The Effect of a Sustainable Technology of Delignification and Tcf Bleaching on Physical Properties of Recovered Cardboard

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Research Article

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Abstract

Old Corrugated Containers (OCC), also known as waste corrugated cardboard, multilayer packaging and wrapping sacks are complex and heterogeneous materials composed of various sources of unbleached cellulose pulp derived from several raw material processes. However, OCC pulp have a high proportion of long fiber because are mainly manufactured from softwood pulp by the kraft process. OCC are the main category of recovered paper; however, due to their high lignin content, hornification and other problems resulting from the pulp to cardboard conversion processes, additives and pollutants, their physical properties decrease with each recycling which justifies evaluating various treatments with existing technologies to improve it. The objective of this work was to obtain improved unbleached and bleached old corrugated container (OCC) pulp more ecologically justifiable than wood for higher grade papers using sustainable processes evaluated in pilot scale tests OCC were collected from a landfill, cleaned, repulped, and treated with extended delignification with the alkaline soda process, obtaining a pulp with significant physical-mechanical improvements in relation to the original material, such as tensile strength, tearing resistance, bursting strength and folding endurance. The OCC soda pulp was bleached by a sequence totally free of chlorinated compounds (TCF), obtaining bleached pulp with optical and mechanical properties comparable to virgin pulps of annual plants such as bagasse but with improved drainage properties and lower processing costs. According to their properties, it is a competitive pulp obtained with existing technologies, available for use in various grades of printing and writing paper replacing totally or partially bleached wood pulp.

Introduction

The pulp for papermaking may be produced from virgin fiber by chemical or mechanical means or by the repulping of paper for recycling. Recycling accounts for about 50 % of the fibers used; in several regions. Nevertheless, hardwood, bagasse, bamboo, straws, hemp, grasses, cotton and other cellulose sources from non-wood plant waste can be used, notwithstanding, they have complex technical problems to be solved with research and developments in current technologies (Jahan et al. 2021; Abd El-Sayed et al. 2020).

Paper and cardboard production is a two-step technological process in which a fibrous raw material (wood, agro-industrial waste, non-woody plants, and recovered paper) is converted, first into unbleached cellulose pulp through chemical, biotechnological, thermochemical, semi-mechanical, mechanical and recycling processes or a combination of them. Then, the bleaching process is carried out based on conventional sequences with chlorine compounds, ECF (elemental chlorine free) and TCF (totally chlorine free) techniques and other chemicals, and, finally, the resulting bleached pulp is converted into paper in stock preparation with mechanical operations such as beating or refining and the addition of additives (Bajpai 2018).

The manufacture of cellulose pulp, paper and cardboard is one of the world’s oldest industries. However, due to its intensive usage of plant raw materials, energy and water, it is also considered one of the most polluting industries. Nonetheless, it is a leader in the application of recycling technologies. This is largely because it will not be possible to meet the growing need for non-wood pulp sources in a sustainable and competitive manner without technological innovations in the processes to obtain pulp from agro-industrial lignocellulosic waste and improve the low quality of recycled fibers due to the heterogeneity of the origin of wastepaper and cardboard (Adu et al. 2018).

Recovered fibers are characterized by a number of negative factors such as a high degree of contaminants present in the fibers with organic and inorganic materials such as plastics and inks, a sharp reduction in physical-mechanical resistance properties due to the decrease in bonding capacity between fibers and surface areas, depolymerization, low swelling ability and flexibility due to fiber breakdown, generation of fines due to continuous repulping, deinking processes, high use of additives and chemicals in the conversion to paper and cardboard after recycling and the phenomenon of hornification due to drying, all of which impact on the quality of final products (Hubbe et al. 2007; Diniz et al. 2004; Laivin and Scallan 1996).

Strategies such as beating or refining in a chemical environment usually promote swelling, thereby increasing flexibility and surface conformability but, on the other hand, certain properties are only partially restored with the conventional recycling process (Gulsoy and Erenturk 2017).

Therefore, the pulp and paper industry is researching alternatives to further upgrade the quality of recovered fibers as eco-friendly pulping, bleaching and delignification processes to decouple the negative effects entailed by processing, environmental impacts and high dependence on process additives such as chemicals, starches, enzymes, polymers or nanocellulose in paper manufacture (Balea et al. 2020) and in turn to minimize the use of forest resources to obtain virgin fiber (Bergquist and Söderholm 2018).

In relation to the above, Scott (2019) carried out a review of the worldwide literature related to the technologies applied to recovered paper and the socioeconomic and environmental factors associated with this type of fiber when used by the pulp and paper sector.

Sahin et al. (2020) concluded that some interventions during paper recycling can improve the quality and yield of paper products, while some undesirable effects can also be prevented. However, high-quality paper products can be obtained only from improved recovered cellulose fibers.

Therefore, the pulp and paper industry's goal in the 2030 agenda and the circular bioeconomy is to find alternative new fiber sources and technological means, such as biotechnology, to improve mechanical, optical and drainage properties of recycled fiber for use in printing and writing paper production as a source of long, medium and short fiber in stock preparation, thus minimizing the environmental impact generated by the processing of raw fiber from wood and preserving forest resources (Sharma et al. 2019; Vukoje and Rožić, 2018).

