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# Beating of Eucalyptus Pulp Fibers under Neutral and Alkaline Conditions – A Valley Beater Study

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Author KD supervised the study. Author BB performed the laboratory study and analysation. Author KD wrote the first draft of the manuscript and approved the final manuscript.*

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## ABSTRACT

Beating is one of the most important and complicated processes that influences paper production and paper quality from both a process and a paper property standpoint.
With increasing costs, environmental regulations and competitiveness in the today's global market, paper and board producers revisit existing production process to decrease production costs. New approached with additives such as new developed in-situ precipitated paper fillers materials have the potential to reduce production cost and increase profit margins.
For this research bleached eucalyptus Kraft pulp adjusted to a pH of 7.5, 11.0 and 12.3, and laboratory manufactured in-situ precipitated calcium carbonate with a filler level based on oven dry fiber content of 20.9% and 41.7% and a pH of 7.5, and commercial produced precipitated calcium carbonate filler of 10% and 20%. All pulp suspensions were beaten for 80 minutes with samples taken at the unbeaten level and 20 minutes increments.
The beating curve over 80 minutes beating time show that pulp suspensions with in-situ produced filer material have a higher dewatering ability with increasing filler content compared to the pulps with commercial PCC and different pH values.
Viscosity slightly decreases for pulp suspension with commercial and in-situ produced filler content. Pulp suspension at a pH of 12.3 showed a significant decrease in viscosity over the 80

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minutes beating time, superseding the filler containing pulp suspensions.
Basis weight decreased over beating time for all pulp suspensions, which can be explained with an increased fines production during beating and lower fiber retention during handsheet forming.
The breaking length index increase for all pulp suspensions till 40 minutes of beating time for the filler containing pulp suspensions.
Tear index and burst index curves based on beating time are similar for all pulp suspensions with a maximum at 40 minutes beating for the tear index and 60 minutes beating for the burst index. High filler containing pulp suspension showed the lowest tear index.

*Keywords: Alkaline; beating; calcium carbonate; eucalyptus; filler; in-situ precipitation; hybrid filler; neutral; paper; precipitated calcium carbonate; refining.*

## 1. INTRODUCTION

Today, beating also called refining, is one of the most important and complicated processes of the pulp manufacturing process. Refining influences paper production and paper quality from both a process and a paper property standpoint.

At present time increasing utility costs, stringent environmental regulations and high competitiveness in today's global market results in declining profits for paper and board producers. This requires them to search for new ways as well as revisit existing production process to decrease production costs [1,2,3].

To save production cost and lower raw material usage paper companies today add Precipitated Calcium Carbonate (PCC), Kaolin, and Ground Calcium Carbonate (GCC) with a combined market share of nearly 98% of which 70% is accounted to PCC. The remaining 2% is accounted to Titan dioxide, Silica / Silicates, and Talc and Aluminum Trihydrate [4] to the pulp fiber suspension, e.g. in the blend chest in wet-end section of the paper mill and at the fan pump shortly before the fiber suspension is entering the paper machine headbox after which the sheet forming process occurs [5]. However, the application of filler material causes a decrease of the paper's strength and lowers the product quality [4,5,6], but has the potential to save up to $ 4.0 for each 1% increase in filler content [4].

PCC is added in slurry or powdered form to the papermaking suspension in the blend chest at the wet-end section of the paper mill or at the fan pump shortly before the fiber suspension is entering the paper machine headbox after which the sheet forming process occurs [7].

Typically, before the fiber suspension enters the wet end the mechanical preparation of the fibers by beating has been completed. Interaction of filler materials during beating, especially for $TiO_2$ has been of interest by various researchers since the 1970's. Adding calcium carbonate-based filer materials prior to beating had been not the focus in the recent past [5].

Beating or refining, of pulp fiber is the mechanical treatment and modification of fibers so that they can be formed into paper or board of desired properties. The main target of beating is to improve the bonding ability of fibers so that they form strong and smooth paper sheets with ideal properties for converting and printing [3].

To improve production costs, paper manufacturers may target fiber production processes such as beating to save on production costs and to improve and optimize fiber properties of the paper and board grade produced. Often there is a trade-off between different paper properties required and the beating process. Changes made by beating on the fiber materials are irreversible and influence the paper production process and final paper properties of the product produced.

Beating of pulp fibers is done in the presence of water at consistencies of 3% to 5% with metallic plates or fillings in disc (disc refiner), cylindrical (cylinder refiner) or conical form (conical refiner) [3]. The plates or fillings are grooved so that the bars that treat fibers and the grooves between bars allow fiber transportation through the refining machine [8].

