Original Research Article

Recycling of Aseptic Packaging Container for Paper Board Applications - A Laboratory Study

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ABSTRACT

High board and packaging material demands due to increased internet sales require the board and packaging manufacturing industry to increase production capabilities. Legislature actions require the utilization of environmentally friendly packaging materials as well as upgrade existing and implement new manufacturing processes that are sustainable. Liquid containerboard packaging materials is considered a sustainable packaging material and utilized in the beverage, food, and pharmaceutical industry.

In this study, techniques to recycle used beverage cartons were investigated. It aims to find the optimum conditions to pulp the aseptic package containers and obtain maximum fibers from pulping. The extracted pulp may be used as a raw material to produce carton boards, card boxes, and recycled paper. Recycling of aseptic packaging materials involves the mechanical separation of the paper fibers from the polyethylene and or aluminum layers by chemical and non-chemical methods. Results indicated that the use of chemicals gives a high yield of paper fibers of 58% using the chemical Oxone and 63% using Sodium Hypochlorite, for the non-chemical method obtained a yield of 72% and a comparison of paper properties for each pulping method.

Keywords: *Aseptic packaging materials, beverage carton, liquid container board, milk carton, paper board, paper properties, recycling, repulping*

1. INTRODUCTION

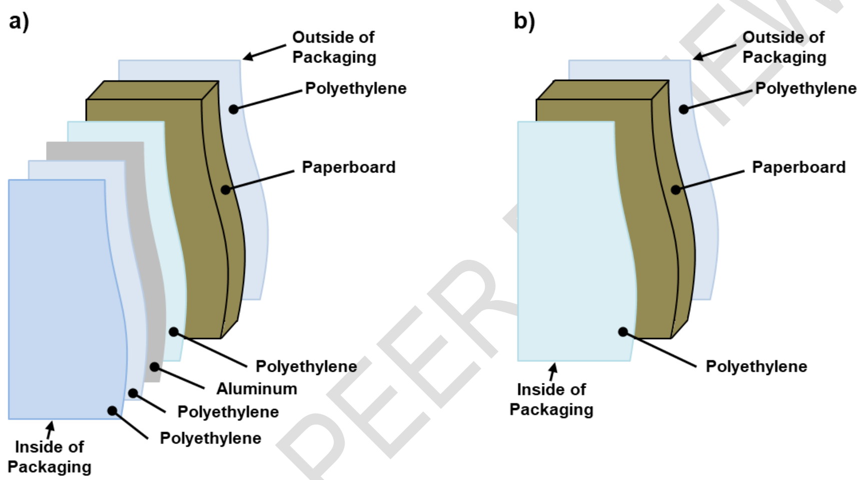
The production of paper and board material increased in pre pandemic years according to Statista to 400.9 million tons in 2019 with a peak of 415.2 million tons in 2017 [1,2]. According to the American Forest & Paper Association, the US containerboard production has increased in 2021 by 5.6% for the ninth time in 10 years [3].

With the start of the COVID-19 pandemic in 2020 internet sales have risen steadily and are expected to reach one trillion dollars in 2022 [3]. This requires larger amount of packaging products to be produced and expansion of existing and installing new production capacities [3]. Despite this, the production of board and paper products for packaging materials faces increasing environmental concerns regarding raw material, additive and energy usage, and pressures producers to pay more attention to a more favorable environmental footprint of the paper and packaging material produced [4].

Legislature action all over the world forces the food, beverage, and pharmaceutical industry sector to use more environmentally friendly packaging products, such has paper-based packaging products to reduce plastic consumption and the associated microplastic pollution [3]. With these changes, the industry moves towards packaging their solid and liquid products into paper-based packaging containers. Juice, wine, and milk products are already packaged in containers that are paper based. These containers are called liquid container board cartons or Aseptic Packaging Containers (APC/GTC) and or Gable-Top Cartons (GTC).

To meet environmental regulation and being accepted as eco-friendly packaging solution and recycling processes, like the Tetra Pack Process in Europe, need to be implemented in the United States of America and elsewhere to recover the materials contained in the APC/GTC packaging [1].

APC/GTC material, as shown in Figure 1. Is defined by the Industry of Scrap Recycling Industries (ISRI) 2021 Scrap Specification Circular (SSC) as Grade N0. 52 [5]. These material can be considered a composite material, and according to the ISRI-SSC includes generally no less than 70% bleached chemical fibers, up to 24% Polyethylene (PE) film , up to 6% Aluminum, and prohibitive material and outthrows may not exceed 2% and 5% respectively [1-6]. In North America the amount of fiber material used, depends if an Aluminum layer is present based on



product requirements. In general, the paper board layer manufactured of virgin or recycled pulp, embedded between multiple layers of PE is the most valuable material for recovery the PE layer in most cases is downcycled and or used as byproduct for composite material, because it cannot be used at present time as raw material for food packaging.

Fig.1: Illustration a) General Aseptic and Gable-Top Cartons Packaging Material b) North American Moister Resistant Packaging [7]

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The use of APC/GTC is estimated to increase to a worldwide market volume of $ 716.70 billion by 2030 [8] with an expected growth potential of 5.7% in North America [9].

With the increased use of sustainable packaging such as APC/GTC, it can be assumed more APC/GTC material is collected through the recycling stream and is made available for reuse in paper and board manufacturing processes, and solution are needed to utilize the fiber material that composes over 75% [1,6] of the APC/GTC packaging material.

In order to recycle/recover the fiber material contained in the APC/GTC material, processes already implemented in the paper manufacturing industry in the so-called stock preparation, should be utilized. Figure 2., illustrated commercial repulping processes at Low Consistency (LC) with Solids Contents (SC) of up to 5% to 8%, High Consistency (HC) systems at up to 18% SC utilize a helix type rotor design designed, whereas Drum Pulping (DP) systems can repulp the recovered fiber material at around 28% [10,11]. Repulping processes use friction, centrifugal and gravity forces to disintegrate the fiber material and are designed to process of over 3000 metric tons of dry material per day [12]. LC, HC, and DP systems are tailor made to the raw material used can be arranged in different configurations. LC and DP repulpers work on a continuous basis, while HC pulpers are operated in batch type process that may take approximately up to 30-40 minutes based on the raw material processed [10]. Internal screen devices and or external screening machines are employed based on the type of recovered material processed. After the repulping the pulp is diluted to approximately 4% to better remove unwanted material. Metal, sand, plastic and hard to process recycled material that has been removed from the repulped fiber slurry, is thickened and or baled and then feed into the recycled industries material stream for the manufacture of new recycled metal and plastic materials [13]. The cleaned fiber slurry is processed further and utilized for papermaking.

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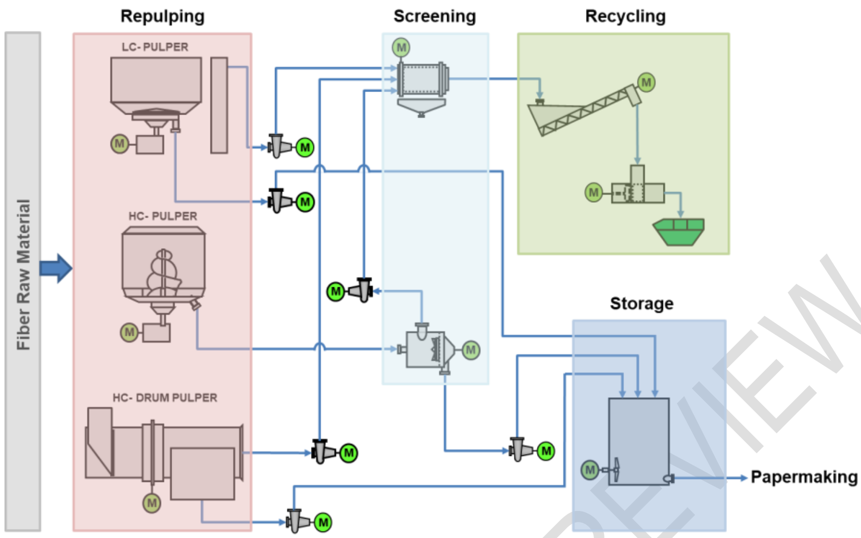

Fig. 2. Low Consistency (LC), High Consistency (HC), and Drum Pulping System [1]

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The following manuscript describes research work executed for the recovery of fiber material from APC/GTC packaging with and without chemicals such as Oxon, Sodium Hypochlorite, and Sodium Hydroxide already utilized in the paper manufacturing industries repulping processes.

2. MATERIALS AND METHODS

The following materials and methods were used for the laboratory evaluation on recycling APC/GTC for board paper applications.

