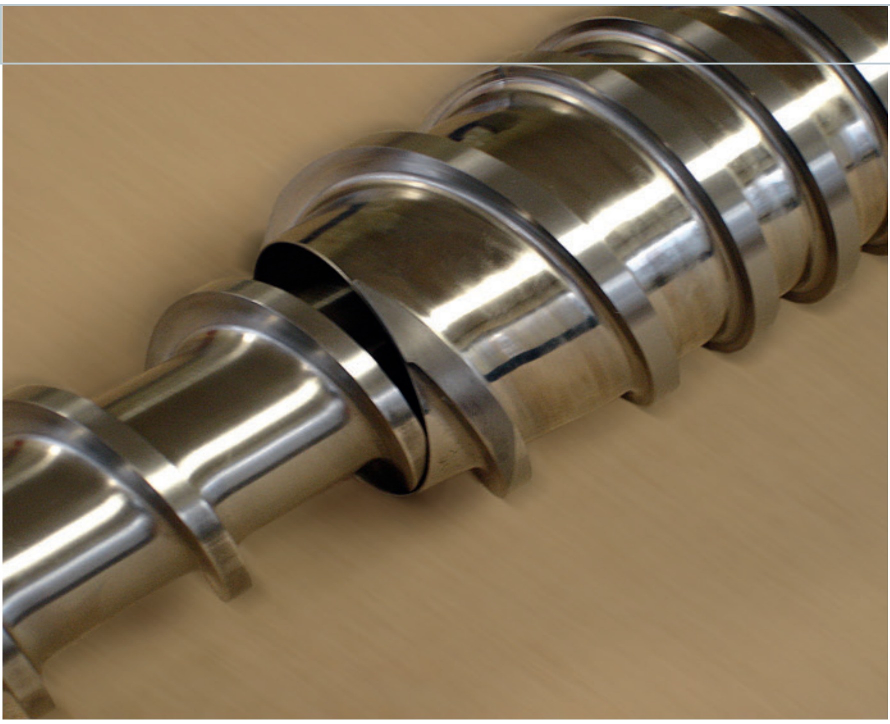

**Degassing Extruder.** A new extrusion concept increases flexibility in the processing of different raw materials as well as raw material mixtures. Throughput differences due to varying bulk material characteristics can be compensated for and the full efficiency of extrusion is reached independently of the rheological/thermodynamic characteristics of the material.

# New Degrees of Freedom

JOHANNES WORTBERG
HASSAN RAHAL
ROBERT MICHELS

During the processing of hygroscopic thermoplastics in extrusion processes steam bubbles develop in the melt due to the humidity contained in the raw materials. These and other volatile materials lead to negative influences on the characteristics of the final product. Thus degassing extruders are frequently used for removing the humidity as well as remaining monomers and other volatile materials from the plastic melt.

Translated from Kunststoffe 5/2008, pp. 70–75

## Conventional Single Screw Degassing Extruder

A conventional single screw degassing extruder (Fig. 1) essentially consists of a feed zone and two consecutively coupled multi-zone screws with an intermediate more deeply cut, partly filled, pressure-free degassing zone. The first screw stage (1) takes care of the input and plasticizing of the material. The degassing zone follows. In it through an opening in the cylinder, usually aided by a vacuum pump, the humidity and other volatile materials are degassed from the melt. The screw stage 2 works purely as melt conveyer with pressure build-up for the output of the degassed melt.

