Filtration Systems as Static Mixers in the Processing of Plastic Melts

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1. Function of Filters in the Processing of Plastics

Polymer melts and solutions contain foreign particles of different sizes and shapes caused by catalyst breaks, contamination, abrasion of moving parts, delamination of burnt deposits between the extruder screw and barrel, corrosive action, contaminated recycled materials, etc. [1, 2] In addition to this, extremely large particles and agglomerates in additives and reinforcing substances, not completely melted pellets as well as inhomogeneities in the melt in form of deformable, highly viscous gels can be found. These foreign or “problem” substances should be filtered out of the polymer melt or be broken down, since they

- reduce the stability not only of fibres and films, but also of other moulded parts
- have a negative impact on the density of films
- reduce the conductivity of insulated electric moulded parts
- increase the surface roughness of coatings and mouldings
- can change the colour impression of mouldings
- have an impact on the number of faults in films
- can accelerate the aging process of a moulding in the case of reactive components
- in general have an impact on the quality of a component
- can block nozzles and potentially damage gear (melt) pumps

1.1. Filtration media

In the field of process engineering and plastic processing filtration is defined as the removal of hard or liquid particles from fluids by using filtration media. Filtration media are ring gap filters, different types of woven wire mesh elements, random fibre sinter metal fibres, sand filters, sintered grain (sand) filters and membranes.

Fig.1 shows some examples and typical application areas for the filtration of polymer melts. Due to the specific requirements with regard to temperature, corrosion and strength, most filter elements are made from stainless steel.

In the case of ring gap filters (Fig. 1 a) the filtrate usually flows through a ring gap filter element from the inside to the outside while the particles are deposited on the smooth and narrow inner wall. The channel widens in the downstream direction, in order to avoid jamming of the particles. As the contamination increases, the pressure rises. At a certain pressure differential ($\Delta P$), a back-flush process from the outside to the inside can be initiated. If several ring gap filter elements in form of candles are grouped in a housing, flushing including dirt discharge can be carried out in sequence via a swivel pipe without interrupting the melt flow. However, in this case similar to all dual chamber or multi chamber systems substantial variations of the differential pressure between the changing and normal operating modes are encountered, leading very often to a disruption of the manufacturing process or at least to unacceptable losses in quality.
There are different weaving methods for the manufacture of woven wire-mesh (wire cloth) filter elements. Fig. 1 (b) shows a simple square weave and (c) a Dutch Weave. According to the type of weave the strength and to some extent the dirt holding capacity can be modified. For many applications it is the most economically priced and a completely adequate filter medium. As far as the simple square mesh wire cloth filter element is concerned, long and thin particles can slip through, together with deformable gels.

The free effective surface area $A_F$ is the result of the wire diameter $d$ and the mesh size $w$:

$$w: \quad A_F = \frac{w^2}{(w + d)^2}$$

Since (d) is determined by the required strength, the free surface $A_F$ is reduced with decreased $w$. The pressure loss increases and the dirt intake capacity decreases. This is the reason why...
Dutch weaves and special weaves (broad mesh twilled Dutch weave or reverse plain Dutch twilled weave) are used if finer sizes and higher quality requirements are essential. [3]

Sinter metal fibre felt media, as shown in Fig.1 (d), consist of a multitude of thin stainless steel fibres, which - in order to prevent displacement and to increase stability - are tightly connected at the contact points by sintering. A highly porous filtration medium can be created, resulting in a high contamination holding capacity. Most of the contamination particles do not rest on the surface but in the inner area, thus this process is called depth filtration. Sinter metal fleeces also can slightly be folded to the cross sectional shape of a star, so that in the case of candle filters the filtration surface can be increased. However, here the bent edge can cause problems, since as with wire cloth, the filter fineness at this point is not guaranteed and the edge can even be broken or damaged during folding. Particularly with regard to the very expensive candles, these are often regenerated (thermal cleaning) in order to save costs, however the mechanical strength of the filter elements is reduced by the heating process and damage to the wire cloth or sinter metal fibre felt is common.

As for filtration with wire cloth and sinter metal fibre felt, a multi-layer compound structure is often used as shown in Fig. 2. Such systems are widespread in commonly used screen changers, in special configurations as well as in candle and disk filters according to Fig. 3. As far as large-surface, so-called leaf disk filters, are concerned, the polymer flow speed is very low and with slight pressures soft particles, like e.g. gels, can be retained. However, due to the large volume of the filter device the dwell or residence time of the polymer exposed to temperature can cause a problem – one of the causes of gels in the first place!