2.1. Repulping Development Procedure

The projects repulping development procedure, as shown in Figure 3., consisted of preparing the collected APC/GTC material by cutting it into approximately 1-to-2-inch (25 to 50 mm) long pieces with scissors followed by re pulping at 9% Solids content (SC) in a laboratory pulper using 400 g of APC/GTC on an Oven Dry (OD) basis. Repulping trials consisted of: (i) repulping of without chemical addition at temperature of 150°F (65.56°C) at a repulping time of 30, 60 and 120 minutes, (ii) repulping at a temperature of 100°F (37.78°C), 125°F (51.67°C), and 150°F (65.56°C) using 1% Oxone ($2KHSO_5.KHSO_4.K_2SO_4$), acquired from Beantown Chemicals, in granular form based on Oven dry (OD) fiber content, and (iii) repulping at 150°F using Sodium Hypochlorite (NAOCL) as a 5% solution from Sigma Aldrich at an addition rate of 1.50%, 1.00% and 0.50%based on OD fiber content. For all repulping experiment, the pH was adjusted to a pH of 10 using Sodium Hydroxide. For temperature adjustment of the repulping trials, low pressure steam at a pressure of 100 psi (689.48 kPa) was used.

Temperature and pH measurements were conducted using a portable Milwaukee MW102 pH/temperature meter as well as a Therm-Pro handheld temperature probe.

Screening of the repulped APC/GTC material was done with a No. 5 mesh (4 mm) 200 mm diameter screen pan. Usable fiber material was collected in a large screening box with a No. 150 mesh (105 µm) screen lining. The recovered fiber material was then used to make paper handsheets for evaluation of mechanical and optical properties.

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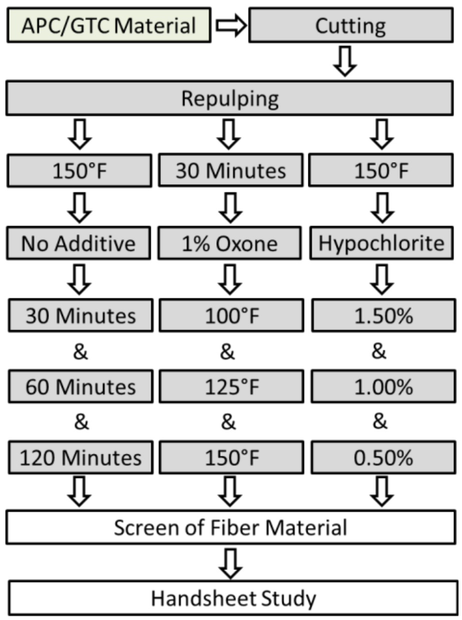

Fig. 3. Repulping Development Procedure

2.1. Materials Used

For the laboratory study APC/GTC material from the Oneida Herkimer Solid Waste Authority (OHSWA) in Utica New York was used [14]. The integrates solid waste management systems collects recyclable household garbage in a single stream collection process and separates the recyclable material. From a 2000 lbs. (907 kg) APC/GTC bale, Shown in Figure 4.a) 240 lbs. (108.6 Kg) of material was collected for this study. Figure 4.b) shows the different APC/GTC material containers contained in the 2000 lbs. APC/GTC bale used for this study.

Fig. 4. Aseptic Packaging Container a) 2000 lbs. Bale, b) Material Content [15]

For repulping the APC/GTC material, a 1 hp (0.75 kW) Laboratory Pulper was used able to repulp 3 gallons (11.35 liter) of liquid.

2.2. Testing Methods

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

Handsheets were prepared according to TAPPI T 205 sp-12, “Forming handsheets for physical tests of pulp” [16]. Physical testing of handsheets was performed in accordance with T 220 sp-06, “Physical testing of pulp handsheets” [17]. The Zero span breaking length was measured using T 231 cm-96, ‘Zero-span breaking strength of pulp (dry zero-span tensile)” [18] Consistency of the pulp suspensions was measured with TAPPI T 240 om-07 “Consistency (concentration) of pulp suspensions” [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 Strength 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]. Thickness/Caliper of paper was measured in accordance with T 411 om-10, “Thickness (caliper) of paper, paperboard, and combined board” [23]. Moisture content of pulp

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was determined by T 412 om-06 “Moisture in pulp, paper and paperboard” [24].
The hand sheets tear resistance was measured with T-414 om-98, “Internal tearing resistance of paper (Elmendorf-type method)” [25].
Air resistance was measured with T 460 om-02 “Air resistance of paper (Gurly method)” [26].
Tensile strength properties were measured according to T-494 om-01. Tensile properties of paper and paperboard (using constant rate of elongation apparatus) [27].
Surface roughness of the paper product was measured with T 538 om-08. Roughness of Paper and Paperboard (Sheffield method) [28].
Short span compressive strength was measured according to T 826 pm-92 “Short span compression strength of containerboard” [29].
Brightness was measured according to ISO 2470 “Paper, board and pulps - Measurement of diffuse blue reflectance factor – Part 1: Indoor daylight conditions (ISO Brightness) [30]. Opacity was determined according to ISO 2471:2008 Paper and Board: Determination of Opacity (Paper Backing) – Diffuse Reflectance Method [31].
Whiteness/Color was measured according to ISO 11476:2016 “Paper and Board – determination of CIE Whiteness, C/2° (Indoor Illumination Conditions)” [32].

2.3. Repulping if Aseptic Packaging Materials

Repulping of APC/GTC material was carried out to simulate an industrial process. Figure 2., shows a simplified process sketch of such a process utilizing a repulper machine as continuous process. In general, a commercial continuous pulper has an internal screen device for presorting and an external screening machine for secondary screening based on the type of recovered material processed. A batch process may take approximately up to 30-40 minutes based on the raw material processed [10]. In general, after the repulping operation the pulp is diluted to approximately 4% or less to remove unwanted material such as metal, sand, plastic and hard to process recycled material from

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the fiber slurry. The slurry containing the recycled fibers is forwarded to the papermaking operation, whereas the recovered material is thickened and baled and then feed into recycling industries recovered material stream for the manufacture of new recycled metal and plastic materials [13].
The chosen laboratory operation, based on Figure 2., consists of repulping the APC/GTC packaging material at a solids content of 9% in a 0.75 kW (1.0 hp), 3 gallons (11.35 liter) laboratory pulper, shown in Figure 5., using 400 g of APC/GTC material and 4.5 liter of water. For all repulping experiment, the pH was adjusted to a pH of 10 using Sodium Hydroxide. The desired pulping waters temperature is adjusted by injecting low pressure steam at a pressure of 100 psi (689.48 kPa) into the pulper with a steam hose prior to adding the APC/GTC material as well as chemicals for repulping.
Prior to repulping the APC/GTC materials were cut into approximately 1 to 2 inch (25 to 50 mm) long pieces with scissors to simulate an industrial shredding process. Shredding enhances the fiber recovery process by allowing contact between the water, including eventual added chemicals, and the paper and other layer of the APC/GTC. Centrifugal and mechanical forces during repulping separate the layers of the APC/GTC and bring the fibrous material as well as the aluminum and polyethylene components in suspension for later recovery.

Fig. 5. Low Consistency Laboratory Repulper [33]

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2.4. Screening

Screening out usable fiber material from the repulped APC/GTC/GTC material slurry was done by filling a portion of the repulped slurry into a No. 5 mesh (4 mm) screen pan and washing out the usable fiber material with water at a temperature of 40°C applied with a water hose. Unusable material such as polyethylene, aluminum, wet strength material, etc. was retained on the screen, collected, and moved into a 4-liter plastic beaker. The usable fiber material passing the screen was collected in a larger scree box with a 150 mesh (105 µm) screen lining. The retained fibers I the screen box were double checked for contamination before they were moved in a 5-gallon storage pail. The collected rejects were diluted again and screened a second and third time to recover all usable fibers.

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2.5. Paper Handsheet Making

Handsheets with a target basis weight of 60 g/m² were prepared from the recovered APC/GTC fiber material by using TAPPI test method T 205 sp-06 [16]. Prior to handsheet making the recovered fiber material was diluted to 1.2% consistency and processed in a TAPPI style disintegrator to disperse the fibers. To prepare the handsheets, a 0.3% pulp solution was prepared and added to the handsheet forming apparatus to produce 60 g/m² handsheets for later optical and mechanical evaluation.

The produced handhseets were labeled and placed in a climate-controlled room with 50% relative humidity and a temperature of 23°C for conditioning, according to TAPPI T-402 sp-06 test method [20]. These steps were repeated for all pulp of other runs.

3. RESULTS AND DISCUSSION

3.1. Repulping Approach

Two different approaches were considered for repulping recycled APC/GTC material. First, a Chemical Repulping (CR) approach using Oxone and Sodium Hypochlorite as repulping additive, and second a Chemical Free Repulping (CFR) for comparison was performed.

The primary purpose of using chemicals in repulping is to reduce pulping time by faster disintegration of the material to be repulped, obtain more fibers (yield), and increase the mechanical properties of paper formed. A high pulping temperature helps that the pulping liquid (water) can penetrates the pulp fibers more easily and increases the removal of the fiber material from other impurities like polyethylene and aluminum.