Consequently, all the countries of the world have environmental public policies and, together with the paper industrial sector, actions focused on the recovery of the various grades of paper and cardboard for reuse in the paper industry to achieve the above objectives according to *The Food and Agriculture Organization* of the United Nations (FAO 2019) (Figure 1 and Table 1).

Studies on the effect of recycling on pulp properties, based on repulping and refining, have found that different types of pulp have different responses to recycling and that usually pulp strength drops after the first recycle during the process of sheet formation, consolidation and drying (Cai et al. 2020). In the case of chemical pulps, this is because viscosity, bonding, flexibility, swelling potential or water retention of the recycled fibers are reduced, compared to never-dried or virgin pulps (Tarrés et al. 2017).

Old corrugated containers (OCC)

Repulped OCC with screening stages without deinking treatment consist of a combination of recovered fibers derived mainly from virgin unbleached softwood kraft pulp (USBK) at an average percentage of 60% and the remainder from neutral sulfite semi-chemical pulping (NSSC) and other processes. It is the most widely-used fiber in the world after its recovery and a mechanical treatment, it is used to produce corrugated cardboard boxes, multiwall sacks or bags for industry and commerce for wrapping and packaging or as an alternative fiber to be mixed with virgin pulp to reduce manufacturing costs depending on its quality as content of long and fine fibers (Gulsoy et al. 2013). It is the most significant category of waste papers or post-consumer waste for recycling with a recovery rate of 96,4% in 2018 (AF and PA 2019). Therefore, in the paper industry, recycled OCC provide a potential alternative resource of fiber to obtain unbleached, semi-bleached or bleached pulps with sustainability and profitability (Kang et al. 2017).

However, most OCC have specific constraints and negative factors for repulpability and recyclability: (1) heterogeneous fibrous composition (chemical, semi-chemical, mechanical and recycled pulps), high amount of fines, and short and broken fiber length; (2) low water retention value; (3) poor drainage properties (below 200 mL CSF); (4) high amounts of contaminants such as wax, inks, starches, stickies, plastics, inorganic and organic particles and polymeric and non-polymeric materials and hot melts; (5) high dissolved solids (mainly primary and secondary fines or material passing a 200 mesh screen), (6) high lignin content of OCC fibers, making bleaching very difficult and the appearance of the product manufactured with recycled OCC is poor (Wan et al. 2011). Therefore, the recycling process (pulping, kneading, flotation, washing, thickening, dispersion, deflaking, screening) or the simple separation of fines and refining with whole or slit type fractionators is not believed to give the desired separation of the fines and contaminants from the OCC furnish without the blending of other recycled or virgin fibers for best performance (Kasmani et al. 2014)

The possibility of improving the mechanical and optical properties of old corrugated container (OCC) pulps, through an alkaline delignification stage by means of a chemical process, and subsequent bleaching it has been extensively studied since De Ruvo et al.(1986) and Jackson et al. (1994) with alkaline process and extended delignification with O_2. Recently, studies have been proposed by Jahan et al. (2016) using formic acid (FA) and $D_0E_pD_1E_pD_2$ bleaching sequence to obtain dissolving pulp. Shafiei and Latibari (2015) using Na_2SO_3 /NaOH, AQ and $D_0E_PD_1$ to produce brightness of 82.6%. Danielewicz and Surma-Slusarska (2015) with kraft process, oxygen delignification and D_0ED_1 sequence found properties compared with hardwood pulp.

Therefore, the delignification of OCC by chemical processes and bleaching has been considered as a competitive technological option to improve the pulp recovered from OCC, remove non-fibrous contaminants, additives and heavy metals and, at the same time, obtain high-quality bleached OCC pulp equivalent in mechanical resistance to virgin pulp of annual plants such as sugarcane bagasse or some hardwood. In addition to having a reduced environmental impact and low production cost, it has significant economic advantages due to existing recycling technology, low cost of OCC and higher pulping yield relative to pulp obtained by kraft or sulphite processes with softwood, and the ability to use unit operations equipment in an existing virgin pulp line as kraft o soda pulp from wood, bagasse, bamboo or rice straw and a chemical recovery process of black liquor (Aguilar-Rivera 2016).

Recycling OCC pulp to obtain bleached pulp is extremely difficult due to its heterogeneous fibrous composition, origin and quality, but although cardboard waste is abundant, current recycling technologies cause the reduction of physical properties in each cycle. Therefore, delignification and bleaching to obtain pulp with yield > 60 %, brightness > 80% ISO and with acceptable mechanical strengths and physical appearance is a technological, environmental and financial option to be considered in any plant producing virgin pulp from wood or agro-industrial waste to produce long fiber pulp from waste cardboard with lower production cost. Although the OCC pulp prior to this process has a high lignin content with a kappa number > 70. Several researchers have concluded that it is technologically feasible to delignify it in a batch or continuous digester with white liquor composed of chemicals from the kraft or soda processes with or without additives such as anthraquinone (AQ) or oxygen delignification followed by a bleaching sequence of two or three stages, mainly ECF to obtain a bleached pulp with > 70% ISO with acceptable physical and chemical properties and thus reduce absorbable organic halogens (AOX), chemical oxygen demand (COD) and total organic carbon (TOC) characteristic of effluents from a bleaching system (Koc et al. 2017). The brightness requirements of the end product drive the decision on the number of delignification and bleaching stages (Rahmaninia and Khosravani 2015; Azadfar et al. 2011).

