Recycling Cartons into Moulded Pulp Products

Report presented to the
Carton Council of Canada

Prepared by
Innofibre – Innovation Centre for Cellulosic Products

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1. Introduction

Cartons are a type of food and beverage packaging available in two forms: shelf-stable cartons (also known as aseptic cartons) and refrigerated cartons (gable top cartons). Cartons are primarily composed of paperboard to which fine layers of polyethylene are added. Shelf-stable cartons also contain a thin layer of aluminum.

Aseptic cartons are composed of on average 74% fibre, 22% polyethylene and 4% aluminum. Shelf-stable cartons are used to hold juice, milk, plant- or grain-based milk, soup, broth and wine. Refrigerated cartons are made up of approximately 80% fibre and 20% polyethylene. Refrigerated cartons are used to hold milk, juice, cream, egg substitutes, plant- and grain-based milks.

The fibrous material used in cartons in North America is kraft pulp for gable top cartons and, for aseptic cartons, a mixture of mostly kraft pulp and some CTMP (chemi-thermomechanical process) pulp[1].

The Carton Council of Canada (CCC) is a coalition of carton manufacturers[2] working together to deliver long-term solutions to help increase carton collection and recycling in Canada. This work includes developing new markets for end-of-life cartons.

The CCC mandated Innofibre, the innovation centre in cellulosic products based in Trois-Rivières, Québec, to conduct an applied-research project on recycling cartons into moulded pulp products, in the following context.

On the one hand, manufacturers of recycled fibre-based packaging and containers are facing a lack of raw materials due to the decline in newspaper and office paper volumes and the increase in demand for corrugated cardboard boxes[3]. On the other, cartons contain some of the highest-quality fibres in the recycling supply chain (long, bleached fibres).

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[1] References: Yilgor et al. (2014). “Composites from Tetra Pak®,” BioResources 9(3), 4784–4807. Ahmed H. Hassanin et al. (2016). “Novel Bio-based Composites Panels from TetraPak Waste”. In Key Engineering Materials (Vol. 689, pp. 138–142). Jan Zawadiak et al. (2017). “Tetra Pak Recycling – Current Trends and New Developments,” American Journal of Chemical Engineering; 5(3): 37–42.

[2] The members are Tetra Pak, Elopak, Pactiv Evergreen, and SIG Combibloc.

[3] Although corrugated boxes made of recycled content are mostly made of old corrugated boxes, a small quatity of mixed papers, which are made up in part of old newspapers and office paper, can also be used as feedstock.

Currently, four paper mills in North America transform cartons into new cellulosic products such as tissue and writing paper[4,5]. Although cartons are transformed into moulded pulp products elsewhere in the world[6], this is not currently the case in Canada.

As part of the research project, the following activities were performed at Innofibre's pilot plant located on the campus of Université du Québec à Trois-Rivières:

- Repulping of post-consumer cartons, analysis and characterisation of the recovered pulp.
- Production of two types of moulded products from the carton fibre pulp: Type II products, in the form of egg cartons, and Type III cartons, in the form of thermoformed sausage trays, and assessment of the physical and mechanical properties of each type of product.
- Repulp moulded pulp parts to analyze them according to the Fibre Box Association's voluntary standard for repulping and recycling.

Furthermore, samples of the non-fibrous material (polyethylene-aluminum) obtained when separating fibres were sent to the Coalia research centre in Thetford Mines, Québec, where they were densified and extruded.

This report describes these activities. It is intended primarily for pulp and paper industry actors looking for a new source of quality fibres for their products made from recycled fibres.

Samples of moulded pulp and polyethylene-aluminum parts are available upon request[7].

4 They are Sustana (Lévis plant in Québec and De Pere plant in Wisconsin), Essity in Alabama, as well as the Kimberly-Clark plant in Ecatepec, Mexico.
5 Cartons are also recycled into building materials (mainly roof cover boards) by Continuus Materials in Des Moines, Iowa, as well as by Kelly Green Products in Connecticut.
6 See, for example, Proplanet in Colombia.
7 Please contact CCC's Managing Director, Isabelle Faucher, at ifaucher@recyclecartons.ca.

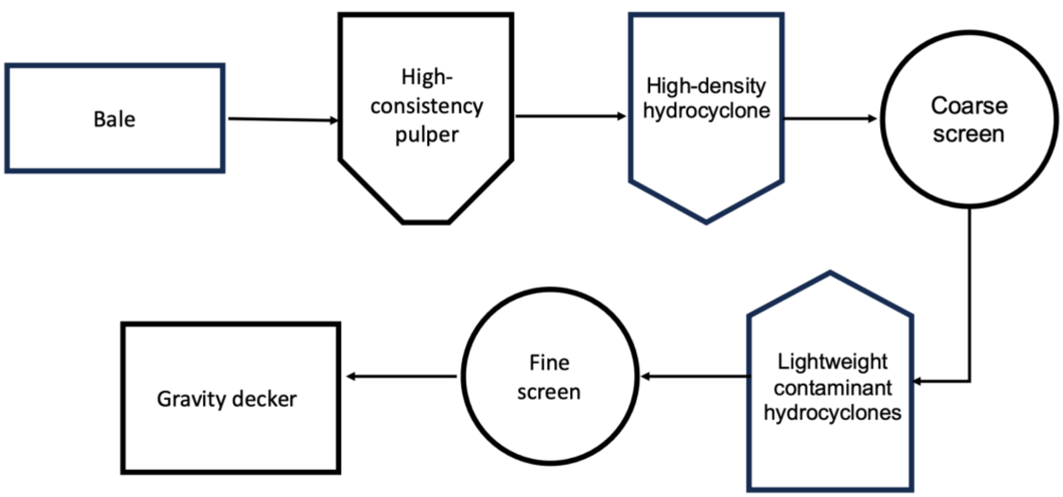
2. Methodology

A bale of post-consumer cartons weighing approximately 500 kg (wet mass)[8] was sent to the Innofibre pilot plant by the Récupéraction Centre-du-Québec material recovery facility (MRF) in Drummondville, Québec (Figure 2), in the weeks before it was repulped on November 28, 2023.

