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Aseptic Packaging Container Recovery – A Review

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The composition of beverage cartons also called aseptic packaging materials is paper, polyethylene, and aluminum to provide the packaged products with long shelf life without refrigeration or adding preservatives.
Various recovery processes in the chemical, thermochemical and repulping methods can be used to separate plastic, aluminum, and fiber material for reintroduction for manufacturing new products.
Today, composite material is produced by shredding the packaging materials and selectively pressing them under heat and pressure into new products. Another method is the repulping method introduced by Tetra Pack.
In many areas, these packaging materials are collected with regular recycling materials, and then these materials enter the recycling waste and paper recovery stream. To selectively recycle beverage containers and recover paper, polyethylene, and aluminum materials a recycling program needs to be in place that is able to provide enough materials that allow the installation of a complex and costly recovery process to utilize the material contained in the collected beverage containers.

Keywords: Aseptic packaging materials; beverage carton; liquid container board; milk carton; recycling; pulping; repulping.

1. INTRODUCTION

Increasing environmental concerns draw more attention to paper-based packaging materials which have a more favorable environmental footprint as conventional packaging solutions [1].

The production of paper and board material increased according to Statista from 77.1 million

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tons to 400.9 million tons in 2019 with a peak of 415.2 million tons in 2017& [2].

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].

The steady increasing internet sale and boost through the pandemic years in 2020 and 2021 resulted in a boost of board and packaging products requiring producers to expand their production capacities. 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]. Paper companies investing hundreds of million dollars in manufacturing upgrades and new paper machines in the US and Europe to keep up with market demands [3]. For example, Nine Dragons headquartered in China invested in board mills in Wisconsin and Maine over 300 million dollars in 2019 and 2020 [3,4]. Palm the largest family-owned paper manufacturing business in the paper industry located in Germany invested over 500+ million Euro in a new board production site producing 750,000 metric tons of board product annually [3,5-6]. Green Bay Packaging in Wisconsin invested in a new production facility 500+ million dollar to produce 685,000 short tons (621,422 metric tons) of paperboard products [4,7-9].

Today, paper packaging material is mass produced with paper machines that can produce over 4,500 metric tons daily. These machines can be up to 600 m long and 11.5 meters wide and produce the paper speed at speeds of up to 2000 m/min [10,11].

In the past years usage of paper-based packaging has increased due to its environmentally benefits compared to low-density polyethylene-based packaging, which contribute significantly to macro and micro plastic pollution in oceans as it breaks down [12].

Based on this it can be expected that the use of paper-based packaging products will increase in the future. The following manuscript reviews the application and recycling technology needed for liquid beverage products manufactured from carton-based packaging materials. Finding ca n be used to develop a process and strategy to utilize these products in the recycling stream.

2. FUTURE OF ASEPTIC PACKAGING CONTAINERS

Many countries over the world have enacted legislature to promote paper-based packaging to replace plastic bags for example [3]. This results that food, beverage and pharmaceutical industries shifting toward renewable packaging using more.

The estimated worldwide market volume for liquid packaging containers in 2021 is $ 460.58 billion with an expected growth to $ 716.70 billion by 2030 [13] with a growth potential in North America of 5.7% [14].

In another study, the aseptic packaging market was worth $15,408.8 million in 2020 and is predicted to grow to $32,301.4 million by 2028, with a Growth of 9.8% between 2021 and 2028 [14]. However, these numbers might be subject to change with unforeseeable impact of future COVID-19 and the Ukraine war.

It is certain that the business outlook for liquid container board cartons or Aseptic Packaging Containers (APC) is promising, but to meet environmental regulation and being accepted as eco-friendly packaging solution recycling processes for the used APC need to be implemented.

3. ASEPTIC PACKAGING CONTAINERS

Today, not only plastic bags can be replaced with paper-based packaging. Many other products, liquid and solid, that are sold in plastic containers such as milk and juice products, bread, chips, etc. can be packed in paper-based packaging products.

For instance, milk products can be packaged in APC instead of plastic jugs and glass. APC packaging can contain 94%, plastic containers 96%, and glass containers 75% of the product [15]. This makes APC the better environmental solution as packaging material, because APC board cartons can be made from virgin fibers (a renewable material source) and recycled fiber material. The manufactured packaging itself can be recycled, whereas plastic containers are downcycled, due to sanitary concerns and not made into new packaging materials or other products [15].

