PET Thermoform Recyclability

A CANADIAN STUDY

PROJECT

PET Thermoform Recyclability

A Canadian Study

PRESENTED TO

Groupe d'action plastiques circulaires (GAPC)

Circular Plastics Taskforce

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Background 01

PET bottles are often identified as the most commonly recycled plastic in Canada. However, other PET packaging formats, such as thermoformed trays and clamshells (which can be colored and opaque), are experiencing significant growth. Currently, the most common practice is to mix the PET thermoforms into the PET bottle bales, which are then sorted and washed to be used into different applications (including food contact applications). Yet, it has been reported that some small quantities of thermoforms are separated from bottles and washed separately. In Quebec, the implementation of an expanded deposit system will decrease the quantity of beverage bottles found in curbside collection, and therefore most likely increase the proportion of thermoformed PET in the bales.

A first series of meetings with Canadian PET recyclers identified the following potential issues related to PET thermoform recycling:

- The processing of PET thermoforms mixed with bottles can increase fines generation[1], therefore reducing yield. This is mainly due to the fact that thermoformed containers have lower intrinsic viscosity (IV) compared to bottles and are therefore more brittle.
- Additionally, PET thermoforms can have lower thickness, which also increases the risk of higher fines levels.
- The lower IV of PET thermoforms can also reduce the IV of the recycled clean flakes or pellets when they are in higher proportion in the bottle bales. Maintaining a high IV value is often important, specifically for making bottles or strapping.
- Some PET thermoforms can contain layers of PE, EVOH or other materials which can have detrimental effects on the end product.
- PET thermoforms often have labels with high coverage ratios and use glues which are more difficult to wash compared to labels used for PET bottles.
- It has been reported that, in some letters of non-objection (LONO), Health Canada has specified a limit for PET thermoforms sources when converting and using this material for food contact applications, even though a very high proportion of PET thermoforms found in the bales are coming from food applications.

In view of the above, it is necessary to document the impact on recyclability when increased quantities of thermoformed PET are present in the bales collected.

Objectives 02

The overall objective of the project is to evaluate the technical capability of the technologies currently used in Canada to recycle PET bales containing high proportions of thermoformed containers.

This main objective can be divided in four sub-objectives:

- Evaluate the impact of processing high proportions of PET thermoforms on current sorting and washing lines.
- Measure the impact of increasing the proportion of PET thermoforms on the color, haze, IV and general quality of the recycling end-products.
- Evaluate specifically the processibility and quality of PET sheets extruded using high proportions of PET thermoforms.
- Assess current sorting and recycling technologies and identify the potential technological needs required to improve the processibility of PET thermoforms.

[1] For the purpose of this study, we will consider fines to be PET particles smaller than 1.7 mm.

Methodology 03

Material sourcing

3.1

This study requires material that contains high proportions of PET thermoforms. According to bale audits and various MRF operators, current levels of PET thermoform in curbside residential PET bales commercially available in Canada are believed to be in the range of 15 to 30%. This estimate is based on the total bale weight, which includes non-PET contamination and colored/opaque thermoforms, representing a very small fraction (less than 5%). Therefore, when only considering the percentage of clear thermoforms on the total of clear PET (thermoforms and bottles), the level of PET thermoforms is estimated to be between 20 to 40%. This is important to consider, as colored containers and non-PET material will be sorted out before the washing process. In this report, values will therefore refer to the percentage of thermoform based on total clear PET.

Three different bales with varying levels of PET thermoforms were tested in this study. The control sample consists of commercially available bales that are considered representative of standard residential curbside bales commonly processed in Canada. The second sample was acquired through EFS-plastics and contains a higher level of PET thermoforms. This material came from a secondary sorting line which recovers PET from non-PET bales. The third sample was acquired from a MRF in California, where PET thermoforms are positively sorted out to produce thermoform-only bales.

Sorting and washing

3.2

One truckload of each of the three samples were sent to a Canadian PET recycler with extensive experience in sorting and washing PET bales. The washing line used for this trial was modified over the years in order to improve efficiency and to specifically reduce generation of fines.

The material was processed through the sorting line, including NIR and color automatic sorters, then through the wash line and the flake sorting equipment. The material was processed using similar parameters for all three types of bales, with only minor adjustments done to optimize the process for each sample. The initial target was to run the material at the line-rated capacity, but this was not possible for some of the material for reasons which will be explained further in this report.

Sheet processing

3.3

For the thermoform-only sample from California, 5,000 lbs of clean flakes were sent to a Canadian company producing sheets and thermoform containers mainly used in food packaging applications. This company uses extruders commonly used in the industry processing PET. Once produced, the thermoformed sheet was then evaluated both by the company's internal lab and an independent lab (PTI) for color, haze and IV analysis. The trial also included running the extrusion process using 100% post-consumer recycled (PCR) bottle flakes as a control sample.

From the sort and wash trials, samples were taken and sent to an independent lab (PTI) to perform the following tests:

- → Complete contamination analysis with bake test
- → Measure solution IV of flake and particle size analysis
- → Crystallize and desiccant dry the flake samples and extrude/melt filter to generate pellets (measure color and IV)
- → Solid-state polymerization (SSP) to 0.80 IV +/-0.2 and measure IV build rate.

Some of the samples from this study were measured for their color, haze and IV, as defined below.

COLOR

→ Color is measured as L*, a* and b*:

- The lightness value, L*, defines black at 0 and white at 100.
- The a* axis is relative to the green–magenta color component, with negative values toward green and positive values toward magenta.
- The b* axis represents the blue–yellow color component, with negative numbers toward blue and positive toward yellow.

HAZE

→ This measurement refers to the Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics (ASTM D1003-21)

→ Light that is scattered upon passing through a film or sheet of a material can produce a hazy or smoky field when objects are viewed through the material. This test method covers the evaluation of specific light-transmitting and wide-angle-light-scattering properties of planar sections of materials such as essentially transparent plastic.