To simulate the beating process in the laboratory a simplified beating process at a solids content of 1.57%, shown in Fig. 1, is performed using a laboratory Valley Beater in accordance with the Technical Association of the Pulp and Paper Industry (TAPPI) testing method T 200 sp-06 "Laboratory beating of pulp (Valley beater method)" [9].

During beating operation, the stator bed plate assembly (5) consisting of beater bar (3) and beater bar spacers (4) is pressed with force F against the turning rotor (1) with beating blades (2). The interaction between rotor and stator applies the following beating interaction to the fibers. In the fiber Pick-Up stage in Fig. 1a). pulp fibers are collected on the leading edges of the rotor and stator bars. When the leading edge of the rotor bar approaches the leading edge of the stator and moves over the stator bar an edge to surface treatment shown in Fig. 1b) is initiated. During the edge to surface treatment, the pulp fibers are compressed and receives a forceful strike. As a result, most of the water is compressed out of the pulp fibers. Simultaneously, short fibers with low flocculation ability are likely to be separated and flow into the grooves between the bars. Only those fibers remaining between rotor and stator surface are compressed between the two metallic bar surfaces and receive beating interaction. After this, both leading edges slide along the pulp fibers and press them against the flat bar surface of the rotor ad stator. Most beating is performed during this surface-to-surface stage, shown in Fig. 1c), when the bar edges give mechanical treatment and friction between fibers. This stage continues until the leading edges reach the tailing edges of the opposite bars. During the edge-to-surface stage, the pulp fibers are still pressed between the flat bar surfaces until the tailing edge of the rotor bar has passed the tailing edge of the stator bar, releasing the fibers into the grove of the filling during the release stage shown in Fig. 1d) [3,10].

The following research project of beating eucalyptus pulp fibers has two objectives: First to compare the effect of beating under neutral and alkaline conditions without filler material. Second, to compare the effect of beating of in-situ precipitated calcium carbonate and commercially available precipitated calcium carbonate under neutral conditions.

Tests were performed using a Valley Beater laboratory beating devices for the evaluation of dewatering and mechanical paper properties (breaking length, burst and tear).

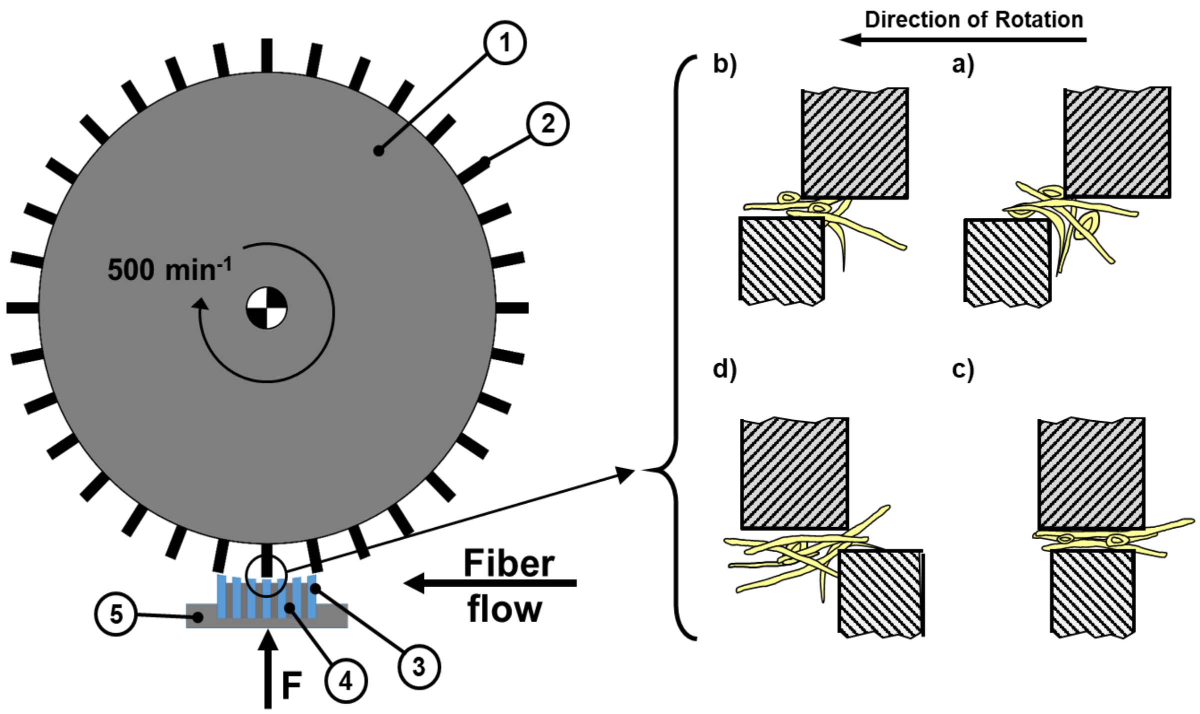


**Fig. 1. Valley Beater principle and rotor stator beating interaction, 1) Beater roll, 2) Beater blade, 3) Bed plate beater bars, 4) Bed plate beater bar spacer, 5) Bed plate assembly [11]**

## 2. MATERIALS AND METHODS

For this research project producing In-Situ Precipitate Calcium Carbonate (SIPCC) hardwood pulp in the form of Bleached Eucalyptus Kraft Pulp (BEKP) from CMPC Celulosa was used. Calcium hydroxide ($Ca(OH)_2$) powder was obtain from Lhoist North America.

