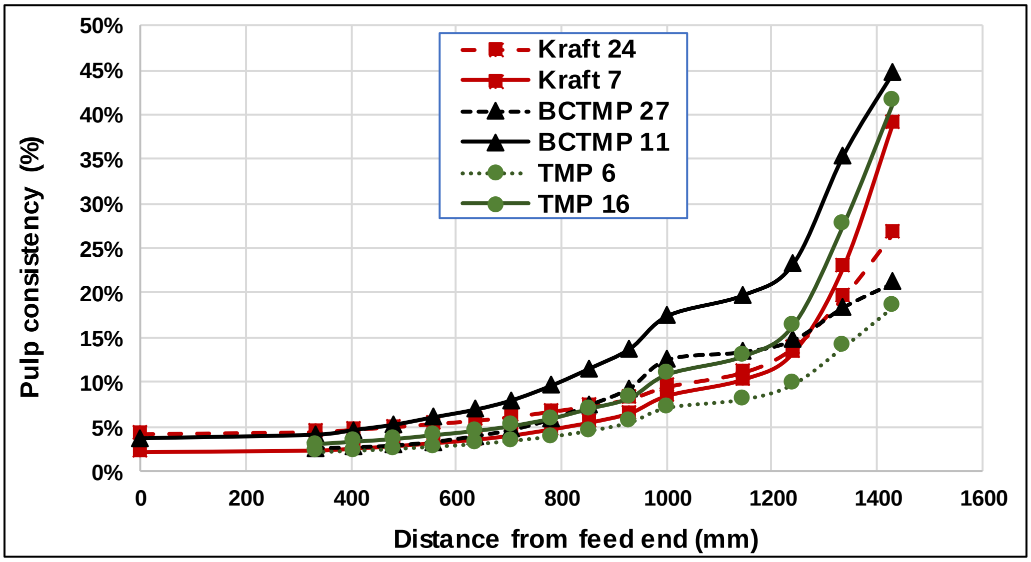

Fig. 8. Pulp consistency along the screw press

Table 7. The Operational Parameter Values for the Pulp Consistency Extremes

Pulp	Trial	Rotational Speed (rpm)	Consistency (%)	Freeness (mL)	Feed Pressure (kPag)	Counter-pressure (kPag)
Kraft	24	44	4	176	10	200
	7	22	2	464	10	400
BCTMP	27	22	2.44	151	16	300
	11	9	3.32	262	13	400
TMP	6	30	2	276	18	200
	16	10	2.77	197	13	400

Table 8. Water Retention Values in Comparison to the Outlet Consistency

Pulp	Trial	Outlet consistency (%)	Water Retention Value (%)
Kraft	7	39.2	174.9
Kraft	24	26.8	199.1
BCTMP	11	44.7	211.2
BCTMP	27	21.1	228.5
TMP	6	18.5	168.7
TMP	16	41.5	163.5

Pulp Axial Speed

Figure 9 shows the pulp axial velocity along the screw press, and Table 9 lists the operational parameters for the pulp axial velocity extremes. Obviously, the pulp axial velocity was higher when operating at high rotational speeds. The axial velocity decreases near the discharge end because of the high shear. To compare the pulp axial velocity with the screw linear advance, an axial ratio was calculated by dividing the average pulp velocity by the nominal advance of the screw flight.

Figure 9 shows that the pulp axial velocity for the kraft pulp exceeded the screw flight advance in the feed end. This result can be explained as follows: When feeding the web at a greater rotational speed, the drainage is very high, so the pump is injecting more pulp suspension into the screw press with a velocity that can exceed the linear advance of the screw flights. This result was not noticed for the BCTMP and TMP because trials with extreme conditions (the same as for the kraft pulp) could not be conducted, as the pulp was so fast that collected pulp had a very low consistency. A low axial ratio indicates that the pulp is slipping in the screw press, due to the pulp flow resistance.