2.1 Pulp production

The steps in producing pulp from recycled cartons are shown in Figure 1.

Figure 1. Diagram of the pulp production process in the applied research project



First, the bale was placed on the loading conveyor and manually split (Figure 2).

[8] The bale's dry mass was later established at 432 kg.

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Figure 2. Carton bale sent to Innofibre by Récupéraction Centre-du-Québec (left) and preparation of the bale for transfer to the high-consistency pulper (right)

Meanwhile, the high-consistency pulper was filled with water. The cartons were then dumped into the pulper where they were mixed for 30 minutes. The parameters are listed in Table 1.

Table 1. High-consistency pulper parameters

Machinery	Pulper
Manufacturer	Hymac
Model	4.2 HC 43
Rotor type	High-consistency
Rotor speed	232 rpm
Extraction plate hole diameter	16 mm
Consistency	14–15%
Pulping time	30 min
Temperature	19–28°C
Carton bale mass	500 kg wet 432 kg dry

After pulping, the pulp was diluted with room-temperature water and transferred into the discharge tank. Two rounds of sampling were performed during the process, between 12:00:00 and 12:24:19.

Non-pulpable materials were collected on the pulper's extraction plate. These materials were essentially made up of polyethylene films, aluminum films and plastic caps and spouts. They were rinsed with water twice in the pulper to simulate a reject cleaning system. These pulping rejects were evacuated by the 200 mm output and collected in a drainage bin. In total, nearly 330 kg of wet non-pulpable materials were collected. This represents approximately 101.4 kg of dry non-pulpable materials. The quantity of fibres remaining among the rejects was estimated in the laboratory at approximately 13.9% (14.1 kg dry). Presumably, a good reject-washing system would make it possible to partially recover these fibres in an industrial process[9].

The consistency of the pulp in the discharge tank was 3.6% (331 kg dry/9,201 L). The average temperature of this pulp was 26°C during the duration of the test. The pulp was processed in a continuous process from the discharge tank.

The following machinery sequence was used:

1) High-density hydrocyclone
2) Coarse screen
3) Lightweight contaminants hydrocyclone
4) Fine screen (including 2 slotted baskets)
5) Gravity decker

The pulp was cleaned with a high-density hydrocyclone, whose features and operating conditions are listed in Table 2.

[9] See p. 19 for additional information on the fibre yield.

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Table 2. High-density cleaning

Machinery	HD Hydrocyclone
Manufacturer	Hymac
Model	HY-300HD 2.5
Diameter	300 mm
Temperature	25–30°C
Consistency	2.85%
Feed flow rate	1099 L/min
Flow accepted toward the coarse screen	183 L/min
Acceptance pressure	268 kPag

Before the cleaning process, the high-density hydrocyclone discharge tank was filled with water. This was fed with elutriation water for part of the operation with the goal of diluting the discharge tank and helping to clean the pulp in the HD hydrocyclone system.

This was stopped after a while, as it seemed unnecessary and to avoid unnecessarily diluting the pulp. When it exited the HD hydrocyclone, the slurry was in part recirculated to the discharge chamber and in part directed to the coarse screen feed tank where the consistency was continuously reduced with dilution water.

The slurry was then screened to remove coarse contaminants according to the operating conditions listed in Table 3. Accepted pulp from the coarse screen was directed into the lightweight contaminant hycrocyclone feed tank, where the slurry was continuously diluted. Rejects were accumulated in the tank adjacent to the coarse screen feed tank. When the feed tank was empty, the rejects were used to feed the screen. Thus, a second coarse screening stage was simulated to reduce fibre loss.

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Table 3. Coarse screen

Machinery	Screen
Manufacturer	Beloit-Jones
Model	S-18
Rotor type	Closed (Rotor T)
Basket	0.33 mm
Temperature	25–30°C
Feeding consistency	1.35%
Feeding flow	272 L/min
Tangential rotor speed	21 m/s

The consistency was measured throughout the process and was generally less than expected. It was not necessary to use dilution water in the coarse screen feed tank.

The pulp was then cleaned of lightweight contaminants using two lightweight contaminant hydrocyclones. Table 4 lists the operating conditions of this step. Accepted pulp from the lightweight contaminant scrubbers was directed to the fine screen feed tank. Rejects were sent to the fibre-reject chamber.

Table 4. Lightweight contaminants hydrocyclone

Machinery	Hydrocyclone
Manufacturer	Kadant Black Clawson
Model	X-clone
Diameter	80 mm
Temperature	25–30°C
Feed consistency	0.78%
Feed flow rate	354 L/min
Feed pressure	180 kPa
Acceptance pressure	70 kPa
Reject pressure	0 kPag

The pulp was then screened with a two-stage cascade fine screen system according to the test conditions listed in Table 5. Accepted pulp from the system was directed to the feed tank of the gravity decker. Rejects from the second stage were directed to an inclined screen.

