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Important Factors of Influence during Plastics Recycling Process

Presented by samples from PET Bottle Flakes Recycling

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1. Introduction

The rapid growth in the consumption of PET bottles, improvements in the collection systems and changes in European legislation present new possibilities and challenges for the fast – growing PET recycling industry.

There is a range of products where the substitution of virgin material with recycled material makes economic and processing–technical sense: staple fibre, thermoforming sheet, non woven fibre, packaging straps or even masterbatches and bottles.

Each of these processes places requirements on the properties of the recycled polyester, which are close to those of virgin material. Apart from the molecular weight (often referred to as intrinsic viscosity – IV), from the specific viscosity and colour/transparency of the material, foreign particles or contamination in the melt (for example: paper, sand, adhesive, other plastics such as PP, PVC etc.) will have an effect on the product quality.

The highest quality requirements of all are found in the so called “bottle to bottle” recycling processes. In this case, the processes are only realistic and/or economically viable where the used bottles are taken from a defined, controlled source (for example, returned deposit bottles).

If the used bottles are taken from household plastic waste, there is a danger of unknown contamination. Additionally, highly sophisticated sorting and washing plants will be required, adding to the cost of the bottle flake. The quality of the bottle flake required for different processes can be defined as follows:

Quality level I:

- Bottles for beverages/foodstuffs

Quality level II:

- Technical filaments
- Strapping tape (for packaging
- POY[1]
- Fine Spun Bond Nonwoven Fibre
- Steel Coating

Quality Level III

- Clear Cast Film
- BCF[2]
- Non Food Bottles
- BOPET[3]

Quality Level IV

- Heavy Spun Bond Fibre
- Staple Fibre

Quality Group V

- Engineering Plastic

[1] POY = Partially Oriented Yarn

[2] BCF = Bulked Carpet Filament

[3] BOPET = Biaxially Oriented PET Film

The existing processes for the collection, baling, sorting, grinding, washing, drying (of the PET bottle flakes), extrusion, filtration, chips cutting and solid state polymerisation (SSP) all offer potential for efficiency improvements and therefore cost savings. One significant trend is the reduction of production costs by processing the cleaned and dried bottle flakes directly into the above products, without the intermediate step of extruding the PET bottle flakes into pellets or chips.

To process PET bottle flake direct into one of the above products makes the production process susceptible for disturbances. In this case, filtration is of particular importance. The filtration system must be able to handle a varying contamination load, it must operate automatically, make efficient use of the filtration medium (a running cost) and it must of course operate with a high level of process stability.

In the following, the most important problems and disturbing factors regarding the processing of PET bottle flakes will be presented; along with possible solutions and recommendations of how to face the respective problem. In this context, the focus is put on the aspect of melt filtration.

2. Major disturbing factors in the processing of PET bottle flakes

2.1. Disturbing factor: Moisture

An often underestimated disturbing factor is the moisture of the flakes and their constancy when they are melting. The moisture of the flakes is a variable that varies according to the state of supply and the respective humidity of the air. Normally the humidity is 0,3 – 0,5 % .

Regarding the drying process of the flakes, one can distinguish between surface moisture and core moisture. The surface moisture can be reduced relatively quickly whereas air flow, air speed, moisture of the dry air and temperature are of particular importance. In the majority of cases this happens when the material is crystallizing at about 170°C.

In contrast to this it is much more time-consuming to reduce the core moisture since the transport speed of the moisture of the PET cannot be accelerated at any rate. The drying process also gets complicated since the drying speed decreases with increasing thickness of the flakes and increasing level of crystallization.