3.1.1. Repulping with Oxone

For the first CR approach repulping temperatures selected to be 100°F (37.78°C), 125°F (51.67°C), and 150°F (65.56°C), close to various technical conditions. Previous research by by Huston et al. [34] in 1995 selected similar conditions. Oxone addition was 1% based on dry material used for repulping. 444 g of APC/GTC material was prepared as described in section 2.3., and then repulped for 30 minutes at a solids content of 9% at the above-mentioned temperatures and Oxone addition.

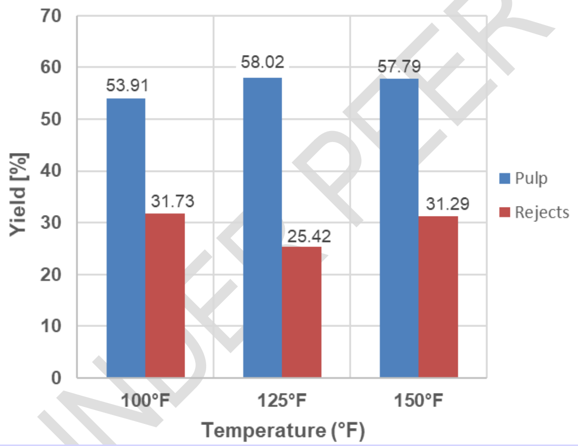

Fig. 6. Percentage Yield of usable Paper Fibers and Rejects of Polyethylene and Aluminum using 1% Oxone as Repulping Chemical

Figure 6. displays the recovered pulp fibers on the No. 150 mesh (105 µm) screen and retained rejects (Plastics and other Impurities) on the No. 5 mesh (4 mm) 200 mm diameter screen pan, based on the initial 400g of APC/GTC material used for

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laboratory repulping with 1% Oxone. At a repulping temperature of 100°F (37.78°C), 53.91% of the fiber material could be recovered, 31.73% of rejects were retained, and 15.36% of the material was lost during repulping and washing process. For a repulping temperature of 125°F (51.67°C), 58.02% of the fiber material could be retained and 25.42% of rejects resulted, 16.56% of the material was lost during pulping and the washing process. Repulping at 150°F (65.56°C) resulted in a retention of 57.79% of the fiber material and 31.29% of rejects, and 10.92% of the material was lost during the repulping and the washing process.

Overall, the temperature at 125°F gave the highest yield at 58.02% with less rejects of 25.42%. There was not a significant difference (0.23%) of recovered fibers between 125°F and 150°F, but the screened reject amount retained at 150°F was at 31.29%, 5.87% higher. when compared to 125°F (25.416%). Lost usable fiber materials was lowest for repulping at 150°F (65.56°C), and may contain fines (small fiber materials) that cannot be retained on the No. 150 mesh (105 µm) screen and are therefore lost during the washing process. Repulping at 150°F (65.56°C) gave in addition an 3.88% higher recovered fiber rate while the reject amount was 0.44% lower compared to repulping at 125°F (51.67°C). This makes repulping at 150°F (65.56°C) the most efficient option in regard to recovered fibers, retained rejects, and lost usable fiber materials. Lost usable fiber materials may contain fines (small fiber materials) that can not be retained on the No. 150 mesh (105 µm) screen and are lost during the washing process.

Increasing the addition of Oxone to 2% for repulping at 150°F (65.56°C) resulted in a fiber retention of 61.77% and 34.34% of rejects, and 3.89% of the material was lost during the repulping and the washing process. This increased the efficiency of the laboratory repulping process

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3.1.2. Repulping with Sodium Hypochlorite

For the second CR approach the optimum repulping temperature of 150°F (65.56°C) from 3.1.1. was selected. Sodium Hypochlorite at 0.5%, 1%, and 1.5% based on dry material used for repulping was added. Prior to repulping 444 g of APC/GTC material was prepared as described in section 2.3., and then repulped for 30 minutes at a solids content of 8.7% at the above-mentioned temperature and Sodium Hypochlorite additions.

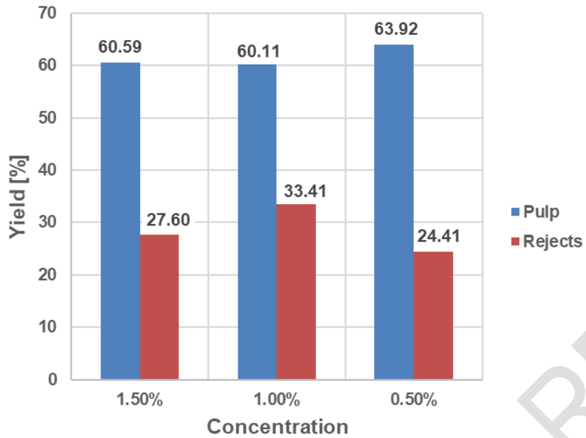

Fig. 7. Percentage Yield of usable Paper Fibers and Rejects of Polyethylene and Aluminum with Sodium Hypochlorite as Repulping Chemical at 150°F (65.56°C)

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Figure 7., displays the recovered pulp fibers on the No. 150 mesh (105 µm) screen and retained rejects (Plastics and other Impurities) on the No. 5 mesh (4 mm) 200 mm diameter screen pan, based on the initial 400g of APC/GTC material used for laboratory repulping at 150°F (65.56°C) and Sodium hypochlorite. Repulping at a 1.50% addition of Sodium Hypochlorite 60.59% of the fiber material could be recovered, 27.60% of rejects were retained, and 11.81% of the material was lost during repulping and washing process. For repulping with 1.00% Sodium Hypochlorite, 60.11% of the fiber material could be retained and 33.41% of rejects resulted. 6.48% of the material was lost during pulping and the washing process. Repulping with 0.50% Sodium Hypochlorite resulted in a retention of 63.92% of the fiber material and 24.41% of rejects, and 11.67% of the material was lost during the repulping and the washing process.
The yield of the recovered fiber material for repulping with Sodium Hypochlorite showed only a difference of 0.48% between

repulping with 1.50% (60.59%) and 1.00% (60.11%). Repulping with 0.50% Sodium Hypochlorite increased the fiber recovery by 3.33% and 3.81% for 1.50% and 1.00% addition of Sodium Hypochlorite respectively.

Lost usable fiber materials that may not be retained on the No. 150 mesh (105 µm) screen and are therefore lost during the washing process were lowest for repulping with 1.00% Sodium hyper chlorite addition at 6.48%. Sodium Hypochlorite addition of 1.50% and 0.50% showed similar losses with only a difference of 0.14%. therefore, a sodium hyper chloride addition of 0.5% resulted as the best option in regard to recovered fibers and reject rates.

Repulping at 150°F (65.56°C) at 0.50% Sodium Hypochlorite and adding 1% of Oxone addition resulted in 61.00% retained fiber material, 33.04% of rejects, and 5.96% of losses during the repulping and the washing process. The Oxone addition lowered the fibers retained and over all material lost during the screening and washing process, but increase the rejects recovered.

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3.1.3. Repulping Without Chemical Addition

The Third repulping approach consisted of repulping APC/GTC material without addition of Oxone and Sodium Hypochlorite at the optimum repulping temperature selected under 3.1.1. of 150°F (65.56°C). As for the previous CR trials, prior to repulping 444 g of APC/GTC material was prepared as described in section 2.3., and then repulped for 30, 60, and 120 minutes at a solids content of 9% at the above-mentioned temperature. The pH of repulping was adjusted to pH 10 with sodium Hydroxide.

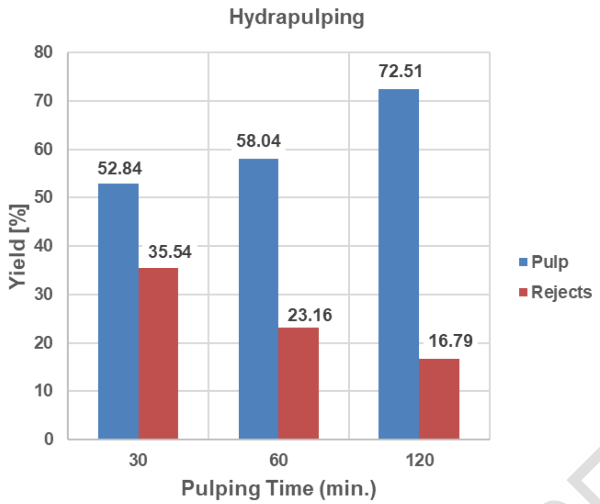

Fig. 8. Percentage Yield of Usable Paper Fibers and Rejects of Polyethylene and Aluminum without Chemical Addition at 150°F (65.56°C)

Figure 8. displays the recovered pulp fibers from 444 g of APC/GTC material at a repulping temperature of 150°F (65.56°C). Recovered fibers and rejects (Plastics and other Impurities) were retained on a No. 150 mesh (105 µm) and No. 5 mesh (4 mm) 200 mm diameter screen pan respectively.

Repulping for 30 minutes resulted in recovered fiber material of 52.84%, 35.54% of rejects were retained. 11.62% of the material was lost during repulping and washing process.

A repulping time of 60 minutes gave 58.04% of retained fibers, 23.16% of retained rejects, and 18.80% of material lost throughout the laboratory processing.