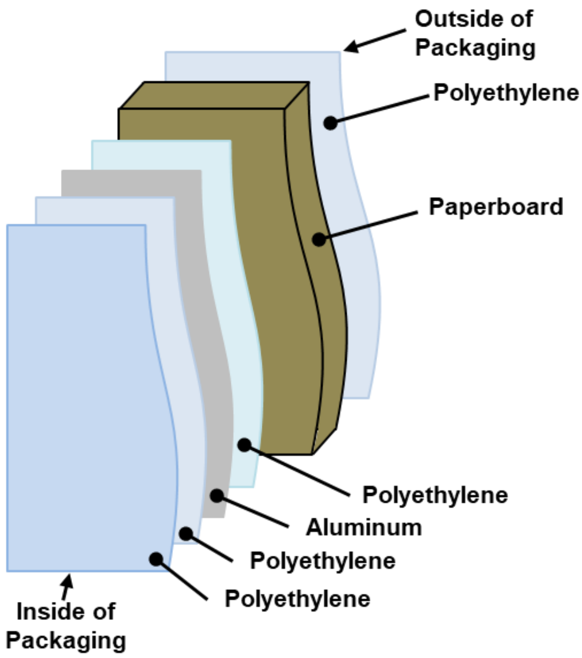

Fig. 1. Illustration of an aseptic packaging container material [19]

The APC products essential functions include transportability and storage capacity [16]. However, unlike aluminum cans or glass bottles, APC containers cannot be recycled in conventional municipal recycling facilities, because they contain contains multiple layers of plastic, aluminum, and raw paper, cannot be recycled as "regular" paper trash and must be sent to specialized recycling facilities to separate the various constituents of the APC [17].

Fig. 1. illustrates the various layers of aseptic packaging composite material. The composite materials are composed of 75% Paper, 20% Low-Density Polyethylene (LDPE), and 5% Aluminum [18]. The Paper board layer is embedded between multiple layers of LDPE. The aluminum foil layer is sandwiched in between LDPE layers based on product requirements.

4. RECYCLING OF ASEPTIC PACKAGING CONTAINERS

Initially, packaging was made of only one type of material. This notion works well in many circumstances, such as glass jars, polyethylene terephthalate (PET) soda bottles, or metal cans. However, each of these materials has a drawback that prevents them from being used more widely: glass is heavy, eventually causes high fuel consumption for the transportation, and is fragile, PET does not provide a sufficient oxygen barrier for many items, and metal is opaque. Ideal packaging designs for most packaging requirements can be designed by mixing different materials [13,14].

However, every packaging solution may require different recycling approaches. Collected Glass containers are separated in clear, brown and green glass fractions, In Europe most of the glass containers are collected, washed and disinfected and reused again [20]. Aluminum cans all over the world are collected and reused again [21]. Plastic materials are recycled and collected to make new materials [22]. Paper materials are collected all over the world and recycled again [23]. However, collection of reusable materials requires special collection processes to be introduced. In Germany and Austria for example plastic, aluminum, APC containers, and other composite material are collected since 1993 in the so called yellow bag or yellow can (in German: Gelber Sack, Gelbe Tonne). The collected materials are separated in an recycling center and reused to manufacture new products [24].

For APC containers the company Tetra Pack which is the market leader in APC packaging developed a recycling process based on the thermodynamics of polymer solutions can describe delamination methods based on the chemical degradation of an inter- or adhesive layer, methods based on selective dissolution, and methods based on the combined processing of the multiple ingredients [25,26].

Tetra Pak uses mLLDPE (metallocene-based linear low-density polyethylene) after the year 2006 [17], which is relatively thinner than LDPE. Based on their design APC materials require a different recycling approach, able to recover the individual components of the APC material. The pulp extracted from the recycled APC materials can be reused as fiber materials to manufacture new paper-based materials such as corrugated containers [27]. The recovered Aluminum and Polyethylene residues can be repurposed by mixing for the manufacturing of tiles [28].

Tetra Pak product philosophy includes packaging products with sustainability in mind to make recycling easy. [29]. In 2021 Tetra Pak cartons have been recycled globally at a rate of 26% [30]. The firm said that global recycling rates would no longer be one of its significant criteria in sustainability reports. New metrics, such as public awareness, access to recycling facilities, and recycling capacity, would be used as a substitute. TetraPak and Veolia, a utility and waste management company, signed an agreement in 2018 to "recycle all the components of used beverage cartons collected within the EU by 2025" [17].

In Brazil TetraPak and its company partners such as Alcoa, Klabin, and TSL Engenharia Ambienta have already implemented procedures for recycling aseptic packaging materials [16].