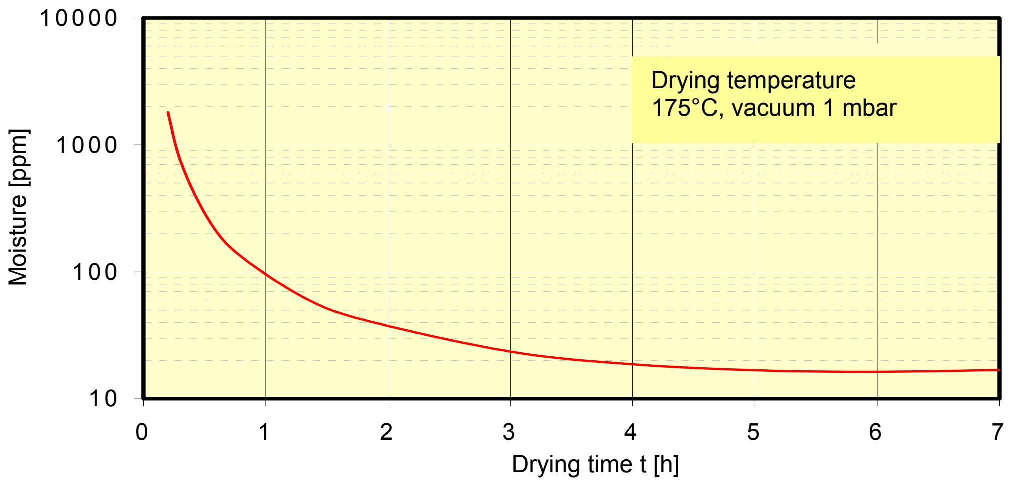


Fig. 1: Drying curve of PET pellets with an edge length of 2,6 mm at a temperature of 175°C in a vacuum (1 mbar).

The investment of time and costs increases considerably by reducing the remaining core moisture and therefore it is advisable to reflect thoroughly on what is really required to gain the final product.

Another method to reduce moisture is the application of a vacuum on the melted PET. If single-screw extruders are used this effect is rather small, however if twin screw extruders are used this method is very good and effective. This difference results from the much bigger melt surface in the vacuum area that, twin screw extruders provide, however this difference also varies according to the brand as well as specifications. Of course, the height of the vacuum is also an important additional factor. A basic conclusion: The higher the vacuum, the better the moisture reduction and the more cost-intensive the process.

For example: to obtain a moisture reduction of 0,005 %, a vacuum of approx. 2mbar is required. The costs arising from this are remarkable.

However, for a reduction to a moisture of 0,03 %, a vacuum of 20-50mbar is sufficient. The costs and operating expenses are considerably lower.

Therefore the question is: Which moisture can remain to successfully process the product?

For this see the following details:

- Regarding staple fibers a remaining moisture of about 0,03 % is sufficient, since for the manufacturing of yarns an IV-value of 0,6-0,63 is absolutely sufficient. In this case the hydrolytic degradation of the melt viscosity caused by the remaining moisture of approx. 300 ppm, is even desired and reasonable. Of course, this also applies for non-woven materials.

- However, regarding the processing of pellets for the production of bottles, a hydrolytic degradation of the melt is not wanted, since the final product requires a viscosity as high as possible. However, here a cost-intensive pre-drying or an adequate vacuum can be avoided with a trick by restricting the residence time of the melt to < 30 seconds and this way minimising the hydrolytic degradation. Regarding pelletising this is basically possible, since the process is short and clear. If the manufacturing process is correspondingly thoroughly planned, this objective can also be achieved. But a short dwell time in plasticized condition is a prerequisite.

- This also does apply for the manufacture of films, however in this case a reduction of the residence time to < 30 seconds cannot be attained. However it is possible that with a consistent reduction of the residence time of the melt and the corresponding compromises, the drying of the flakes can be successfully accomplished. For example, with a good reduction of the surface moisture and processing on a doublelead screw with a vacuum of approx. 20 mbar afterwards, brilliant films, that also guarantee tensile strength, can be produced. There are many good and promising methods of resolution.

2.2. Disturbing factor: Hard particles

Hard particles like e. g. sand, glass, aluminium, degraded material etc. can be extracted from the melt via an adequate filtration system. Here it is important that the filtration is running pressure- and process-constant; has a short residence time of the melt and the dirt cake as well offering the facility to obtain a filtration as fine as possible. The basic conclusion here is also not to filter as fine as possible - but to filter as fine as necessary. Here are some facts for orientation:

Manufacture of non-woven materials	25-40μ
Manufacture of staple fibers	30-60μ
Bottle material	40-60μ
Flat films	30-60μ
Monofilaments and fibrillated tapes	60-100μ

Fig. 2: The most common filter finenesses

Since generally a melt pump is installed to process flakes, it is indispensable that in front of the melt pump there is at least a filtration of 300-500μ in order to protect the pump. The wide differences that exist to some extent in the recommended filter fineness are based on the sometimes also wide differences in the various final product qualities, that according to its field of application and specifications also requires other qualities.