INTRINSIC VISCOSITY (IV)

The polymer chain length in PET determines the molecular weight of the material and, consequently, the physical properties that make PET useful for packaging. Intrinsic viscosity (IV) is a measure of the polymer molecular weight, and therefore reflects the material's toughness, melt strength and processibility. IV is used as part of the specifications used to select the right grade of PET for a particular application and is measured at various points in the supply chain.

Results 04

Material sourcing

4.1

Three samples of 15 kg each were taken from the three types of bales and sent to Stratzer for analysis. The table below shows the average bale composition for each bale type.

TABLE 1: Bale composition results

	MATERIAL SOURCING		
Material classification (weight %)	**Standard bales (control)**	**Medium % bales**	**High % bales**
PET Clear - Non-food bottles	3.4%	8.8%	0.5%
PET Clear - Food bottles	47.0%	23.3%	7.4%
PET Clear - Non-food thermoforms	1.1%	0.1%	11.5%
PET Clear - Food thermoforms	34.0%	56.4%	60.4%
PET Clear - Unknown grade thermoforms	0.5%	0.1%	0.7%
PET Opaque - Non-food bottles and thermoforms	0.6%	0.2%	0.3%
PET Opaque - Food bottles and thermoforms	2.7%	1.1%	1.0%
PET Opaque - Unknown grade bottles and thermoforms	0.1%	0.0%	0.0%
PVC containers (#3)	0.2%	1.2%	1.8%
PE / PP containers (#2-4 and #5)	1.3%	5.7%	6.0%
PS containers (#6)	0.2%	0.5%	1.3%
PLA containers (#7)	0.0%	0.0%	0.0%
Paper and cardboard	2.3%	0.3%	1.0%
Other contaminants	6.5%	2.2%	8.1%
Total	**100.0%**	**100.0%**	**100.0%**
Critical data (weight %)	**Standard bales (control)**	**Medium % bales**	**High % bales**
Ratio of PET Clear - non-food on total of Clear PET	5.2%	10.1%	14.9%
Ratio of PET Clear thermoforms on total bale weight	**35.6%**	**56.7%**	**72.6%**
Ratio of PET Clear thermoforms on total of Clear PET	**41.4%**	**63.8%**	**90.2%**
Ratio of PET Opaque on total PET	3.9%	1.4%	1.6%
Ratio of PET on total bale weight	89.4%	90.1%	81.8%

Key Observations

→ The control standard bales have a relatively high percentage of thermoform at 35.6% when compared to the range given in section 3.1 (15%-30%). The percentage of clear thermoforms (vs total bale weight) in the two other samples are 56.7% and 72.6%.

→ When only considering the total weight of clear bottles and thermoforms, thermoform fractions are respectively 41.4%, 63.8% and 90.2%. As expected, those percentages are higher in comparison to the total bale weight. <u>For the remainder of this study, the different test bales will therefore be referred to as 41%, 64% and 90%.</u>

→ <u>The percentage of PVC increases along with the percentage of PET thermoforms</u> (0.2%, 1.2% and 1.8%). It is assumed that the ratio of PVC thermoforms vs total thermoforms is higher than the ratio of PVC bottles vs total bottles.

→ <u>The percentage of PS increases along with the percentage of PET thermoforms</u> (0.2%, 0.5% and 1.3%).

→ <u>The percentage of PE/PP containers also increases along with the percentage of PET thermoforms</u> (1.3%, 5.7% and 6.0%). This is assumed to be due to the fact that clear PP and PE containers are visually very similar to PET containers. The same comment also applies to clear PVC and PS containers.

→ <u>There is a limited quantity of non-food PET containers</u>, with non-food thermoforms reported to be respectively 1.1%, 0.1% and 11.5%. The 11.5% of non-food thermoforms found in the 90% bales was investigated, and it was found that one bale had 27.5% of non-food articles stacked together. This can be explained by the fact that the MRF where this bale came from sometimes accepts non-residential material. It is thus believed that this sample is not representative of normal residential curbside material. Considering that the other two samples taken from the 90% bale had 3.6% and 3.3% non-food PET containers, the 90% bales corrected value should see:

- 3.5% instead of 11.5% for the ratio of clear non-food thermoforms in the bale.
- 5.0% instead of 14.9% for the ratio of non-food PET in clear total PET.

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Sorting and washing trial

4.2

The sorting and washing trial was conducted on a production line in Canada. With the percentage of thermoform continuously increasing over the last 10 to 15 years, the line was considerably modified in order to generate less fines. It was reported that before those modifications, the lost fines percentage was around 8%.

You will find below the sorting and washing yields and percentage of weight loss for the different by-products.

TABLE 2: Sorting and washing yields

	MATERIAL SOURCING		
Sorting/washing yields (% weight)	**41%**	**64%**	**90%**
Clear washed flake	56.5%	64.4%	61.1%
Aluminum	0.2%	0.1%	0.1%
Caps (PP/PE)	1.6%	1.3%	1.2%
Smalls, paper, debris	22.3%	15.8%	15.3%
Mixed plastics	10.8%	9.0%	11.2%
Green bottles	2.9%	0.6%	0.0%
Lost fines (corrected)	2.7%	4.6%	8.1%
Other contaminants	2.9%	4.3%	2.9%
Total	100.0%	100.0%	100.0%

Key Observations

→ The overall clear washed flake yield can be considered similar for the three types of sourced material. Please note that the 56.5% yield for the control material (41%) is considered as a low-quality bale for the processor, as a high-quality bale provides a yield of around 70%. This low-quality bale had a high level of "Smalls, paper, debris".

→ Considering that the 90% material should have a very low percentage of cap material (PP/PE), the ratio of 1.2% for this material is quite high. The processor has reported that as thermoform flakes sink slower than the bottle flakes, some of the thermoform PET flake ended up with the floating cap material.