One differentiates between smooth barrel extruders (here also called conventional extruders) and grooved feed extruders. If one works predominantly or exclusively with new materials in the form of pellets the extruder can be equipped with an input promoting feed zone (grooved feed zone). If recovered material (cut up foil material or cut up products such as cups, covers, etc.) is to be included, then in practice extruders are preferably equipped with a smooth feed zone. Smooth barrel extruders have



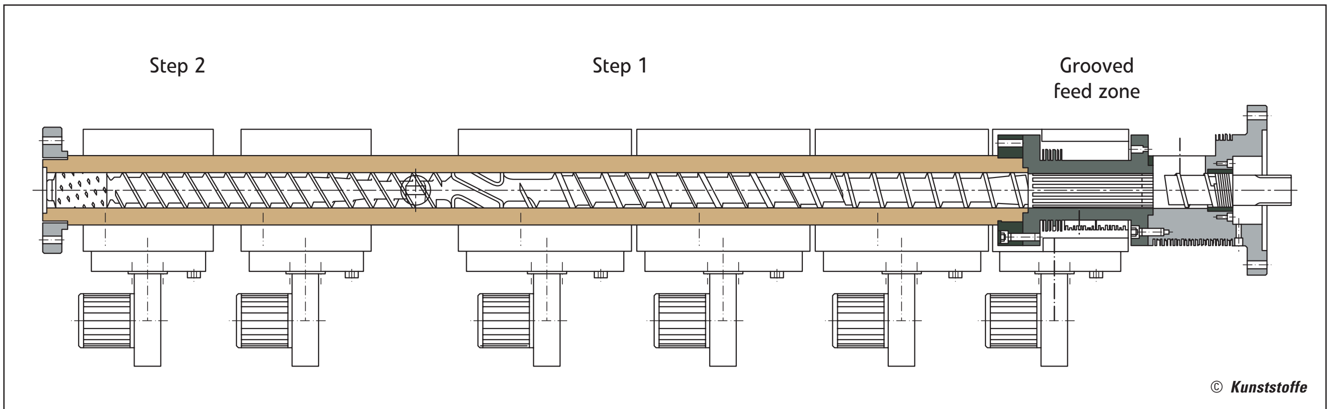


**Fig. 1. Degassing plastification unit with air-cooled grooved feed zone and barrier screw** (photo: ETA Kunststofftechnologie)

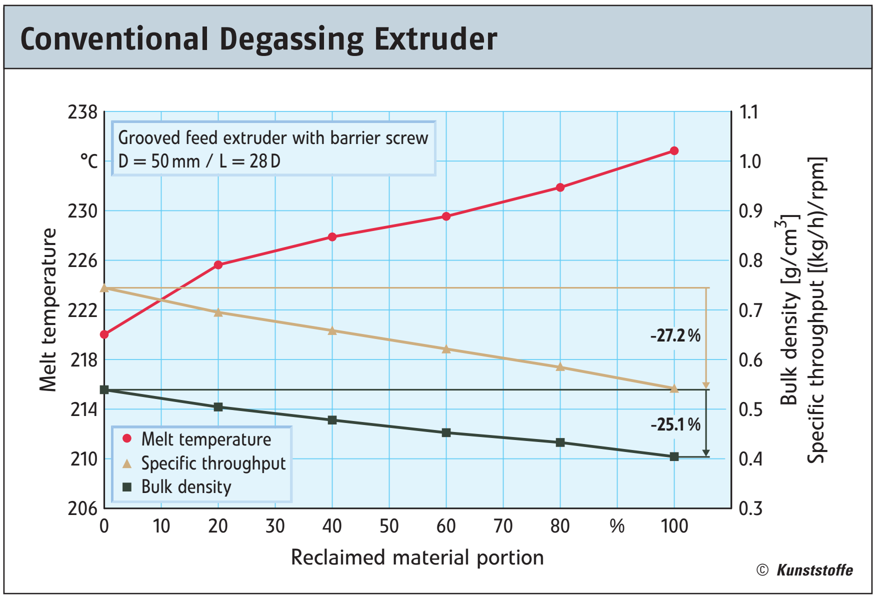


**Fig. 2. Specific throughput and melt temperature of a degassing extruder as a function of the reclaimed material portion [2]**

more deeply cut screws in their feed region, and their throughput is not determined only by the material handling in the feed area, they therefore react "more easily" to fluctuations in shred size and bulk density than grooved feed extruders and permit mixing of larger amounts of recovered material. However, integration of a melt pump between the extruder and the nozzle is usual for compression and even melt conveying through the die.