2.3. Disturbing factor: Soft particles

In the majority of cases soft particles can also be filtered if the proper filtering agent is used. Nevertheless it is advisable to identify the origin of these particles and, if possible, to eliminate them at a preliminary stage. Unfavourable extruder specifications can e.g. produce gel particles, whereas well specified melting areas and succeeding compound particles may reduce or disintegrate gels. In addition to melt filtration, there do exist further methods of resolving the problem of soft particles in the melt by means of a corresponding line design. Nevertheless, the applied filtration can only be efficient provided that the gels are not produced after the filtration due to dead spots in the melt pump, in the static mixer, in the line system or the injector.

2.4. Disturbing factor: Foreign plastics

Foreign plastics like e. g. polyethylene, polycarbonate etc. are largely eliminated in the washing and separation process, however generally there are still remnants in the PET bottle flakes. In principle this is not tragic, since a small content is not disturbing, if it’s well and homogeneously dispersed in the extrusion. To filter it out of the melt is not possible.

However if they are imperfectly dispersed or homogenised in the melt, like this is often the case, if single screws are used, there could appear stripes in the final product or yarn breaks with regard to fibres.

2.5. Disturbing factor: PVC

As for PVC, it is difficult to eliminate it in the washing and separation process, since the specific weight of PVC corresponds pretty much to the specific weight of PET. Very often black spots in the final product are supposed to be PVC, however – provided that pre-treatment and extrusion have been carried out carefully – this is not correct since PVC dissolves itself in polyester as well as all other plastics, but only has the negative side-effect of changing the colour of the polyester to yellow-brown depending on the quantity. These changes in colour can be very massive (Fig. 3) and be an absolute quality criterion.

Fig. 3: the influence of PVC on the colour of PET

2.6. Disturbing factor: Adhesives

Most of the adhesives disperse very well with the polyester, nevertheless the dispersion and homogenisation also depends on the extruder. Some adhesives if insufficiently dispersed not only lead to an increasing appearance of stripes, but also to the appearance of so-called fish eyes (gels). In this case the twin screw has also proved itself to be a very good method of resolution.

2.7. Disturbing factor: Wood

As far as wood is concerned the same disturbances as for „hard particles“ are applied. It can be filtered out quite easily. Regarding wood there is only one factor that must be taken into account, i. e. that at a too high temperature the wood burns and creates many small black charred particles. This has a negative effect on all kinds of final products. However, this can be very easily avoided, if care is taken that a too high Δp in the dirt cake (more than 20-30 bar) is avoided, since when flowing through the dirt cake the wood particles will heat up in a way, that there will be the risk of wood burning. This danger can be easily controlled with the pressure-constant running RSF*genius*, since the parameters can be monitored here and the control parameters for the residence time of the dirt cake can also be defined. It is even better to separate the wood in the pre-stages of the flake processing due to its much lower density compared to PET.

2.8. Disturbing factor: Rubber

Over the past years rubber was extremely rare to be a component of PET bottle flakes. It is also very difficult to separate it from the polyester flakes due to its similar specific weight and appears nowadays more and more often as a component of the flakes. Basically rubber can be quite easily removed with a melt filtration system. However, the smaller the rubber particles are, the more difficult it gets, and requires the application of special screen specifications, since otherwise the back-cleaning of the filter elements hardly is possible and therefore poses a problem (Fig. 4). In this case a well-regulated pressure-constancy and a Δp in the dirt cake that is not too high (< 20-30 bar Δp according to the size of the rubber particles) is very important.