Increasing the repulping time to 120 minutes increased the ability to recover fiber to 72.51% and 16.79% of retained rejects. The material lost accounted for 10.70%.

Increasing the repulping time for APC/GTC material increased the recovered fiber amount by 5.20% and 14.47% for 30 minutes to 60 minutes and from 60 minutes to 120 minutes respectively. Rejects retain on the No. 5 mesh (4 mm) 200 mm diameter screen pan decreased by 12.38% and 6.37% after repulping time increase from 30 minutes to 60 minutes and from 60 minutes to 120 minutes respectively.

Increasing repulping time yields more useable fibers and lowers the rejected materials by allowing the disintegration of harder to repulp material contained in the APC/GTC material, such as wet strength materials, heavily bonded material such as APC/GTC container bottoms which contain multiple layers. However, increasing repulping time significantly above 30 minutes increases energy needed and equipment size 2-fold for an increase to 60 minutes and is not economically justifiable. Similar finding has been found in a study by Georgiopoulou et al. [5] which resulted in a 96% recovered fibers by for running the pulper for 5 hours at ambient temperature.

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3.1.4. Repulping Energy Consumption

The Energy consumption of repulping 444 g of recycled APC/GTC material at 8.7% solids content based on dry weight was measured for a repulping temperature of 125°F (51.67°C) and 30 minutes of repulping time. Figure 9, shows the kWh needed per metric tons of APC/GTC material. Repulping with water required 33.8 kWh, repulping with Oxone 28.2 kWh, and repulping with Sodium Hypochlorite required 31.5 kWh.

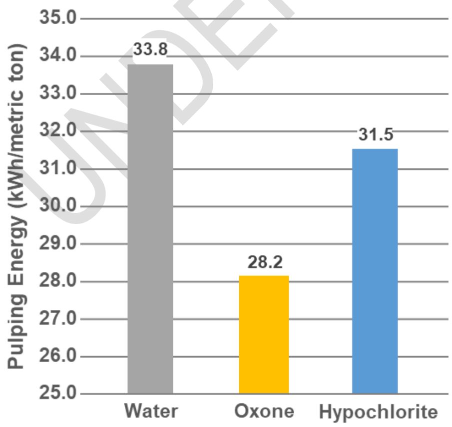

Fig. 9. Repulping Energy Consumption

3.2. Paper Properties

The handsheet study on paper properties was done as follow: (i) a repulping time of 30, 60 and 120 at a temperature of 125°F (51.67°C) to investigate the influence of pulping time, (ii) chemical addition of 1% Oxone at 30 minutes pulping time and repulping temperatures of 100°F (37.78°C), 125°F (51.67°C), and 150°F (65.56°C), and (iii) Sodium Hypochlorite addition at 0.5%, 1%, and 1.5% based on dry material and a repulping temperature of 125°F (51.67°C). 60g/m² handsheets made from each repulping run according to T 205-sp-12 and tested to the in Section 2.2. listed TAPPI testing standards for mechanical and optical properties. All tests were performed in the standard conditioning and testing atmospheres according to T 402 sp-08 at a temperature of 23°C ± 1°C and a humidity of 50% ± 2%. All results stayed in the precision statements for the referenced TAPPI and ISO methods.

3.2.1. Tensile Index

Figure 10. to 11., shows the Tensile strength of handsheets made from repulped APC/GTC fiber material according to T 494 om-06 [27]. For handsheets made from APC/GTC pulp without chemicals a constant rise in the value of the Tensile Index from 30 min to 120 min of repulping time the tensile index increased. 30 min of pulping without chemicals give a value of 11.81 Nm/g, 60 min and 120 min value was 16.12 Nm/g and 17.51 Nm/g respectively.

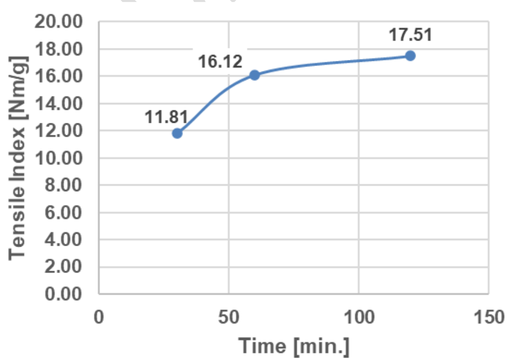

Fig. 10. Tensile Index for repulping without chemicals

Figure 11. shows the Tensile index for the handsheets using Oxone for repulping. It was apparent that the handsheet made at 100°F and 125°F had a Tensile Index of 16.77 Nm/g and 16.75 Nm/g respectively. The Tensile Index of the handsheet at 150°F has a lower value than the other runs.

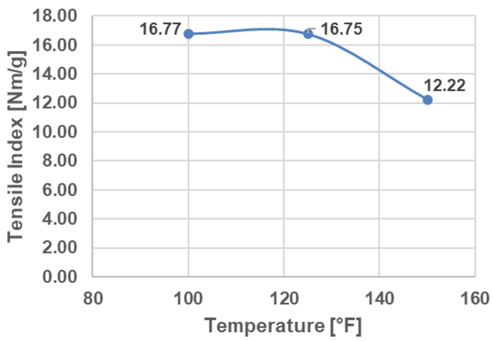

Figure 11. Tensile for strength repulping with Oxone

Figure 12. shows the Tensile strength of the handsheets for repulping with Sodium Hypocloride. At 0.5% gives the highest value of 22.86 nm/g. For the handsheets with 1% Sodium Hypochlorite (11.43 Nm/g) and 1.5% Sodium Hypochlorite (12 Nm/g).

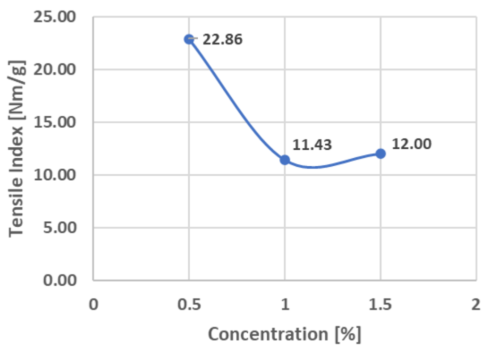

Fig. 12. Tensile Index for repulping with Sodium Hypochloride

3.2.2.Zero Span

Figure 13 to 15., represent the Zero-Span data measured with T 231 cm-07 [16]. Handsheets for repulping without chemical addition, as shown in Figure 12., showed a rise in the paper's property from 6.69 Kg/15mm for 30 minutes, and 7.08 Kg/15mm for a repulping time of 120 minutes. The 60-minute repulping time showed a lower value of 6.23 Kg/15mm compared to 30 minutes and 120 minutes of repulping time.

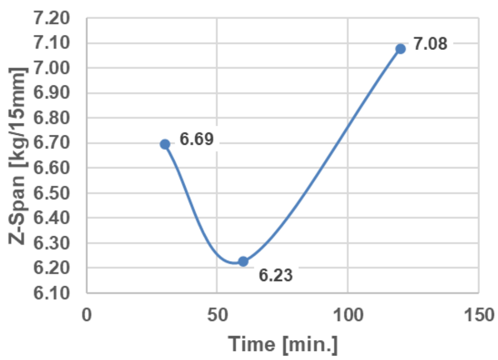

Fig. 13. Zero Span for repulping without chemicals

Figure 13. illustrates the Zero-Span data for the handsheets made from repulped fibers with Oxone addition. It shows that zero-span of paper increases from a value of 5.90 Kg/15mm at 100°F (37.78°C), to 7.61 Kg/15mm at 125°F (51.67°C), and then decreased to 6.50 Kg/15mm at 150°F (65.56°C).

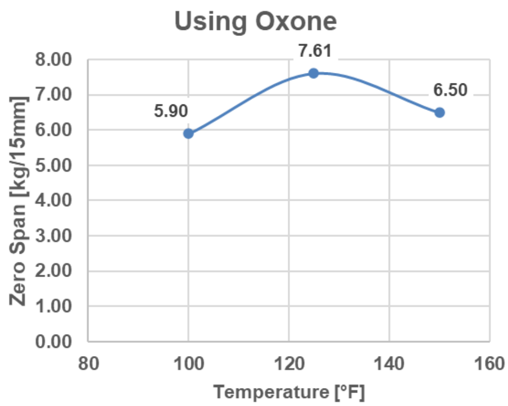

Fig. 14. Zero Span for repulping with Oxone

Figures 15. illustrates the Z-Span test data for Sodium Hypochlorite as chemical repulping additive. For the 0.5% a value of 7.55 Kg/15mm resulted. A 1% addition showed a slightly lower value of 7.09 Kg/15mm. The 0.5% addition showed a incresed value of 8.40 Kg/15mm.