Commercial PCC was used a filler material with a particle size spectrum of 1.0 µm to 4.0 µm at a filler content of 10% and 20%.

Industrial grade carbon dioxide ($CO_2$) gas was used with a 99% purity, supplied in a pressurized container containing 50 lbs. (22.68 kg) of gas.

### 2.1 Manufacture of Hybrid Pulp

The manufacturing of the in-situ precipitated calcium carbonate (ISPCC) filler in the presence of EC pulp fibers for this beating and paper properties study was done according to the procedure described by Doelle & Bajrami [2,3]. The ISPCC pulp fiber suspension with a filler content of 20.9% and 41.7% filler content is referred to as HP 20.9% Filler and HP 41.7% filler in the following results discussion.

### 2.2 Manufacture of Commercial Filler Containing Pulp

Commercial available precipitated Calcium Carbonate (PCC) was added prior to beating to the BEKP pulp suspension at a level of 10% and 20% based on Oven Dry (OD) fiber content.

### 2.3 Testing Methods

For this research project the following testing methods of the Technical Association of the Pulp and Paper Industry (TAPPI) were used:

Beating of pulp (Valley beater method) in accordance with T 200 sp-06 “Laboratory beating of pulp (Valley beater method)” [9]. Handsheets preparation was done according to T 205 sp-06 “Forming handsheets for physical tests of pulp” [12]. The ash was measured after T 211 om-02, “Ash in wood, pulp, paper and paperboard: combustion at 525°C [13]. Pulp pads were prepared according to T 218 sp-06, “Forming handsheets for reflectance testing of pulp (Büchner funnel procedure)” [14]. Physical testing of handsheets was performed in accordance with T 220 sp-06, “Physical testing of pulp handsheets” [15]. Freeness of pulp was measured as Canadian Standard Freeness (CSF) according to T 227 om-09 “Freeness of pulp (Canadian standard method)” [16]. Pulp suspension viscosity was measured according to TAPPI T 230 om-08. “Viscosity of pulp (capillary viscosimeter method) [17].

Consistency of a pulp suspension was measured with TAPPI T240 om-07 “Consistency (concentration) of pulp suspensions” [18]. Beating of pulp (PFI mill method) was performed in accordance to T 248 sp-08 “Laboratory beating of pulp (PFI mill method)” [19].

Conditioning of the paper samples was done according to T 402 sp-08, “Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products” [20]. Burst Index was measured in accordance with T 403 om-02 :Bursting strength of paper” [21]. Basis weight was measured with T 410 om-08. “Grammage of Paper and Paperboard (weight per unit area)” [22]. Moisture content of pulp was determined by T412 om-06 “Moisture in pulp, paper and paperboard” [23]. Tear resistance was measured according to T 414 om-04 “Internal tearing resistance of paper (Elmendorf-type method)” [24]. Tensile strength was performed following T494 om-06, “Tensile properties of paper and paperboard (using constant rate of elongation apparatus)” [25].

For measuring temperature and pH of the pulp suspension an Accumet AP85 instrument was used.

### 2.4 Pulp Viscosity

For the pulp viscosity measurement T 230 om-08 was used [17]. For this research, a deviation to the T230 method was implemented for the pulp pads prepared with the Büchner funnel procedure according to T 218 sp-0 [18]. Due to the high strength of the air-dried pulp pads, a micro-blender was used as a mechanical pre-treatment properly disintegrate the pulp pads and allow the cupriethylenediamine (CED) to properly penetrate into the pulp. Without this pre-treatment, the CED was not able to adequately break down the pulp to a homogenous mixture, consequently making the viscosity readings invalid. The T 230 was then followed exactly from that point on.

## 2.5 Pulp Beating Methods

Beating of the pulp suspensions (was done using a laboratory Valley Beater shown in Fig. 2. according to TAPPI test method T200 sp-06 [9].