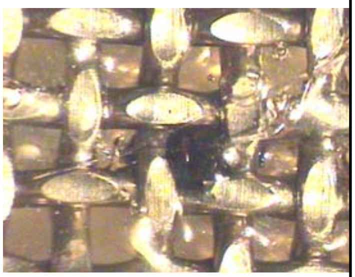
	Rubber particle 1	**Rubber particle 2**
Front		
Back		

Fig. 4: Adhesion of rubber in the filter screen (filter fineness 200 µm, △p pressure 100 bar)

2.9. Disturbing factor: Variations in the extrusion process

Variations regarding dimensions and tolerances in the final product, as well as alterations in the tensile strength or brilliance of the material, are generally originated by the processing process. The complete processing process consists of different configuration components. Their interaction may have a negative impact on the process, if they are running instable and deficiently. Here are some examples:

- As for the single screw extruder: variations in the moisture of the material will also lead to variations in the viscosity of the melt and therefore to all negative characteristics resulting from this.
- Variations and alterations in the vacuum station of twin screws will lead to changes in the viscosity of the melt as well as in the brilliance of the final product.
- Melt filtration: In this case changes in the pressure consumption will lead to changes in the melt viscosity (Fig. 5). Additionally, dead spots and long residence times will lead to degraded material, gelation and thermal degraded melts. In addition to this, nearly all back-flushing melt filtration systems have large variations in the throughput constancy; having serious consequences on the different factors of the quality of the final product. The RSF*genius* developed by Gneuss is a positive exception with regard to back-flushing filtration systems (see below).
- Melt pumps, dead spots and inadequate lubrication of the bearings can lead to fish eyes, degraded products and other disturbances. High residence times of the melt due to too large material pockets also have a negative effect on the quality of the melt.

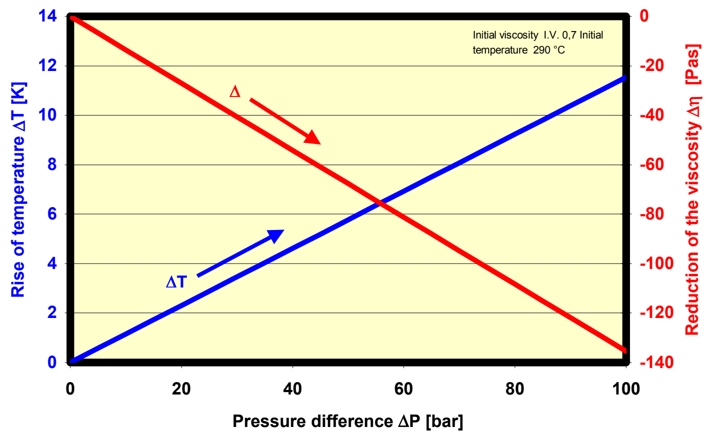


Fig.5: Variations in the melt temperature and viscosity due to pressure variations during the filtration of PET

3. The RSF*genius* as the perfect filtration system for processing PET bottle flakes

The RSF*genius* filtration system developed by Gneuss Kunststofftechnik GmbH operates continuously, pressure- and process-constant as well as fully-automatically. The continuous operation is guaranteed by the Rotary Technology, i.e. by the rotation of the filter disk. The constant pressure is achieved by the control of the rotating movement of the filter disk. The control is determined by the upstream pressure or by the differential pressure. The max. pressure variations are ± 2 bar. The clean screen surface area as well as the level of contamination is always constant.

The operation of the filter is process-constant, because the change of screens does not cause any variations with regard to temperature and viscosity, in addition to an absolutely stable throughput and because the shear stress of the melt always remains the same. Additionally, the Rotary Technology prevents any degraded particles from entering into the melt flow when changing the screens.

