New production potential for PET processors with the innovative MRS extrusion technology

A new, patented technology for the devolatilising or degassing of polymer melt, the Multi Rotation System MRS was presented to the general public for the first time at the K-show 2007 in Düsseldorf.

How it’s done:
The MRS extruder in general is a single screw extruder with a very special degassing section. The polymer melt is delivered into a large single screw drum.

The drum contains 8 or 10 (depending on the model size) small extruder barrels, parallel to the main screw axis. Installed in these small extruder barrels are the "satellite" screws, which are driven by a ring gear in the main barrel. The satellite screws rotate in the opposite direction to the main screw while they rotate around the screw axis. This disproportionately increases the surface exchange of the polymer melt. The extruder barrels which are cut into the drum of the multi rotation system are approximately 30% open to ensure the optimum melt transfer into the barrels and so that the evacuation can take place without restrictions. Further, precise control of the melt temperature is possible as the temperatures of all the surfaces in contact with the melt can be controlled accurately.

Thanks to its patented multiple screw section, the MRS makes a very large area available and permits unmatched degassing performance, even with a vacuum of only 20 to 40 mbar. The extrusion of undried PET bottle flakes or pellets (for example up to moisture contents of 12,000 ppm H₂O) is therefore possible without making any compromises. This even applies to high viscosity end products such as strapping tape.

This evacuation technology (and the multiple screw section) is based on the robust and proven single screw extruder concept. In this way, the MRS avoids the problems of
alternative multiple shaft or screw designs (intermeshing) which are considerably more sensitive to mechanical damage due to their tight clearances. This last point can be decisive in the reprocessing of PET bottle flake which frequently includes coarse contamination.

Further positive effects of the MRS technology are the 100% dehumidification of PET as well as the possibility of increasing the intrinsic viscosity of this material.

The extrusion drum – the heart of the MRS technology

Thanks to the multi rotation elements, a melt surface is made available which is far greater than that of conventional extruders. For example: the MRS system creates a melt surface exchange rate which is 25 times greater compared with a co-rotating twin screw extruder.

<table>
<thead>
<tr>
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<th>Single screw extruder</th>
<th>Twin screw extruder</th>
<th>MRS</th>
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<tbody>
<tr>
<td>Surface (cm²)*</td>
<td>100 %</td>
<td>150 %</td>
<td>450 %</td>
</tr>
<tr>
<td>Surface exchange (m²/min)*</td>
<td>100 %</td>
<td>200 %</td>
<td>5,000 %</td>
</tr>
<tr>
<td>Free volume (cm³)*</td>
<td>100 %</td>
<td>150 %</td>
<td>300 %</td>
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* in expansion section
Compared with other multi screw systems, the MRS is characterized by its extremely compact and rugged design. The rotating satellite screws run in individual bearings and are therefore comparable with a drum containing a number of single screws.

The evacuation or degassing system is modular and can be ideally matched to the individual requirements, thanks to its remarkable performance. The position, length and design of the modules can be varied. The MRS system can be used as an element of an extruder screw or can be integrated in a polymer melt pipe transfer system.

**PET concept**

The performance of the MRS system has been proven in several production lines:

First the performance of the MRS was put into practise in PET applications. Several lines (sheet, non-woven, granulating and strapping lines) have been equipped with the MRS extruder.

The typical chemical process inside the extruder is a reverse process. Moisture in the PET shortens the molecular chains, and therefore the viscosity and mechanical properties are reduced.

This chemical reaction is reversible and the point of equilibrium can be driven to one or the other side by reducing or increasing the water content.

For producing thermoforming film out of 100% bottle flakes, totally un-dried, in South America, the humidity is up to 10,000 ppm. In this line the polymer was analysed to figure out the viscosity during processing. The i.V. of the un-dried processed PET bottle flakes has been analysed as well as the polymer upstream of the degassing section, directly afterwards and in the finished product.
It is obvious that in the very first section of the extruder the viscosity of the polymer is reduced, because the water content is integrated into the chains of the PET. The more moisture is in the input, the more the decrease. In the degassing section these water molecules are extracted by vacuum (driven by diffusion), here the reversed chemical reaction takes place. Therefore the MRS is able to increase the chain length, the molecular weight, the viscosity and the mechanical properties of the polymer. The viscosity built up can be controlled by the vacuum level itself; consequently it is possible to use an online viscosity measurement to control the vacuum in order to stabilize the viscosity level by a closed control loop.