**Fig. 2. Valley beater [26]**

T 200 sp-06 requires a sample weighing 362 ± 3.0 g oven dry (OD) fiber material for a beater run. Filler containing pulp suspensions were added based on 362 ± 3.0 g oven dry (OD) fiber material as required by T 200 sp-06 testing standard [9]. Each sample is diluted to 23 l prior to beating which corresponds to a fiber consistency of 1.57 ± 0.04%. After the 23 l sample is filled in the Valley Beater (Fig. 3), the beater is run for three minutes with no load. When the pulp is properly disintegrated, the clamp from the lever arm is removed, and the standard 5500-g weight is added to the lever arm and the beating process is started. After successive time intervals (20 minutes for this research project), a 1200-mL sample is withdrawn from the beater to yield a total of five samples at approximately equal freeness intervals. Each withdrawal provided a sample of 18.8 g OD to yield sufficient pulp for TAPPI freeness determination in accordance with T 227 om-09 "Freeness of Pulp" [16], and for the making 12 standard 1.2g handsheets in accordance with T 205 sp-06 "Forming handsheets for physical tests of pulp" [12]. An additional 380 ml of pulp suspension was removed for viscosity tests for each 20 minutes beating interval as a change to the established T200 sp-06 beating procedure [9].

## 3. RESULTS AND DISCUSSION

All tests for this research were performed in according to the in Section 2.3. referenced TAPPI methods. All results stayed in the precision statements for the referenced TAPPI methods.

### 3.1 Manufacture of Hybrid Pulp

The manufacturing of the in-situ precipitated calcium carbonate (ISPCC) filler in the presence of EC pulp fibers for this beating and paper properties study was done according to the procedure described by Doelle & Bajrami [2,3]. The ISPCC pulp fiber suspension with a filler content of 20.9% and 41.7% filler content is referred to as HP 20.9% Filler and HP 41.7% filler in the following results discussion.

### 3.2 Beating Study

In this chapter the behavior of the HP 20.9% and HP 41.7% pulp was compared to: a) commercial available precipitated calcium carbonate (PCC) filler material at a filler content of 10% and 20%, in the following referred to as PCC 10% Filler and PCC 20% Filler, and b) EC pulp at a pH of 7.5, 11.0 and 12.3 without filler content, in the following referred to as EC pH 7.5, EC pH 11.0, and EC pH 12.3.

The pH adjustment to the EC pulp for a pH of 11.0 and 12.3 was done with a $Ca(OH)_2$ suspension with 20% dry solids content by titrating to the respective ph level. Beating curves were generated using a Valley Beater laboratory machine following TAPPI test method T200 sp-06.

The Valley Beater beating curve is shown in Fig. 3, displays data for the seven EC pulp suspensions. Each Valley Beater run provided enough pulp samples for the subsequent analyses of dewatering value expressed in CSF and viscosity as well as analyses of mechanical handsheet paper properties including basis weight, bulk, breaking length, tear, and bust.

The beating curve starts at 0 minutes (unrefined pulp sample) and goes up to 80 minutes (highly refined sample) in intervals of 20 minutes for all seven pulp samples.

The beating curve over 80 minutes beating time show that the HP pulps have a higher initial dewatering ability (CEF-value) with increasing filler content as the EC pulp with commercial PCC filler and the EC pulp with no filler at different pH values. The initial CSF number of the EC pH 12.3 pulp was the highest and had the least decrease in dewatering ability over the 80 minutes beating time.

EC pulp at pH 11.0 and EC pulp with commercial filler (PCC10% Filler and PCC 20% Filler) had close initial CSF values and the decrease in initial dewatering ability was the same over the 80 min beating time.

EC pulp with an neutral pH and HP pulp with 20% filler content had almost identical initial CSF value, whereas the HP pulp with 41.7% filler content has a slightly higher initial CSF value. Over the 80 minutes beating time the dewatering ability of the EC pH 7.05 pulp decreased the least and is comparable to the EC pH 11.0 and PCC 10% Filler and PCC 20% Filler pulp. HP 20.9% Filler and HP 41.7% filler pulps have a similar decrease in dewatering ability to approximately 25 minutes of beating. The minimum of the pulp dewatering ability of the HP pulp is reached at 40 minutes for the HP pulp with 41.7% filler content and about 55 minutes for the HP pulp with 20.9% filler content. From there on the dewatering ability increases to its initial value after 80 minutes of beating for the HP 41.75 filler pulp and half of the initial value of the HP 20.9% Filler pulp. The EC pulp suspension with PH of 7.5, 11.0 and 12.3 as well as the EC pulp with PCC 10% Filler and PPC 20% Filler do not reach the reverse point after 80 minutes of beating. It can be concluded that the HP pulp reaches a lower CSF value earlier than the EC pulp with less beating time and therefore consumes less energy. This phenomenon can be linked to the precipitated filler particles attached to the fiber surface allowing a higher degree of refining [2,3].