→ The 90% material had 0% of green bottles, which was expected.

→ As expected, the lost fines content is increasing as the percentage of thermoforms increases. Please note that the reported values were corrected to consider the fines coming from the wet screw. In order to consider the worst-case scenario, the lost material when doing the mass balance has also been considered lost fines. For the majority of recyclers, the lost fines fraction of 8.1% could be considered as acceptable.

Other observations when running the washing trial

→ Due to contamination in the sink/float bath and clogging in the extraction screw coming out of the prewash, the line speed when running the 90% material was lowered to 60% of normal throughput. According to the processor, the reason for this issue is that the thermoform flakes sink slower than the bottle flakes. The processor also commented that this problem could be solved if there was a need to process material with very high levels of thermoformed PET on a regular basis.

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Sheet processing

4.3

Sheet extrusion trials were conducted at a recycler that extrudes and thermoforms PET to be used mainly in food packaging applications. This recycler has considerable experience in using up to 100% of PCR bottle flakes.

The sheet was extruded using 25% of the 90% material blended with 75% of their standard PCR bottle flakes. A control sheet was also produced using 100% of the same standard PCR bottle flakes.

Both recipes were extruded using their standard parameters and rates. No particular behavior for the test material was noted and rolls were produced from both recipes. Samples were taken and sent to PTI for color, haze and IV measurements, as seen in the following table.

TABLE 3: Extruded sheet properties

Sheet properties	Control sample	Test sample
Recipe	100% PCR bottle flake	75% PCR bottle flake + 25% (90% flake)
Sheet IV - ASTM-D4603 (dL/g)	0,75	0,69
Color - L* (D65)	94,58	93,71
Color - a* (D65)	-0,17	-0,16
Color - b* (D65)	1,00	1,56
Haze (D1003-97) (%)	4,54	7,79
Color - b* (D65)	1,00	1,56
Haze (D1003-97) (%)	4,54	7,79

Note: 90% flake IV = 0.65 dL/g

Key Observations

→ The IV of the 100% PCR bottle flake sheet was measured at 0.75. The IV of the flakes themselves was not measured, but it can be estimated at around 0.77, which would be in the proper range for standard PCR bottle flakes.

→ The IV for the sheet extruded using the 90% material was measured at 0.69. Considering that the 90% flake IV was measured at 0.65, the 0.69 value is quite low when considering that only 25% of this lower IV flake was incorporated. Further investigation might be needed in order to explain this low IV value.

→ The L*, a* and b* color values are similar for both trials. A difference in the b* values of +0.56 is seen for the sheet containing the 90% material (i.e. color tend to be more yellow), but this difference is lower than 1.0, which is usually the minimum value for the human eye to notice a difference.

→ The main difference in the sheet visual quality was definitely seen in the haze values (7.79% compared to 4.54%). While this difference is visible to the human eye, the recycler reported that the sheet containing thermoforms could be sold in some markets, with approval from the end customers.

04

Laboratory analysis

4.4

The clean flakes produced using the 41%, 64% and 90% bales were sampled and sent to a laboratory (PTI) for further analysis. The main purpose for those tests is to measure the effect of having thermoformed washed flake mixed with the bottle material. The 41% material is considered the control for those laboratory analysis.

Normal PCR flake produced for use into bottles, sheets, strapping or fiber applications normally include some minor amounts of contaminants, notably pieces of aluminum, colored PET flake, other resins (PVC, PP, PE, PETG, etc.), glass, rock, and wood. They are typically measured in the low ppm levels (0-1000ppm). However, it was found that the flake samples included relatively high levels of colored contaminants. In order to make sure that those contaminants would not create false results, the flake samples were cleaned from visual contaminants before being send to the laboratory. The 41% sample was cleaned using a Buhler flake sorter to remove a high level of blue flake. However, some remained in the sample sent to PTI (Figure 1). The 64% and 90% samples were cleaned by hand. Removing most of the colored flake ensured that the test results will be affected mainly by the contamination related to the presence of thermoforms.

4.4.1 Flake analysis

The samples were sent to PTI and submitted for IV testing, as well as particle size and contaminant analysis. The contaminant analysis was first carried out by separating the colored fractions, and then submitting the flake to a bake test to detect some non-PET flake or PET flakes containing some type of additives.

The description for each type of contaminant can be found below.

- → **Blue tinted:** flakes mainly coming from translucid blue tinted water bottles.
- → **Green tinted:** flakes mainly coming from translucid green tinted bottles.
- → **White PET:** flakes mainly coming from shampoo or detergent bottles.
- → **Black PET:** flakes mainly coming from shampoo or detergent bottles.
- → **Other colored:** flake mainly coming from other types of containers or colored PET articles.

After bake test

- → Brown/Low melts: flakes coming from PET which may contain additives turning the flake brown when submitted to heat. The low melt material is typically PETG or PLA (could also be PP or PE), which could melt at the normal PET drying or solid stating temperatures.
- → Charred black flake and PVC: typically, non-PET flake which turn black when submitted to high temperatures. All charred/black flakes were processed for PVC content by melt-mounting on a copper wire and placing in a propane flame. The presence of chlorine is indicated by a green flame. Samples which produced a green flame were considered to be PVC.

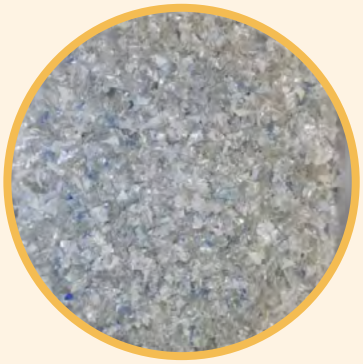
The flake analysis results are shown in the following table.