Recycling paper fibers from TetraPak packaging can reduce CO_2 consumption by 10-15%, leading to a carbon footprint between 37% and 47% compared to similar products [31]. Some bacteria can eat the LDPE (Low-Density Polyethylene), but the main disadvantage is it takes 16 days to consume plastics; they are Brevibacillus, Aspergillus, and Bacillus group. *Exiguobacterium sibiricum* strain DR11 is a special kind of micro-organism that can also eat polyethylene which was found in India at Shiv Nadar University [32]. To recycle APC packaging materials a large-scale process of several 100 tons per day is needed to be put in place to supply the needed fiber material for paper production. Processes that will be implemented need to be able to recover the individual components such as paperboard fibers, aluminum and polyethylene utilizing already implemented processes in the paper manufacturing processes. For the manufacturing, recovery and preparation of fiber containing materials in the paper production manufacturing chain different pulping processes have been used since the mid 1850’s.

4.1 Pulping Process

Pulping has two distinguished meanings in the paper manufacturing process. The first meaning is the process of generating fiber from a lignocellulosic feeds stock which is done in so called pulp mills. For example, in North America fibers for papermaking are leave tree fibers, called Hardwood (HW) and needle tree fibers called Softwood (SW) fibers, other renewable fibers such as straw, bagasse and hemp are under discussion [33,34].

The second meaning of pulping refers to reproducing/repulping of fibrous material from recycled fibrous material and/or virgin pulp sheets produced from mechanical and/or chemical pulping operations, by employing large blending//disintegration machines called pulpers in the fiber preparation section, called stock preparation, of a paper mill.

Pulp mills can be classified into (i) mechanical pulp mills, (iii) chemical pulp mills, and (ii) semi-chemical pulp mills. In each pulp mill type, the woody raw material is processes (pulped) in various ways.

Mechanical pulping process and subsequently chemical pulping processes were invented, because in the mid 1800’s fibrous raw material for papermaking, at that time mostly recycled rags from old clothes, became rare [35].

4.1.1 Mechanical pulping

In 1843 Friedrich Gottlob Keller invented the mechanical wood grinding process [36]. Keller sold the invention to Heinrich Voelter a paper maker located in Heidenheim Germany in 1847. Voelter already has a long-lasting work relationship with Voith a mechanical workshop owner in the same city since 1821 [37]. Voelter and Voith improved the invention and Voelter patented a wood grinding machine in various countries of Europe, in France in 1847 and England in 1853, followed by a United States Patent No. 21,161 in August 10, 1858 [38]. The patent was reissues in 1869 [39] and 1871 [40]. Voelter and Voith then developed from 1848 on together a commercial wood grinding machine, machine for the commercial conversion of wood into pulp for the production paper products. The wood grinding machine was introduced in 1852 followed by a Voith refiner in 1859 [37,41]. The refining machine is producing the same fibrous material as the ground wood process. Instead using a grinding stone metal disks are used to grind wood chips instead of wood logs. However, stone groundwood was the preferred manufacturing method of wood pulp till the 1960s, when first the mechanical pulp production with refiners was commercially introduced [42]. Groundwood production declined to 75% in the mid-1975 and declined to 50% in 1990. Today disk grinding is the preferred production method to produce mechanical pulp [42].

4.1.2 Chemical pulping

The development of the chemical pulping methods appeared during the same time period as the mechanical pulping method development. The first chemical pulping process called "Soda Process", was invented by the English scientist Charles Watt and Hugh Burgess in 1854 [43,44] and patented in 1854 [45]. However, France scientists Theodore Coupier and Marie Amedee Charles Mellier from Paris invented the soda process prior to Watt and Burges in 1853, Unites States Patent No. 9,910 [46]. The patent was reissues in 1862 under Unites States Patent No. RE 1,295 [47]. In 1866 the "Sulfite Process" was invented by Benjamin Tilgham a chemist from Pennsylvania, Philadelphia [43,44]. He patented the process in 1866, Unites States Patent No. 70,485 [48]. The "Kraft" pulping process" [43,44,47,49], also known as sulfate process, was invented, and patented by the German Scientist Carl Friedrich Dahl in 1879, Unites States Patent No. 296,935 [50].

All pulping processes have been improved since their invention and many decades the soda and sulfite process were the dominant chemical pulping processes till the 1930's [44]. In the 1930's the Kraft process became the dominant process, because it could utilize many different types of woods that could not be pulped with the soda or sulfite process [44]. Today, the most common process used to chemically extract cellulosic fiber material worldwide from SW and HW fiber materials is the Kraft process, which was used the first time commercially in Sweden [44,49].

4.1.3 Semi-chemical pulping

Mechanical and chemical pulping processes have been improved continuously since their implementation. In the 1970's semichemical processes have ben developed and employed commercially. These processes combine chemical treatment of wood chips and chip refining utilizing heat and pressure, allowing improved fiber properties and significant energy savings compared to previous chip refining processes [48].