After leaving the MRS section the extruder builds up the necessary pressure for the die head or the downstream filtration system with no longer hydrolysis degradation.

The main conclusion is that it is possible to process bottle flakes without a pre – drying and using a “simple” vacuum system of roughly 25 to 30 mbar, which can be achieved by a conventional water ring pump.

**Defogging of recycled Polyolefin materials:**

In polyolefin recycling one of the biggest problems is the odour after extruding. There are several post consumer applications like wrapping or thermoforming film recycling.

In some automotive applications smell and outgasing are the biggest issues.

One application is the production of virgin material used in automotive section. The degassing of some VOCs is a big problem:

Volatile organic compounds (VOCs) are organic chemical compounds that have sufficiently high vapour pressures under normal conditions to significantly vaporize and enter the atmosphere. A wide range of carbon-based molecules, such as aldehydes, ketones, and other light hydrocarbons are VOCs. These VOCs inside the polymer used in cars may
evaporate under sun light: there will be some deposits found on the windscreen, and some of these are toxic.

Virgin polymer is run into the MRS system, and the results are compared to a conventional twin screw extruder, for a back-to-back test.

The analysis is carried out in cooperation with the Fraunhofer Institut, using some “man-made” noses (Thermal desorption analysis according to VDA 278/VOC emission) to analyse the pellets after extrusion and calculate the VOC content.

The input material in both trials is the 100% VOC figure. It was found that the twin screw extruder is able to take out 50 % of this value by running a high vacuum and some CO₂ entrainer. This value is reached by using the MRS system without any vacuum, in other words using only atmospheric degassing. By using a conventional vacuum system (20 mbar) the VOC figure was reduced by more than 90 %.

Another example in post consumer recycling is a PE film recycling. First life of the film was for the wrapping of fish. The target is to recycle the film for shopping bags. In this case, the producer of these bags was able to use only 5 % of the fish film for the production; otherwise the vegetable bag was too “smelly”. By using the MRS extruder it is now possible to use 60 % of the fish film, which was not possible previously, which represented a major breakthrough and big savings. The pay back period for the MRS system was less than half a year in this example.

**Polymer production**

Another example of performance possibilities offered by the MRS is extraction in the polymer production industry. In manufacturing of polyamide one of the expensive steps is the extraction of caprolactam (C₆H₁₁NO) during production of PA6
Polyamide 6 is made by adding water to \( \varepsilon \)-caprolactam under heat.

\[
\begin{align*}
\text{H}_2\text{C} & \quad + \text{H}_2\text{O} & \quad \text{H}_2\text{N} & \quad \left[\text{CH}_2\right]_6 & \quad \text{COOH} & \quad \xrightarrow{\text{H}_2\text{O}} & \quad \text{NH} & \quad \text{CO} & \quad \left[\text{CH}_2\right]_6
\end{align*}
\]

\( \varepsilon \)-caprolactam \quad \varepsilon \)-aminocapronacid \quad \text{polyamide 6}

After this melt-polycondensation the polyamide melt contains roughly 10 – 12% of low-molecular oligomers and some rest of caprolactam. The viscosity at this stage in the process is around 100 – 400 Pas.

In order to use this polymer the monomers as well as the oligomers must be extracted. This is mainly done by hot water extraction after pelletizing. Here the granules are washed in a large vessel with a distilled hot water stream. The quality of the water and the pureness of the oxygen used is most important.

By using the MRS this step of reducing the monomer and oligomer content can be carried out in the melt phase, as a last step upstream of the pelletizer. Because of this the expensive step of water cleaning and recovery of the caprolactam it is no longer necessary. The caprolactam can easily be recovered from the catchpot of the vacuum system. The amount of the oligomers and monomers vs. the vacuum of the MRS system can be seen in the diagram.