TABLE 4: Flake analysis data

Flake properties	MATERIAL SOURCING 41%	64%	90%
Particle size analysis (ASTM D-1921)			
> 0.312" (> 7.9mm)	4,057%	6,707%	1,947%
0.187"-0.312" (4.7mm - 7.9mm)	46,231%	56,239%	39,109%
0.132"-0.187" (3.4mm - 4.7mm)	26,806%	23,507%	25,490%
0.066"-0.132" (1.7mm - 3.4mm)	22,242%	13,037%	26,644%
0.039"-0.066" (1.0mm - 1.7mm)	0,647%	0,487%	5,797%
< 0.0394" (< 1mm)	0,017%	0,023%	1,013%
Contaminant analysis (ppm)			
Blue Tinted Flake	11 375	0	0
Brown/Low Melts	7 025	6 225	3 600
Green Tinted	150	400	225
White PET Flake	0	0	0
Black PET Flake	0	0	0
Other Colored PET	425	2 225	775
Charred (black) flakes	50	14	96
PVC	0	295	104

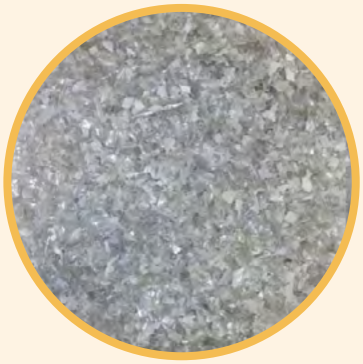
Key Observations

- The IV for the 90% material is low compared to normal PCR bottle flakes (measured at 0.65 dL/g. vs. typically 0.77+/-0.02 dL/g), as thermoforms currently on the market have an IV of between 0.65 and 0.75 dL/g. The high values would correspond to material made using high percentages of virgin resin and the low values would represent thermoforms made using high level of PCR and post industrial (PIR) flake. Therefore, 0.65 dL/g is probably in the low range of what could be expected for thermoforms and may represent worst case scenario.
- The reported IV values for the 41% and 64% samples are in the expected range.
- For the 90% material, the fines level in the clean flake is high when considering particles smaller than 1.7mm. This might need to be considered when choosing flake sorting equipment, as their efficiency is often lower when considering flake smaller than 2 or 3 mm.
- As seen from the contaminant analysis data, the blue flake was completely removed from the 64% and 90% flake samples (see also pictures shown below).
- The brown flake level is lower for the 90% material, which might indicate that additives used in bottles (often responsible for turning the flake color to brown) are not used as often in thermoforms (see pictures on next page showing flake after the bake test).
- The PVC level increased with the percentage of thermoforms. That was also noted in section 4.1.
- The ppm levels for the "other colored PET" are quite high, but it was assumed that they had a negligible effect on the results. Indeed, after looking at the pictures showing those contaminants, most are tinted blue flakes, while others are tinted pale colored flakes which have little effect on the color. Actually, tinted blue flake is sometime wanted in PCR bottle flake in order to shift the b* color value away from yellow and more toward blue.



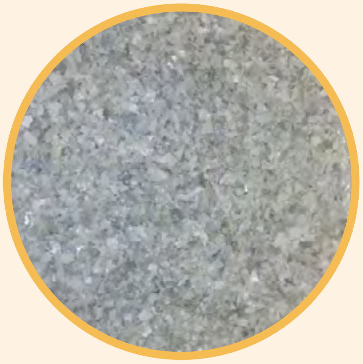
41% before bake

41% after bake



64% before bake

64% before bake



90% after bake

90% after bake

FIGURE 1: Flake before and after bake tests

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4.4.2 Extrusion and solid state polymerization (SSP)

Solid-state polymerization (SSP) of PET is carried out by heating the low molecular weight polymer at temperatures below its melting point but above its glass transition temperature. Post condensation occurs and the condensation byproducts can be removed by applying vacuum or inert gas. This process is often used to increase the IV of PET in order to use the flake/pellets in beverage bottle, strapping or fiber applications. The IV build rate is defined by the rate at which the IV value is increasing per hour. The IV build rate has an effect on the size of the equipment required to increase the IV to a specific value. If the IV build rate is high, a smaller and lower cost equipment can be used. The same logic applies to the starting IV value: the lower the starting IV value, the larger the equipment needs to be in order to achieve a specific IV value, for a specific IV build rate at the required capacity.

For this study, the flake samples were dried and extruded into pellets using a laboratory extruder. The extrusion rate was 7.8 kg/h, and a 250-mesh screen pack was used. The crystallized pellets were then solid stated to an IV of 0.80 dL/g.

The table below reports the IV measurements, color values for the crystallized pellets and solid stating data.

TABLE 5: Extrusion into pellets and SSP data

	MATERIAL SOURCING		
Extrusion into pellets and SSP data	**41%**	**64%**	**90%**
IV (ASTM D-4603)			
Flake IV (dL/g)	0.70	0.70	0.65
Pellet IV (dL/g)	0.68	0.67	0.63
Extrusion IV lost (dL/g)	0.02	0.03	0.02
Color (L*, a*, b*) of crystallized pellets			
L* (D65)	62.26	62.04	61.41
a* (D65)	-1.98	-1.15	-1.13
b* (D65)	3.18	5.14	5.00
SSP process DATA (target = 0.80IV dL/g +/-0.02)			
Solid Stating Temperature (°C)	215	215	215
Starting IV (dL/g)	0.68	0.67	0.63
Final IV (dL/g)	0.80	0.80	0.80
Time to Reach Target IV (hours)	7	8	9
IV Build Rate (dL/g/hr)	0.017	0.016	0.019

Key Observations

→ The extrusion IV losses are in the range of 0.02 to 0.03 dL/g, which is a normal range for an extrusion process. It also indicates that the material was properly dried.

→ The b* values are higher (yellower) for the 64% and 90% samples. Colors are similar for L* and a* values. The high b* value could be due to a higher level of PVC.

