DO NOT JUST RECYCLE – BUT UPCYCLE
(Value added products from waste PET bottles)

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WASTE HIERARCHY

Most favoured option

Reduce
lowering the amount of waste produced

Reuse
using materials repeatedly

Recycle
using materials to make new products

Recovery
recovering energy from waste

Landfill
safe disposal of waste to landfill

Least favoured option

Up cycling of PET
WASTE HEIRARCHY & ENVIRONMENTAL IMPACT

ENVIRONMENTAL IMPACT (LEAST)

REduce – Materials, Resources & Wastage

REUSE - Post consumer & industrial waste

RECYCLE - Up cycle rather than down cycle

ENERGY RECOVERY - Pyrolysis

DISPOSAL – Landfill or Incineration

ENVIRONMENTAL IMPACT (HIGHEST)

Upcycling of PET
Value added products from recycled pet bottles

Upcycling of PET

- **Sheet for Packaging**
- **Strapping Tape**
- **Recycled PSF / POY / DTY**

Recycled PET Resin Pellets

- **Non-Food Bottles**
- **Bottles Grade PET Resin**
- **Blending with Virgin PET Resin**
HOT WASHED PET FLAKES

RECYCLED PET SHEET THERMOFORMED END PRODUCTS

Upcycling of PET
Upcycling of PET
Containers for non-food applications

PET Strapping Tape

Upcycling of PET
Partially Oriented Yarn (POY)

Polyester Staple Fiber (PSF)

Upcycling of PET
Recycled PET Granules (Pellets)

PET Bottles

Upcycling of PET
Non-woven PET Fabric

PET (Polyester) Film

Upcycling of PET
## Indicative Intrinsic Viscosity levels for different applications

<table>
<thead>
<tr>
<th>INDUSTRY / APPLICATION</th>
<th>Desired I.V. (dL / gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin PET from resin producers</td>
<td>0.76 – 0.88</td>
</tr>
<tr>
<td>Filled bottles by marketers</td>
<td>0.76 – 0.88</td>
</tr>
<tr>
<td>Sheets for thermoformed packaging</td>
<td>0.70 – 0.80</td>
</tr>
<tr>
<td>Strapping bands</td>
<td>0.84 – 0.92</td>
</tr>
<tr>
<td>Monofilaments</td>
<td>0.66 – 0.76</td>
</tr>
<tr>
<td>Master batch</td>
<td>0.76 – 0.84</td>
</tr>
<tr>
<td>Injection moulded articles</td>
<td>0.80 – 0.84</td>
</tr>
<tr>
<td>Industrial Yarns (Tire Cord / Conveyor Belt / Sewing Thread)</td>
<td>0.92 – 1.00</td>
</tr>
<tr>
<td>Polyester Staple Fiber</td>
<td>0.60 – 0.65</td>
</tr>
<tr>
<td>Polyester Oriented Yarn</td>
<td>0.60 – 0.65</td>
</tr>
<tr>
<td>Non-Woven fabric</td>
<td>0.60 – 0.65</td>
</tr>
<tr>
<td>Fully Drawn Yarn / Drawn Textured Yarn</td>
<td>0.60 – 0.65</td>
</tr>
</tbody>
</table>
Re-cycling of Post-Consumer PET Bottles

PET is one of the few thermoplastics that can be Up-Cycled and not only Re-cycled. However, there are certain impediments when PET is recycled. The PET resin is highly hydrophilic i.e. readily absorbs moisture from the surrounding air. When post-consumer PET bottles flakes are recycled (extruded) the polymer undergoes Thermal, Oxidative & Hydrolytic Degradation leading to undesirable drop in mechanical & chemical properties such as

- The Intrinsic Viscosity (IV) of the PET polymer decreases leading to a drop in physical - mechanical properties
- Generates impurities like Aldehydes and other VOCs due to which it cannot be used further for food contact applications
- Leads to Dis-colouration or yellowing of the resin
- Formation of agglomerates & lumps
- The post consumer PET bottle flakes contain foreign matter & impurities that needs to be filtered out.

Upcycling of PET
What is the way out? There are various methods & technologies available. Some of them are used together in conjunction to do the job as per end requirement.