![Fig. 2: Example of 5-layer screen pack](image)

![Fig. 3: Large-surface filters: Candle [4] and leaf disc filters [5] [6](image)
Sintered granular material filters, as shown in Fig.1(e) often consist of ball-shaped particles and sometimes have more coarse particles on top and finer particles at the bottom. The pore channel winds around the solid bodies, it has different thicknesses and a size of approx. \( d_p = 0.1 \times \). The fine foreign particles are deposited in the inner area, so that this process is often called “deep bed filtration”. Larger dirt particles get deposited as cake on the surface. Regeneration by means of thermal cleaning is only possible to a certain extent. In the case of fibre spinning, loose sand fills with a particle size ranging between 50 – 700 \( \mu \text{m} \) according to specifications, bed heights \( L \) between 10 – 30 mm and porosities with \( \varepsilon = 0.4 \) are used. In order to create a higher porosity with \( \varepsilon = 0.6 – 0.7 \) bulk metal particles are also used. [7] However, since a filter change means an important loss in production, in this field of application the bulk material or sand filter actually does not serve as a filter, but is mainly used as a homogenizer and for pressure distribution. In this case an upstream central filter is used.

Membranes according to Fig. 1 (f) require low viscosity media, so that the pressure drop in the small pores and thin filter layers (cut off) is not too high. The membranes consist of several layers supporting the actual filtration layer. [8]

### 2. Static Mixers in the Processing of Plastics

Mixing is defined as the dispersion of a component in at least one other for which location changes are required. Static mixing means homogenizing without moving parts. The mixer itself creates the mixing effect by repeated and continuous dissociation, expansion and re-arrangement of the components as shown in Fig. 4. [9]

The mixer has open intersecting flow channels. The polymer is continuously cut into layers by bars which are at an angle to the pipe axis and flow direction and across the complete melt channel. The greater the number of mixing elements (which are located at 90° to one another) the number of layers increases and the thickness is reduced.

Due to this design the pressure loss through the mixer can also be kept relatively low, this is the reason why it can also be used for shear sensitive polymers.

Variations in concentration, temperature as well as speed are compensated over the pipe cross section.

By using correctly chosen and dimensioned static mixers a more homogenous material flow in the mould or die as well as a closer tolerance of the extrudates can be achieved. This homogenisation permits the stabilization of the process and increased productivity.

![Fig. 4: Static mixer, configuration and effect on the melt](image)

Thus a consistent polymer flow is created which can be handled more easily and more safely in a subsequent process such as the manufacture of blown films, cast films, mono - and biaxially oriented films, fibres and injection moulded parts. Due to this equalisation, costs often can be reduced by an increased output rate and/or reduced rate of scrap material.
3. Homogenisation with Screen Elements

3.1. Mixing Effect of Screen Elements

In this context the question arises, if filtration media can at least be useful to improve the micro-dispersion.

If a fluid flows through a channel with a constant cross-section, this is a shear flow. The location of the Filterpack is such that the free surface area is constantly changing. This means that in addition to the shear flow, a “stretch” flow also takes place, which leads to an orientation of the particles. If there are areas where the flow is reduced, an inhomogeneous flow can be created.

A special segregation effect can be observed with regard to viscoelastic fluids. If such a fluid with regularly spread isometric particles of different sizes is filled between two microscope plates (Fig. 5), distinctive chain structures are generated after repeated agitation where the particle fractions are nearly completely isolated [10]. The basic conclusion for polymer processing is therefore, that well mixed systems can be segregated in rheologically poorly designed screen changers or dies with dead areas or areas of low agitation.

In order to decide whether in a screen pack with particles of e.g. $\bar{x} = 240 \, \mu m$ and a height of $L = 24 \, mm$ the flow condition is (a) or (b) according to Fig.6.

![Fig. 5: Structuring effects with a periodic shear in a viscoelastic fluid.](image)

![Fig. 6: Possible flow conditions in a particle package](image)
Studies were made in a spin pack. The fluid used was transparent and coloured epoxy resin, which hardens. After the filtration bed was sawn open and the surface was polished the behaviour of the pigments became visible. Fig. 7 shows the findings. Cross-flows do not appear, there is no partitioning and re-arrangement of single flows and therefore no dispersion has taken place.

![Fig. 7: Line of the flow in a sand filter [7]](image)

Trials, where the flow passes deflectors, have shown that with a perpendicular flow the flow strand closes again after having passed the obstacle (Fig. 8). The flow strand is only expanded and split if an inclined deflector is used. If these findings are transferred to screen packages, wire cloth filters must take a larger amount of space in flow direction.