Fig. 4 shows the development of the viscosity over 80 minutes beating time the seven pulp suspensions. A slight decrease in the viscosity over the 80 minutes beating time can be seen for the EC pulp suspension with PCC 20% Filler, HP 20.9% Filler and 41.7% Filler and EC pH 7.5 and 12.3 pulp. Whereas the initial viscosity of the EC PH 7.5 pulp and PCC 20% Filler pulp suspension was almost identical. Furthermore, it can be observed that the viscosity of the HP with 41.7% filler content has a significant lower initial viscosity in comparison to all other pulp suspensions. In contrast the PCC 10% filler showed first a decrease and then an significant increase in viscosity after 40 minutes of beating. The PCC 10% filler pulp had the highest initial viscosity of all tested pulp suspensions. The EC pH 12.3 pulp showed a significant decrease in viscosity over the 80 minutes beating time beating time superseding the HP 41.7% Filler pulp after approximately 45 minutes of beating.

The basis weight development and bulk (thickness) of the handsheets prepared according to TAPPI test method T 205 sp-06 is shown in Fig. 5 and Fig. 6 for the seven pulp suspensions taken at 20 minutes intervals during beating show a decrease in basis weight or lower retention, except for a beating time of 40 minutes for the EC PH 7.5 pulp suspension and the EC pH11 pulp suspension at 60 minutes beating time. The decrease in basis weight for the prepared handsheets can be explained with an increased fines production during beating. These fines in the pulp suspension are not retained on the 89 microns (150 mesh) wire of the TAPPI sheet former during hansheet forming. This results in an increased fiber loss, lower retention resulting in a lower basis weight of the prepared handsheet.