1) **Pre-drying of PET bottle flakes to reduce moisture content**
2) **Vacuum De-gassing** to remove moisture and VOCs during extrusion
3) **Melt Filtration** through Screens to remove agglomerates and solid contaminants
4) Adding chemicals called **Chain Extenders** to increase polymer IV
5) **Liquid State Polycondensation (LSP)** process utilizes the inherent capability of the PET polymer to condensate in the molten phase under vacuum that leads to an increase of IV. The high performance vacuum effectively decontaminates the material from harmful chemicals enabling it to be used for food contact applications.

6) **Solid State Polycondensation (SSP)** at elevated temperature and under vacuum of the recycled PET pellets to increase IV followed by thermal crystallization.
Important Characteristics of PET Resin

Intrinsic Viscosity (IV):

- PET resins are classified on the basis of IV (like MFI in the case of polyolefin’s), which is a measure of average length of polymer molecular chains or molecular weight.
- It influences the melt viscosity and processing behaviour of PET and properties of the end products.
- If an application requires higher strength, a higher IV is recommended.
- The IV of PET is determined from the flow times of polymer solution and pure solvent in a viscometer at a designated temperature.
- Usually IV is measured in a Viscometer using Phenol + 1,1,2, 2-Tetrachloroethane (60:40 w/w) solvent at 25°C.
Residual Acetaldehyde (AA) Content: Acetaldehyde (CH₃CHO) is generated during polycondensation process as a by-product of thermal degradation and gets entrapped in PET resin when molten polymer is cooled. Acetaldehyde is a harmless chemical, but it does have a flavour. Since it has low Boiling Point (21°C) and sweet fruity odour, it can influence taste of packed products, if present in excessive amounts. For bottle applications AA content is usually below 1 ppm in PET resins.

Colour: Reflected/ transmitted colour, yellowness and haze affect the appearance. Colour should be as close to neutral. measured on L, a, b scale
‘L’ denotes - Black to White. When L value is ‘0’, it indicates Black & ‘100’ indicates White. Black to White goes through ‘Grey’.
‘a’ denotes – Red to Green. When ‘a’ value is ‘+ ve’, it indicates Red & ‘-ve’ indicates Green.
‘b’ denotes – Yellow to Blue. When ‘b’ value is ‘+ ve’, it indicates Yellow & ‘-ve’ indicates Blue.
**Crystallinity:** It is a measure of the degree of orderliness of PET resin molecule. The crystallinity is directly related to the density of polyester and is normally derived from the density value. Crystallinity should be above 50%, so that the chips do not soften and form agglomerates during drying prior to moulding or extrusion.

**Moisture Content:**
- PET resin is hygroscopic in nature i.e. it picks up moisture from air.
- Presence of moisture leads to processing problems and defects in the finished products such as haziness, voids, sliver streaks, and also to derive better physical and mechanical properties.
- It is desirable to reduce moisture to less than 40ppm (0.004%) before processing which can be achieved only by a de-humidifying dryer.
- An in-line desiccant hopper dryer is required to process PET
- PET in Amorphous form (bottle flakes) absorbs moisture more rapidly than in crystalline form.

Upcycling of PET
Importance of moisture extraction in the PET extrusion process

Drying of PET resin is expensive in terms of investment costs, factory space and running costs (higher energy consumption) as the material is typically dried using dehumidified dry air at 180°C up to 8 hours - reduces the processor’s flexibility.

In the processing of PET resin or post-consumer bottle flakes with an extruder at normal processing temperatures, a chemical process takes place - any water molecules which are present reduce the PET polymer chain lengths which results in a reduction in the viscosity. This process is known as hydrolysis.
In order to avoid this PET flakes are pre-dried over a period of time to remove moisture prior to extrusion (in order to prevent hydrolysis during extrusion)

- This chemical reaction is however reversible and the point of equilibrium can be driven to one or the other side by reducing or increasing the water content.
- By removing water molecules during processing, the damaged PET molecule chains can rebuild themselves. This is known as polycondensation and in layman terms refers to re-combination of broken PET polymer chains to form longer chains

**Melt phase moisture removal with vacuum degassing**

Main function of this extrusion concept is to remove the moisture / water in the polymer when it is molten state inside the extruder. The moisture is removed from the molten polymer by means of vacuum degassing through multiple venting ports arranged along the extruded. The evacuation or degassing system is modular and multiple ports can be arranged at different sections of the extruder
Use of twin-screw extruders
Twin screw extruders provide better shear melting of the polymer at different zones of the extruder and provide better melt mixing than single screw extruders. Twin screw extruders are able to handle post-consumer PET bottle flakes without any pre-crystallization of the flakes. Most important is the effectiveness of the moisture removal.
Re-crystallization of PET bottle flakes

Post-consumer PET bottle flakes are amorphous in nature i.e. the polymer chains are arranged in a random manner. Hence, amorphous PET (bottle flakes) are transparent whereas semi-crystalline PET bottle grade resin pellets are hazy milky white in appearance.