Comment [o22]: Spelling mistake

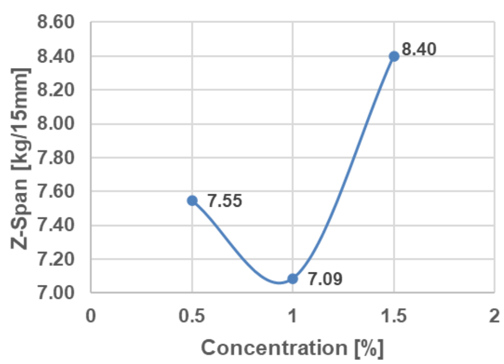

Fig. 15. Zero Span for repulping with Sodium Hypochlorite

3.2.3. Burst

Figures 16, 17, and 18 show the burst index measured according to T 403 om-02 [21]. indicate the burst data for different parameters. Repulping at 30, 60 and 120 minutes at a temperature of 125°F (51.67°C) showed a burst index of 0.44, 0.61, and 0.56 kPa*m²/g respectively, with the highest value at a 60-minute repulping time. Oxone as repulping additive at temperatures of 100°F (37.78°C), 125°F (51.67°C), and 150°F (65.56°C) showed lower burst index value with increasing temperature starting at 0.66, 0.51, and 0.34 kPa*m²/g respectively. This might be due to a possible degradation of fibers at higher temperatures. Similarly, values are shown for the addition of Sodium Hypochlorite for repulping at 125°F (51.67°C). The highest burst index of 0.80 kPa*m²/g was observed at a 0.5% addition. An addition of 1.0% and 1.5% resulted in a lower burst index of 0.49 kPa*m²/g for both the 125°F (51.67°C) and 150°F (65.56°C) repulping temperature.

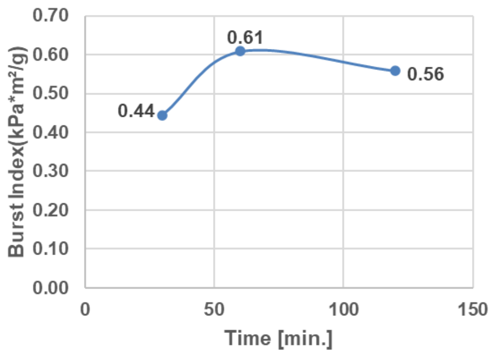

Fig. 16. Burst Index for repulping without chemicals

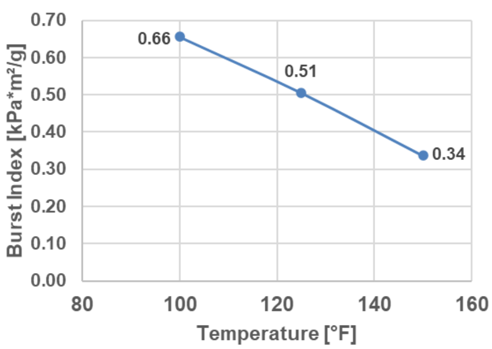

Fig. 17. Burst Index for repulping with Oxone

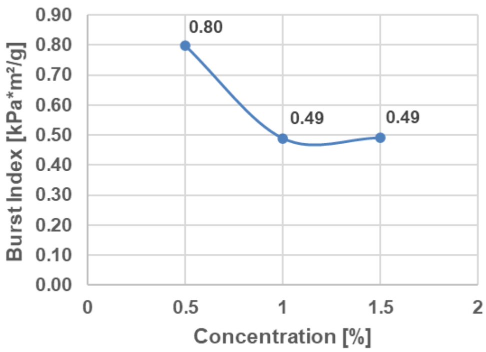

Fig. 18. Burst Index for repulping with Sodium Hypochlorite

3.2.4. Tear

Figure 19 to 21., illustrates the tear index measured according to T 414 om-98 [25]. Repulping without chemicals as shown in Figure 19., showed the highest tear index of 6.63 mNm²/g at a repulping temperature of 150°F (65.56°C). Repulping at a temperature of 100°F (37.78°C) and 125°F (51.67°C) resulted in a tear index of 4.92 and 4.40 mNm²/g respectively.

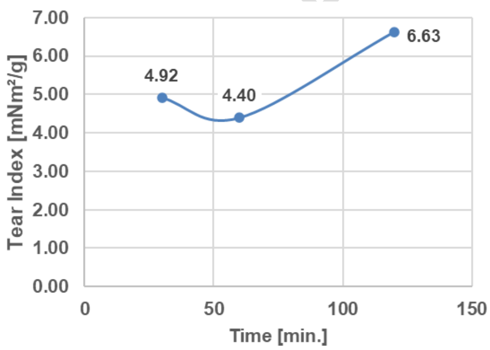

Fig. 19. Tear Index for repulping without chemicals

Figure 20., illustrates the tear index using Oxone as repulping chemical. The lower repulping temperature at 100°F (37.78°C) showed the highest tear index of 8.69 mNm²/g. Repulping at

125°F (51.67°C) and 150°F (65.56°C) lowerd the tear index to 7.58 mNm²/g and 6.90 mNm²/g respectively.

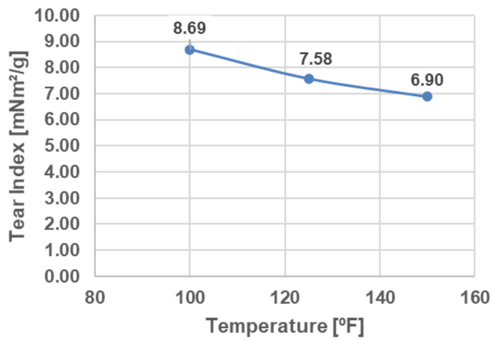

Fig. 20. Tear Index for repulping with Oxone

Figure 21., depicts the Tear Index using Sodium Hypochlorite for repulping as an chemical additive at a concentration of 0.5, 1.0 and 1.5% with measured values of 7.48, 7.58, and 5.45 mNm²/g respectively. Results indicate that a concentration of 0.5% and 1.0% resulted in comparable values, whereas a concentration of 1.5% resulted in a significant lower value.

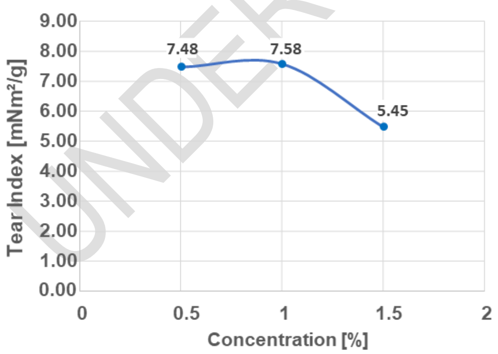

Fig. 21. Tear Index for repulping with Sodium Hypochlorite

3.2.5. Short Compression Test

The Short Compression Test Strength (SCTS) index as shown in Figure 22 to 24., was measured according to T 826 pm-92 [29]. The SCTS index for repulping at 30, 60 and 120 minutes as shown in Figure 22., of repulping time showed an increase from 0.31 kNm/g to 0.33 kNm/g, and to 0.34 kNm/g respectively.

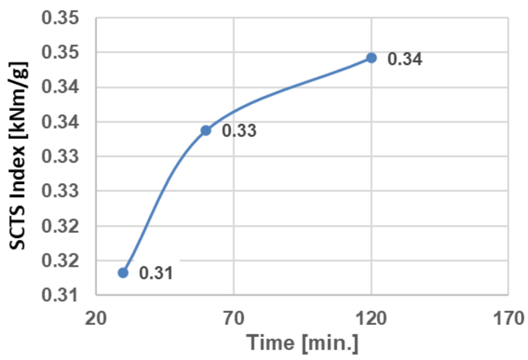

Fig. 22. SCTS Index for repulping without chemicals

Figure 23., illustrates the SCTS index with Oxone as repulping chemical additive. Similar to repulping without chemicals; from the graph, there is an improvement noticeable for the SCTS index from 100°F (37.78°C) to 150°F (65.56°C) from 0.26 kNm/g to 0.37 kNm/g respectively. No significant increase was noticed for a repulping temperature of 125°F (51.67°C) with a SCTS index of 0.28 kNm/g.

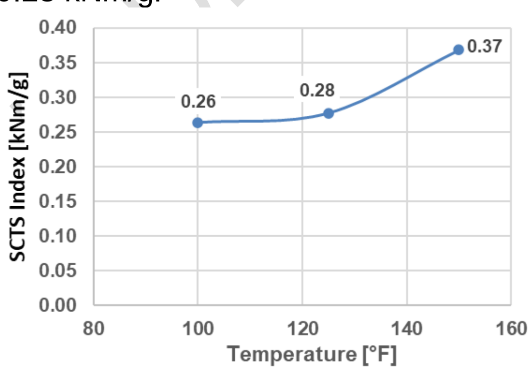

Fig. 23. SSCTS Index for repulping with Oxone

Figures 24., shows that using Sodium Hypochlorite as repulping chemical at 0.5 % resulted in the highest SCTS index value of 0.40 kNm/g. repulping concentration of 1.0% and 1.5 % showed lower values of 0.36 kNm/g and 0.33 kNm/g respectively.