Table 5. Fine screen

Stage	1	2
Machinery	Screen	Screen
Manufacturer	Kadant Black Clawson	Kadant Black Clawson
Model	Selectifier 8P	Mini-screen MS50
Rotor type	Open with 2 foils	Open with 2 foils
Slotted baskets	0.15 mm	0.15 mm
Temperature	26–30°C	26–30°C
Flow rate	562.5 L/min	288 L/min
Feed consistency	0.37%	0.25%
Slot speed	1 m/s	0.9 m/s
Tangential rotor speed	20.6 m/s	25.3 m/s
Volumetric discharge rate	20.1%	26.7%

Finally, the pulp was washed with a gravity decker according to the operating conditions in Table 6. The washed pulp was accumulated in a tank. A total of 1,851 L of pulp at a 3.96% consistency was obtained (73 kg dry). The decker filtrate was purged in its entirety. It was not reused to make dilutions upstream of the process, as it was not possible to work in a continuous system to reduce water consumption.

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Table 6. Gravity decker

Machinery	Gravity decker
Manufacturer	Hymac
Model	48 X 48
Wires	Lower: 10 mesh/in Upper: 40 mesh/in
Temperature	26–30°C
Feed flow rate	451.7 L/min
Feed consistency	0.23%
Vat level	80%
Drum speed	65%

Grey foam was observed on the surface of some vats and on the surface of the gravity decker. This could be attributed to ink and aluminum particles.

2.2 Pulp analysis

After these five cleaning steps, the pulp was recovered and analyzed with a Valmet FS5. Pulp drainage (CSF, pulp drainage time) was analyzed in accordance with TAPPI T-221. The results are presented in Table 11 (Section 3).

2.3 Moulded pulp products

Moulded pulp products were produced from the recycled cartons from November 29 to December 1, 2023.

Two types of moulded products made from carton fibre pulp were produced: Type II products, in the form of egg trays, and Type III products in the form of thermoformed sausage trays. Type II is generally used in protection packaging where food contact certification is not required. For Type III, the mould available at Innofibre corresponds to industry needs[10]. The moulded products produced are shown in Figure 3.

[10] The analyses available at Innofibre, however, do not certify pulp for food contact.

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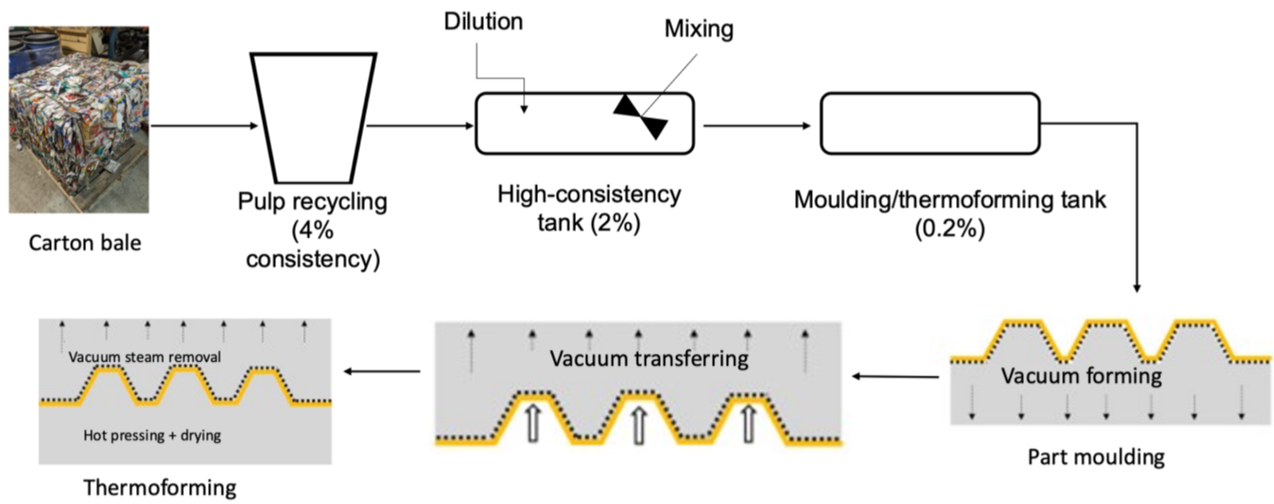
Figure 3. Thermoformed sausage tray (Type III moulded product, left) and egg tray (Type II moulded product, right)

Type II moulded products (transfer moulding) have 3- to 5-mm walls. They are manufactured using a forming mould and a transfer mould. The result is a product with relatively smooth surfaces on both sides. The product formed is dried in a heated oven. Currently, recycled newspaper is the raw material commonly used for these products. Typical examples include egg trays and electronic equipment packaging**.**

For Type III moulded products (thin thermoformed wall), the initial partially formed product is placed in a warm mould, where it is pressed, densified and dried. No oven cooking is necessary. This process makes it possible to produce high-quality products with thinner walls (1 to 2 mm), good dimensional precision and smooth, rigid surfaces. The result resembles products made from thermoformed plastic. Thermoforming is the most recent manufacturing approach in the pulp moulding field. The steps are shown in Figure 4.

Figure 4. Carton recycled pulp moulding and thermoforming process (adapted from Katherine E. Semple et al. [2022])



The moulded products were then conditioned in a humidity- and temperature-controlled room according to the standard TAPPI T-220 method. Sample dryness was measured accordingly; three homogenous samples were weighed and dried overnight in a 105°C oven. Dry mass was weighed directly after drying to prevent moisture uptake.

Moisture content and dryness were reported as follows:

$$\text{Humidity (\%)} = [(W_1 - W_2)/W_1] \times 100$$

$$\text{Dryness (\%)} = [100 - \text{Humidity}]$$

2.4 Analysis of moulded pulp products

The physical and mechanical properties of the products were analyzed according to the standard methods indicated in Table 7.