Virgin PET resin in its “semi-crystalline” state has both crystalline and amorphous portions in its molecular structure. PET bottle flakes require crystallizing prior to drying so that the particles don’t stick together as they go through the material’s glass transition temperature (Tg). By ensuring that crystallinity of the PET flakes is high, prior to processing, the result will be a more uniform and higher quality product.
Upcycling of PET
Extruded Sheet for Thermoformed Packaging Material

- Single layer or Three-layer co-extruded (A-B-A) sheet
- 15% Virgin PET + 70% R-PET + 15% Virgin PET (A-B-A structure)
- 0.2 to 1.5 mm thickness
- A-PET / PET-G / C-PET Sheet for Thermoformed Packaging
Upcycling of PET
Upcycling of PET
Upcycling of PET
### Typical Specifications of 100% Recycled PET Sheet

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Test Method</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Thickness</td>
<td>ASTM D 6988</td>
<td>mm</td>
<td>0.20 to 1.20 (± 5%)</td>
</tr>
<tr>
<td>2 Width</td>
<td>ISO 4592</td>
<td>mm</td>
<td>800 (± 2)</td>
</tr>
<tr>
<td>3 Shrinkage @ 80 °C for 15 min (in MD, TD)</td>
<td>DIN 53377</td>
<td>( % )</td>
<td>≤ 5</td>
</tr>
<tr>
<td>4 Density</td>
<td>ASTM – D 792</td>
<td>g / cc</td>
<td>1.33 ± 0.02</td>
</tr>
<tr>
<td>5 Pendulum Impact Strength</td>
<td>ISO 8256</td>
<td>KJ / M²</td>
<td>≥ 300</td>
</tr>
<tr>
<td>6 Tensile strength at break</td>
<td>ASTM – 882</td>
<td>Kg / cm²</td>
<td>≥ 550</td>
</tr>
<tr>
<td>7 Vicat Softening Point (@ 5kg load)</td>
<td>ASTM – D 1525</td>
<td>°C</td>
<td>71 ± 2</td>
</tr>
<tr>
<td>8 Light Transmission</td>
<td>ASTM – D 1003</td>
<td>%</td>
<td>≥89</td>
</tr>
<tr>
<td>9 Thermoforming temperature</td>
<td>--------</td>
<td>°C</td>
<td>120 - 160</td>
</tr>
</tbody>
</table>

#### Guidelines for Hot Washed PET Flakes (clear)
- Intrinsic Viscosity: 0.70 to 0.78 dl / g, Moisture content < 1.5%
- PVC content < 150 ppm, PP / PE content < 30 ppm
- Paper content < 30 ppm, Organic content < 20 ppm
- Metal content < 20 ppm, Total Impurities < 200 ppm
Clean PET Flakes

Re-generated Polyester Staple Fiber

Upcycling of PET
Upcycling of PET
Some Application of Regenerated PSF

Upcycling of PET
Bottle Grade PET Resin (B to B Process)

Different technologies are available for the purpose, notably **Liquid State Polycondensation** (LSP) process that enables rapid increase in polymer IV and high level of decontamination for producing US FDA compliant food contact bottle grade PET resin pellets – either clear (APET) or crystalline (CPET). **Solid State Polycondensation** (SSP) and Thermal **Crystallization**. The extruded recycled PET resin pellets undergo SSP that involves application of heat under vacuum which increases the polymer IV and effectively decontaminates the material making it suitable for food contact applications with US FDA approval.
Solid State Polycondensation

Courtesy: EREMA™

Upcycling of PET
Solid State Polycondensation

1. **PET flake pretreatment**
   Highly efficient decontamination
   The patented pretreatment at elevated temperature and under vacuum before the extrusion process removes moisture and migration materials from the feedstock very effectively and in a stable process environment. This prevents any hydrolytic and oxidative decomposition of the melt in the extruder.