## Process-technical and Economic Requirements

For reasons of economy in practice degassing extruders are frequently not used for processing only one raw material and/or raw material mixture, but for processing a broad spectrum of raw materials and/or raw material mixtures of new products and recovered goods. From practical experience with extruders with grooved feed zones it is well-known that the feedback of recovered goods (as ground stock) and/or increasing the portion of recovered goods in the mixture leads to substantial lowering of the bulk density of the raw material mixture to be processed and to degradation of the solids conveying behavior.

In order to use degassing extruders without process engineering problems (e. g. flooding the degassing opening) economically, the mechanical conveying capacity of the screw stages before and after the degassing zone must be co-ordinated during design of the screw geometry. A higher mechanical conveying capacity of the first screw stage causes "flooding" of the degassing opening; that is the melt runs out of the degassing opening. If the mechanical conveying capacity of the second screw stage is substantially smaller, the efficiency of the extruder is not utilized. Optimal co-ordination of the two screw stages can take place only if the screw geometry is designed for only one raw material and/or only one raw material mixture and a fixed operating point. The mechanical conveying capacity of the screw before and after the degassing zone cannot be adapted thus to a broad spectrum of raw materials and raw material mixtures, and so flooding the degassing opening in individual cases cannot be avoided. Flooding the degassing opening can surely be prevented if the screw is designed for the raw material mixture with the lowest throughput in the second screw stage and the highest throughput in the first screw stage. Thus for all mixtures the best possible throughput performance of the screw is not fully used. That is, for processing different raw material mixtures it is not possible to do without a time-consuming screw change.

In practice one makes do with different methods in order to process raw material mixtures with different portions. On the one hand it is possible to feed too little raw material into the feed opening with a dosing screw so that the mechanical conveying capacity of the first screw stage is determined separately from the adjustable rotation rate of the dosing screw and adjusted to the mechanical conveying capacity of the second screw stage. A further possibility is to pre-compound the raw material mixtures.

## Increasing the Production Capacity

If one first assumes constant raw material characteristics, then an increase of the mass throughput for a fixed extruder size