→ IV build rates are similar for the three samples tested and are in the acceptable range according to the recycler (considering the high SSP temperature). Some equipment manufacturers recommend temperatures of around 190°C for flake. At those temperatures, the expected IV build rates are often in the 0.01 dL/g/hr range.

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4.4.3 Key study takeaways

- The sample used as the control for this trial (41%) contained 35.6% of thermoforms (vs total bale weight), which can be considered very high when compared to known percentages for US and Canada (between 10% and 30%).
- The percentages of PVC, PS and PE/PP containers found in the bales increased with the percentage of thermoforms. It was also found that PVC levels in the clean washed flake increased with the percentage of thermoforms. This is a sorting issue that should be considered both at the MRFs and the recycling facilities.
- For all three bale types, the sorting/washing yields (56.6%, 64.4% and 61.1%) are considered to be in the same range. A better sorting efficiency both at the MRFs and recyclers and the use of recyclability guidelines are to be prioritized in order to raise the overall yield.
- The lost fines percentage increases with the percentage of thermoforms, but not at a detrimental level. Indeed, the 8.1% level for lost fines for the 90% sample is deemed acceptable. Also, the percentage of clean flake smaller than 1.7mm increased with the percentage of thermoforms.
- Sheets were successfully extruded using 25% of the 90% material, showing an increase in b* and haze values that could be acceptable for existing end-markets, according to the sheet processor.
- IV build rates for the pellets were found to be similar for all three types of material. Therefore, the thermoform percentage is not affecting the IV build rate.
- In applications requiring a higher IV for the 90% material, the low starting IV would require larger and more costly equipment.

Current washing and sorting technologies

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Nowadays, most PET recyclers buy commercially available turnkey processing lines for converting bales into clean flakes or pellets. Those PET recycling lines sometime use different methods and technologies, which can generate different results regarding yield, throughput and quality of the flake or pellets. Most of those lines were originally designed to process PET bottles, as opposed to PET thermoforms. Some equipment manufacturers have tested running PET thermoforms on their lines, and some have sold and installed production lines running PET thermoforms.

For this study, a few equipment manufacturers were asked about the capability of their recycling technology regarding processing PET thermoforms, and their answers are reported below. Please note that the following comments do not come from any trials done on those lines, and strictly include statements coming directly from the manufacturers.

5.1 Washing technologies

Amut S.p.A. (Italy)

- All Amut standard lines can handle up to 10-15% of PET thermoforms without creating problems in the main stream.
- To reduce quality problem in bottle-to-bottle applications, the bottlers are pushing the recyclers to separate trays from bottles
- Therefore, the new lines will be dedicated to running 100% trays.
- Amut has one line in Italy upgraded to work with 100% trays (line capacity is 2800 lbs/h net output).
- Amut is currently working on three more projects for processing trays.
- Yield lost due to fines when running PET thermoforms on the new lines is below 10%.

Krones AG (Germany)

- Krones PET wash lines in service are running with thermoforms comingled in the bales at up to 30%, without a recipe change.
- Higher than 30% thermoforms may require a recipe change, and 100% thermoform bales will require a separate recipe or mechanical alterations.
- Krones is currently working on potential projects for processing PET thermoforms.
- Typical yield lost due to fines when running PET thermoforms is 4 to 8%, depending on the region where the bales were sourced from.
- Available line capacity when running thermoform bales ranges from 1,000 kg/h to 6,000 kg/h.
- Thermoform bales carry with them 5 to 10 times more fiber content (large surface area pressure sensitive labels) and 10 to 20 times more adhesives than traditional PET bottle bales. Krones is one of the worlds largest suppliers of labelling machines to the beverage industry. The process to remove fibers and adhesives from containers has been part of the Krones portfolio for over 50 years. The proper mechanical, thermal and chemical processes are needed to ensure recycled PET (rPET) from a thermoform bale can be processed.

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If not properly treated rPET sheet applications will not meet the high standards regarding injectability, inclusions and color.

Sorema Plastics Recycling Systems (Italy)

→ Sorema has several lines running with thermoforms, mostly in Europe but also in the US. Two different approaches are made by countries/regions:

- A mix of PET bottles and PET trays
- 100% PET trays.

→ Every wash line supplier and customer have a different way of processing thermoforms.

→ Sorema advises to consider the following:

- Thermoforms are not stretched and still amorphous. Through the glass transition phase, they become brittle and therefore generate fines.
- For the presence of multilayer thermoforms, two options exist to process the multilayer thermoforms: by optical sorters or delaminate and separate the layers.
- European market is made of 70% multilayer and 30% monolayer PET thermoforms.
- US market is made of 90% monolayer and 10% multilayer PET thermoforms (or less)
- To produce a good rPET for trays-to-trays application, high frictions and high temperature are needed. There is a lot of fatty products and label adhesive to remove.

→ Therefore, here is Sorema's approach:

- If feedstock is made of 95% PET bottles and 5% PET thermoforms or less, there is no significant impact on the yield.
- Most of European collection systems are generating a mix of approximately 80% PET bottles and 20% PET thermoforms. With this mix, fines generation would increase from 4% to 10- 12%.
- Sorema´s approach is to separate and remove the thermoforms from the bottles washing line.
- One possibility is to build a small 1.0 ton/h line used for running the thermoforms with different process parameters and equipment (smaller screens). The size of the lost fines is generally 1.0 to 2.0 mm, so reducing screen size opening to 1.0 mm is sometimes necessary.

→ At the moment, the global market agrees that "tray-to-tray" is the solution to ensure sustainable management of plastic trays. There is no harmonization yet

→ Some collection systems are now sorting the thermoforms separately form the bottle stream.

→ Sorema have lines running with a mix of bottles and thermoforms (low percentage), and also lines running with thermoform only material.

→ Design of the line can be basic and simple to very complex and expensive. It depends on the end market and the applications.