![Fig. 8: Influence of deflectors on flow [11]](image)

From these considerations, we can reach the conclusion that wire cloth, with mesh wires that are all at right angles to the melt flow, as shown in Fig. 9, can only have a negligible mixing effect.
With this type of weave, the polymer flows more or less at right angles to the warp and weft wires resulting in division and downstream a reunification of one and the same flow strands. However, wire cloths with angularly oriented warp wires (deflectors) as for example is the case with Plain Dutch Weave shown in fig. 10, their similarity to a static mixer is striking. On the large scale illustration and the CAD drawing, this becomes quite apparent:

The polymer melt flows through the tissue and hits the warp wires which according to the wire diameters used are arranged at a certain angle to the flow direction. While flowing around the wire, the melt has to be re-arranged once more in order to pass the neighbouring wire. Thus the melt flow is at least split up twice leading to a consolidation of different flow strands afterwards. However, it was observed that the mixing effect of single, round wires is not very efficient.

This effect is improved, if special warp wires are used. For these wire cloths, square cross-section weft wires are used (Fig. 9).
The square cross-section improves the splitting and subsequent merging of the flow strands. Of course, the mixing effect of these wire cloths cannot be compared to the effect of static mixers, since the flow length is much shorter. Thus only one or a few installations are used, in static mixers often more than five, which furthermore are staggered. Attention should also be paid to the fact that, with regard to common static mixers, the distance between the different deflectors is measured in millimetres, in order to obtain a mixing effect in the melt channel, which mostly turns out to be one dimension (centimetre) larger. However, as for the wire cloths the distance between the different warp wires a few 1/10 mm, a mixing effect in the range of a few mm is to be expected.

A comparison of the different kinds of wire cloths, by means of the above-mentioned test method using hardening and partially coloured epoxy resin, is not applicable since the range in which a mixing effect is to be expected is too small and potential dispersions are superimposed by diffusions and gravitation processes during hardening.

However, basically it can be assumed that there is a dispersion of the different material flows in the microscopically range. Variations in temperature can be homogenised as soon as the right peripheral conditions are adhered to. This evidence was provided by R. Sebastian [7] in extensive test series.

3.2. Dispersion Effect in Filtration Elements

In plastic melts in which additives are introduced, primary particles often stick together forming agglomerates which are simple concentrations of these particles. Dispersion is defined as the part of the process in which the agglomerates are broken into primary particles and their complete coating of each single primary particle with the polymer film.

The dispersion effect of screens and other installations depends on the stress the different particles are exposed to. Surface tensions, shear stresses and rotations put stress on agglomerates. Positive and negative pressure regions are generated in the periphery of the particles as shown in Fig. 12. The level of the shear stresses normally is not sufficient to destroy compact primary particles; however, its effect on agglomerates is remarkable.
For this, different studies were made with a PET melt to which TiO$_2$ – particles were added as a masterbatch [13]. A poor quality masterbatch was deliberately selected so that many agglomerates could be found in the polymer.

An SEM-micrograph of the polymer with TiO$_2$ particle agglomerates is shown in Fig. 13.

E. Schröder [14] has run test series under similar conditions where the wire cloth screens shown above were used for filtration. These were framed in 5-layer screen packs and inserted into the melt flow. The test result is shown in Fig. 14.
First of all it is possible to conclude, that the pressure differential without a dirt cake is the lowest when using a square mesh wire cloth - and the highest when using Micromix. Among other things this is due to the fact, that the surface for free passing of a square mesh wire cloth is much larger than the surface of a weave with round or square warp wires.

Fig. 15 shows the same result in a different way. Here the relative pressure is shown in relation to the initial pressure against time.

![Graph showing relative pressure differential increase against time](image)

**Fig. 15: Relative pressure differential increase against time**

It becomes obvious that the pressure increase is the smallest for Micromix. There could be two reasons for this:

1. The wire cloth emits less particles, i. e. the emitted marginal particle size is larger despite the same filter fineness being used (absolute filter fineness).
2. Particles and agglomerates are being destroyed or deformed at the screen cloth and can then pass through the screen cloth without clogging it.

Standard Dutch Weaves with a round wire cross-section also show only a slight increase in pressure drop.

In order to verify, which of these two statements is right, further filtration tests were carried out with the filtered material. In this case it is the so-called pressure filter test, in which the gradient of the pressure above time is recorded for a defined test screen.