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Table 7. Methods for analyzing the physical and mechanical properties of moulded products

Analysis	Sausage tray	Egg tray
Sample dryness after moulding (%)	TAPPI T-402	TAPPI T-402
Sample avg. weight (g)	TAPPI T-256	TAPPI T-256
Thickness (µm)	TAPPI T-411	N/A
Grammage air dried (g.m^2)	TAPPI T-256	
Dryness (%)	TAPPI T-402	
Brightness (measured at wavelength λ=457nm)	TAPPI T-452	
Brightness CIE	TAPPI T-524	
LAB colour L*		
LAB colour a*		
LAB colour b*		
ERIC (ppm)	TAPPI T-567	
Air permeability (mL.min^{-1})	TAPPI T-460	
Burst index (kPa.m^2/g)	TAPPI T-810	
Tensile modulus	TAPPI T-494	
Elongation at break		
Tensile Energy Absorption (TEA)		
Tensile index		
Water Cobb $_{60}$ (g.m^2)	TAPPI T-441	
Oil Cobb $_{60}$ (g.m^2)		
Compression 10%	N/A	Internal method
Shrinkage		Internal method

In addition, the moulded pulp samples were subjected to heavy-metal analysis using inductively coupled plasma mass spectrometry.

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2.5 Repulpability assessment

The moulded pulp products were cut into 31.8-x-102 mm strips. Each sample weighed 25 g. Samples were then dispersed in 1,500 mL of hot water at 52±5°C. Afterwards, samples were mixed and disintegrated in a Waring blender (15,000 rpm/min for four minutes) and a British disintegrator (3,000 rpm/min for five minutes). Pulp was then screened with a Somerville screen with a 0.010" plate.

Pulp yield was calculated as follows:

$$\boldsymbol{\eta}(\%) = \frac{\boldsymbol{m}_{\mathbf{accepted}} \times \mathbf{100}}{\boldsymbol{m}_{\mathbf{accepted}} + \boldsymbol{m}_{\mathbf{rejected}}}$$

Accepted pulp was mixed with 80% old corrugated cardboard (OCC)[11] pulp to produce 150 g.m $^{-2}$ handsheets. The handsheets produced were then analyzed according to Table 8 below.

Table 8. Repulpability standard analysis

Analysis	TAPPI method
Grammage	T-220
Compression STFI	T-826
Burst strength	T-403
Coefficient of static friction (slide angle)	T-815
Water absorption	T-831
Macro stickies content in pulp	T-277

[11] Old corrugated cardboard (OCC) corresponds to the control pulp in the voluntary recyclability standard of the Fibre Box Association.

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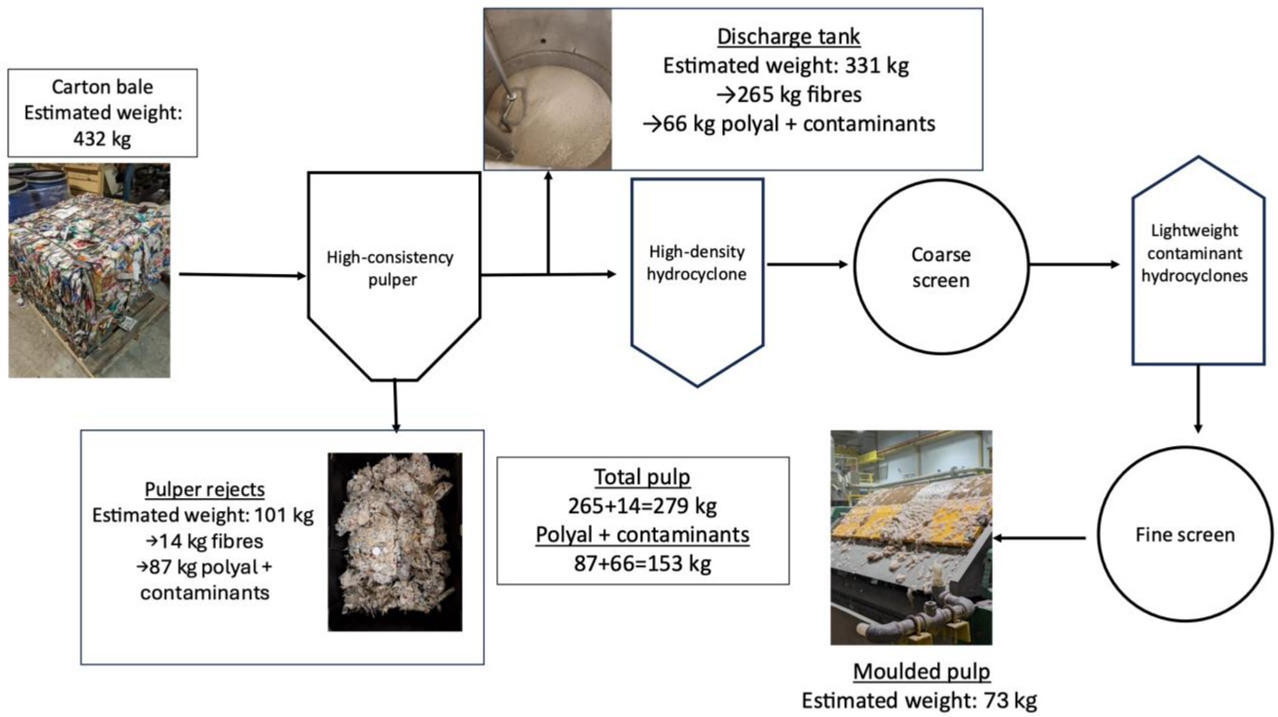
3. Results

3.1 Yield

Carton fibre yield was calculated using the steps illustrated in the diagram in Figure 5.