→ Every option is customized to the customer request.

STF Group (Germany)

→ STF has spent some time and effort studying the problem of thermoform washing and is collaborating with a recycler in Mexico who currently washes PET thermoforms. Together, they have designed a 2,000 kg/hr washing line based on the recycler's experience. According to STF, this existing line is the only PET washing line in North America that washes 100% thermoform material with very good results and minimal fines production.

→ Typical yield lost due to fines when running PET thermoforms is < 2%.

5.2

AMP Robotics (USA)

- Using their Cortex™ high-speed robotic sorting system guided by artificial intelligence (AI) technology, AMP can differentiate thermoforms from PET bottles. Out of a bale made by optical sorting machinery, they are able to methodically remove all non-bottle plastics from the bale, or vice versa.
- Each robotic arm can pick at least 60 items per minute on conveyor belts (1.5 m/s) and as high as 120 in some conditions. Capacity depends on contamination rate and belt burden.
- AMP has over 35 robots in the field doing quality control for PET bottles, and a majority of those applications require thermoforms to be separated from bottles.
- There are also robots in the field that are strategically removing PET bottles from container or residue lines. This capability requires the ability to identify thermoforms as a separate group from bottles.
- The AMP technology does not currently differentiate between monolayer and multilayer PET. However, they have the capability to add this classification in the future if the industry demand increases. Their broad footprint across MRFs, PRFs and geography gives their AI technology a massive database to learn new classifications quickly when the industry requirements change.
- AMP reported that robotic sorting enables high throughput and consistent sortation to be brought to a quality only humans were able to accomplish in the past. It has the capability of sorting into further fractions such as mono and multilayer, or even potential differences in thermoform quality that may exist between a deli container and a cup. The strength of AI is that it can evolve with the supply and demand of the industry, allowing a company like AMP with a team of AI training professionals to keep up with the changing landscape and needs.

Pellenc Selective Technologies (France)

- Mistral+ connect optical sorter differentiates PET thermoforms from PET bottles. This feature has been further improved with Pellenc's latest sorter generation, thanks to:
  - **FLOW Spectrometer:** the latest generation spectrometer offering a combination of focused lighting for the best light signal on the market and optimized wavelength (spectrometer is focusing on the chemically relevant wavelength of the spectrum for a more precise analysis).
  - **Advanced Classification:** the latest generation sorting engine to differentiate slight differences in polymers like PET bottles and trays or paper vs cardboard.
- Sorting efficiencies for PET monolayer thermoforms and PET bottles will vary depending on input stream quality. Customer feedback and customer tests showed efficiencies of 90%+.
- Pellenc sorters can separate multilayer thermoforms from monolayer PET. Typically, they can achieve 95%+ efficiency as their spectrometer does detect multilayer[2].

MSS (USA)

- MSS has recently developed a new sorter called Vivid AI which can sort PET thermoforms from PET bottles. In a quality control function, they use the AI as the only sensor to sort PET thermoforms from PET bottles as well as, if required/requested, sort out any non-PET in a single-eject or dual-eject configuration[3]. In case sorting the thermoforms during the primary sorting step is required (for example, sort out the PET bottles only but not the thermoforms), then they would pair the AI with the standard NIR sensor. Efficiency for sorting PET thermoforms from PET bottles is expected to be >90%.
- MSS currently has one of those machines installed on the US West Coast, and four more are in the works until the end of 2023 and early 2024.
- MSS reported that their ability to differentiate between monolayer and multilayer PET thermoforms would include layers of PE, EVOH or other material depending on the thickness of the non-PET layers.

[2] See video at: https://youtu.be/Om94saLuaPU

[3] Here is a video done when they conducted the testing: VIVID_AI_PET_QC_with_Air_Jets.mp4

05

National Recovery Technologies - NRT (USA)

- Using their Max-AI® Vision Identification System (VIS), NRT can detect and differentiate PET thermoforms from PET bottles. The VIS can be used to pair with robots, NRT´s NIR optical sorters (SpydIR®-HS) or just used for data collection. According to NRT, NIR optical sorters alone could not make this differentiation, as it detects the object by polymer type. Since both the thermoforms and bottles would have the same signatures in the NIR spectrum, the sort would not be successful. This would be the case with any NIR sorter in the market.
- When using the above technology, material presentation is critical for the level of performance. NRT have seen detection efficiencies in the mid-90's for this type of sort.
- NRT currently have installed units running with NIR sorters and Max-AI® VIS for separating PET thermoforms and bottles. Using the standard Max-AI® Robotic technology, they typically create a separate material category for thermoforms. This allows customers to have the flexibility to sort thermoforms separately from other PET.
- NRT have recently been testing bales of thermoforms in their facility. The idea is to clean the contaminants for recycled PET thermoform markets. In this application, they are separating black thermoforms, colored bottles including PET and non-thermoform materials using the NIR optical sorter with Max-AI® VIS.

Sesotec GmbH (Germany)

- Using AI supported NIR classification, Sesotec can distinguish between PET bottles and PET monolayer thermoforms. Sesotec have a VARISORT+ sorter in their demo center capable of sorting these materials. The sorting efficiency for PET bottles/PET monolayer thermoforms is approximately 90%.
- The AI supported NIR classification can also distinguish between PET monolayer, PET+PE and PET+PP multilayer containers. In some applications, PET+PA (juice and tea bottles from Asia) can also be distinguished.
- The ability to differentiate between PET+PE multilayer and monolayer thermoforms depends on the thickness of the PE layer. Currently, there is no definitive information on what thickness or content of the PE layer is relevant for correct detection. Based on trials in their demo center, the sorting efficiency would be approximately 90 to 95%.