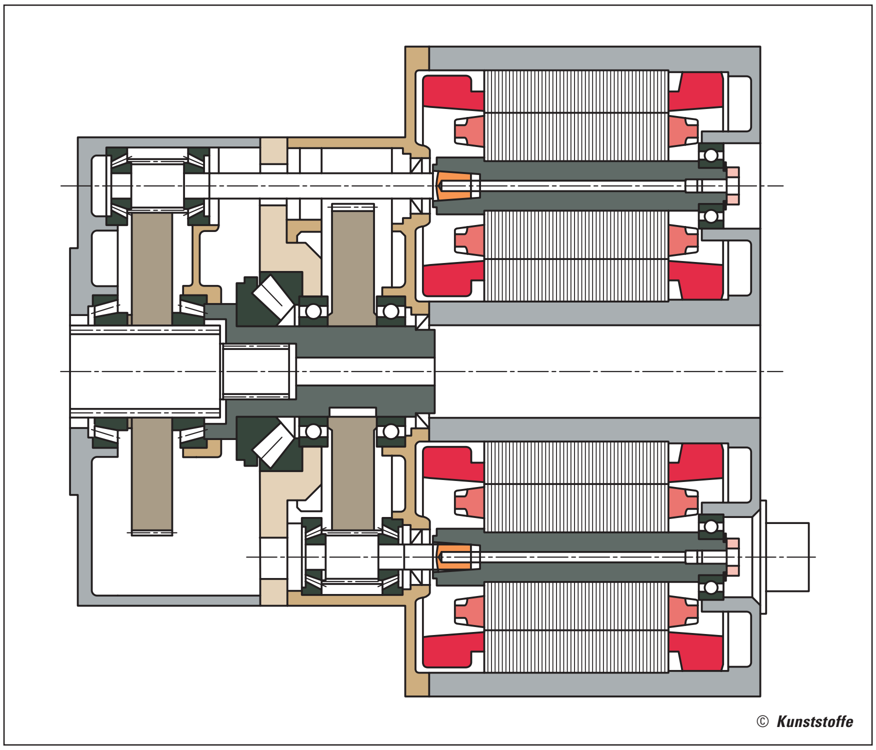


**Fig. 3. Multi-motor concept**

## System Comparison

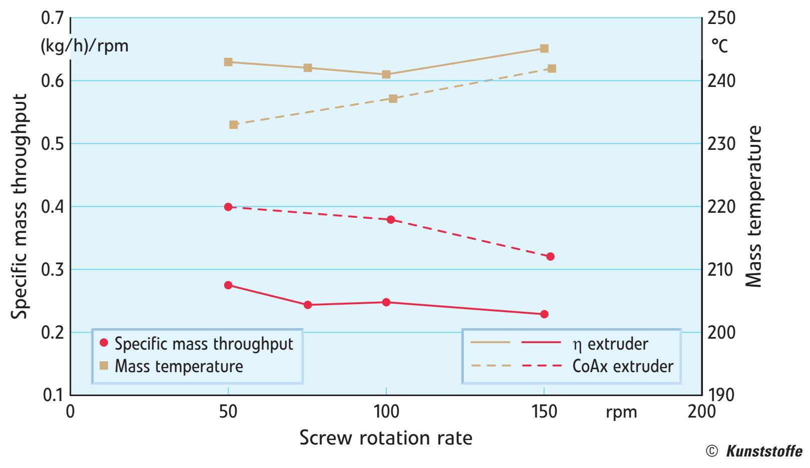


**Fig. 4. Specific mass throughput and mass temperature versus screw rotation rate**

can take place in two different ways: either by an increase of the specific mass throughput (ratio of mass throughput to screw rotation rate) or by a higher screw rotation rate.

A well-known problem here is the decrease of the specific throughput for increased screw rotation rate, which entails an unfavorable rise of the melt temperature [1]. With any geometry of the input and feed zone (cylinder and screw) the specific mass throughput is strongly affected by the bulk material characteristics of the material to be processed. Compared with new material pellets, for example, recovered material always has a smaller bulk density. During mixing with new material pellets also the mixture has a smaller bulk density and it is the smaller the greater the recovered portion is. This then entails smaller specific throughput and higher melt temperatures during processing. Fig. 2 shows the raw material bulk density as well as the specific throughput and the melt temperature for processing polystyrene with a degassing extruder as a function of the recovered material portion [2]. It is to be recognized that with 100 % recovered material a throughput performance around 27 % smaller is obtained compared with 100 % new material, whereby the melt temperature is substantially higher at the same time. However, it must be noted here that the mechanical conveying capacity of the screw zones is designed for processing 100 % new material.

New machine concepts with increased degrees of freedom in operation of the machines can support the advancement of degassing extruders. In addition this increased degree of freedom makes the processing of different polymers and the feedback of reclaimed material possible with different mixture portions, which represents a significant advantage with degassing extruders.

## Melt Production Independent of Bulk Material Characteristics

The question of an adjustable feed rate arises due to the requirements described above. In other words: The mechanical conveying capacity of the feed screw (and/or the first screw stage for degassing extruders) is to be changed independently of the rotation rate of the main screw (and/or degassing screw). If this condition can be fulfilled, then the melt production of the main screw will always be optimally utilized independently of the bulk material characteristics of the polymer and/or the raw material mixture. In addition optimal degassing of the melt in the second screw stage can be ensured.