The already pre-filtered material, which was pelletised afterwards, was re-plasticized and pressed through the pressure filter testing wire cloth. The result of this test series is shown in Fig. 15.
This test leads to the conclusion that statement 2 is correct. The agglomerates are sheared by the Dutch Weave or Micromix respectively and can afterwards pass through the wire cloth of the test screen. Thus there are more primary particles which can pass through the fine test screen as well. As for the square mesh tissue, only agglomerates of a certain size are held back. Smaller agglomerates continue to pass through and accumulate during the subsequent pressure filter test in front of the test screen this way generating a higher and/or quicker pressure rise.

This dispersion effect is even higher, the thinner the dirt cake is and could be observed in a very distinctive way, when Micromix wire cloths were used. A reason for this could be the moment of impact. The „impact“ on the wire cloth is more intensive, if the cross-section of the warp wires is square as compared with the round cross-section of the normal Dutch Weave. The freer the wire cloth, the more intensive the impact, which finally leads to a destruction of the agglomerates. To assure this, the screen surface must be renewed constantly within the melt flow without leading to a frequent disturbances of the manufacturing process in order to obtain high economic efficiency. If a filter element change only can be effected by stopping the equipment or only be achieved with considerable fluctuations in the process, economic production cannot be achieved.

4. Filtration System RSFgenius for Static Mixer Screens

The fully– automatic, pressure- and process-constant Filtration System RSFgenius, developed by Gneuss Kunststofftechnik GmbH, and has proven its reliability over the years.

The RSFgenius is a guarantee for consistently high extrusion quality. [15]

Basically the RSFgenius consists of three parts: and inlet and an outlet block, and the rotary disc, located between these blocks. (Fig.17). The seal between the rotating disc and the blocks is achieved by an extremely thin gap and very hard and flat surfaces.
Fig. 17: Configuration of the RSFgenius

This configuration ensures that all the components are completely isolated from environmental influences such as e. g. oxygen. On the disk there are several screen elements arranged in a ring pattern, which moves through the melt channel.

Fig. 18: Functional principle RSFgenius
When the polymer melt flows across the filter medium, particles accumulate on it (dirt cake), leading to a slight increase in the pressure differential. The control system responds to this pressure increase and indexes the filter disc by approx. 1° at a time, as shown in Fig. 18.

Thus contaminated filter area is continuously moved out of the melt channel and fresh, clean filter area is moved into the channel. This system permits process- and pressure-constant operation of the filtration system. The maximum variation of the pressure differential across the filter ($\Delta p$) is 2 bar.

The contaminated filter area is automatically cleaned before re-entering the melt channel. The dirt cake is removed by a high pressure segmental back-flush system. For this, already filtered melt is withdrawn from the outlet side into a hydraulically powered back-flush chamber and shot at high pressure at approx. 30-80 bar across the reverse side of the filter elements. The contaminated material is subsequently discharged to the outside. This cleaning pressure (which can be adjusted according to the process requirements) is controlled constantly. Only a small segment (approx. 1% of the screen face) is cleaned at a time, so that each time there is a high defined pulse available. Via the hydraulic control the travel of the back-flush piston (=amount of melt to be cleaned) as well as the speed (=intensity of cleaning) are freely adjustable, so that for each application an optimum small quantity is used for cleaning. By this method of operation the screens are cleaned practically 100% and, depending on their filter fineness, can be re-used up to 200 times.

Due to the constant pressure, trouble-free processing is possible ensuring 100% availability of the equipment.

Thus a constant high quality of the melt is guaranteed at any time - regardless if the filtration system is in standby position, indexes, back-flushes or if the screens are changed. In most cases, the return of investment for this Filtration System is less than one year. [16]

### Case example

Due to an insufficient mixing within the compounder, the world-leading manufacturer of PET masterbatches produced large quantities of a masterbatch filled with carbon black for colouring of PET fibres, which could not be sold due to the formation of agglomerates. Trials with conventional screenchangers showed, that the used screens with a filtration fineness of 12 µm were able to destroy or retain the carbon black agglomerates. However, at a given throughput rate of 140 kg/h, a screen with a diameter of 90 mm was plugged within a very short time (< 5 min.) so that it was necessary to change the screens quite often. After the filtration with the pressure-constant and fully-automatic Filtration System RSFgenius 90, the defective batch was saleable. The amortisation period of the Filtration System was 8 months.

### 5. Conclusion

Thanks to the fully automatic and pressure-constant Filtration System RSFgenius, it is for the first time possible to obtain a noticeable dispersion and homogenisation effect. Thus this system is particularly suited for manufacturers and processors of top-quality masterbatches and compounds.
Fig. 19: Example of RSFgenius 300L (patented) specifically designed for a twin-screw compounding extruder
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