Figure 5. Steps in calculating the carton fibre yield (all values are in dry mass)



The fibre yield was calculated using the data in Table 9.

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Table 9. Fibre yield calculation (all values in dry mass)

Amount of fibre in the pulper rejects	14.1 kg
Amount of fibre in the discharge tank	265 kg (~80% of total material in the discharge tank)
Total fibre	279 kg (14 kg + 265 kg)
Amount of fibre obtained after cleaning	73 kg
Fibre yield	~26% (73 kg divided by 279 kg)

Notes about the fibre yield

- Yield is calculated based on the consistency (solid-mass content after drying in the 105°C oven, to reduce water). It is therefore a calculated yield.
- The very low fibre yield (26%) can be attributed to the inability in this project to extract all the fibres from the initial hydropulping of the cartons and to recirculate in the system the rejects from the subsequent pulp cleaning process to which fibre was attached, in order to recover this fibre.
- During the pulp cleaning, fibre was lost primarily at the fine and coarse screening stages.
- The yield obtained as part of the project is not representative of what could be obtained with an industrial process.

The total percentage of non-fibrous materials was calculated using data from Table 10.

Table 10. Calculation of the total percentage of non-pulp materials (all values in dry mass)

Carton bale mass	432 kg
Non-fibrous material mass (polyal[12], plastic caps and spouts, and contaminants)	153 kg Total quantity of pulp (279 kg) – bale mass
Non-fibrous material percentage (polyal, plastic caps and spouts at contaminants)	35%

[12] The term “polyal” is used to refer to the polyethylene and aluminum components of cartons.

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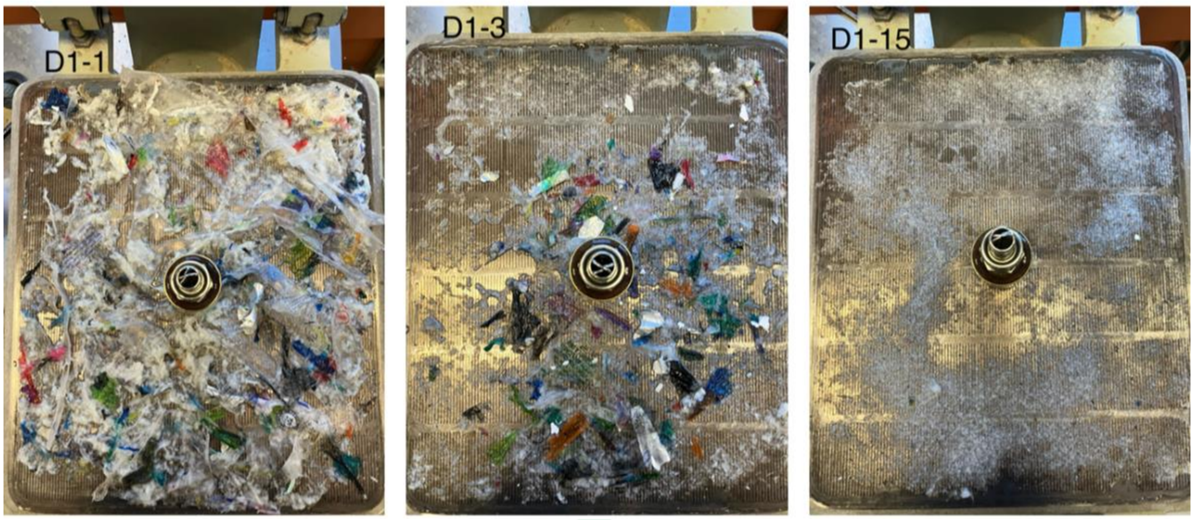
Contaminants included polystyrene beads, which were observed in the coarse screen and lightweight contaminant hydrocyclone rejects. The polystyrene was probably included in the carton bale in error at the sorting centre. Furthermore, a large amount of plastic (some not of carton origin) was rejected by the coarse screen (Figure 6).

Figure 6. Somerville debris: D1-1: high-consistency pulper, D1-3: high-density hydrocyclone, D1-15: fine-screen rejects



3.2 Pulp analysis

The recovered pulp's freeness was measured at 595 mL ± 10 mL. Generally, virgin bleached softwood kraft pulp (BSKP) freeness is approximately 690-675 mL. Thus, recovered carton pulp moulded products showed mechanical and physical properties between unrefined and slightly refined BSKP (CSF ≈500 mL). Carton and BSKP pulp fibre characteristics as well as those from bleached hardwood kraft pulp (BHKP) and OCC pulp are reported in Table 11.

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Table 11. Physical properties of pulp fibres, by source

Fibre origin	Mean length (mm)	Mean width (µm)	Fines content (%)	CSF (mL)
Cartons	2.11 ± 0.02	24.1 ± 0.2	18.6	595 ± 10
BSKP	2.29 ± 0.02	28.1 ± 0.1	17.6	675 ± 25
BHKP	0.93 ± 0.04	19.7 ± 0.1	14.0	600 ± 25
OCC	1.83 ± 0.01	23.9 ± 0.1	51.1	350 ± 25

BHKP generally has shorter fibres than its BSKP counterpart. Thus, the composition of cartons' kraft pulp fibres could be a mix of BHKP and BSKP.

OCC is mainly used for recycled-pulp product manufacturing. OCC pulp usually has high fine fibre content (approximately 50%) correlated with low drainage properties (low CSF). Moreover, pulp with shorter fibres usually produces paper with lower mechanical strength.