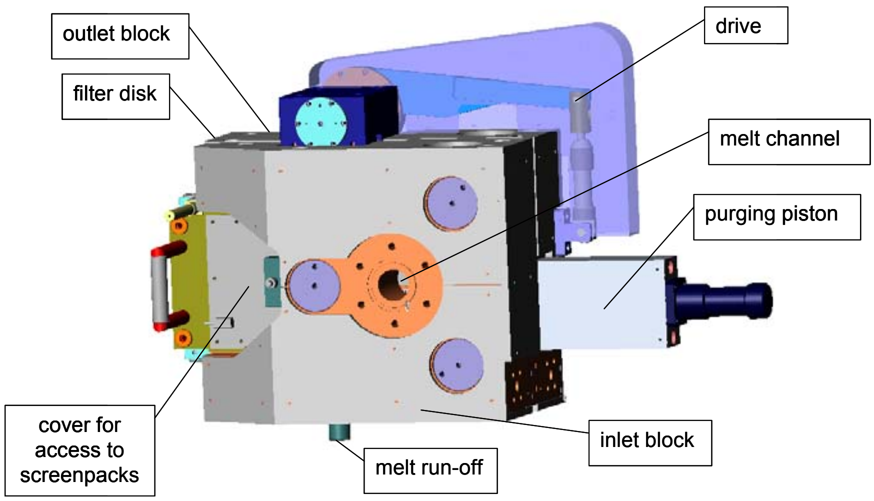


Fig. 6: RSF*genius* filtration system

The filter operates fully-automatically because of the integrated cleaning of the screens. When using conventional screenchangers, the operator has to take out the contaminated screens coming out of the melt and replace them by new ones. The filter disk with its cavities located in a ring pattern is completely enclosed by the two filter blocks. The cavities are equipped with a cover, which can be opened in case of need. The process will not be disturbed by the screen change.

Compared to other self-cleaning screenchangers, this cleaning procedure is characterized by its extremely high efficiency. On one hand this leads to a very small loss of melt. On the other hand the screens can be used very often; this is only limited by the mechanical life time of the filter elements.

The fact that the RSF*genius* filter is universally applicable, constitutes a further characteristic. It can be used in totally different applications, e. g. in the filtration of monomers, recycling or when processing finest fibres and sheet. There are no limitations regarding either the viscosity or the pressure of the medium to be filtered, nor regarding the filtration fineness.

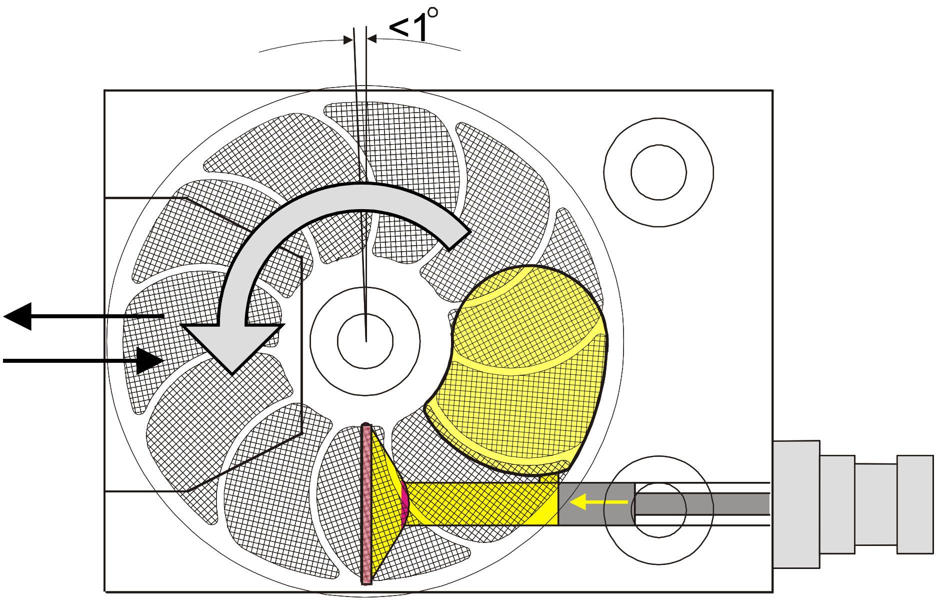


Fig. 7: Operation of the RSF*genius* Filtration System

When the pressure increases upstream of the filter, the screen disk will be rotated in indexing steps (steps < 1°). This ensures that the clean screen surface area at disposal and its load of dirt cake always remain constant.

A short time before the contaminated screens are re-introduced into the melt channel, they are cleaned by means of a patented integrated purging piston system. Filtered melt is removed from the outlet block into a purging piston. After each indexing movement, this melt is shot by the piston via high pressure impulses across a small gap through the contaminated screen to the outside. The quantity needed for this can be adjusted individually and corresponds in practice to approx. 0,02%, max. 0,5% (with high contamination) of the throughput.