4.1.4 Repulping

Repulping or pulping of fibrous material is known since the utilization of woody material for paper production, for mixing and repulping the produced fiber material. A United States Patent, No. 247,016 on September 13, 1888, granted to Charles Coon from Saugerties, New York, describes the repulping/recycling of paper clippings and scrap paper together with newly fiber material into the paper manufacturing process by utilizing a beater type grinding machine [51]. Since then, the repulping has been perfected with the extensive use of recycled material in the paper making process. For example, according to the United States Environmental Protection Agency (EPA) in 1960 about 5,080,000 US tons of paper material have been recycled. In 2018 the recycled paper material increased 9-fold to over 45,970,000 US tons have been recycled. in the beginning of the 1960's [52].

Involved along with paper making technology development and has been from recycled fibrous material and/or virgin pulp sheets produced from mechanical and/or chemical pulping operations is utilizing different processes in the stock preparation section of the paper mill. Fig. 2. shows in a imple process schematic of today's commonly used repulping process methods [53].

The repulping technology today can be done at Low Consistency (LC) repulping with solids contents of up to 5% to 8% using start type rotor designs [42,43,54]. Tank sizes vary and can be in the size of approximately 2 m³ to as large as over 160 m³ able to produce up to over 1600 metric tons of pulp per day. High Consistency systems utilize a helix type rotor design designed to pulp the recovered fiber material at up to 18% consistency in tanks that can have approximately sizes of 20 m³ to as large as over 140 m³ [43,55]. Another HC systems are drum pulpers, which can pulp the recovered fiber material at consistencies of around 28% [43,55]. The material is repulped by friction, centrifugal and gravity forces in long rotating drum like vessels.

Drum pulpers can be over 78 m long and able to process of up to 3,000 metric tons per day [56].

As illustrated in Fig. 2, LC, HC, and drum pulpers can be arranged in different configurations. LC pulpers and drum pulpers work on a continuous basis, while HC pulpers are operated in batch type processes. A batch process may take approximately up to 30-40 minutes based on the raw material processed [43]. LC and HC systems can contain internal screen devices and or separate screening machines employed based on the type of recovered material processed. In general, after the pulping operation the pulp is diluted to approximately 4%. Unwanted material such as metal, sand, plastic and hard to process recycled material is removed from the extracted fiber slurry. The fiber slurry is sent further in the recycling for papermaking. The recovered material section is thickened and baled and then feed into the recycled industries material stream for the manufacture of new recycled metal and plastic materials [57].

4.2 Recycling of Aseptic Packaging Materials

4.2.1 Recycling of aseptic packaged materials using sodium hydroxide and sodium hypochlorite

In a study, Seno et al. recovered Aluminum by dissolving the recovered APC material (Tetra Pak) in Sodium Hydroxide (NaOH), which generates sodium aluminate and H2 gas. It was dissolved in the ratio of 50:50 by weight %. There is a separation from the above process (Pulp of Paper, PolyAl) [58]. The pulp was sent to hydra pulper to clean and produce papers. This is called Bayer Process; the Sodium hydroxide will digest the bauxite to generate alumina (Al2O3). The process produces hydrogen gas that can be used as an alternative fuel in refineries. It is preferred to have the reactor near calciner or boilers where the H2 gas can easily be transferred. In this process the problem most recycling plants face was fiber loss, contamination of hyrdra pulper to avoid it was washed and will be ready for the next batch; hence less loading was preferred to prevent washing the drum for every cycle.

Bales of wastepaper are sent to a circular tank, and water is added simultaneously. It is used mainly for separating the waste from the pulp. Methods and apparatus for separating paper fiber and plastics from mixed waste materials and products obtained thereby, generally separating the paper from other composites (PolyAl) are sent to hydra pulper and mixed to form a slurry. We need to pretreat the feed before sending it to hydra pulper which means disinfecting the material. It is cut into small pieces, sent for washing. The bleaching agent is added to soften the feed due to water absorption and act as a disinfectant [58].