However, although there is a plethora of technologies to recycle cardboard already, as separation of fines, classification of OCC streams, refining, mixing of recovered and virgin fibers, uses of chemical additives etc. Most of them are hardly profitable and sustainable. Besides, the approaches such as extended delignification, conventional bleaching and ECF have been evaluated at the pilot plant level with successful results, but research on TCF bleaching with OCC pulps is still scarce although could be a feasible option, with current technology and existing pulp and paper industry facilities to have a sustainable stream of long fiber bleached pulp from recovered OCC (Figure 2)

The objective of this research, applying an alkaline delignification treatment and a subsequent TCF bleaching to pulp recovered from OCC was to develop greater mechanical resistance properties, compared to those of the initial OCC, achieve a brightness of + 70% ISO, and increase its application in various paper grades reducing production costs and environmental consequences of current process with wood mainly in developing countries.

Alkaline pulping of OCC

The OCC used in this research was a mixture 50/50 % from landfill of American Old Corrugated Container (AOCC) and Local Old Corrugated Container (LOCC) as kraft liner (top and bottom surface layers) and sacks because this OCC blend has better properties as high long fiber content. Analytical grade chemical reagents were used in the delignification and bleaching. OCC after separating into small portions was immersed in water at 5 % consistency for 24 h to separate individual fibers in a hydropulper. A portion of pulp was kept after screening to carry out a fiber length by classification and a refining curve (Table 2 to 5). Afterwards, it was necessary to reduce the residual lignin content in OCC pulps through extensive delignification to improve the quality of recycled OCC fibers, with a high degree of structural damage and a high content of lignin and other chemicals from stock preparation and reduce the environmental impact due to their final disposal after successive recycling and synergistically reducing costs of wood, bagasse or other non-wood materials sustainably. According to the framework of Aguilar-Rivera (2016, 2012) the cooking trial was carried out in a batch stainless steel rotary digester, electrically heated with a temperature control system and maximum pressure of 8,5 kg cm^{-2}. The white liquor used was sodium hydroxide (NaOH) at 13 % alkali (as Na_2O based on OD weight of pulp) with a liquor to fiber ratio of 5:1, reaction time of 30 minutes and a temperature of 170 ° C, like bagasse fiber treatment. At the end of pulping (lignin removal), the pulp was washed, disintegrated in a laboratory pulp mixer and screened with a 0.15 mm slot, and the physicochemical properties of the OCC soda pulp were subsequently evaluated with standards of Technical Association of Pulp and Paper Industry (TAPPI 2000) (Tables 6 to 8). Figure 3 shows microscope images of OCC pulps after the alkaline delignification process.

The OCC pulp had 42% of long fiber when was compared to virgin unbleached softwood pulp and 385% higher than virgin unbleached bagasse pulp which justifies a delignification and bleaching treatment. The delignification treatment applied to the pulp recovered from OCC, obtained a yield of 72.2% with a reduction of lignin of 44,5 %. Moreover, applying the mechanical treatment of beating or refining at 42 ° S.R. resulted in an increase in the mechanical strength properties of paper of 11.44% for breaking length, 22.73% for tear index, 23.6% for burst index and 58.2% for folding endurance which is equivalent along the refining curve; however, drainage time and porosity will increase significantly, by 33.5 and 57.8% in relation to the original OCC. This degree of refining results in very significant drainage and operational problems for pulp washing systems and the paper machine (Table 9).

Therefore, depending on its end use as a single material or for mixtures with pulp of annual plants or hardwoods, the degree of refining must be adjusted for each individual case. Because OCC is a recycled material, the OCC pulp it only presents mechanical resistance equivalent to non-wood pulps such as bagasse pulp or some hardwood one, which makes this pulp a diversified material for a wide variety of paper grades mixed with several pulps to improve properties. When carrying out the mixture of 20% on a dry basis of OCC soda pulp and virgin unbleached bagasse pulp and later refined, it was found that bagasse pulp had increased significantly mechanical resistance and mainly drainability properties with the use of only 20% unbleached OCC soda pulp (Table 10).

Totally chlorine free (TCF) bleaching of OCC soda pulp

The aim of bleaching is to obtain a high and stable brightness on OCC soda pulp to diversify its use in various grades of paper and minimize its environmental impact being financially sustainable. TCF refers to bleaching sequences in which chlorine (C, H or D) consumption is zero. In relation to the above, Latibari 2012 reported with alkaline-sulfite pulping and TCF bleaching sequence QP bleached OCC pulp with 52% ISO, Delnevazet al. (2012) with soda-oxygen pulping and bleached with H_2O_2 and NaOH sequence brightness of 57.97% ISO.

Initially the OCC soda pulp was preliminary bleached to evaluate the effect of a conventional sequence CEHH, chlorination (C), alkaline extraction (E) and hypochlorite bleaching (H). Bleached OCC soda pulp was obtained with a brightness of 68 % ISO and a reversion of 65,5 % ISO. Therefore, this type of treatment is not recommended from a technical and environmental point of view.

Therefore, the research focused on adapting as hypothesis an elemental chlorine-free bleaching system, more appropriate to the chemical pulp soda OCC to achieve a brightness of + 70% ISO, and the least possible damage in the mechanical resistance properties.