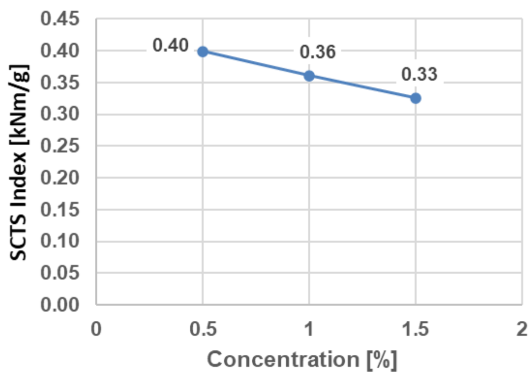

Fig. 24. SCTS Index for repulping with Sodium Hypochlorite

3.2.6. Porosity

Figures 25, 26, and 27 show the air resistance measured according to T 460 om-02 [21] for 100 ml per second. Repulping at 30, 60 and 120 minutes at a temperature of 125°F (51.67°C) showed an air resistance increase from 0.55, to 0.80, and to 0.96 per 100 ml/s respectively, with the highest value at a 60-minute repulping time.

Oxone as repulping additive at temperatures of 100°F (37.78°C), 125°F (51.67°C), and 150°F (65.56°C) showed a decrease in air resistance with increasing temperature starting at 1.80, 0.88, and 0.80 ml per second respectively. This might be due to a possible degradation of fibers at higher temperatures creating a more compact sheet. Similarly, values are shown for the addition of Sodium Hypochlorite of 0.55, 1.05 and 1.5% with corresponding values of

2.52, 1.30, and 1.12 seconds per 100 ml air flow.

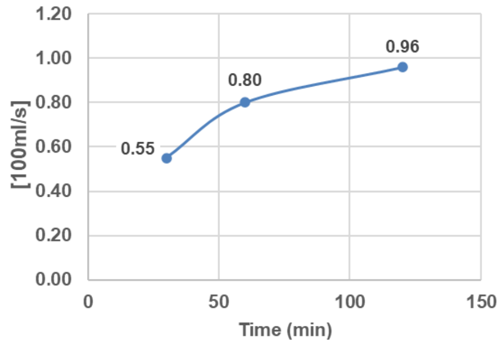

Fig. 25. Air Resistance for repulping without chemicals

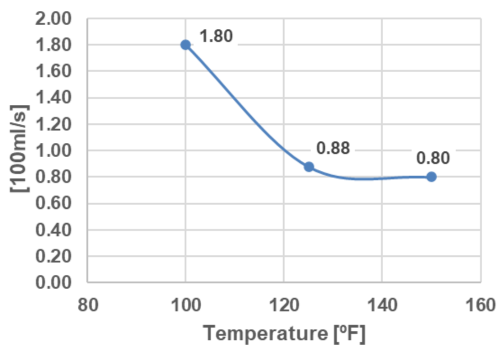

Fig. 26. Air Resistance for repulping with Oxone

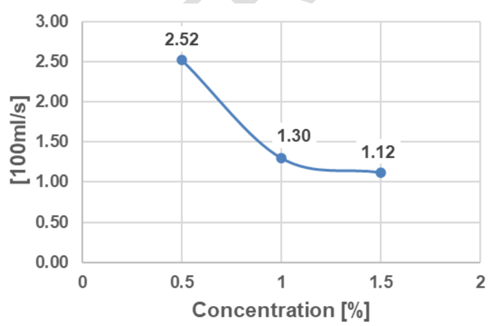

Fig. 27. Air Resistance for repulping with Sodium Hypochlorite

3.2.7. Smoothness and Roughness

Figures 28, 29, and 30 show the Roughness measured according to T 538 om-08 [28] for the smooth, metal plate side (MP), and rough side, blotter paper side (BP) of the paper handsheet manufactured in Cubic Centimeters per Minute (ccm). Repulping at 30, 60 and 120 minutes at a temperature of 125°F (51.67°C) showed a roughness from 2720.80, 2762.60, and 2789.20 ccm for the BP side, whereas the MP side had decreasing values of 2591.00, 2564.00, and 2551.80 ccm respectively. Oxone as repulping additive at temperatures of 100°F (37.78°C), 125°F (51.67°C), and 150°F (65.56°C) showed a decrease for both the BP side with values of 2800.80, 2798.80, and 2706.20 ccm respectively. The MP side showed a roughness of 2513.80 for 100°F (37.78°C) and increase to 2568.40 ccm for repulping at 125°F (51.67°C), and a decrease to 2430.40 for repulping at 150°F (65.56°C). Sodium Hypochlorite as repulping additive at a concentration of 0.5%, 1.0% and 1.5% showed for both the BP and MP side and increase of the roughness value. Values were 2647.80, 2876.6 and 2954.4 for the BP side and 2392.60, 2577.60, and 2758.20 for the MP side respectively.

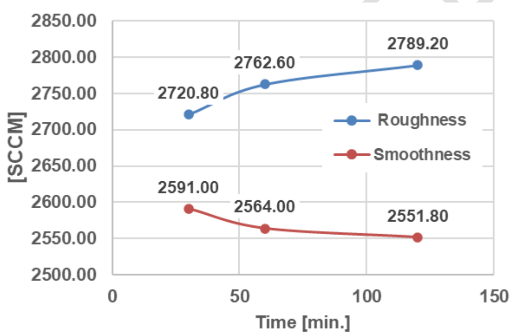

Fig. 28. Roughness for repulping without chemicals

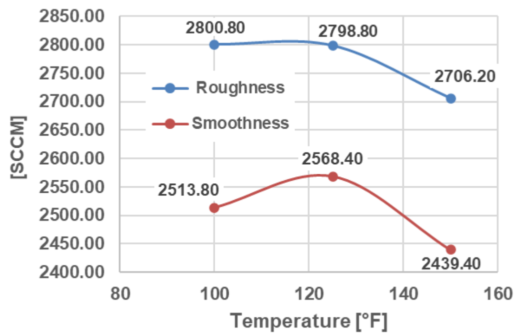

Fig. 29. Roughness for repulping with Oxone

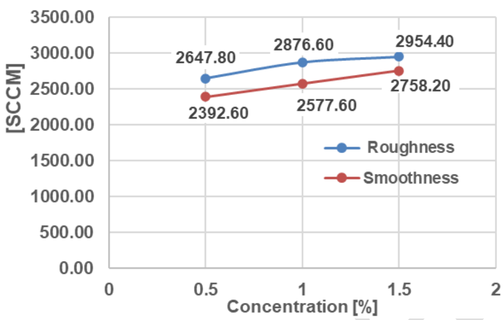

Fig. 30. Roughness for repulping with Sodium Hypochlorite

3.2.8. Optical Properties - Opacity

Figures 31, 32, and 33 show the opacity value according to ISO 2471:2008 [31]. Repulping at 30, 60 and 120 minutes decreased the Opacity for the handsheet from 75.70% to 74.44% to 72.55% respectively. Using Oxone at 100°F (37.78°C) resulted in the highest Opacity value of 81.92%. 125°F (51.67°C), and 150°F (65.56°C) had a value of 79.34% and 77.33% respectively. Repulping with Sodium hyperchlotite at 0.5%, 1.0%, and 1.55 resulted in a opacity value of 76.20%, 75.01%, and 77.10% respectively with the lowest opacity value at a concentration of 1%.

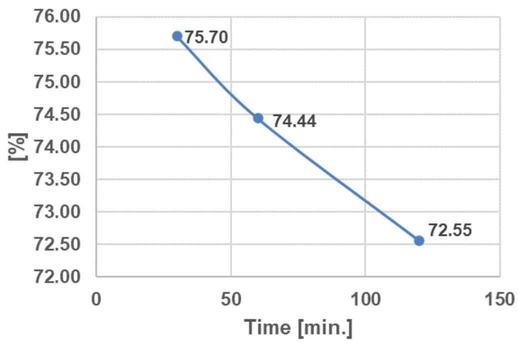

Fig. 31. Opacity for repulping without chemicals

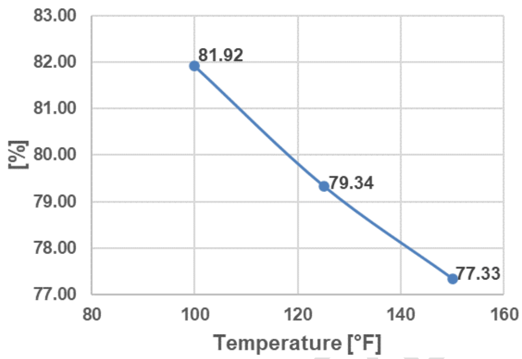

Fig. 32. Opacity for repulping with Oxone

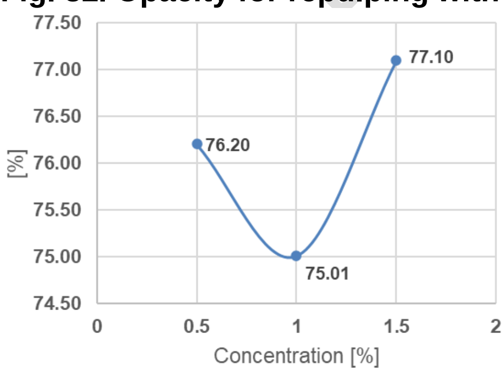

Fig. 33. Opacity for repulping with Sodium Hypochlorite

3.2.9. Optical Properties - Brightness

Figures 34, 35, and 36 show the Brightness ISO value according to ISO 2470 [30]. Increasing the repulping time from 30 to 60 minutes decreased the ISO Brightness from 79.55% slightly to

Comment [o23]: Figure [34 – 36]

79.46%. Repulping at 120 minutes showed a ISO Brightness of 79.48%. Using Oxone as repulping additive at 100°F (37.78°C) resulted in a ISO Brighness value of 79.59%. 125°F (51.67°C) resulted in a value of 79.46%, and repulping at 150°F (65.56°C) showed a value of 79.62%. Repulping with Sodium Hypochlorite at 0.5%, 1.0%, and 1.55 resulted in a ISO Brighness value of 80.15%, 80.03%, and 80.25% respectively with the lowest ISO Brightness value at a concentration of 1%.