3.3 Moulded pulp products

The pulp moulding parameters for the two product types (Type II and Type III) are listed in Table 12. The device used was the TF-45.

Table 12. TF-45 pulp moulding parameters

Parameters	Sausage tray Type III – Thermoforming	Egg tray Type II – Transfer moulding
Vacuum ("Hg)	-27	-27
CSF (mL)	595	595
Pulp consistency (%)	0.2	0.2
Forming time (s)	12.5	15
Drainage time (s)	0	0
Thermoforming pressure (t)	2	N/A
Thermoforming temperature (°C)	185	
Thermoforming time (s)	70	

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Recovered carton pulp had relatively low production time or high production throughput (formation, drainage, and thermoforming time, Table 12). This feature was attributed to the fibre length and drainage properties. Thus, carton pulp showed good potential for moulded pulp manufacturing.

3.4 Analysis of moulded pulp products

3.4.1 Physical and mechanical properties

The physical and mechanical properties of the moulded product samples are listed in Table 13.

Table 13. Analysis of physical and mechanical properties of moulded fibre products made from recycled cartons

Analysis		Sausage tray	Egg tray
Sample dryness after moulding (%)		28.5	33.3
Sample avg. weight (g)		30.81	50.31
Thickness (µm)		1044	N/A
Grammage air dried (g/m²)		706.9	
Dryness (%)		93.5	
LAB colour	CIE brightness	19-20	N/A
	R457 brightness	60	
	L*	86.11	
	A*	0.71	
	B*	9.79	
	ERIC (ppm)	67.9	
Air permeability (mL.min $^{-1}$)		313	N/A
Burst index (kPa*m²/g)		1.99	
Tensile modulus (MPa)		2122	
Elongation at break (%)		2.73	
TEA (J/m²)		316.2	

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Analysis	Sausage tray	Egg tray
Tensile index (N*m/g)	28.65	
Water Cobb $_{60}$ (g/m^2)	896.2	
Oil Cobb $_{60}$ (g/m^2)	123.8	
Compression 10% (N)	N/A	2214.9
Shrinkage (%)		3.5

Regarding the CIELAB (LAB colour) colour space, the samples showed high L* value. In addition, a B* positive value indicates yellowness. This feature could be attributed to the CTMP pulp. Paper brightness quantifies a paper's ability to equally reflect a balance of all light wavelengths across the visible spectrum. CIE (International Commission on Illumination) paper brightness was reported at 19-20 and R457 brightness (also called the whiteness index) at 60. Relatively low brightness could be attributed to the B* value. Since samples display a yellowish (B*) colour, visible light could be absorbed and thus reduce part brightness.

Effective residual ink concentration (ERIC) was also measured, using infrared reflectance. This method determines the ERIC in deinked pulp and paper made from recycled raw materials. Carton moulded products had ERIC values below 100 ppm, which indicates that the packaging is likely to be compatible with food contact.

3.4.2 Comparison of the physical and mechanical properties of moulded carton pulp products with those made from virgin pulp

To compare the physical and mechanical properties of moulded carton pulp products with those made from virgin pulp, the refined and unrefined virgin kraft moulded pulp properties are listed in Table 14 below.

Table 14. Comparison of the physical and mechanical properties of thermoformed products in virgin kraft pulp and those in recycled carton pulp

Analysis	Unrefined virgin kraft pulp	Recycled carton pulp (sausage tray)	Refined virgin kraft pulp
CSF (mL)	675	595	500
Thickness (µm)	1117	1044	1104
Grammage air dried (g/m2)	666.9	706.9	654.2

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Analysis	Unrefined virgin kraft pulp	Recycled carton pulp (sausage tray)	Refined virgin kraft pulp
Dryness (%)	89.8	93.5	89
Air permeability (mL.min -1)	485	313	260
Burst index (kPa*m2/g)	1.95	1.99	2.78
TEA (J/m2)	440.2	316.2	794.1
Tensile index (N*m/g)	28.8	28.65	44.6

Carton thermoformed products show mechanical properties similar to unrefined virgin kraft pulp products. In addition, carton pulp displayed high pulp freeness. Thus, carton pulp could be further refined to improve the mechanical properties of products[13].

Moulded carton pulp egg trays (Table 13) show higher mechanical strength than conventional egg trays, i.e., trays made from old newspaper (ONP). Generally, ONP egg trays show compression strength of approximately 1800–1900 N, compared to 2214.9 N for egg trays made from cartons. This characteristic can be attributed to the pulp composition. Cartons are primarily made from kraft pulp, which shows higher mechanical strength than ONP, CTMP or other mechanical pulp. In addition, carton egg tray shrinkage was reported at 3.5%, which is similar to the normally produced ONP egg trays. Therefore, carton pulp could be implemented into industrial pulp moulding manufacturing without nesting issues.

3.4.3 Presence of heavy metals

The samples showed low heavy metal content (Table 15). However, for food contact use, the chromium (Cr) measurement should be performed by ion chromatography to confirm that the Cr(VI) is below 1 ppm[14]. For lead (Pb) measurements, an ICP analysis should be performed to confirm that the detection limit is below the standard (0.4 ppm)[15]. Innofibre does not have the equipment necessary to perform these two tests[16]. Full results are presented in Table 15.

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[13] A high CSF indicates a pulp that drains well. Refinement reduces CSF, but also increases mechanical and physical properties.
[14] The toxic form of Cr is Cr(VI). Innofibre is able to measure only the total Cr. For food contact, the Cr(VI) value must be measured.
[15] Standard solutions for limit tests, EUROPEAN PHARMACOPOEIA 7.0.
[16] See Appendix A for more information about food contact requirements.