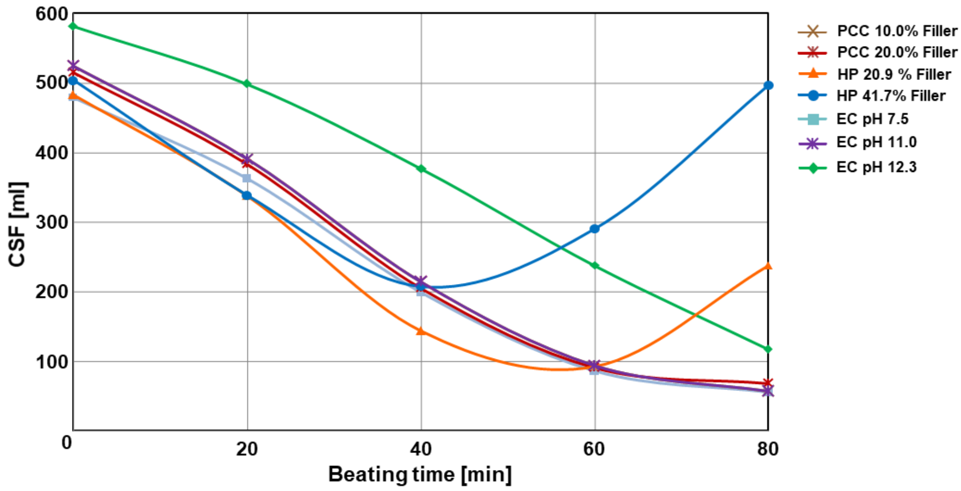


**Fig. 3. Valley beater beating curve**

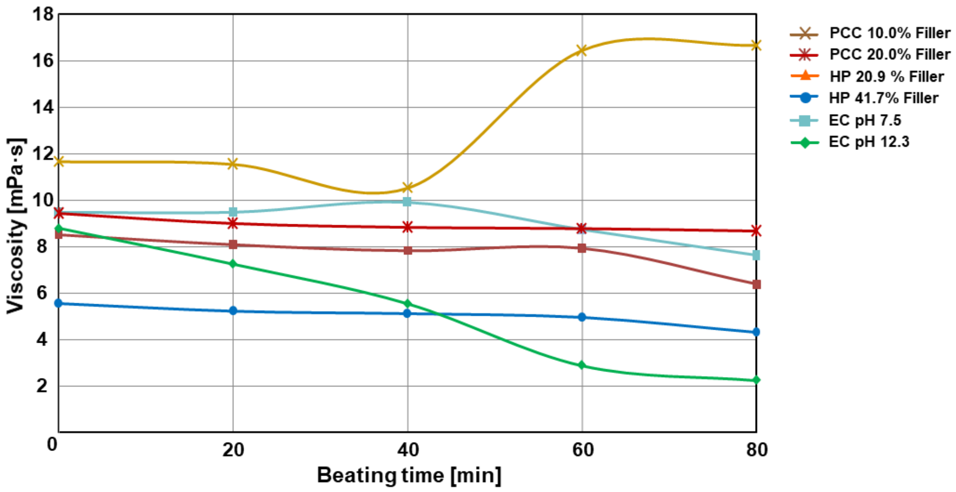


**Fig. 4. Valley beater viscosity**

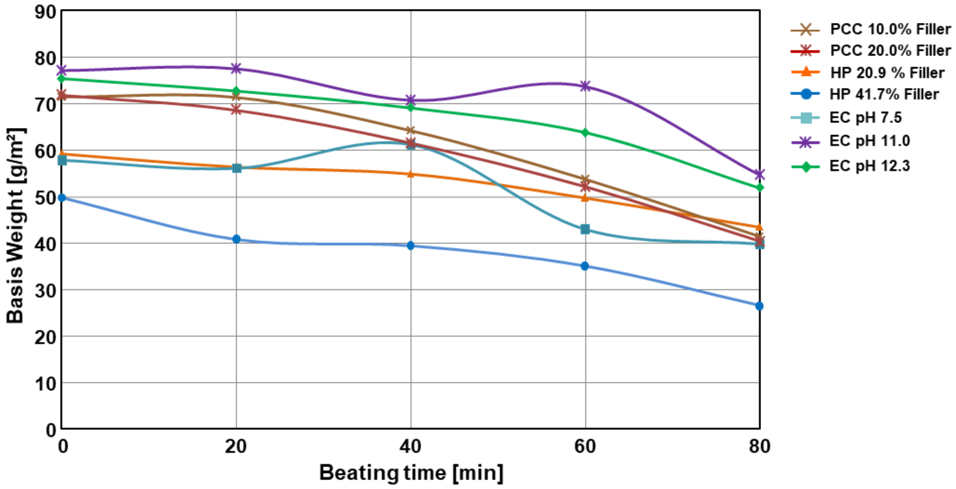


**Fig. 5. Valley beater basis weight**

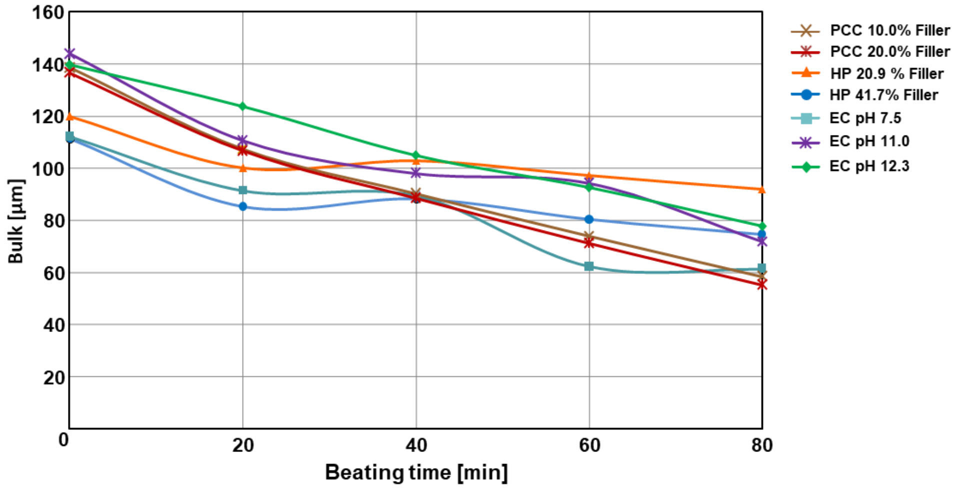


**Fig. 6. Valley beater bulk**

In Figs. 7, 8, and 9 show the beating curves development in 20 minutes increments for the breaking length index, the tear Index and burst index over a beating time of 80 minutes.

It can be seen in Fig. 7 that the breaking length index increases with increasing beating for all 7 pulp suspensions, except for the EC pH 11.0 pulp suspension at 60 minutes of beating, which could be due to a sampling error or uneven solids content in the beater during sampling. The breaking length for PCC 10%, PCC 20% and HP 20.9% is comparable till a 40 minutes beating time. After that the breaking length index flattens out for the HP 20.9% Filler pulp suspension, while the PCC 10% Filler and PCC 20% Filler pulp suspension continued to increase. The HP 41.7% Filler pulp suspension had the lowest breaking length index of all seven pulp suspensions, preceded by the EC pH 12.3 pulp suspension. The EC pH 7.5 pulp suspension had the highest breaking length index of all pulp suspension, however with varying results for the 40 minutes and 60 minutes beating time.

The HP 41.7% Filler pulp did not show an increase after 60 minutes of beating.

Tear index curves based on beating time are similar for EC pulp suspensions with 10% PCC Filler, 20% PCC Filler, EC pH7.5, EC pH 11.0, and EC pH 12.3 with the exception for the EC pH 7.5 at 60 minutes of beating time, which showed a significant change in comparison to the other pulp suspensions. The maximum for the tear index for the above pulp suspensions is a t 40 minutes beating time. HP 20.9% Filler and HP 41.7% Filler pulp suspensions shoed the lowest tear index. However, the maximum of the tear index for the HP 20.9% pulp suspension was at 20 minutes beating time and for the HP 41.7% Pulps suspension was at a beating time of 60 minutes.