OCC soda pulp with brightness of 31,7 % ISO and kappa number 35,5 was processed according to the PE_PP sequence, i.e. peroxide delignification, alkaline-oxidative extraction and peroxide bleaching, with ethylenediaminetetraacetic acid (EDTA) as chelating agent (Q stage), for the removal of transition metals, before the start of the bleaching sequence and acid washing (pH 5 to pH 6,5 with H_2SO_4) (A stage) between stages to improve the process and to obtain a final brightness of at least 70 % ISO according to Tripathi et al. (2020) and Zeinaly et al. (2017). Thermally closed plastic bags were used for reaction immersed in a stainless steel thermostatic bath with constant temperature control. At the end of bleaching, the pulp was handled and evaluated similarly to unbleached pulp. (Table 11 and Figures 4 and 5).

Mechanical properties of bleached OCC pulp

Bleached OCC soda pulp was refined in a centrifugal mill (Jokro Mühle) at 150 rpm, using 16 g of oven-dried pulp per pot and 265 ml of water. The refining level was determined using the Schopper-Riegler scale (°S.R.) (Table 12).

For the bleached OCC soda pulp, the TCF bleaching sequence resulted in a brightness of 72.35% with a yield of 89.55%. The global yield for bleached OCC soda pulp was 64.65%. However, it was not possible in this research to achieve brightness greater than 80% ISO using only peroxide. The general conclusion of the numerous investigations is that it is difficult to achieve ISO brightness over 80% with acceptable mechanical resistance and physical appearance without apply several steps as oxygen, peroxide, enzymes and chemicals as Peracetic Acid (PAA) or with the traditional Elemental Chlorine-Free (ECF) using chlorine dioxide mainly because the fiber from cardboard OCC is low quality (Jasmani et al. 2021, Aguilar-Rivera 2012). Nevertheless, the delignification and TCF bleaching of OCC soda pulp could be a financially and environmentally competitive option with current technology in existing pulp and paper industry facilities to have a sustainable stream of long fiber bleached pulp from recovered OCC (Figure 6)

Conclusions

It was found how to make profit old corrugated cardboard (OCC) with certain treatments such as extended delignification to produce bleachable pulp with improved strength properties to achieve a zero-waste goal and preserve biological resources such as wood from forests. Results showed that alkaline digesting pretreatment of OCC pulp at low alkaline charges (13 % based on dry pulp, using a pulp mill's existing facilities without significantly modifying current processes, such as those used for cellulose from bagasse or wood are enough for enhancing the mechanical strengths of OCC recycled pulp and later the TCF bleaching sequence can lead to the brightness of 72% ISO. The alkaline delignification treatment applied to the recovered OCC pulp achieved acceptable properties and compensated for the inherent disadvantages of recycled fibers by average increments of 10.2% for tensile strength, 14.3% tear, 23.4% burst and 68.1% for folding endurance, 11.2% for drainability and 90.5% for porosity in relation to OCC recycled during a refining curve from 13 to 62 ºSR.

The TCF soda pulp has mechanical strengths and optical and drainage properties significantly higher than TCF pulps from non-wood and some hardwood but with competitive advantages as reduction in refining energy, developing paper characteristics, and enhancing productivity financially and environmentally sustainable because it does not require specific industrial facilities. Besides, TCF soda OCC pulp has potential use in various paper, packaging, cardboard and specialty biochemical products such as alpha cellulose for derivatives or biorefineries.

Otherwise, equivalent technological strategies to improve the sustainability of OCC pulp such as extended delignification with oxygen can be evaluated, or processes such as soda-AQ, alkaline-sulfite / anthraquinone (AS / AQ), alkaline sulphite-AQ methanol (ASAM) to assist lignin removal with the use of O, Z, P bleaching sequences, combining one, two or more stages, or using peroxide reinforced with oxygen (PO stage), biobleaching or a combination of them.

Declarations

Due to technical limitations Declarations Section is not available for this version.

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Tables

Table 1. Recovered fiber pulp by country in 2019 (Food and Agriculture Statistics FAOSTAT 2020)

Country		Tons
1	China	52,437,000
2	United States of America	44,533,000
3	Japan	19,609,000
4	Germany	14,751,576
5	Republic of Korea	8,162,000
6	United Kingdom of Great Britain	7,348,000
7	France	6,736,000
8	Spain	5,150,000
9	Italy	5,059,736
10	Brazil	4,868,000
11	Mexico	4,597,000
12	India	3,700,000
13	Russian Federation	3,450,000
14	Indonesia	3,233,309
15	Thailand	2,909,000

Table 2. Properties of repulped OCC

Repulping yield (%)	86,1	Repulping rejects (%)	3,25
Total dissolved solids (%)	2,25	Organic dissolved solids (%)	1,1
Inorganic dissolved solids (%)	1,1	Ash (%)	2,6
Kappa No.	64	Klason lignin (%)	9,6
Refining degree (°S.R.)	14	Canadian Standard Freeness (° C.S.F.)	722
Viscosity (cP)	12	Brightness (% ISO)	23,6
Breaking length (m)	2265	Burst Index (kPam^2/g)	1,92
Tear Index (mNm^2/g)	26,68	Folding endurance (Double Folds)	27
Drainage time (s)	4,28	Porosity (s/100 mL)	Porous