2. **IV increase**
   IV value is increased to the required level.

3. **Melting under vacuum**

4. **Low thermal stress**
   The very short extruder screw without additional extruder degassing reduces the thermal stress on the material through minimised residence time.

5. **Large area ultrafine filtration**
   The robust, fully automatic filter removes even the smallest of aluminium, steel and other particles from the melt. The very large active filter areas enable filtration with up to 32 μm fineness with a low pressure level. The result is highly clean pellets.

**Easy operation**
The intelligent Smart Start operating concept combines production efficiency with remarkably straightforward operation. The accent is on usability. Featuring a high degree of automation, ergonomic touchscreen and practical recipe management.
Liquid state polycondensation process (LSP)
The process utilizes inherent capability of PET to condensate in the molten phase under vacuum. This condensation leads to an increase of IV. The high performance vacuum effectively decontaminates the material from harmful chemicals, – securing further use of the material for 100% food contact.
### Sorption of Surrogate Contaminants into PET After 365 Days at 25°C

<table>
<thead>
<tr>
<th>Surrogate</th>
<th>Sorption Value (mg/kg)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volatile, Polar</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroform</td>
<td>4860</td>
<td>Begley et al., 2002 (modeled value)</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>1080</td>
<td>Demertzis et al., 1997&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>1,1,1-Trichloroethane</td>
<td>1050</td>
<td>Demertzis et al., 1997&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Diethyl ketone</td>
<td>4860</td>
<td>Assumed to be the same as chloroform, based on similar molecular weights</td>
</tr>
<tr>
<td><strong>Volatile, Non-Polar</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td>780</td>
<td>Begley et al., 2002</td>
</tr>
<tr>
<td><strong>Non-Volatile, Polar</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzophenone</td>
<td>49</td>
<td>Begley et al., 2002</td>
</tr>
<tr>
<td>Methyl salicylate</td>
<td>200</td>
<td>Begley et al., 2002</td>
</tr>
<tr>
<td><strong>Non-Volatile, Non-Polar</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tetracosane</td>
<td>154</td>
<td>Begley et al., 2002 (modeled value)</td>
</tr>
<tr>
<td>Lindane</td>
<td>750</td>
<td>Begley et al., 2002</td>
</tr>
<tr>
<td>Methyl stearate</td>
<td>150</td>
<td>Assumed to be the same as tetracosane, based on preliminary FDA experimental results</td>
</tr>
<tr>
<td>Phenylcyclohexane</td>
<td>390</td>
<td>Demertzis et al., 1997&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>1-Phenyldecane</td>
<td>170</td>
<td>Demertzis et al., 1997&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2,4,6-Trichloroanisole</td>
<td>1100</td>
<td>Based on value for lindane with molecular weight correction</td>
</tr>
</tbody>
</table>

<sup>a</sup>These values are measured at 40°C.

FDA has used a mathematical model, based on Fick's law of diffusion, to predict the amount of a contaminant (represented by the surrogate contaminants described above) that will sorb into a PET bottle during a period of one year at 25°C, the shelf life and use temperature of a typical non-food substance packaged in PET.

In order to obtain the initial concentrations shown in Table, FDA recommends exposing PET flake rather than intact bottles to the surrogate solutions for at least 14 days at 40°C.
Why recycle waste PET bottles?

- India’s virgin PET resin consumption in 2017-8 was more than 1.5 million tons and will grow to 2.5 million tons by 2021-22.
- Environmental imperative (non-biodegradable, choking of sewage lines, landfill, burning produces toxins) ---- Sustainability
- Recovery and recycling makes economic sense as recycled PET price is 60 to 80% of virgin PET
- Saving of Natural Resources
- Much lower carbon footprint
- Waste PET bottles are easier to segregate and recycle vis-à-vis other polymers
Indian PET Resin Consumption (in ‘000 MT)
Actual (2011-12 to 2017-18) and projected (2018-19 to 2021-22)

Source: Chemical & Petrochemical Manufacturers Association of India, Industry Estimates
THANK YOU

THE FUTURE BELONGS TO THOSE WHO SEE POSSIBILITIES BEFORE THEY BECOME OBVIOUS

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