Fig. 9 shows that the burst index increases with beating time. All seven-pulp suspension show similar curves development with a maximum of the burst index at 60 minutes of beating time, except for the EC pH 11.0 and EC 1pH 2.3 pulp suspension. The HP 41.7% Filler pulp had the lowest burst index followed by the HP 20.8% Filler pulp suspension after 40 minutes of beating. For a beating time of up to 40 minutes the burst index development is very similar for all pulp suspension except for the HP 41.7% Filler pulp suspension. However, EC pH11.0 had the highest burst index, followed by the PCC 10% and PCC 20% Filler pulp suspension. EC pH 7.5 pulp suspension was in-between the PCE 10% and PCCC 20% Filler pulp suspension while the EC pH 12.3 pulp suspension showed similar results to the HP 20% filler suspension for a beating time of 20 minutes but exceeded for a beating time of 40 minutes.

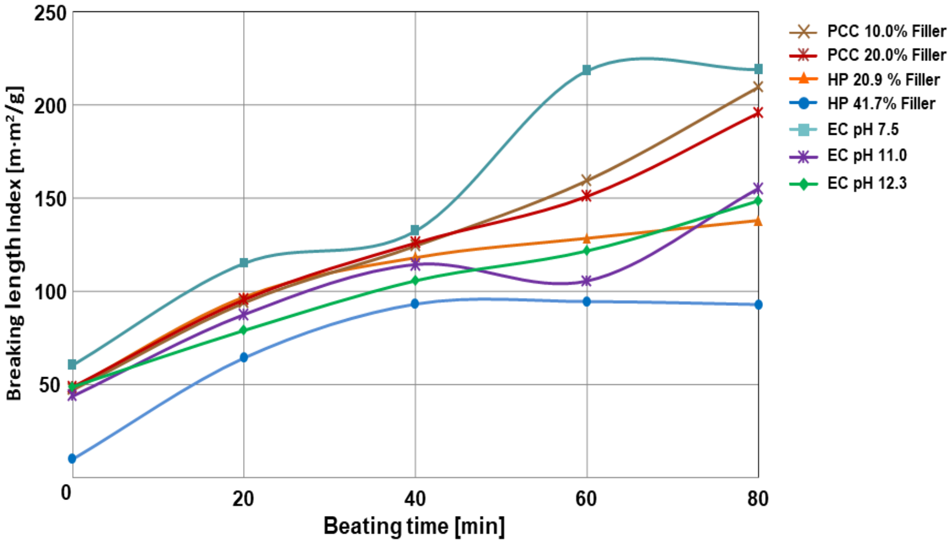


**Fig. 7. Valley beater breaking length index**

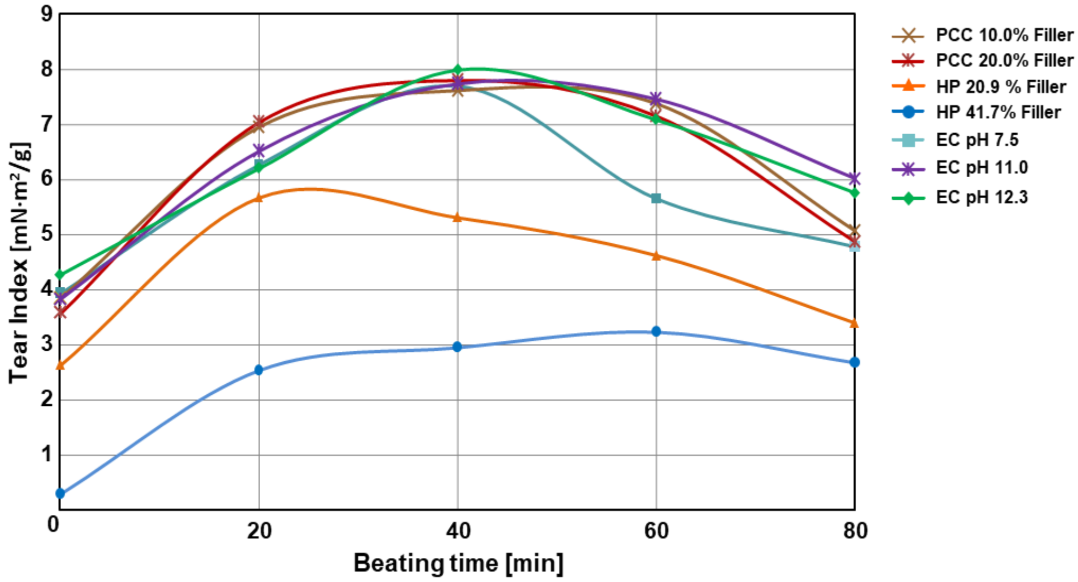


**Fig. 8. Valley beater tear index**

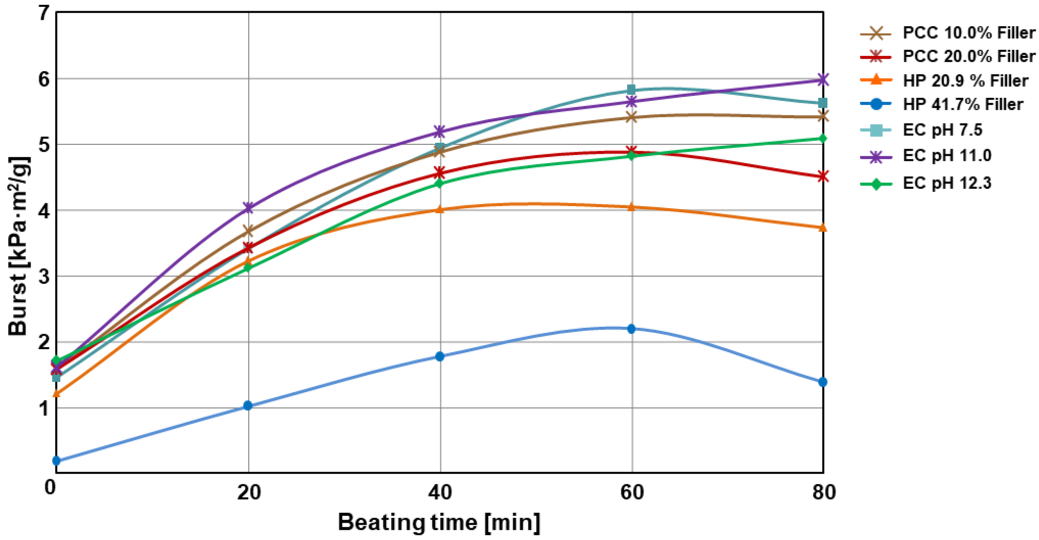


**Fig. 9. Valley beater burst index**

## 4. CONCLUSION

For this research BEKP pulp adjusted to a pH of 7.5, 11.0 and 12.3, laboratory manufactured ISPCC pulp with a filler level based on OD BEKP fiber content of 20.9% and 41.7% and a pH of 7.5, and BEKP pulp at a pH of 7.5 with added commercial PCC with a filler level based on OD fiber content of 10% and 20% was beaten for 80 minutes with samples taken at the unbeaten level and 20 minutes increments allowing for analyses of CSF, viscosity, basis weight, bulk, breaking length, tear, and bust. All testing was done according to TAPPI testing standards using a laboratory Valley beater.

The beating curve over 80 minutes beating time show that the BEKP pulps with ISPCC have a higher dewatering ability with increasing filler content compared to the pulps with commercial PCC and different pH values.