Table 3. Determination of fiber length by classification (Bauer-McNett fiber classifier) of repulped OCC

Mesh (%)	Repulped OCC	Unbleched softwood pulp	Unbleched bagasse pulp
30	47,2	81,1	9,7
50	20,75	6,6	30,75
100	13	5,4	28,35
200	4,2	0.9	13,8
<200	14,85	6,0	17,45

Table 4. Refining of repulped OCC

Refining time (minutes)	Refining degree (°S.R.)	Canadian Standard Freeness (° C.S.F.)
0	14	722
3	18	633
6	22	556
12	25	504
18	32	401
24	40	306
36	48	229
42	55	172
48	62	122

Table 5. Physical repulped OCC properties

Refining degree (°S.R.)	Canadian Standard Freeness (° C.S.F.)	Breaking length (m)	Tear Index (mNm^2/g)	Burst Index (kPam^2/g)	Folding endurance (Double Folds)	Drainage Time (S)	Gurley Porosity (S/100 mL)
14	722	2294	26,67	1,92	27	4,28	∞
17	653	4845	24,12	2,47	156	4,42	∞
23	538	5802	17,34	3,95	501	4,79	3.53
25	504	5912	16,93	4,17	511	4,89	4,2
32	401	6301	15,50	4,93	550	5,24	6,56
37	340	6658	13,40	5,17	587	5,48	10,03
42	255	6799	12,54	5,00	562	5,84	15,64
48	229	6969	12,42	4,8	530	6,29	22,37
55	172	7279	12,09	5,92	580	7,12	33,37
62	122	7589	11,77	5,55	631	7,94	44,37

Table 6. Delignification stage (soda pulping) cooking conditions of repulped OCC

Active alkali as Na_2O (%)	Residual Active alkali as Na_2O (g/L)	Active alkali yield (%)	Final pH	Pulping yield (%)	Screening Coarse Rejects (%)	Kappa number	Residual Lignin (%)	Delignification ratio (%)	Viscosity (cP)
13	1,7	94,05	12,8	72,2	0,5	35,5	5,33	44,53	12,23

Table 7. Refining of OCC soda pulp

Refining time (minutes)	Refining degree (°S.R.)	Canadian Standard Freeness (° C.S.F.)
0	13	740
3	17	653
6	21	575
12	23	538
18	26	485
24	33	375
36	37	340
42	46	255
48	54	180
55	62	122

Table 8. Physical OCC soda pulp properties

Refining degree (°S.R.)	Canadian Standard Freeness (° C.S.F.)	Breaking length (m)	Tear Index (mNm^2/g)	Burst Index (kPam^2/g)	Folding endurance (Double Folds)	Drainage Time (S)	Gurley Porosity (S/100 mL)
13	697	2174	24,09	1,57	18	4,27	∞
17	653	5487	21,86	4,15	524	4,49	∞
23	538	6045	26,47	5,38	707	4,86	2,56
25	504	6558	20,92	5,72	975	5,18	8,25
32	401	6979	16,98	6,01	1013	5,47	9,78
37	340	7200	16,34	6,10	951	6,11	25,5
42	255	7577	15,39	6,18	889	6,78	34
48	229	8029	14,24	6,29	816	7,58	43,3
55	172	8482	13,10	6,40	837	8,38	53
62	122	8843	12,75	6,00	910	10,60	70

Table 9. Percentage difference (%) in physical properties of OCC & OCC soda pulp

Refining degree (°S.R.)	Canadian Standard Freeness (° C.S.F.)	Breaking length (m)	Tear Index (mNm^2/g)	Burst Index (kPam^2/g)	Folding endurance (Double Folds)	Drainage Time (S)	Gurley Porosity (S/100 mL)
13	697	-5,23	-9,67	-18,23	-33,33	-0,23	-
17	653	13,25	-9,37	68,02	235,90	1,58	-
23	538	4,19	52,65	36,20	41,12	1,46	96,43
25	504	10,93	23,57	37,17	90,80	5,93	49,09
32	401	10,76	9,55	21,91	84,18	4,39	154,24
37	340	8,14	21,94	17,99	62,01	11,50	117,39
42	255	11,44	22,73	23,60	58,19	16,10	93,56
48	229	15,21	14,65	31,04	53,96	20,51	58,83
55	172	16,53	8,35	8,11	44,31	17,70	57,76
62	122	16,52	8,33	8,11	44,22	33,50	96,43

Table 10. Physical properties of mixture of 80 % unbleached sugarcane bagasse pulp and 20 % OCC soda pulp

Pulp/Test	Refining level (°S.R.)	Breaking length (m)	Tear Index (mNm^2/g)	Burst Index (kPam^2/g)	Folding endurance (Double Folds)	Drainage Time (S)	Gurley Porosity (S/100 mL)
Unbleached Bagasse pulp from industry	43	7749	8	6	475	9,64	217
Unbleached Bagasse/OCC soda pulp (80/20)		9266	7,23	9,3	647	9	117,5
Difference (%)		19,58	-9,62	55,00	36,21	-6,64	-45,85