Tomra Sorting GmbH (Germany)

- Tomra can sort PET thermoforms against PET bottles with the latest generic AUTOSORT 5. However, some thermoforms made of 0.78-0.80 IV PET wouldn't be sorted against PET bottles with NIR alone. In this case, they can differentiate between PET thermoforms and PET bottles using Deep Laiser+NIR with shape recognition, which is a larger sensor package. Efficiency of sorting out PET thermoforms from PET bottles would be similar to what they can achieve on the primary sorting.
- With the latest AUTOSORT, they can differentiate between monolayer PET thermoforms and multilayer thermoforms with layers of other polymers. Efficiency would be similar to what can be achieved when separating PET thermoforms and PET bottles.

Waste Robotics (Canada)

- Waste Robotics reported that their robot/AI technology can separate PET thermoforms from PET bottles with an efficiency of 90+%. They currently have some robots separating PET thermoforms from a PET clear stream of thermoforms and bottles.

06 Considerations for using recycling PET thermoform food contact applications

Recycled PET flakes and pellets have been used into food contact applications for a long time. Most PET recyclers selling or using flakes into food contact applications have received a non-objection letter (NOL) from the FDA or Health Canada. This opinion letter is usually based on results coming from a challenge test run on the processing line aimed at demonstrating the efficiency of the process at removing chemicals which could potentially end up in the packaged food product.

In Canada, all packaging materials (including those containing recycled plastics) used to package foods are subject to the provisions of Division 23 of the Canadian Food and Drug Regulations. Section B.23.001 of the regulations prohibits the sale of foods in packaging materials that may impart harmful substances to their contents. Currently, Canadian regulations don't require pre-market clearance of food packaging materials. It is indeed the responsibility of the food seller (manufacturer, distributor) to ensure the safety of packaging materials and compliance with B.23.001. Packaging materials or recycled materials intended for use with foods in Canada may be submitted voluntarily to the Health Products and Food Branch (HPFB) for a pre-market assessment of their chemical safety and subsequent issuance of an advisory opinion by Health Canada (Letter of Non-Objection or LONO) on their acceptability.

When a recycler is submitting an LNO/LONO request to the FDA or Health Canada, they must fully describe the source material, the process, and the conditions of use (including food type and type of container). Most of the time, the source material description will include the source type (curbside, deposit, etc.) and sometimes limitations regarding the percentage of non-food containers. Most FDA LNOs (which are available to the public through the FOIA) either specify a limit of 20% or do not have any limitations for non-food containers. The purpose for limiting the percentage of non-food containers in the source material may be related to the fact that some non-food containers may contain additives which are not suitable for contact applications.

Authorities may also have guidelines regarding limitations regarding the percentage of thermoform containers present in the source material. It was reported to the Circular Plastics Taskforce (CPT) that Health Canada has specified in some letters of non-objection (LONO) some limitations for the use PET thermoforms when using this material into food contact applications. The control material used in this study has 3.1% of non-food thermoforms, while the percentage of non-food bottles is 6.7%. Therefore, a recycler using bales made of 100% thermoform containers will most likely find less than 5% of non-food containers in their source material. This is much lower than the FDA and Health Canada usual limit of 20%.

Considering this very low proportion of non-food thermoforms and the fact it is lower than non-food bottles, it is believed that Health Canada should review their policy regarding limiting the percentage of thermoform containers when using material sourced from curbside collection.

Considerations and potential technological improvements for equipement manufacturers

07

The findings of this report help establish a list of important factors to help equipment manufacturers and processors in designing better processing lines for PET thermoforms. The considerations and basis for this list are yield, quality and productivity.

- → Depending on the capabilities and markets of recyclers, there might be a need to differentiate between PET thermoforms and PET bottles. Some sorting equipment manufacturers have already designed and tested their equipment in order to be able to separate those two types of containers. This can be accomplished using AI/robots for low-capacity requirements or high speed NIR sorters for high-capacity requirements. Considering that those technologies are not yet used in a widespread fashion, further testing and additional improvements might be needed.

- → PET thermoforms are mostly monolayer in Canada and US, but some have multiple layers such as PE, EVOH, nylon or other types of resins. Those multilayer containers might render the package detrimental or not compatible with PET recycling. Therefore, they might need to be sorted out from the clear PET stream, which can be done using NIR sorters. Again, considering that those technologies are not yet used in a widespread fashion, further testing and additional improvements might be needed.

- → Thermoforms have different mechanical properties, weight, shapes, and handling characteristics when compared to bottles. Therefore, they require special considerations when designing a sorting line. For example, their relative brittleness, their lower bulk density, and their large surface area to thickness ratio when flattened need to be considered.

- → Because of their lower IV, non-oriented amorphous material and sometimes lower wall thicknesses (when compared to bottles), thermoforms tend to be more brittle, to break apart and to generate fines in the sorting line and, more importantly, in the flake wash line. Those fines are often lost through the processing equipment, and this potential issue needs to be considered as it might have a very important effect on yield, as well as create extra waste. In general, equipment which handle flakes in a delicate fashion might be prioritized. However, a compromise is often required between delicate handling and the intensity needed to remove adhesive and soil.

- → Labels used on PET thermoforms usually cover a large surface area and use more glue in comparison to PET bottles. Therefore, it is necessary for the wash line designer to consider the larger amount of glue which will be handled.

- → After being washed, the PET flake is usually decontaminated using flake sorting machines, which are using NIR, laser or vision technologies. Those technologies are limited with respect to minimum flake size (2 or 3mm). Therefore, if the flake is smaller than 2 or 3mm, the machine efficiency drops to a level which could be detrimental to the quality of the end product. Some equipment manufacturers recommend removing the small flakes before the flake sorter, but this has a negative effect on yield. At the end, the best solution might be the one decreasing the generation of fines in the wash line. However, more solutions might exist and since thermoform material tend to generate fines, it is important to consider this potential issue when dealing with PET thermoforms.