The shot speed can also be selected individually and will be adjusted in a way that the controlled screen cleaning pressure is higher than the pressure consumption across the screen. This guarantees an optimal cleaning of the screens. This cleaning occurs without influencing the production process.

The control of the RSF*genius* is realized fully-automatically by the Genius-control, which as an option can also be integrated into the existing control of the line. Until the ultimate re-usage of the screens, the RSF*genius* filtration system operates without the need for any operator attention or any operation of the filtration system. Integrated sensors allow the monitoring of the operating parameters (temperatures, differential pressure, purging pressure, current number of screen usages etc.) by the process control system.

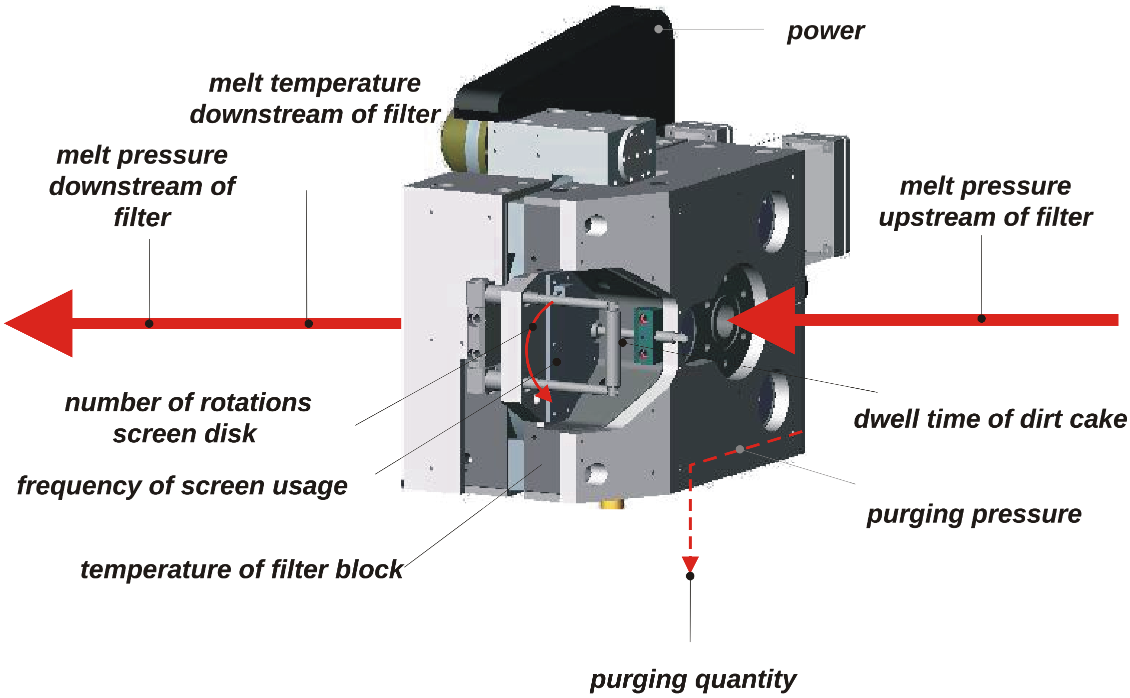


Fig. 8: Controlling Principle of the RSF*genius*

When processing sensitive material, the intrusion of air or already oxidatively or thermically degraded melt must be prevented. The RSF*genius* meets the demands through its fully encapsulated design. The screen disk with the inserted screens rotates between two metal surfaces and thus prevents contact of the melt and screens with air or air humidity. When changing the screens, a cover is opened which makes it possible to work at the screen disk. The newly inserted screens only enter into the melt flow after having passed the purging area. The purging system completely bleeds the air out of the screens and fills the cavities with fresh and filtered melt, just before they are rotated into the melt channel.

4. Examples of Direct Recycling of PET Bottle Flakes

4.1. PET Bottle resin

The further processing of PET bottle flakes to bottle resin requires the highest material quality. Provided the flake cleaning and finishing processes (for example the URRC process) operate efficiently, then there are still numerous process-technical requirements, which are to be fulfilled in order to achieve chips which are qualitatively comparable to virgin material. In this context, the following aspects are just some examples: optional pre-drying, extrusion with or without vacuum, melt filtration, chip cutting, crystallisation and SSP.