Table 11. Bleaching TCF conditions for OCC soda pulp

Alkaline peroxide stage

H_2O_2 (%)	NaOH (%)	$MgSO_4$ (%)	Na_2SiO_3 (%)	Pulp conc. (%)	Temperature (°C)	Reaction time (min)
3,0	3,0	1,0	1,0	10	90	30
Kappa No. (initial)	Kappa No. (Final)	Delignification ratio (%)	Residual H_2O_2 (%)	Consumption of H_2O_2 (%)	Residual NaOH (%)	Consumption of NaOH (%)
35,5	12,7	63,7	-	100	-	100

Oxidative alkaline extraction stage

H_2O_2 (%)	NaOH (%)	$MgSO_4$ (%)	Na_2SiO_3 (%)	Pulp conc. (%)	Temperature (°C)	Reaction time (min)
1,0	4,0	0,5	0,5	10	90	60
Kappa No. (initial)	Kappa No. (Final)	Delignification ratio (%)	Residual H_2O_2 (%)	Consumption of H_2O_2 (%)	Residual NaOH (%)	Consumption of NaOH (%)
12,7	6,2	51,2	-	100	-	100

Bleaching stage with alkaline peroxide

H_2O_2 (%)	NaOH (%)	$MgSO_4$ (%)	Na_2SiO_3 (%)	Pulp conc. (%)	Temperature (°C)	Reaction time (min)
1,0	3,0	0,5	0,5	10	90	90
Kappa No. (initial)	pH (initial)	pH (final)	Residual H_2O_2 (%)	Consumption of H_2O_2 (%)	Residual NaOH (%)	Consumption of NaOH (%)
6,2	12	9,8	0,0967	96,7	-	100

Table 12. Mechanical, drainability and optical properties of TCF bleached OCC pulp

Pulp properties/Trial	T1	T2	T3	T4
Refining time (min)	0	5	8	12
Drainage time (s)	4,04	4,34	4,60	5,46
Refining level (°S.R.)	17	25	30	46
Freeness (° C.S.F.)	653	504	428	247
Basis weight or grammage (g m^{-2})	63,2	61,2	58,2	62,2
Bulk density (g cm^{-3})	0,394	0,548	0,584	0,619
Bulk or Specific Volume (cm^3 g^{-1})	2,541	1,825	1,713	1,614
Breaking length (m)	2081	5076	5724	5345
Fiber deformation(mm)	4,2	4,6	4,6	4,5
Burst (kg cm^{-2})	1,05	2,36	2,49	2,72
Burst factor (gf. m^{-2}/g)	16,55	38,55	42,71	43,67
Burst Index ($kPam^2$/g)	1,62	3,78	4,19	4,28
Tear (gF)	120	73,33	60	56
Tear factor (100.gf.m^2/g)	189,98	119,87	103,11	90,08
Tear Index (mNm^2/g)	18,63	11,76	10,11	8,83
Folding endurance (Double Folds)	11	136	121	131
Brightness FR 457 nm (%)	72,35			
Brightness Reversion (%)	71,30			

Figures

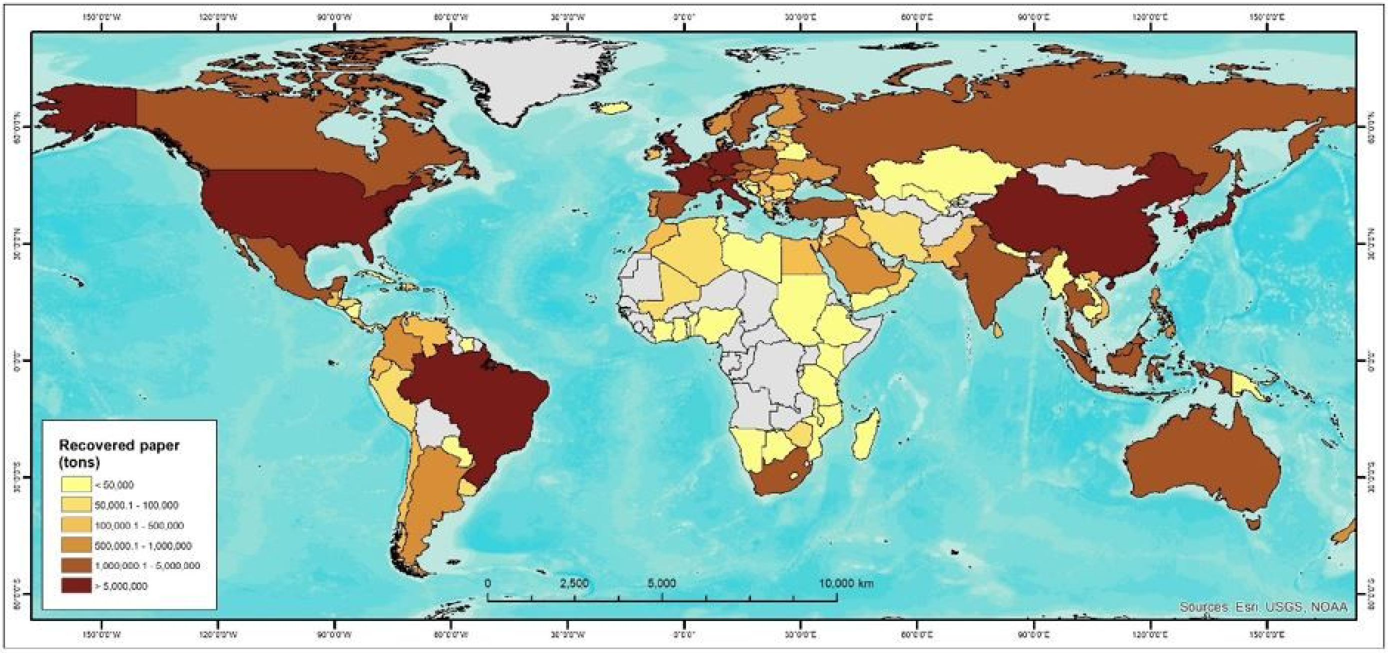

Figure 1

Worldwide paper recovery (Data from Food and Agriculture Statistics FAOSTAT 2020) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