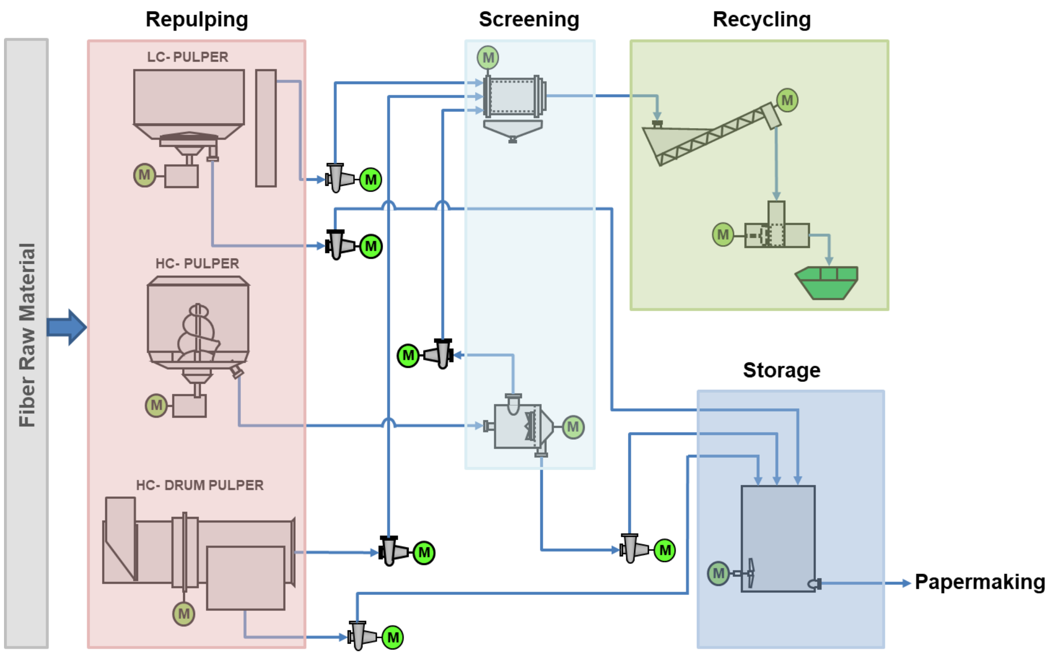

Fig. 2. Low consistency (LC), high consistency (HC), and drum pulping system [53]

To improve feed characteristics (Sodium hydroxide or Sodium Hypochlorite) is added as a chemical reagent. Although this chemical addition is not critical, it can help maintain pH and acts as bleaching to improve process efficiency. The optimum temperature range is 35°C (95°F) to 75°C (167°F) with 15 to 30 minutes retention time. The pH value in the repulper should be maintained between 8.0 and 10.0.

A study by Hyder et al. in 1993, investigated the same process in which the extraction plate at the bottom of repulper removes the heavier components sent to the digester. The slurry has been removed and sent to Liquid Cyclone [59]. The paper fiber component still has debris (PolyAl); hence, it passed through coarse and slotted screens in the order .006' (0.1524 mm). The extraction plate separated the residuals, and Paper fibers were fed into a separation system called centrifugal separators to separate the high- and low-density components. Where one is forward cleaner (preferred for heavy contaminants) due to a pressure drop of about 20 psi (137.895 kPa), it is easily fed into the second, which is reverse cleaner (preferred for light contaminants) [59]. The removed lightweight contaminants were sent to a different recovery process. This separation process is repeated more than once to obtain better results in getting enriched paper fibers for further process. The ink leftover in a few paper fibers was removed by density difference since the ink has a lower density than water. The pulp was then sent to a dewatering device due to froth floatation, and most of the ink was removed. Thickener was used to thicken the pulp. A disperser machine was used to lower the ink size. Then it is either sent to a Pulp mill or dewatering device to remove the amount of water. Similar results were observed by Recycling the residual components coming from the Extraction plate were fed into a Grinder to grind and reduce the size of particles from 20 mm (0.787402 inches) and less than. Reduced size feed was sent to a reactor, a combination of cyclone separator and floatation tank. The holes of size about (2 mm (0.079 inches)-5mm (0.19 inches) were used to collect the fiber that passes through and retains the heavy contaminants. In the following process to remove the heavy particles, Sedimentation Tank can help remove the heavy particles and send them to the second Sedimentation Tank which removes the plastic from metal components. The plastic particles were sent to the separator using centrifugal force and Aluminum particles were sent to a centrifugal separator that retains about 20% and sends the remaining Polyethylene fraction to a Different separator. The collected plastic was sent to a drying system which reduces the water content to less than 1%. And finally, to obtain the pure plastic, it was sent to a rotating drum pulverizer which melts, and pellets were made from Extruder [59].

4.2.2 Separation of components using carboxylic acid

The Separation fluid is a combination of Carboxylic acid (acetic acid, formic acid, or propanoic acid) and a solvent of hydrocarbon (Xylene, toluene, or naphtha type solvents) as a swelling agent (Short-chain liquid hydrocarbon) that swell polymer layer of polyethylene.