If a separately controlled input system is envisaged, with which the solid material stream can be controlled, then a usable degree of freedom can be gained through a feed screw propelled independently of the plastification screw [3, 4], from which elementary advantages are derived:

- The reduction of the specific mass throughput for increased rates of rotation can be reduced or compensated for completely (particularly within the high-speed range).
- For materials with high friction values and for material mixtures with a smaller bulk density the feed rate can be increased as the feed screw is operated as a stuffer machine.
- Thus the rise in melt temperature at higher rotation rates can be reduced or avoided. In addition, for material mixtures the melt production of the main screw can be utilized in this way without making a screw change.
- Through the change of the main screw rotation rate with a constant throughput and/or at a constant feed screw rotation rate there is the possibility of affecting the mixture quality and the melt temperature. In addition, with the main screw rotation rate the pressure build-up capacity of the second stage of the degassing screw can be changed for a constant throughput.
- With material mixtures, which are inclined to production fluctuations, they

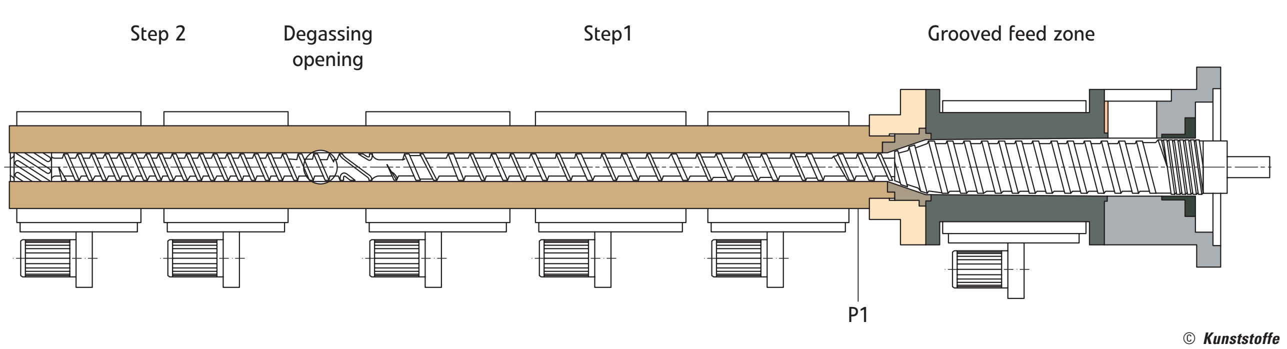


**Fig. 5. Degassing extrusion with a feed screw provided with an adjustable drive independent of the main screw**

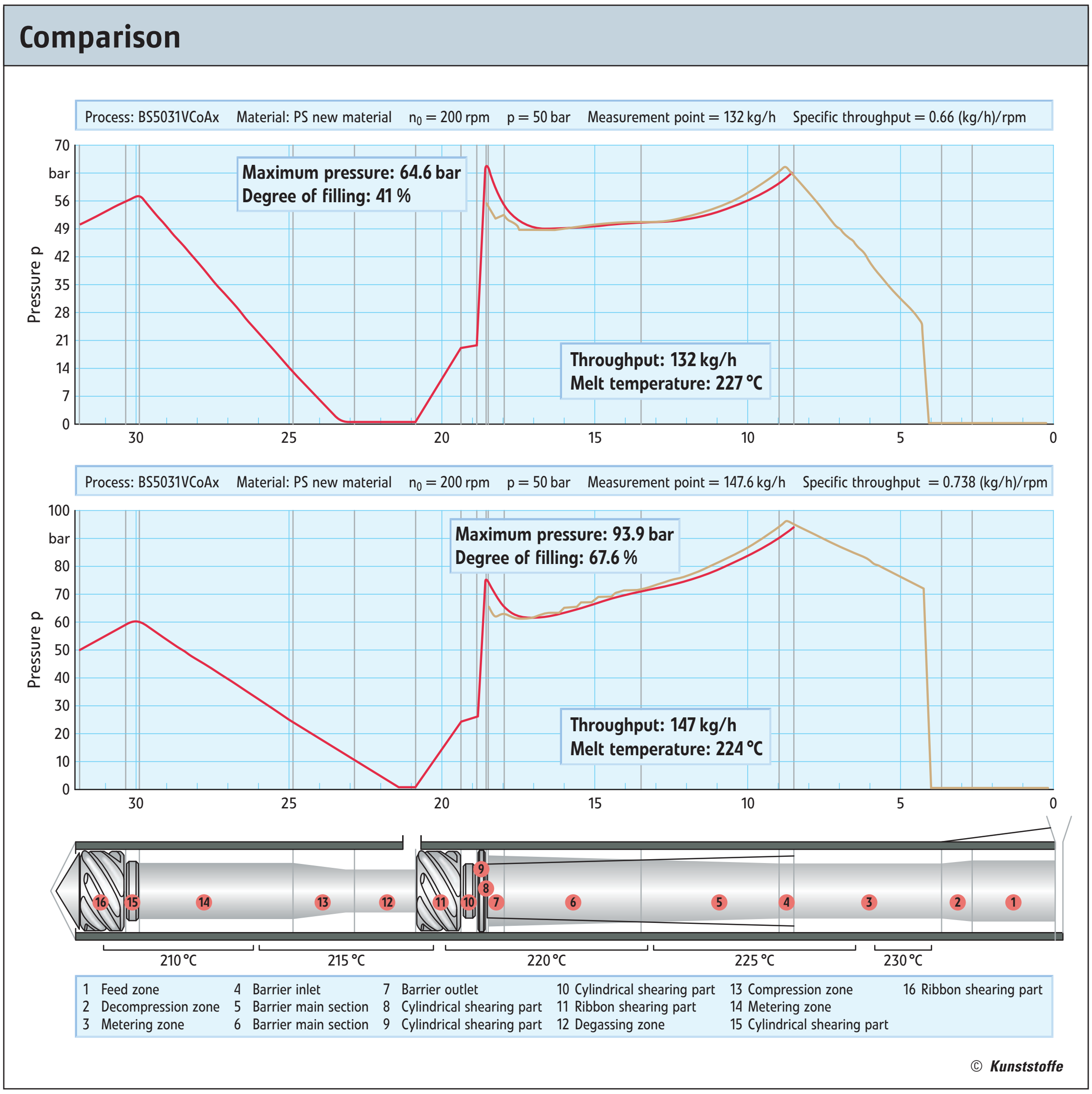


**Fig. 6. Computed pressure profile for the processing of 100 % polystyrene new material (main screw rotation rate: 200 rpm)**

can be compensated through the feed screw rotation rate, while the melting and mixing in the main screw is uncoupled from it at a constant rotation rate.