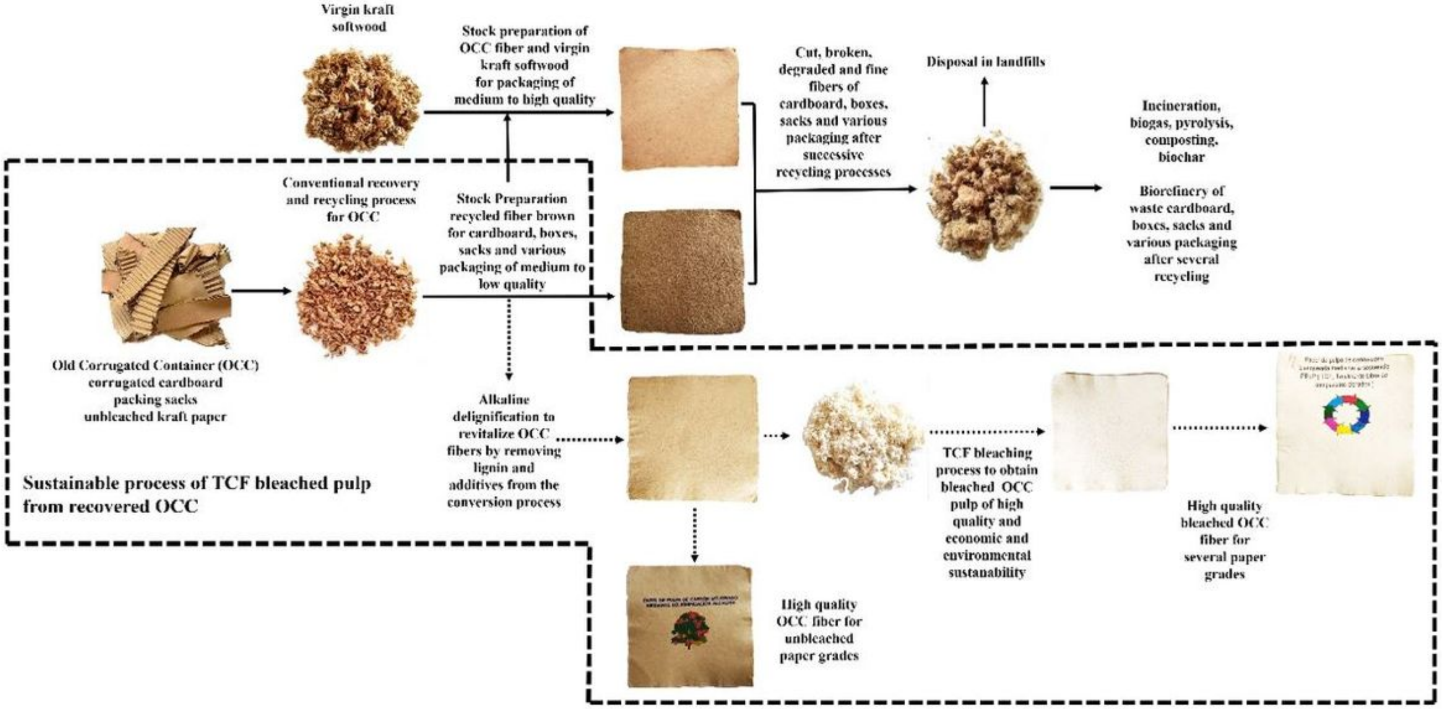

Figure 2

Potential productive structure for recovered OCC pulp, delignification and bleaching.