![Diagram showing extract percentage vs. vacuum in mbar](image-url)
Strapping Tape Production

Polyester strapping tape is highly resistant, as limited elongation capacity and is therefore a valid alternative to steel strapping. Inalterable in conditions of sudden temperature changes and unaffected by ultraviolet rays, PET strapping tape guarantees constant tension during each and every stage of the package handling, thus providing conditions of absolute safety during transport. PET tape is rust-proof and easy to handle, thus guaranteeing maximum ease of use for the handler. It can also be used on automatic strapping equipment. As a consequence PET strapping tape is a very economic alternative to steel strapping, especially by using post consumer bottle flakes.

PET Straps’ Market – Comparison Table

<table>
<thead>
<tr>
<th>Characteristics PET vs Steel</th>
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<tbody>
<tr>
<td>Mechanical Strength</td>
<td>The achievable values are comparable and impact resistance is better</td>
</tr>
<tr>
<td>Elongation</td>
<td>PET offers 12% more than steel, so better retained tension for loads that move or shrink due for any reason</td>
</tr>
<tr>
<td>Oxide Attitude</td>
<td>No rust marks on product, thus better to pack synthetic fibers and cotton bales</td>
</tr>
<tr>
<td>Elasticity</td>
<td>PET don’t damage the edges of the strapped goods</td>
</tr>
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<table>
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<tr>
<th>Safety PET vs Steel</th>
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<tbody>
<tr>
<td>Handling</td>
<td>PET bobbins could be handled more easily</td>
</tr>
<tr>
<td>Injury</td>
<td>PET offers less safety hazards than Steel</td>
</tr>
</tbody>
</table>

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<th>Cost PET vs Steel</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>PET Bottle Flakes offer a Major Advantage</td>
</tr>
</tbody>
</table>

The MRS90 including the fully automatic filtration system RSFgenius90 and a Gneuss online viscometer was installed in a Sima (Sima Group, Bologna, Italy) strapping line for producing strapping tape. The line is processing 100% of non dried post consumer bottle flakes. There is only a small amount of PE based additive used for impact modifying (splicing inhibitor) of 1,2%, which is normal to be used in strapping applications.
The throughput of the line is around 350 to 400 kg/h, and the vacuum of the installed water ring pump is set to 35 mbar.

The die had contains of 3 gear pumps producing 6 tapes with a dimension of 12.5 mm x 0.65 mm to 0.8 mm, stretching ratio is around 1 to 8 and the haul off speed is up to 120 m/min.

Compared to conventional systems (single screw with crystallisation and pre – drying) it was figured out that the required space for the installation with the MRS system is much smaller. By using the MRS technology it is no longer necessary to use conventional drying and crystallisation. This space saving is around 12%.
Fully automatic filtration system RSFgenius:

The 75 µm screens in the fully automatic RSFgenius are taking out the contaminations like aluminium, wood, etc. With this equipment it is possible to run an always stable differential pressure across the screens, even during back-flushing the screens or screen change.

The RSFgenius consists of three main parts – an inlet block, an outlet block and a filter disk rotating between them. The system is sealed by a metal to metal sealing with very narrow gaps as well as very hard and flat surfaces. It is guaranteed that all components in contact with melt are not in contact with the environment (e. g. oxygen).

The screen elements are located in a ring pattern on the filter disk, moving through the melt channel. When melt flows through the screen, hard particles get caught and the differential pressure increases slightly. The control system reacts to this pressure increase and makes the filter disk index by approx. 1 angular degree. Thus, contaminated screen area is continuously moved out of the melt channel and clean screen area is moved into the melt channel without changing the active filter area. Due to this mode of operation, the filtration system operates process- and pressure-constantly. The variation of the pressure differential across the filter (Δp) amounts to max. 2 bar.

Cleaning of the contaminated screens takes place just before they are re-introduced into the melt channel. The dirt cake is then cleaned via a high-pressure segment purging system. For this purpose, already filtered melt is taken from the outlet block and siphoned into a hydraulically-driven piston and then shot from the back at high pressure, through the filter disk and through the screen into the inlet block. The purging pressure is measured and can be adjusted and optimized. Only a small segment (approx. 1% of the screen area) is cleaned at a time with a defined high impulse. The stroke of the back-flush piston (= melt amount to be used) as well as the speed (= intensity of cleaning) can be adjusted freely and therefore optimized. So on one hand the cleaning is very efficient but on the other hand the melt amount used is minimized (backflush losses are minimal). Due to this mode of operation the screens can practically be cleaned 100% and can be re-used, depending on the filtration fineness, up to 400 times. This makes a fully-automatic filtration (without any operator attention) possible for up to two months.