- Through combination of the coaxial feeding system with a degassing plastification unit the feed rate can also be increased for very different raw materials up to reaching the maximum degassing capacity and at the same time melt exit from the degassing opening can surely be avoided.

At the Institute for Product Engineering (IPE) of the University of Duisburg-Essen, Germany, in co-operation with ETA Kunststofftechnologie GmbH, Troisdorf-Spich, Germany, an innovative drive on the basis of a modified multi-engine concept is used with the newly built extruder [5] (Fig. 3). In order that two independently selectable screw rotation rates can be used, the drive axle of one engine is extended, whereby this propels the feed screw, while the remaining engines propel the actual plastification screw. Through combination of the coaxial feed screw with the modified multi-motor drive concept an independent solid feed aggregate [1, 6] is obtained that achieves absolute integration in the extruder and in function mode is viewed as exactly the same as every other input area.

Fig. 4 shows first results [6]. Here a comparison of two specific throughputs is given. For the 50 mm extruder with closed cylinder this concerns a conventional single screw extruder with a grooved feed zone and barrier screw. The material used was a polypropylene foil material with a bulk density of only 0.22 g/cm³.

On the basis of this concept a degassing extruder (Fig. 5) was developed further in co-operation with ETA Kunststofftechnologie. The CoAx degassing extruder has already been presented at the K 2004. The extruder has a double threaded feed screw (D= 70 mm) and a barrier degassing screw (main screw) with nominal diameter 50 mm with an effective screw length of 31 × D. In the feed zone the cylinder inner surface is provided with axial grooves, whereby this zone is air-cooled like all other zones. At the IPE this extruder was tested with a multiplicity of raw materials.