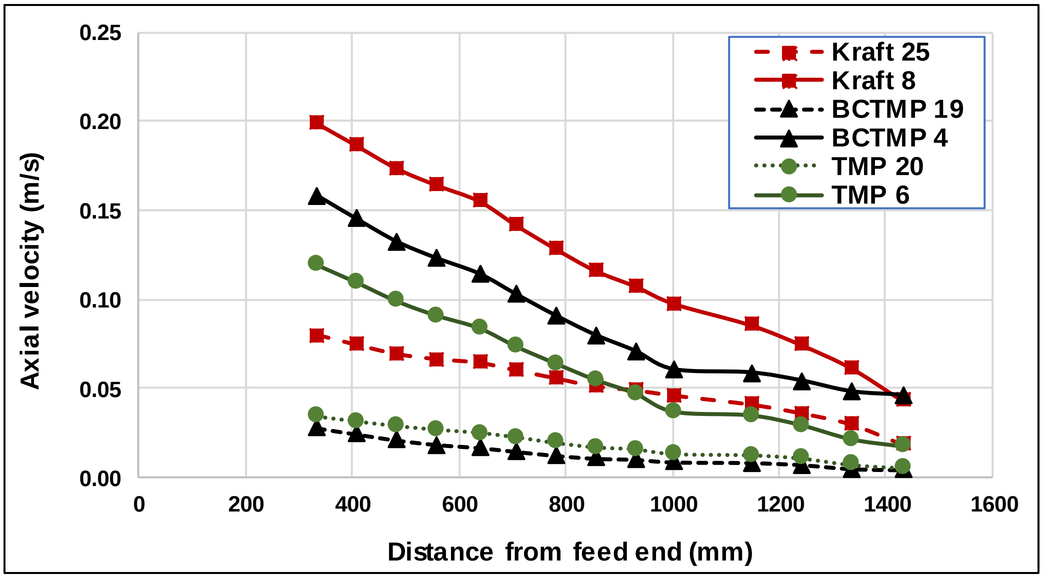

Fig. 9. Pulp axial velocity along the screw press

Table 9. The Operational Parameter Values for the Axial Velocity Extremes

Pulp	Trial	Rotational Speed (rpm)	Consistency (%)	Freeness (mL)	Feed Pressure (kPa)	Counter-pressure (kPa)
Kraft	25	22	4	176	10	400
	8	44	2	464	10	200
BCTMP	19	9	3.8	151	8	200
	4	44	3.18	328	29	300
TMP	20	10	3.57	137	8	200
	6	30	2	276	18	200