After this time, screens have to be changed simply for mechanical reasons. Thanks to the filtration system’s patented mode of operation, a screen change can be carried out without any negative influence on the production process. Depending on the size of the line, a
complete screen change of all filter elements takes approx. 20 minutes and can be carried out by the operating personnel without any influence on the production process.

Gneuss Viscometer:
Downstream the MRS and the RSFgenius the viscosity is measured online. A small part of polymer melt is diverted from the main melt channel and with a high precision gear pump it is pumped through a precisely manufactured slot capillary. Melt temperature and melt pressure (at two locations) is measured. Based on internal calculations the viscometer monitors the value of the representative shear rate and the corresponding viscosity. Different shear rates can be set and by corresponding corrections the real values for viscosity and shear rate can be derived.

The design is very compact. The viscometer can be fitted between two flange connections. The melt channel can be designed according to customers’ specifications between 0.5 and 2 mm. The unit includes a pump drive, a pump, pressure transducers, temperature sensors and the control and evaluation electronics. The setting of process parameters, the evaluation and the display is realized via a user friendly touch screen panel or alternatively can be integrated into an existing control system.

After processing the flakes to strapping tape several tests have been made. Mechanical analysis shows that all straps have an excellent tenacity and an very good elongation.

Energy savings with the MRS system:
In addition to the good mechanical properties of the tapes the energy consumption of the whole plant was measured as well.
Compared to conventional single screw processing with crystallisation and pre-drying down to a water content of less than 50 ppm the specific energy consumption is much less, around 20%, because of the immense energy costs for heating the pellets by hot air during the preparation for extrusion.

In comparison to twin screw processing of the flakes the energy consumption is also less, because a high vacuum of less than 5 mbar is needed with the twin screw and in addition to that normally the flakes have to be pre-dried down to around 1000 ppm, and there is a booster pump needed as well.

<table>
<thead>
<tr>
<th></th>
<th>MRS</th>
<th>Twin Screw</th>
<th>Single Screw</th>
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<tbody>
<tr>
<td>Cristallisation</td>
<td>-</td>
<td>-</td>
<td>90 Wh/kg</td>
</tr>
<tr>
<td>drying &lt; 50 ppm</td>
<td>-</td>
<td>-</td>
<td>120 Wh/kg</td>
</tr>
<tr>
<td>pre-drying to 1000 ppm</td>
<td>-</td>
<td>60 Wh/kg</td>
<td>-</td>
</tr>
<tr>
<td>extruder drive and heating</td>
<td>295 Wh/kg</td>
<td>230 Wh/kg</td>
<td>240 Wh/kg</td>
</tr>
<tr>
<td>vacuum</td>
<td>45 Wh/kg</td>
<td>90 Wh/kg</td>
<td>-</td>
</tr>
<tr>
<td>booster pump</td>
<td>-</td>
<td>30 Wh/kg</td>
<td>-</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>350 Wh/kg</strong></td>
<td><strong>410 Wh/kg</strong></td>
<td><strong>450 Wh/kg</strong></td>
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The specific energy consumption of the MRS technology is 15% to 25% less than the conventional technologies, not to mention the higher flexibility and less maintenance on dryers and high vacuum systems.

**Result:**

The new MRS system is able to efficiently extract volatilise from a polymer matrix by using a much simpler process thanks to the large exchange rate of the polymer surface area. The diffusion process is increased dramatically by the multiple rotating screws inside the vacuum zone of the extruder.

There are many more processes which are not mentioned here which involve diffusion or mixing. The MRS system represents an interesting new alternative to these established technologies, which is already proven in many applications.

Gneuss Kunststofftechnik GmbH  
Dr. Axel Hannemann  
Moenichhusen 42  
32549 Bad Oeynhausen, Germany  
Phone: 05731 5307 43  
Fax: 05731 5307 77  
Email: axel.hannemann@gneuss.de