A further possibility of affecting the rotation rates of the two screws exists in the input of the rotation rate ratio and the rotation rate of one of the two screws. If the machine is equipped with an additional sensor system a pressure/torque control can be used in connection with a throughput control.

## Computation of the Pressure Profile

Knowledge of the pressure pattern linked with the throughput is an important condition for the design of a single screw extruder since this affects the feed procedures, the wear and the pumping of the melt.

From Fig. 6 it is evident that with given throughput of 132 kg/h with a main screw rotation rate of 200 rpm (the rotation rate ratio of the CoAx barrel extruder screw corresponds to an extruder with a one-piece screw) the screw after the degassing opening is not completely filled and a further increase of the throughput by increasing the feed screw rotation rate is possible. With a throughput of 147 kg/h the flow limit is reached (Fig. 6 bottom) and the melt temperature is reduced by about 3 °C. A further increase of the feed screw rotation rate leads to flooding of the degassing opening. This was also seen in the experimental investigations. The computation further shows a lower pressure at the end of the feed zone. The computational results agree well with the experimentally determined pressure. Here a computation of the pressure profile for the mixture requires the actual material data of the mixture.

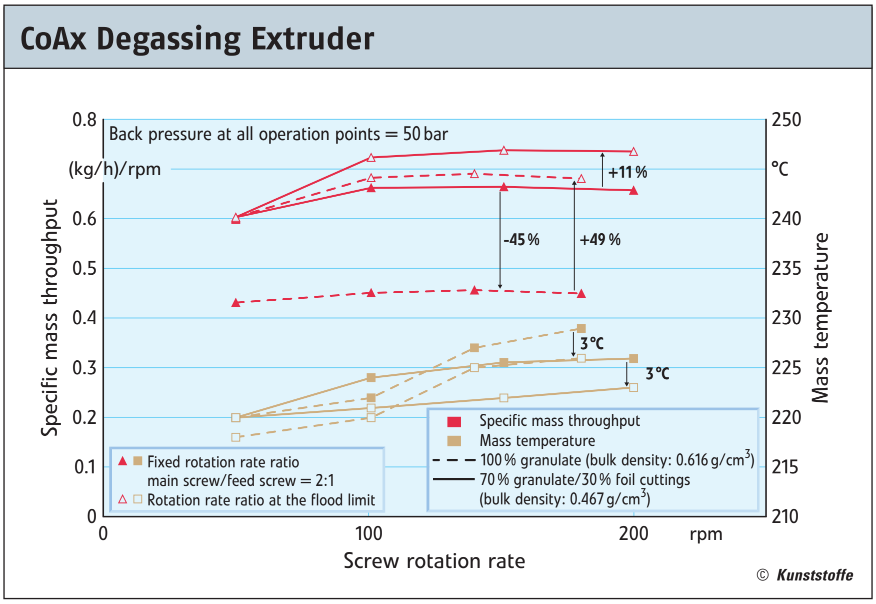


**Fig. 7. Specific throughput of the CoAx degassing extruder 50/31D processing highly transparent polystyrene**

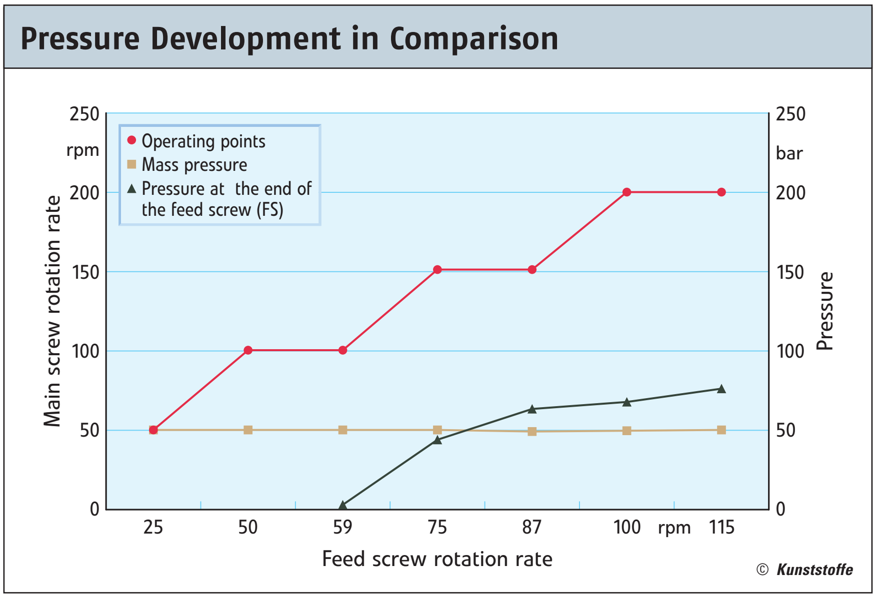


**Fig. 8. Pressure behaviour for processing polystyrene new material**

## Experimental Results

The conditions in a conventional degassing extruder with a single screw can be imitated with the CoAx extruder if the main screw (MS) and the feed screw (FS) are operated at a fixed rotation rate. Precisely at a rotation rate ratio of exactly 2:1 flooding of the degassing opening begins for the processing of 100 % polystyrene granulates and a main screw rotation rate of 50 rpm. That would for example thus be the reference point for which a conventional one-piece degassing screw would be designed. Fig. 7 shows the results of extrusion tests with a highly transparent polystyrene (PS).

During the processing of a polystyrene mixture (70 % granulates and 30 % foil shred) the specific throughput was about 45 % lower than for processing 100 % granulates with the same rotation rate ratio of 2:1. The reason lies in the fact that such mixtures have a substantially smaller bulk density compared with granulates and have worse feed behavior.