- → When processing bales with high levels of thermoforms, there might be higher levels of PVC compared to a 100% bottle bale. It is important to take that into consideration when designing a sort line and when selecting the flake sorting equipment. Furthermore, other clear thermoforms which can be made of PETG, PP, PE, PVC, PLA, and PS need to be considered.

- → One of the main differences between thermoforms and bottles is that there is much more amorphous material in the thermoformed material, as thermoforms are composed mainly of amorphous PET. The sections of the bottle which are mainly amorphous material are the neck and base, which represent 10 to 25% of the bottle weight. When going through the hot caustic wash, this amorphous material can crystalize and turn white or milky. This is even more the case for thinner thermoform flakes, as the bottle flakes are generally thicker and might not fully crystallize when going through the hot wash system. This might cause a problem at the flake color sorting machine: the white/milky PET crystallized flake might be rejected by the flake color sorting machine, even if this flake is "good". Therefore, more development might be needed by the flake sorter manufacturers to find a solution to this potential problem.

- → It was reported by the recycler who carried the sort and wash trial that thermoform flakes sink slower than bottle flakes. This possible issue needs to be considered when designing the sink/float tank.

08 Recommendations for next steps

This study showed that PET bales with high level of thermoforms can be processed efficiently using a modified line, but that they can degrade the quality of the clean flakes due to the presence of PVC, lower IV and increased fines content. Nevertheless, there could be a potential market in thermoform-to-thermoform applications, by blending PET thermoforms flakes with bottle rPET or virgin PET pellets.

Two subjects that were not addressed in this study could be explored as next steps: colored/opaque containers and economic assessment.

8.1 Study on colored/opaque containers

This study has considered only clear thermoform material, and thus the results are not valid for colored thermoforms. Furthermore, the knowledge gained by recyclers processing mixed colored PET bottles into pellets might not apply to mix colored thermoform containers.

It can be noted from this study that the opaque PET content for the bales treated was relatively low (<5%). However, it is known that some MRF operators are sorting out opaque PET containers, otherwise the opaque PET fraction in the clear material might exceed the recycler´s maximum acceptable level. The volumes of opaque PET are thus expected to be higher in the system.

Therefore, a follow-up study looking at volume, quality, best practices, and possible applications for PET opaque containers (bottles and thermoforms) would be beneficial to the industry. Additionally, because there is a market for food contact black PET sheets (e.g. meat trays) and food contact white PET bottles (e.g. dairy industry), it might be relevant to look at stated food contact compliance issues.

8.2 Economic assessment

As seen in this study, the path to follow regarding the treatment of thermoforms remains unclear. Some models are proposing to keep the thermoforms in the PET bottle bales, while others suggest making thermoform-only bales. While technically feasible, the economic viability of both options has not been assessed.

It is known that the market value for bales made of PET thermoforms or bottles are different, and that the recycled PET market is driven by local considerations, such as EPR schemes and the capacities of recyclers. Therefore, in order to find the optimal solution specific to each jurisdiction, an analysis should be performed to determine the potential yields of optimized washing lines and to identify the economic factors influencing the recycling of thermoformed PET and its market value.

8.3 Other recommendations to improve thermoform recycling yield

While thermoform recycling is technically feasible, actions can be taken upstream on eco-design and at the MRF sortation level to help increase the recycling process efficiency and aim to reach at least 70% yield.

Eco-design recommendations

Labels, glue, barrier layers and additives can be detrimental to recycling by affecting flake quality. To increase the value of thermoforms, it is recommended to follow design guidelines for recyclability, such as the APR Design Guide or the Canada Plastics Pact Golden Design Rules. **For instance, those guides recommend to:**

- → Use transparent and uncoloured (preferred), or transparent blue or green PET.
- → Ensure material choice, adhesive choice, inks and size of sleeve or label are not problematic for recycling.
- → Use only mono-material constructions.
- → Ensure material choice, adhesive choice for lidding films, inserts or other components are not problematic for recycling.

Sorting recommendations

Due to the higher diversity of materials used in thermoform products, increasing the volume of PET thermoforms increases the level of other materials such as PVC, PS, PE, and PP. Therefore, it is recommended to identify, test, and implement quality control equipment to remove non-PET resins after the PET sortation.

09 Conclusion

In this study, three different bale types containing 41%, 64% and 90% of thermoforms were successfully processed on a PET commercial recycling line located in Canada, which has been modified to improve the processibility of bales containing high levels of thermoforms. The clean flake yields were similar for each sample and were found acceptable, even for the 90% thermoform material. The loss of fines through the sorting and washing process increased along with higher levels of thermoforms but remained acceptable for the processor.

Then, the 90% thermoform clean flake was sent to a sheet processor and incorporated at a 25% level. The produced sheet showed an increase in yellowing and haze but was deemed acceptable by the recycler to make thermoforms and be sold in some specific markets.

Finally, flake samples taken from each type of bales were also sent to an independent laboratory. The analysis showed that an increase in thermoforms leads to a decrease in intrinsic viscosity (IV), an increase in PVC levels and an increase in fines level in the washed flake. The material was also solid stated, and IV build rates were found to be similar and acceptable for all three types of material. This study also suggested two follow-up studies: an analysis of the benefits of separating thermoforms from the current PET bottle stream, and the identification of best practices in recycling colored/opaque PET containers. It would also be interesting to assess how the increase of thermoforms concentrations can affect bottle and fibre production, as well as to assess the cost implications. **To summarize, three main conclusions emerge from this study:**

- → Equipment is available to sort and process high concentrations of thermoforms when present in the PET stream.
- → Modifications can be made to a wash line to better process thermoforms.
- → PCR sheet can be made and formed into thermoforms of acceptable quality for specific markets using specific ratios of flake coming from thermoform-only bales.

While those conclusions have their limitations, notably due to the small sample size, the results show that there is room to grow with respect to the mechanical recycling of thermoforms, from packaging design all the way through end markets.

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