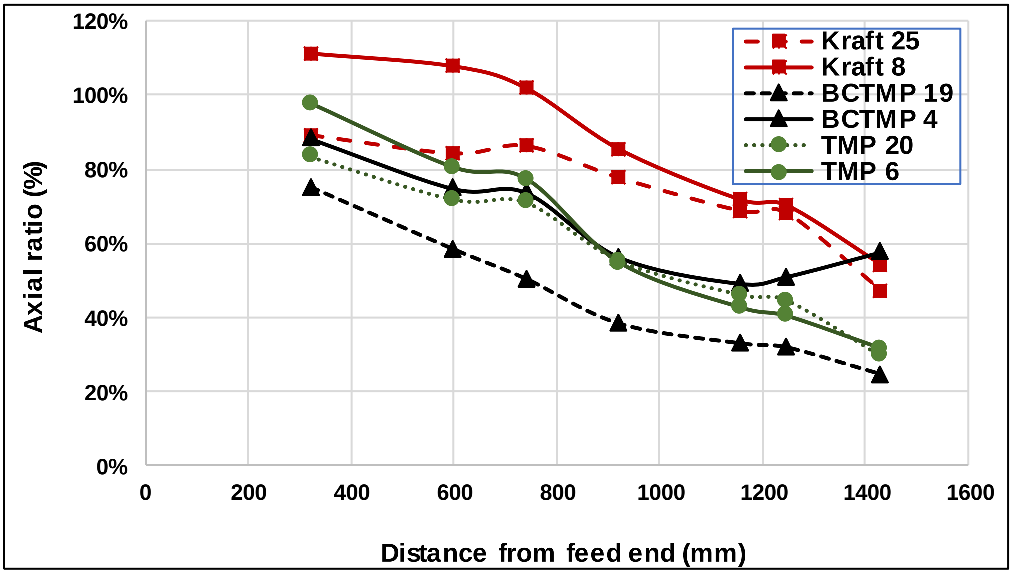

Fig. 10. Axial ratio along the screw press

Summary of the Results

Table 10 summarizes the ranges of the calculated and measured parameters in this study. Even if the screw press can manage the three pulps, permitting it to remove up to 95% of the inlet water, the capacity of the screw press is strongly dependent on the pulp properties. The presence of fines and short fibres reduced the maximum filtrate flow rate by half, comparing the kraft pulp and TMP. The BCTMP was hardwood, with short and stiff fibres with quite high fines content and reached approximately the same volume of filtrate removal as the kraft pulp. As noticed, the pressure did not change much along the screw press until the position near sensor four, so the pressure indicated by this sensor appears in Table 10. The filtrate consistency for BCTMP and TMP was high compared to the kraft pulp, due to the high fines content in both the BCTMP and TMP suspensions. The fines content also affected the pressure in the screw press, and the pressures for the BCTMP and TMP were very close. In Table 11, it is apparent that the energy needed to reach a certain water removal for the three pulps. Kraft dewaters using less energy compared to TMP and BCTMP. The more we dewater, the more the web inside the screw press is compact. In the end, this explains why when reaching high water removal, the energy consumption difference between kraft pulp and the two other pulps is more important. The fines content and fibre stiffness are the main responsible factors, as the web is compact or resistant, more pressure is needed to dewater.

Table 10. Summary of Results

Pulp	Filtrate Flow Rate (kg/min)		Filtrate Consistency (%)		Water Removal (%)		Pressure Sensor 4 (kPag)		Outlet Consistency (%)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Kraft	178.4	512.2	0.07	0.49	85.4	95.0	137	423.2	26.8	39.2
BCTMP	68.5	557.5	0.10	1.22	85.2	96.3	46.6	684.3	21.1	44.7
TMP	74.8	267.4	0.09	0.83	83.2	95.8	55.6	623.9	18.5	41.5

Table 11. Energy Consumption According to the Water Removal %

			Energy consumption (kwh/kg$_{dry}$)
Kraft water removal (%)	Min	85.4	1.0
	Max	95.0	1.41
BCTMP water removal (%)	Min	85.2	1.6
	Max	96.3	2.0
TMP water removal (%)	Min	83.2	1.0
	Max	95.8	2.2

CONCLUSIONS

1. At the feed end, the suspension had the properties of a fibre network. The pressure increased slowly. The filtration started immediately after entering the screw press, and the screw cleared the perforated barrel with every flight revolution.
2. The filtration was a slow process. Thus, increasing the rotational speed implied an increase in the drainage. Thus, the pump fed more pulp into the screw press, causing the axial velocity of the pulp to be greater than that of the screw flight advance. The filtration was inversely related to the fines content; thus, a high fines content can limit the rotational speed at which the screw press should operate. The fines' contents in BCTMP and TMP reduced the filtration effect causing a fluid pulp near the discharge end, made it impossible to operate with high rotational speeds.
3. Near the discharge end, the pressure effect dominated. When the compact web formed, the pulp was more resistant to the flow. Thus, it started to slip, which was noticed when calculating an axial ratio, showing that the pulp was moving much slower than the screw's linear advance.
4. The overall behaviours of the pulps studied seemed similar. The exception was for the kraft pulp, which could be operated in maximum conditions compared with the BCTMP and TMP. Verifying the pulp properties, this behaviour difference could be explained by the fibre properties. The kraft pulp had longer fibres and a greater crowding factor, meaning that the kraft pulp forms a compact web faster than the BCTMP and TMP. Also, the fines content was a dominant pulp property that especially affected the drainage.

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