In a World Patent Application by Horst and Kernbaum in 2019 a hydra pulping process is described for recycling paper fibers. The remaining waste residues were fed into a vat in which the separation mentioned above fluid was mixed. This leads to the separation of LDPE and Aluminum shreds between 20°C (68°F) and 50°C (122°F) for the period of 0.5 hrs. to 5 hrs. Surfactant is used as an emulsifier and wetting agent. Generally, it separates polyethylene from aluminum and other sticky materials. Microemulsion Anionic Surfactants (Sulfonic Acids, Sodium Salts, C14-17-sec-alkane) are added as the stabilizing agents [26].

A study by Martinez-Barrera et.al. in 2017, shows the usage of recycled fibers from TetraPak packaging materials used in polyester composites. The modulus and crystallinity degree is critical parameters and mechanical characteristics degrade in a steady-state manner with greater recycled cellulose concentrations of about 4% and 6% based on weight [60]. The highest values of each mechanical parameter are as follows: flexural strength and modulus of elasticity at 100 kGy (KiloGray) - It is a derived unit of ionizing radiation dose in the SI System); compressive strength at 200 kGy; compressive strain at 400 kGy; and flexural strain at 500 kGy [60].

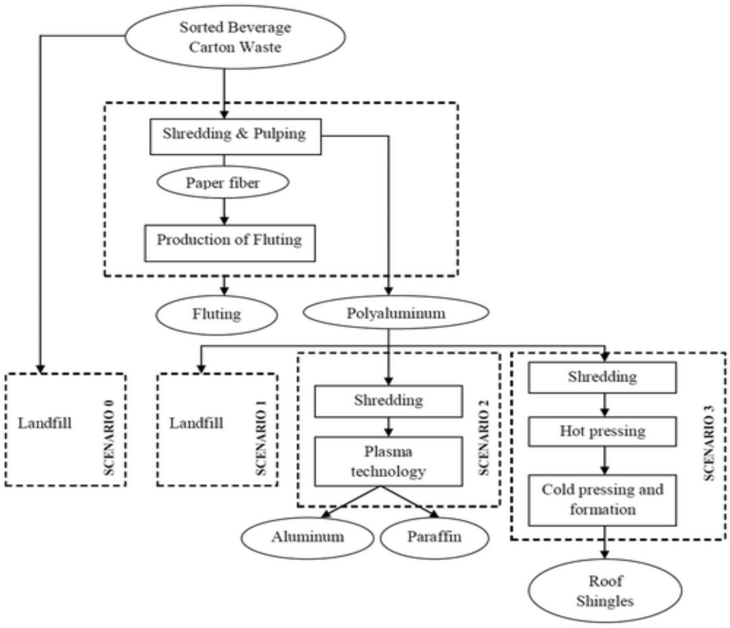

Fig. 3. Decision making support system based on LCA for aseptic packaging recycling. Waste management & research. Image by Varžinskas et.al. 2012 [31]

Fig. 3 portrays how (Tetra Pak/ Cartons) can be recycled in multiple ways to obtain different products. In Scenario 1, the recycled fiber was used by a paper mill to produce fluting paper. Scenario 2, uses Polyaluminium recovery by plasma technology (Obtaining Aluminum and Paraffin from Polyethylene). In Scenario 3 the extracted Polyaluminium was used to produce roof shingles. Which will be discussed in the following methods.

4.2.3 Recycling without pulping

Another way to recycle is to cut down the used TetraPak cartons by shredding them to a size of 1-5 mm, followed by pressing at 170°C and adding low-quality polyolefin to give desired mechanical properties, flexibility, lightweight, and hydrophobic properties of the manufactured composite material, which is used for example in decking planks [61].

To a size of and use them as filler. In the same way, this shredded Tetra Pak is cut down to 1-5 mm of sizes and pressing it at 170°C and low-quality polyolefin to give desired mechanical properties which are flexible lightweight, and hydrophobic in nature. Similarly, there are other ways it can be processed. [61]

4.2.4 Pyrolysis method

In a study, Huo et al. in 2021, state that TetraPak Waste (TPW), paper, and Low-Density Polyethylene (LDPE) are pyrolyzed at 368 and 490 degrees Celsius, respectively. In comparison, aluminum foil is melted at 660 degrees Celsius. Char and undamaged Aluminum foil were produced by carbonizing TPW at 550°C, generating theoretical yields of 20.43% and 6.37%, respectively [1]. Acid-washed char is carbonized at 850°C to produce porous carbon with a surface area of 741 m^2/g and a pore volume of 0.514 cm^3/g. Pores were formed due to thermal cracking and polymerization activities at high temperatures [17].