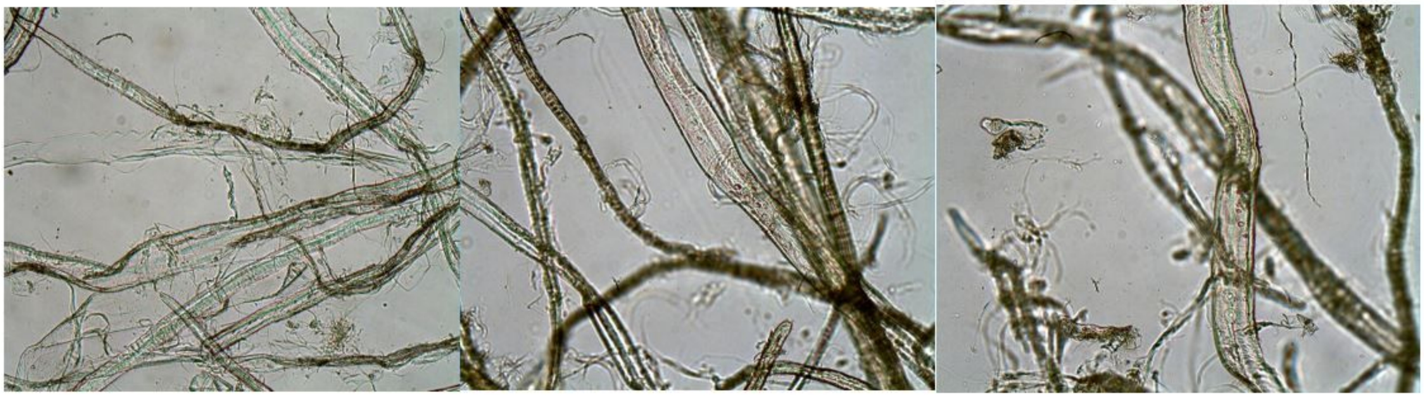

Figure 3

Microscope images of recovered OCC pulps (100X) of kappa number 64 showing broken and highly curled fibers and fines.

Figure 4

Handsheets for physical tests of repulped OCC pulp, OCC soda pulp and TCF bleached OCC soda pulp

Figure 5

Microscope images of bleached OCC soda pulps (400X) showing highly purified fibers similar to kraft softwood.

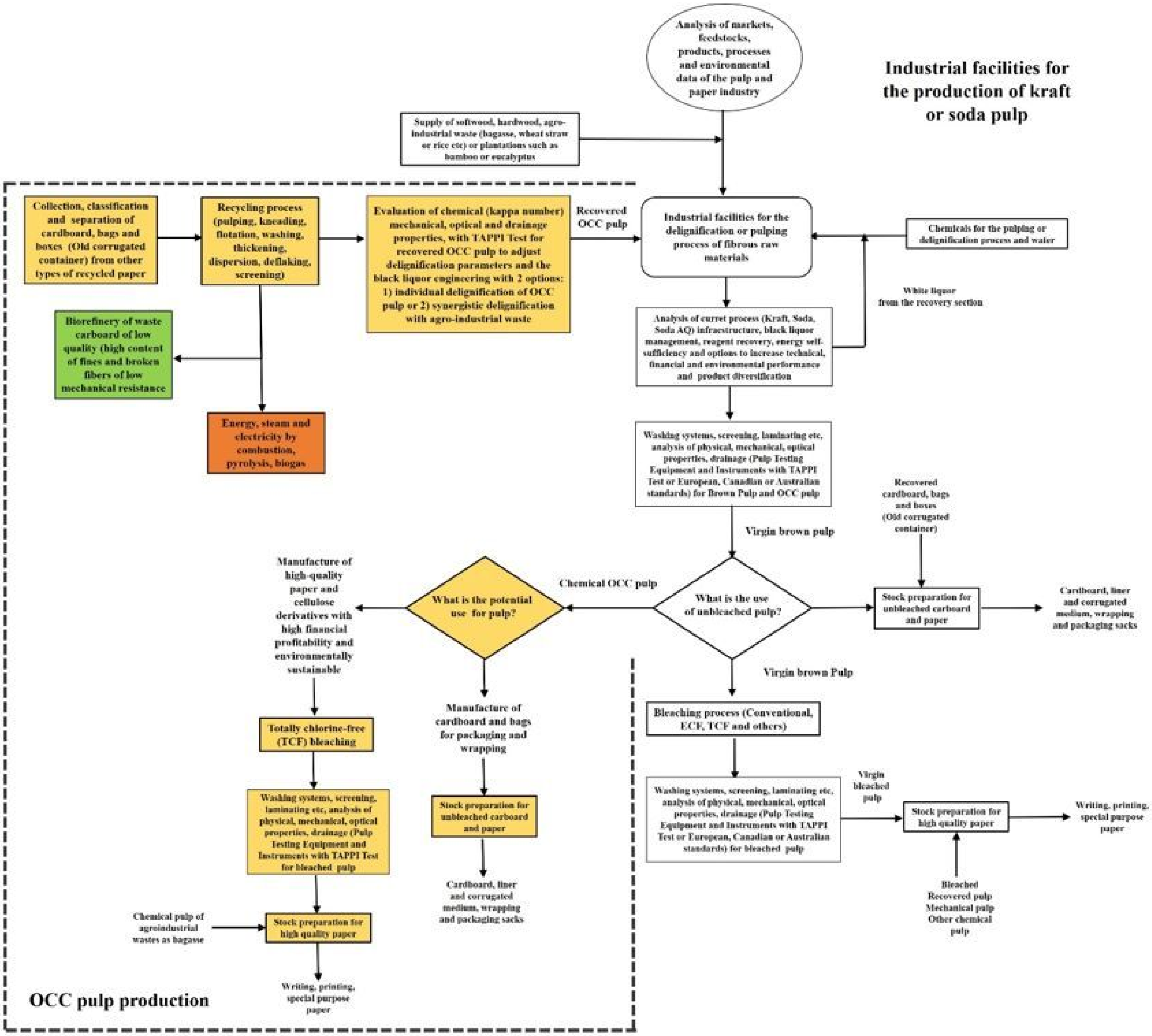

Figure 6

Framework to be used for integration of OCC pulp production into a kraft or soda pulp plant

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