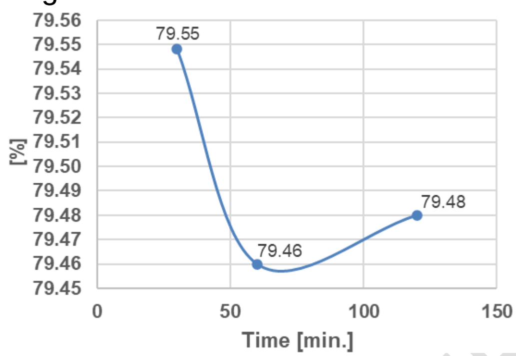

Fig. 34. Brightness for repulping without chemicals

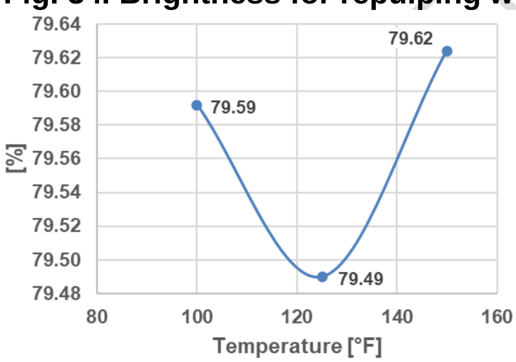

Fig. 35. Brightness for repulping with Oxone

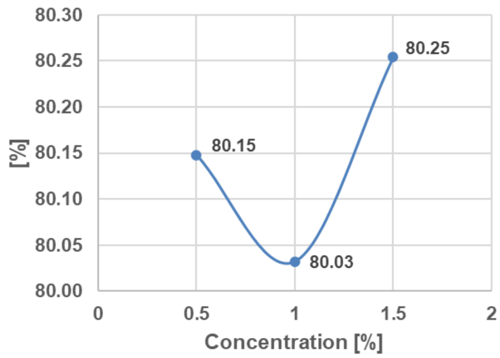

Fig. 36. Brightness for repulping with Sodium Hypochlorite

3.2.10. Optical Properties - Whiteness

Figures 37, 38, and 39 show the Brightness ISO value according to ISO 11476:2016 [32]. Increasing the repulping time from 30 to 60 minutes decreased the Whiteness from 55.35% slightly to 55.19%. Repulping at 120 minutes showed a Whiteness of 55.26%. Using Oxone as repulping additive at 100°F (37.78°C) resulted in a Whiteness value of 55.42%. 125°F (51.67°C) resulted in a value of 55.31%, and repulping at 150°F (65.56°C) showed a value of 55.67%. Repulping with Sodium Hyperchlotite at 0.5%, 1.0%, and 1.55 resulted in a Whiteness value of 57.73%, 57.55%, and 57.83% respectively with the lowest Whiteness value at a concentration of 1%.

Comment [o24]: Figure [37- -39]

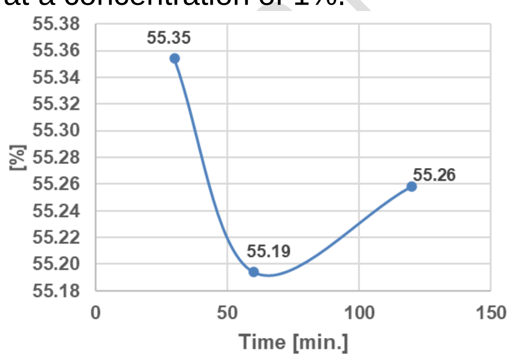

Fig. 37. Whiteness for repulping without chemicals

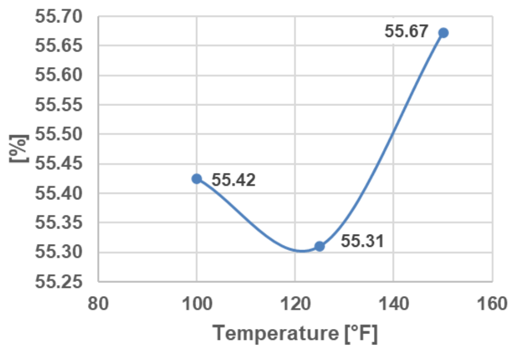

Fig. 38. Whiteness for repulping with Oxone

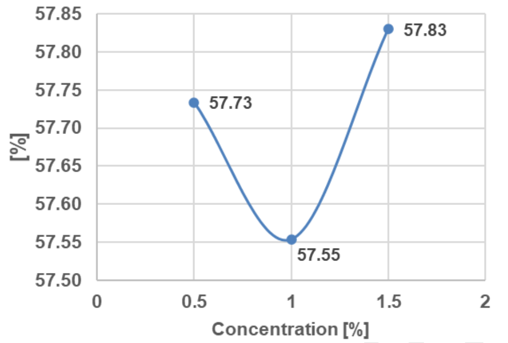

Fig. 39. Whiteness for repulping with Sodium Hypochlorite

4. CONCLUSION

Board and packaging material demands have increase in the recent past due to increased internet sales, change in consumer behavior, and legislature actions that require the utilization of environmentally friendly packaging materials. To keep up with consumer demands, the board and packaging manufacturing industry has increase production capabilities by upgrade existing and implement new manufacturing processes and find new ways to utilize fiber material from the recycling stream. APC/GTC packaging materials contains over 75% of recoverable fiber material and is consider a sustainable packaging material.

In this laboratory study, repulping was investigated to recycle APC/GTC material for the production of fibrous material for board paper production.

Comment [o25]: Irrelevant better to omit this section.

Repulping under laboratory conditions for 30 minutes resulted in recovered fiber material of 52.84%, 35.54% of rejects were retained. 11.62% of the material was lost during repulping and washing process. All tests conducted were done according to TAPPI testing standards. Longer repulping time led to higher fiber recovery rates of fibers and lower reject volumes; however, a longer repulping time is not economic justifiable.

Oxone as chemical additive at 1% showed the highest fiber recovery rate and lowest reject rate of 58.02% and 25.42% for a repulping time of 30 minutes using a No. 150 mesh (105 µm) screen and s No. 5 mesh (4 mm) 200 mm diameter screen pan to retain rejects.

The chemical additive Sodium Hypochlorite was most effective at an addition rate of 0.5%, resulting in a retention of 63.92% of the fiber material and 24.41% of rejects, and 11.67% of the material was lost during the repulping and the washing process.

The Energy consumption of repulping 444 g of recycled APC/GTC material at 8.7% solids content based on dry weight at a temperature of 125°F (51.67°C) for 30 minutes showed that repulping without chemical addition required the highest energy at 33.8 kWh per metric ton. Repulping with 1% Oxone resulted in the lowest energy of 28.2 kWh per metric ton, and repulping with 0.5% Sodium Hypochlorite required 31.5 kWh.

Tensile strength of handsheets showed an increase with longer pulping time. 30 minutes of repulping achieved 11.81 Nm/g, 60 min and 120 min values were at 16.12 Nm/g and 17.51 Nm/g respectively. Chemical addition of Oxone reduced the tensile index from 16.77 Nm/g to 12.22 Nm/g for Oxone with increasing pulping temperature from 100°F (37.78°C) to 150°F (65.56°C) respectively. Pulping at 150°F (65.56°C) gave the highest tensile index for 0.5% sodium Hypochlorite addition.

Zero-Span measurements taken on handsheets showed 6.69 kg/15mm for 30 minutes, and 7.08 kg/15mm for a repulping time of 120 minutes. The 60-minute repulping gave a lower value of 6.23 kg/15mm.the addition of Oxone showed a value of 5.90 Kg/15mm at 100°F (37.78°C), 7.61 Kg/15mm at 125°F (51.67°C), and a decrease to 6.50 Kg/15mm for 150°F (65.56°C). The addition of Sodium Hypochlorite at 0.5% addition gave a value of

7.55 kg/15mm, 1% addition showed a lower value of 7.09 Kg/15mm. The 1.5% addition showed a increased value of 8.40 Kg/15mm.