In another study, Zawadiak et al. in 2017, investigated the performance of woody-like composites made of bio-based polybutylene succinate and 10 to 50 weight percent recycled cellulose acquired from an industrial Tetra Pak processing factory [62]. When 50% Recycled Cellulose (rCell): Fibers recovered from the Liquid package container) were introduced to Phosphate buffer saline (PBS), the composite's hardness was found to increase two times over PBS. The Young's modulus was found almost three times, while the tensile strength and ductility decreased. According to the dynamic mechanical investigation, the storage modulus improved by 4-fold at ambient temperature, while the loss modulus e improved by 6-fold, but the glass transition temperature remains practically constant [63].

Table 1. Experimental data for pyrolysis process, adapted from [17]

Component	Operating Temperature		
	400°C	500°C	600°C
Solid	45.84	25.28	20.52
Char	39.14	18.68	14.02
Aluminum	6.7	6.6	6.5
Liquid	26.65	37.69	38.17
Gas	27.51	37.04	41.31

Traditional fossil polymer-based wood-plastic composites could be replaced with the woody-like composite material, enhancing the TetraPak life cycle by expanding the application of recycled cellulose-based packaging composite materials into the furniture and construction industries, which can increase the bio-based carbon content by 50% to 75%. [63].

4.2.5 Selective dissolution – precipitation method

In this approach, the mixture's various polymers are dissolved one by one at a specific temperature in the same solvent. It has the advantage of not requiring the input to go through a sorting process. The initial polymer's solution is separated from the residue by filtration and then activated before the polymer is recovered using traditional polymer extraction procedures. Tetrahydrofuran, xylene, and toluene are commonly used solvents. Multilayer architectures have also been explicitly evaluated with this method. Because both polymers were in touch with the solvent, the selective dissolving procedure worked for bilayer materials. In a different study by Georgiopoulou et al. [18], in 2021, demonstrated by adding the cut pieces in 1.0 x 1.0 cm of Al-PE laminates pieces and xylene in the ratio of 1:15 (g/mL). The temperature was set around 85°C (185°F) and stirred the mixture for 2 hours at 300 rpm. The xylene was used as a solvent that dissolves the LDPE; further, isopropanol was used to precipitate. The precipitation process is repeated twice or more by the same procedure, and aluminum was recovered due to the dissolution of LDPE and paper [18]. The white powder coming from the reactor shows high purity of LDPE.

4.2.6 Delamination

It is the step where the sandwiched layers of an Aseptic Packaged materials can easily be delaminated by adding Acetone. Separate Technology, a German-based company, invented a method to recycle the waste product from Tetra Pak into valuable products where they use a liquid developed from industry to separate the layers [25,64]. The dissolution of macromolecules can cause multilayer delamination physically, and the disintegration of an interlayer or interactions at the interface can cause it mechanically or chemically. Purification becomes considerably more difficult for multilayers delaminated into more than two different polymer kinds and mixes of multilayers with more than one type of multilayer. New flake-sorting technologies could be used here in the future. In the case of commingled post-consumer multilayer packaging, delamination would necessitate a different sorting process for multilayers and a sortable marking [17]. These are the researched methods and have not been implemented in the industry.

4.2.7 Chloroform method

In one published research by Karaboyaci in 2017, aseptic packaging material was shredded into small pieces of 40mm and mixed with chloroform solution for 2 hours at 65°C. The dissolved polyethylene was separated using a distillation column and the pulp (paper fibers and aluminum) was separated from the dissolved liquid of polyethylene. To recover the paper fibers, water is added to leftover aluminum and paper and boiled to make pulp, separated by washing and filtering it to recover 75% of paper fiber for a 2-gram sample [65].

4.2.8 Lab scale experiment of hydra pulping process

In a study, Lokahita et al. in 2017, aseptic packaging material was cut and mixed with water at a ratio of 1:25 (g/L). The mixture was stirred at 400 rpm for 2 hours at ambient temperature until paper swelled and waste package containers were split into outer LDPE/paper and inner LDPE/Al/paper parts. The process continued for

3 hours and increased the rpm to 700 to remove the paper fibers from the plastic altogether. This resulted in the separation of the pulp from LDPE and aluminum; when hydra pulping was completed, the mixture was filtered to remove the paper pulp from the Al-PE laminate and outer LDPE layer, which were then subjected to an additional hydra pulping cycle for 1 hour at 700 rpm, to remove as much residual paper as possible by dispersing it. The obtained pulp was filtered for water removal, and a vacuum oven was used to dry the compressed filtered material at 100 mbar and 40°C until weight stabilization was observed [66].