Viscosity slightly decreases for BEKP pulp suspension with 20% PCC, 20.9% and 41.7% ISPCC and pulp suspensions with pH 7.5 and 12.3. Pulp with 10% PCC decreased first and the increased with beating time. Furthermore, BEKP pulp at a pH of 12.3 pulp showed a significant decrease in viscosity over the 80 minutes beating time, superseding the ISPCC 41.7% filler containing pulp after approximately 45 minutes of beating.

Basis weight decreased over beating time for all BEKP pulp suspensions, which can be explained with an increased fines production during beating. These fines in the pulp suspension are not retained on the 89-micron (150 mesh) wire of the TAPPI sheet former, resulting in an lower retention and fiber loss.

The breaking length index increase for all 7 BEKP pulp suspensions. The breaking length index for PCC 10%, PCC 20% and HP 20.9% are comparable till 40 minutes beating time. After that the breaking length index flattens out for the HP 20.9% filler pulp suspension, while the PCC 10% and 20% filler suspension continued to increase. The ISPCC 41.7% filler pulp suspension had the lowest breaking length index of all seven pulp suspensions.

Tear index curves based on beating time are similar for the BEKP pulp suspensions. The maximum for the tear index for the above pulp suspensions is at 40 minutes beating time. BEKP pulp with ISPCCHP filler content of 20.9% and 41.7% showed the lowest tear index.

The burst index increases with beating time for all seven-pulp suspension, showing similar curves development with a maximum of the burst index at 60 minutes of beating time. However, the ISPCC pulp with a filler content of 41.7% had the lowest burst index and BEKP pulp with a pH of 11.3 showed the highest burst index development over the 80-minutes beating time.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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