The Burst Index measured was highest at a repulping time of 60 minutes with 0.61 kPa*m^2/g compared to 30 and 120 minutes with 0.44 and 0.56 0kPa*m^2/g respectively., with the highest value at a 60-minute repulping time. Oxone as repulping additive at temperatures of 100°F (37.78°C), 125°F (51.67°C), and 150°F (65.56°C) decreased Burst Index value from 0.66, 0.51, and 0.34 kPa*m^2/g respectively. Sodium Hypochlorite addition showed the highest Burst Index of 0.80 kPa*m^2/g at a 0.5% addition, whereas 1.0% and 1.5% resulted in a lower burst index of 0.49 kPa*m^2/g.

The highest Tear Index of 6.63 mNm^2/g was observed at a repulping temperature of 150°F (65.56°C). Repulping at a temperature of 100°F (37.78°C) and 125°F (51.67°C) resulted in a tear index of 4.92 and 4.40 mNm^2/g respectively. Addition of Oxone decreased the Tear Index from 8.69 mNm^2/g to at 100°F (37.78°C) showed the highest tear index of 8.69 mNm^2/g to 6.90 mNm^2/g at 150°F (65.56°C). Sodium Hypochlorite for repulping gave a Tear Index at a concentration of 0.5, 1.0 and 1.5% of 7.48, 7.58, and 5.45 mNm^2/g respectively.

The SCTS index for repulping at 30, 60 and 120 minutes increased from 0.31 kNm/g to 0.33 kNm/g, and to 0.34 kNm/g respectively. Oxone as repulping chemical additive improved the STIFFI index for repulping temperatures of 100°F (37.78°C) to 150°F (65.56°C) from 0.26 kNm/g to 0.37 kNm/g respectively. Sodium Hypochlorite as repulping chemical at 0.5 % resulted in the highest STIFFI index value of 0.40 kNm/g. repulping concentration of 1.0% and 1.5 % showed lower values of 0.36 kNm/g and 0.33 kNm/g respectively.

Air Resistance for repulping time of 30, 60 and 120 minutes increased from 0.55, to 0.80, and to 0.96 per 100 ml/s respectively, with the highest value at a 60-minute repulping time.

Oxone addition at temperatures of 100°F (37.78°C), 125°F (51.67°C), and 150°F (65.56°C) decreased the air resistance from 1.80, 0.88, and 0.80 ml per second respectively. Similarly for the addition of Sodium Hypochlorite of 0.50, 1.05 and 1.50% with corresponding values of 2.52, 1.30, and 1.12 seconds per 100 ml air flow.

Roughness measurements for repulping at 30, 60 and 120 minutes gave values between 2720.80 and 2789.20 ccm for the BP side, whereas the MP side had decreasing values of 2591.00 to 2551.80 ccm. Oxone as repulping additive at temperatures of showed a decrease for both the BP side with values from 2800.80 to 2706.20 ccm, whereas the MP side showed and an initial value of 2568.40 ccm for at 125°F (51.67°C), and a decrease to 2430.40 ccm for 150°F (65.56°C). Sodium Hypochlorite at a concentration of 0.5%, 1.0% and 1.5% showed for both the BP and MP side and increase of the roughness value from 2647.80 to 2954.4 ccm for the BP side and 2392.60 to 2758.20 ccm for the MP side respectively.

Optical properties for repulping recycled APC/GTC material showed similar values for repulping without chemicals and with Oxone and Sodium Hypochlorite addition. ISO Opacity fluctuated between 72.55% and 79.34%. ISO Brightness and ISO Whiteness values fluctuated between 79.46% and 80.25% and 55.19% and 55.42% respectively.

The best repulping option to consider for recycling APC/GTC material is repulping at 125°F (51.67°C) for 30 min at an Oxone level of 1% and Sodium Hypochlorite addition of 0.5% based on fiber dry weight. However, additional consideration for the addition of Sodium Hypochlorite has to be taken in account, because it is producing chloroform like Dichloride and ethers in the aqueous solution, which is not considered environment friendly and therefore should be only used if a bleaching action is required for the repulping of brown fibrous material.

6. COMPETING INTERESTS

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

7. REFERENCES

1. Dölle, K., & Jeeva, KNC. Aseptic Packaging Container Recovery – A Review. Journal of Materials Science Research and Reviews. 2022;10(1), 38-51.
2. Statista. Accessed August 26, 2022. Available:https://www.statista.com/statistics/270314/global-paper-and-cardboard-production/
3. Dölle K., Serena L. Brandt, Rodrigo Medina Castillo, William S. Contento, Jacob A. Darius, Jonathan M. Day, Sean M. Jr. Ferry, Owen S. Henkler, Emily E. Hicks, Kevin D. Holmes, Kelly J. O'Keefe, Joseph P. Payette, Edith L. Taylor, (2022), "Paper Bag and Plastic Bag – A Brief Review", Journal of Engineering Research and Reports (JERR), 22(5), 45-57.
4. Dölle K., Zier S. (2021). "Application of spruce wood flour as cellulosic-based wood additives for recycled paper applications—A pilot paper machine study". TAPPI JOURNAL, Oct. 2021, Vol. 20 No.10, pp 641-652.
5. Institute of Scrap Recycling Industries. 2022 Scrap Specification Circular. Accessed November 20, 2022. Available: http://www.scrap2.org/specs/II/
6. Georgiopoulou, I., Pappa, G. D., Vouyiouka, S. N., & Magoulas, K. (2021). Recycling of post-consumer multilayer Tetra Pak® packaging with the Selective Dissolution-Precipitation process. *Resources, Conservation and Recycling*, *165*, 105268.
7. Dölle K. Illustration of General Aseptic and Gable-Top Cartons Packaging Material. pdf-file. 2022.
8. Precedence Research. Liquid Packaging Market. Accessed August 30,2022. Available: https://www.precedenceresearch.com/liquid-packaging-market

9. Aseptic Packaging Market. Aseptic Packaging market by Packaging Type. Accessed August 26, 2022. Available: https://www.alliedmarketresearch.com/aseptic-packaging-market-A05984
10. Holik H. Handbook of Paper and Board. Wiley-VCH Verlag GmbH & Co. KgaA. 2006
11. Andritz Pulp & Paper. FibreGuard System. Accessed September 6, 2022. Available: https://www.andritz.com/resource/blob/70920/257c790de533c2d6acbf5a7188177887/pp-pulping-fibreguard-e-data.pdf
12. Voith. Optimizing Solutions for Pulping. Accessed September 6, 2022. Available: https://voith.com/corp-en/papermaking/pulping-solutions.html
13. Fernando Luiz Neves, Edy Maicon Merendino, Marcelo Piva, and Ricardo Honorato, 2015. ASEPTIC CARTON PACKAGES: RECYCLING REVIEW, *2015 PEERS TAPPI*.
14. Oneida-Herkimer Solid Waste Authority (OHSWA). Accessed August 10, 2022. Available: https://www.ohswa.org/
15. Dölle K. Aseptic Packaging Container. pdf-file. 2022.
16. TAPPI T 205 sp-12. Forming handsheets for physical tests of pulp.
17. TAPPI T 220 sp10. Physical testing of pulp handsheets.
18. TAPPI method T231 cm-07, “Zero-span breaking strength of pulp (dry zero-span tensile)
19. TAPPI T 240 om-07 “Consistency (concentration) of pulp suspensions
20. TAPPI T 402 sp-13. Standard conditioning and testing atmospheres for paper, board, pulp handsheets.
21. TAPPI T 403 om-02, “Bursting Strength of Paper”.
22. TAPPI T 410 om-08. Grammage of Paper and Paperboard (weight per unit area).
23. TAPPI T 411 om-10. Thickness (caliper) of paper, paperboard, and combined board.
24. TAPPI T 412 om-06. Moisture in pulp, paper and paperboard.
25. TAPPI T 414 om-98. Internal tearing resistance of paper (Elmendorf-type method).
26. TAPPI T 460 om-02. Air resistance of paper (Gurly method).

27. TAPPI T 494 om-06 Tensile properties of paper and paperboard (using constant rate of elongation apparatus).
28. TAPPI T 538 om-08. Roughness of Paper and Paperboard (Sheffield method).
29. TAPPI T 826 pm-92. Short span compression strength of containerboard.
30. ISO 2470 “Paper, board and pulps - Measurement of diffuse blue reflectance factor – Part 1: Indoor daylight conditions (ISO Brightness).
31. ISO 2471:2008 Paper and Board: Determination of Opacity (Paper Backing) – Diffuse Reflectance Method.
32. ISO 11476:2016 Paper and Board – determination of CIE Whiteness, C/2° (Indoor Illumination Conditions.
33. Dölle K. Low Consistency Laboratory Repulper. pdf-file. 2022.
34. Huston J, Babb C, HomansJ . Pulping High Wet Strength Milk Cartons. 1995 Recycling Symposium Proceedings.