4.2.9 Hydrothermal process

In one of the treatment methods, the waste Aseptic Packaged materials were collected and cut into 1 x 1 cm. The moisture content was calculated based on the solid weight. Added a proportion of solid sample and Distilled water in the ratio of 9:81 into the stirrer. The stirrer operated at 400 rpm, and the volume capacity was 500 ml. The reaction temperature varied at different temperatures (200°C (392°F), 220°C (428°F), and 240 °C (464°F)). The highest aluminum content was found at 220°C (428°F) at (30 & 60 min) for the exact temperature [66]. The characteristics of aluminum are hard and robust. These experiments conclude that carbon content increases during the hydrothermal treatment, resulting in a higher heating value. The temperature at 240°C (464°F) and holding time of 60 min resulted in a higher heating value of up to 25.22 MJ/kg and increased the aluminum yield to 37% [66].

4.2.10 Repulping

Appropriate repulping processes for recycling APC would be LC and HC repulping processes. To separate the APC packaging layers, heat and pressure need to be applied to recover polyethylene, aluminum and produce cellulose fibers for paper production [67]. Repulping is the most common process implemented on a large commercial scale. New developments recently reduced energy consumption by approximately 20% [54,55,56].

A study by Huston and Babb found that milk cartons can be pulped in a HC repulping process recovering the fiber and polyethylene material [68]. Generally, the repulping operation is based on the batch size, rpm, and Rotor design. At the same time, the pulping conditions are Temperature, pH and Time, sample size, Preparation, and Evaluation. A study by Huston et al. states that Aseptic packaged materials were recycled using the chemical Oxone at higher consistency, pH of 10, and temperature around 150°F (65.556°C) – 180 °F (82.222°C), giving a better yield. Due to the high wet strength of cardboard, adding 1-2 % of Oxone can reduce the pulping time by 35 - 40 minutes [68]. Similar finding was obtained by Neves et.al. for repulping APC materials [57].

4.2.11 The tetra pack process

The Tetra Pack Process is the most advanced and commercialized process in recovering APC materials in Europe. However, In Europe separate recycling processes for APC packaging are in Place. The US lacks these processes and other means of recycling of APC materials need to be established.

The key essential equipment needed to recycle the Tetra Pak is a high and low consistency hydra pulper. Several patents have been granted for and around recycling APC packaging.

Brooks Mentions in a US patent to form a board by adding resins (urea-formaldehyde, urea, and melamine) to the recycled cellulose fibers [69]. US Patent No. 3741863 [70] states to heat at 700°F (371.11°C), the used Aseptic Packaged materials and package gets softened, which is more beneficial to remove the plastic same, while US Patent No. 3814240 [71] presented a process to remove plastic by melting using energy (hot gases) from the dehydrator. US Patent No. 4017033 [72] and 4231526 [73] gives more detail about separating the different layer of Aseptic Packaged materials using the Centrifugal separator and Hydro cyclone that vortex the feed and separates the heavy and light contaminants. Us Patent No. 4272315A [74] Espenliller designed a pulper that continuously removes the pulp from plastic and other contaminants. Us Patent No 4283275 [75] discovered a pulper that contains rotor and two different sizes of screens that remove the contaminants. However, neither of the above-mentioned processes have been implemented commercially.

In Brazil, TetraPak made a change in the design of the hydra pulper by installing extraction plate below the rotor, which is not a standard design for high consistency pulper. The water was used at the ambient temperature, and no chemicals were used in the process. In one of the European patents, aluminum foil separations from poly coating were done by adding 25% of Acetic acid in a closed container. This experimental setup is happening at 100 ° C (212°F) for 20 minutes and cools down for a time of 2.5 hours [69].

Unites States Patent No. 5,390,860 assigned to Tetra Laval Holding & Finance SA in February 21, 1995 describes a process that recovers fibers from mixed waste material containing plastic and plastic/metal composites including milk carton APC packaging material [59].

5. CONCLUSION

Cartons for beverage containers, also called aseptic packaging materials are manufactured from a composite material that contains paper fibers, polyethylene, and aluminum to provide the packaged products with long shelf life without refrigeration or adding preservatives.

Recovering of the individual materials contained in beverage containers revealed possible recycling routs in the chemical, thermochemical and various repulping methods including addition of chemicals to separate and recover the individual materials such as plastic, aluminum and fiber material for later reintroduction into the manufacturing process of new products.

Today, the heat treatment method, that produces new composite material by shredding the packaging materials followed by pressing under a temperature above 170°C and the repulping method introduced by Tetra Pack is the most common used method today for recovering of liquid containerboard packaging materials.

In many areas these packaging materials are collected with regular recycling materials and then these materials enter the recycling waste and paper recovery stream. To selectively target liquid containerboard packaging materials recycling programs needs to be in place to selectively collect composite packaging materials and provide enough materials that allow the installation of a complex and costly recovery process to utilize the fiber material contained in the collected liquid container board material.

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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.

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