The filtration system is of vital importance, since the time during which the PET is molten must be kept to an absolute minimum. In order to remove contamination that is visible to the naked eye, the filtration fineness must be between 25 and 50 µm. Burnt particles must be kept out of the final product at all times, including during filter element changes and during the self–cleaning of the filter elements. The filtration system must of course also be able to automatically adjust itself to and handle varying contamination loads – the key features of the fully-automatic Melt Filtration System, RSF*genius.*

4.2. A – PET sheet

Using PET bottle flake is a particularly attractive way for thermoform sheet manufacturers to cut their raw material costs. The filtration system is in this case, too, of crucial importance: the sheet must be free of optical imperfections (black specks, fish eyes, etc.). The process stability of the filtration system is of particular importance. In many cases, melt filtration takes place downstream of the gear pump, and a pressure–stable filtration system is crucial. Due to the acute cost pressure, the melt filtration system must be fully automatic and highly efficient with regard to filter element use and material loss through self–cleaning (back flushing). The RSF*genius* Melt Filtration System meets these demands. Filtration finenesses depend on the application, but normally lie within the range of 20 to 200 µm.

Fig. 9: Tandem Filtration System for a PET sheet line. Throughput rate: 1.200 kg/h.

4.3. POY, staple fibre and spun bond spinning

When spinning recycled pellets, or using bottle flake as the input material, different processing principles apply:

High speed spinning processes for the manufacture of POY normally require a spinning IV of 0,62 to 0,64 dl/g. Using bottle flakes, the I.V. can be controlled via the pre–drying and/or the controlled addition of IV modification additives. Additionally a $Ti0_2$ additive is necessary for a full dull or semi dull finish.

In order to protect the spinnerets from premature blocking, efficient melt filtration is a prerequisite. The required filtration fineness is typically 20 µm or finer.

Staple fibre is spun in a somewhat lower IV range of between 0,58 and 0,62 dl/g. In this case, too, the IV is determined by the level of pre-drying and/or the addition of an IV modifier. Again, efficient filtration is crucial to the economic efficiency of the operation by preventing premature blocking of the spin pack filters. Typical filtration fineness is 36 µm.

Spunbond, both in the fine titer area for textile applications and the heavier types as basic materials for roof coverings or earthworks, can also be manufactured from bottle flakes. The spinning IV in this case must also be adjusted – typically to around 0,64 dl/g. Due to the size of the spinnerets, the filtration system is of great importance. The filtration fineness depends on the spinning titer.

In any fibre spinning application, the process–stability of the Filtration System is crucial – pressure and residence time variations will lead to yarn breaks.

Fig. 10: Twin screw extruder, tandem filtration system with gear pump for staple fibre, throughput rate: 600 kg/h.

4.4. Strapping for Packaging, high tensile monofilaments

High tensile packing straps are extruded and monoaxially orientated. Monofilaments are melt spun and then drawn. Due to the high IV and the relatively thick cross section of the product, the filtration fineness is normally between 70 and 120 µm. Larger foreign particles reduce the tensile strength of the strapping bands. Additionally, the pressure-constant mode of operation of the filtration system is a decisive aspect, since the necessary dimensional consistency is very important with regard to the further processing and the tensile strength.

Using PET bottle flakes is of great interest for the manufacturers of strapping bands and tearproof monofilaments in order to keep the costs for raw material as low as possible, especially since recycled material can be used without any problems - provided that the line has been designed accordingly. Therefore, the PET virgin material with an IV-value of approx. 0,9 to 1,3 will be mixed. The mixing ratio depends on the required strength of the strapping bands as well as on the quality and moisture of the flakes. Further on, the line design plays an important role. The application possibilities of PET bottle flakes are determined especially by the consistency of the used filtration system as well as by the filtration fineness. It is also possible to increase the flake's IV-value in an SSP to 1,0 and more and thus allow the usage of 100% recycled material.