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Table 15. Sample heavy metal concentration

Metals	Sausage tray	Egg tray
Al (ppm)	188	216
Ba (ppm)	2	2
Ca (ppm)	1586	1624
Cd (ppm)	<1	<1
Co (ppm)	<1	<1
Cr (ppm)	4	3
Cu (ppm)	3	<3
Fe (ppm)	92	65
K (ppm)	<15	15
Mg (ppm)	74	75
Mn (ppm)	3	3
Mo (ppm)	4	3
Na (ppm)	45	49
Ni (ppm)	2	2
P (ppm)	<1	3
Pb (ppm)	<3	<3
Si (ppm)	64	54
V (ppm)	<1	<1
As (ppm)	0,05	0,017
Hg (ppm)	0,06	0,07
Zn (ppm)	52	52

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3.5 Repulpability assessment

Moulded pulp products' repulpability properties are reported in Table 16 below.

Table 16. Moulded pulp products' repulpability properties

Properties		Samples		
		OCC control	80% OCC / 20% egg trays	80% OCC / 20% sausage trays
Repulpability yield (0.010") (%)		N/A	99.9	99.9
Grammage (g/m^2)		150.9	149.4	154.9
Dryness (%)		92.4	92.6	92.9
Ashes (%)		3.2	2.8	2.8
Bulk (cm^3/g)		2	1.9	1.9
Thickness (um)		295.2	296.9	301.7
Burst index (kPa*m2/g)		3.6	3.8	3.8
STFI resistance to compression (Nm/g)		325.7	351.5	342.3
Coefficient of static friction (side angle)		0.4	0.5	0.5
Carton water absorption (sec.)	Wire	65	50	51
	Felt	45	40	31
Stickies ≥ 0,4 mm^2	Wire	0	3	2
	Felt	0	2	3

The two moulded pulp products showed similar repulpability properties, as expected, because they were made from the same pulp. Neither product showed any reject, with a repulpability yield of approximately 100%. Moulded carton pulp products showed a reduction in ash content. This could be attributed to the carton pulp composition, which has a lower mineral filler content than OCC pulp.

Ash accumulation on paper-making equipment can lead to defects in recycled paper, lower product sale price and increased downtime with higher cleaning costs.

Packaging materials' friction coefficient indicates how packaging will perform in many critical applications. A paper or cardboard surface (containerboard) with a high coefficient relative to itself means that containers with this surface are likely to resist slipping. A low coefficient may indicate potential package slipping issues in relation to the load. The friction coefficient is also significantly affected by contamination by very small quantities of friction-reducing materials, such as waxes and other oily materials. None of the samples showed significant friction coefficient variation.

The water absorption capacity of paper/cardboard is measured by dropping a drop of water onto the surface of a sample and determining how many seconds it takes for the drop to penetrate the sheet and wet its underside. The absorbency of the corrugated board must be somewhat controlled so that it is sufficiently receptive to the corrugating adhesive. Typically, an aqueous starch suspension coupled with adhesives is used to ensure proper adherence to the so-called corrugating process. Samples showed a reduction in water absorption time when compared to the control sample. This could be attributed to a lower sizing additive content in the carton pulp than the OCC pulp.

The stickies average per sample is illustrated in Table 14. A slight increase in stickies was observed. This characteristic could be attributed to the chemicals applied to carton paperboard and/or in carton pulp production. However, the number of stickies reported is lower than the acceptability threshold (15–20 stickies ≥ 0.4 mm²) stipulated in the repulpability protocol provided by the Fibre Box Association[17].

The two moulded pulp samples showed higher mechanical properties than the OCC control sample. This could be attributed to the pulp composition. As shown in Table 9, recovered carton pulp showed higher fibre length and lower fines content than OCC pulp. Thus, incorporating carton pulp into OCC pulp increased the strength of the recycled paper.

Thus, repulped samples presented no rejects, low stickies content and higher mechanical strength than the OCC control sample. In addition, repulped products had a slide angle, water absorption and ash content similar to the OCC control sample. Therefore, recycled carton pulp could increase recycled paper pulp quality due to its kraft and CTMP content.

[17] Fibre Box Association, (2013) Voluntary Standard For Repulping and Recycling Corrugated Fiberboard Treated to Improve Its Performance in the Presence of Water Vapor, FBA.

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3.6 Polyal

A 250 g pulper rejects (polyal) sample was sent to Coalia, a member of the *Centres collégiaux de transfert de technologie* (college centres for technology transfer, or CCTT) network, located in Thetford Mines, Québec.

There, the rejects were densified using a FBM DE 45 HP densifier. Then, the material was extruded using a DP-029 Amut. The polyal pellets were injection moulded using an Arburg 370A injection press to produce ASTM D638 test specimens, as shown in Figure 7. The Coalia analysis report is appended as Appendix B.

Figure 7. Parts produced by Coalia from polyal (left to right: ASTM D638 test specimens; plate made from densified matter[18]; polyal pellets)

[18] The plate was compression-moulded with the material obtained after the densification step and before putting the material in the extruder. It was produced by putting the material in a picture frame mould at 180°C, which was then compressed and cooled.

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4. Main Conclusions

This research project demonstrated that post-consumer cartons show good potential for manufacturing Type II (transfer moulding) and Type III (thermoforming) moulded pulp products. These types of packaging can be used to contain or protect a wide variety of products in the food and non food industries.