5. Conclusion

When processing PET bottle flakes, numerous disturbing factors may occur, probably leading to further problems. The following table gives a brief survey of the main disturbing factors in PET bottle flakes processing:

Disturbing factor	Appearance in the final product	Elimination or reduction of the disturbances
Moisture	● Stripes in sheet/opaqueness in sheet and bottles ● Reduction of the IV-value	● Optimisation of the remaining moisture / of the vacuum ● Reduction of the melt dwell time
Hard particles *(e.g.: sand, glas, aluminium, degraded material etc.)*	● Optically disturbing particles in the final product ● Reduction of the tensile strength ● Reduction of the spinpack lifetime ● Destruction of the melt pump with particles > 400µm	● Improvement of the melt filtration (≤ 56µm)
Soft particles *(e.g.: gel)*	● Yarn breaks during fibre manufacture ● Optically disturbing appearances (fish eyes) ● Reduction of the tensile strength	● Optimisation of the extruder screw with regard to dynamic dispersion resp. installation of a twin screw ● Improvement and optimisation of the melt filtration
Foreign plastics *(e.g. PP, PE, PS,PA,PC etc.)*	● Yarn breaks, gelation and stripes possible ● Reduction of the tensile strength possible	● Optimisation of the extruder screw with regard to dynamic dispersion resp. installation of a twin screw
PVC	● Colour changes to yellow-brown ● Stripes possible ● Yarn breaks possible ● Reduction of the tensile strength possible	● Colour changes not influenceable ● Optimisation of the extruder screw with regard to dynamic dispersion resp. installation of a twin screw
Adhesives	● Gelation / stripes possible ● Yarn breaks possible ● Reduction of the tensile strength possible	● Optimisation of the extruder screw with regard to dynamic dispersion resp. installation of a twin screw
Wood	● Wood particles in the final product ● Many small black particles in the final product ● Reduction of the tensile strength	● Improvement and optimisation of the melt filtration ● Reduce Δp dirt cake to < 30bar in order to prevent wood burning
Rubber	● Many small particles in the final product ● Reduction of the tensile strength ● Massive interference with regard to filter element self-cleaning	● Improvement and optimisation of the melt filtration ● Application of special filter elements

Fig. 11: Disturbing factors with regard to material quality

Cause	Effects on the final product	Elimination or reduction of the disturbances
- No moisture consistency - No constant feeding - No pressure-constant filtration - No throughput-constant filtration - No consistency in the vacuum	- Variations regarding dimensions and tolerances in the final product - Variations regarding the tensile strength - Yarn breaks	- Optimisation of the additional equipment required fort he process - Installation of a pressure- and process-constant melt filtration system

Fig. 12: Disturbances caused by the extrusion process

Melt filtration is of great importance when processing PET bottle flakes. Many problems specific to material or the production process can only be solved by a consequent melt filtration. In this context, the Gneuss Rotary Filtration System RSF*genius* features some perfect characteristics. It operates fully-automatically, process-constant and highly efficient. Therefore, it perfectly complies with the requirements of direct recycling of PET bottle flakes, proven by its extraordinary world-wide popularity.

The features of the RSF*genius* which are of specific interest for the recycling of PET bottle flakes can be summarized as follows:

- Automatic adaptation to varying contamination loads
- The ability to handle varying contamination loads automatically
- Process-constant operation
- Pressure-constant operation
- Fully-automatic operation
- Shortest possible residence time of all the melt in the system (< 2 min.)
- Shortest possible dwell time of the dirt cake in the melt
- Precise adjustability of the back-flushing system in order to use the back-flushing material efficiently
- Fine tuning of the self–cleaning system to give efficient use of the back–flushed material
- High number of uses of the filter elements (over 200 uses possible)
- Filtration finenesses possible (down to 6 µm)
- Filter element change takes place with no process disturbances or interruptions.

The RSF*genius* is operating successfully on PET bottle flakes in a variety of processes for direct recycling, as follows:

- Re-pelletising of bottle flakes to food grade PET chips (approx. 20 units, 800 to 1.500 kg/h.
- Staple fibre spinning (approx. 40 units, 300 – 1.300 kg/h)
- Spun bond spinning (approx. 20 units, 400 – 1.000 kg/h)
- A – PET thermoform sheet (approx. 110 units, 500 – 1.500 kg/h)

Imprint

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