Pulp manufactured from recycled carton fibres shows mechanical and physical properties between those of refined and lightly refined virgin bleached softwood kraft pulp (BSKP). In addition, its mechanical strength is significantly higher than old corrugated cardboard (OCC). Carton fibre pulp production time (formation, draining and thermoforming) is relatively short (in other words, carton fibre pulp showed a high production rate).

An egg tray mould was used to manufacture Type II sample products. Carton fibre trays showed mechanical strength higher than that of conventional egg trays made from old newspaper (ONP). Carton fibre trays had a shrinkage rate similar to conventional trays, indicating that carton pulp could be used in industrial moulding manufacturing without nesting issues.

Carton pulp thermoformed products (Type III) had mechanical properties similar to those of thermoformed unrefined virgin kraft pulp products. However, the analysis showed that carton pulp could be further refined, which would increase its mechanical and physical properties beyond this point.

All the Types II and III products had a yellowish colour, which could be attributed to the CTMP found in relatively low quantities in carton bales.

Their low residual ink and heavy-metal content suggest compatibility with food contact, but testing requiring additional machinery, particularly for more precise chromium (specifically Cr^{VI}) and lead measurements, would be required to confirm this.

Lastly, with a view to recycling these moulded fibre products themselves, both types of products achieved a repulpability yield of almost 100%, according to the Fibre Box Association (FBA) repulping protocol. The analysis of the handsheets subsequently produced with this pulp recycled for a second time according to the FBA protocol showed that they contained only a low stickies content, that their mechanical strength was higher than that of the old corrugated cardboard control sample and their slide angle, water absorption and ash content were similar to those of the control sample. Accordingly, it appears that even twice recycled carton pulp could improve the quality of recycled paper pulp.

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Appendix A: A note on the compatibility of moulded pulp products made from recycled cartons for food contact applications

Health Canada authorizes the use of pulp from recovered fibres (recycled) for food contact, provided that certain conditions are met[19]. Specifically, the pulp cannot contain "toxic/harmful substances" that leach into food, and the source cannot have been used to hold or ship toxic/harmful substances. However, this regulation does not require the additives in recycled pulp to comply with paper regulations (21 CFR 176.170 et seq.). In other words, although the paper must comply with requirements, additives alone do not.

Pulp, including recycled pulp, in contact with food must be sufficiently pure for the use for which it is intended. It is therefore necessary to study the pesticides and polychlorinated biphenyl (PCB) samples, volatile and semi-volatile organic compounds, dioxin content and presence of per- and polyfluoroalkyl substances (PFAS). In addition, the microbiological load must be analyzed using a swab or disintegration test.

[19] https://laws-lois.justice.gc.ca/eng/regulations/C.R.C.%2C_c._870/index.html (Section B23.001)

Appendix B: Coalia Polyal Analysis Report

ANALYSIS REPORT

Client:	Innofibre (Cégep de Trois-Rivières) 3351, boul. des Forges - C.P. 97 Trois-Rivières, Québec G9A 5E6	**Date:** February 28, 2024
ATTN:	Eric Desnoes	
Order:	BON232403012	
Sample(s) identification:	PolyAl, Carton bale pulper rejects (2 kg)	
Sample(s) reception date:	February 5, 2024	
Client request:	Carton bale pulper reject reclamation testing	
Work performance date(s):	February 8 to 19, 2024	

DENSIFICATION

Device: Densifier FBM DE 45HP 15V 220/60 Z9100027

Parameters	
Loading time (min):	2
Melting time (min):	60
Temperature (°C)	110
Total cycle time (min):	65
Quantity (kg):	1.6

Observations: The melting time was high. Due to the small amount of material available, more time was required to generate the heat needed for densification. A fabric glove and a PET bottle were observed contaminants in the mix. A lot of fibre was still present in the sample. Aluminum films were no longer visible after densification.

Performed by: Steeve Lacasse, Tech.

EXTRUSION/FILTRATION

Device: DP-029 Amut, 48 mm screw,
28:1

Drying: None
Wire: 4 x 4 mm strand
Feed: Manual

Formulation	
Materials:	Densified Matter
Screen calibre	20
Extruder temperature (°C):	200
Rotation speed (rpm):	15
Melt temperature (°C):	160
Filtration pressure (psi):	2800
Cooling	Water tray
Quantity (kg):	0.250

Observations: Feeding the material was difficult and inconsistent at the extruder throat. For this reason, we observed a pressure variation at the die. Almost all the material was consumed just to fill the extruder, filtration system and die. After extrusion, we observed unmelted material in the screen probably corresponding to the initially observed PET bottle.

Performed by: Pier-Luc Marcoux, Tech.

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Device: Injection Unit Arburg 370A (600 kN)

Mould and cavity: ASTM D638 type I
Drying: None
Temperature profile: (Nozzle) 200 / 295 / 205 / 205 / 205°C

Parameters	
Fixed/mobile mould temp (°C)	40
Injection pressure (bar)	1060
Injection speed (cm3/s)	15
Injection time (s)	6.5
Switching point (cm3)	400
Holding pressure (bar)	15
Holding speed (cm3/s)	10
Holding time (s)	20
Cooling time (s)	100
Screw rotation speed (RPM)	50
Counterpressure (bar)	3
Decompression volume (cm3)	27
Dosing volume (cm^3)	9.41
Dosing time (s)	39.2
Total cycle time (s)	5.9

Observations: The injection process worked well. Approximately 10 tensile bars were moulded.

Performed by: Eric Fillion, Tech.

Photos of each step in the process are appended

Checked by:

Eric Leclair, Eng.

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APPENDIX

Densification

Extrusion/Filtration

INJECTION MOULDING