The separate rotation rate control of the two screws permits an increase of the feed screw rotation rate of the CoAx extruder, which leads to balancing and/or avoidance of the reduction of the specific mass throughput with the processing of a granulate/shred mixture. In this way higher specific throughput can be reached up to the limit given by the flooding of the degassing opening, on the average around 49 % higher specific throughputs, whereby at the same time reduction of the mass temperature by around 3 °C was achieved. The values of the specific throughputs even lie over the values reached during the processing of 100 % granulate with a fixed rotation rate ratio.

With increasing rotation rate of the main screw the limit on the rotation rate ratio mentioned above can be reduced when processing 100 % pellets. In other words: The feed screw rotation rate could be further increased for a certain operating point of the main screw. Thus up to the flood limit throughput increases were obtained of 11 % on the average. The consequence is a reduction of the mass temperature by around 3 °C. With increasing screw rotation rate an increase in the melt temperature can be seen, but here the mass temperature is still clearly under the mass temperature reached with a rotation rate ratio of MS/FS = 2/1.

## Pressure Behavior

Fig. 8 shows the appropriate pressure development at different screw rotation rates of the main screw and feed screw. The mass pressure was set to a value of 50 bar for all operating points using a throttle tool. This value corresponds to the pre-pressure of the melt pump plus that of the melt filter. It is to be recognized that on the one hand the pressure at the end of the ▶

feed screw (P1) was at a low value during the entire test series. For processing the mixture it builds up only starting from a feed screw rotation rate of 100 rpm and a main screw rotation rate of 140 rpm and remains under the mass pressure for higher screw rotation rates. On the other hand no precipitous rise is to be seen of this pressure in the case of an increase of the feed screw rotation rate at a constant screw rotation rate of the main screw, which means that the main screw is partly filled.

## Summary

Many elementary advantages can be obtained through an additional degree of freedom when running a degassing extruder. Thus throughput differences can be balanced due to varying bulk material characteristics. Likewise the full efficiency of the degassing extruder can be utilized optimally independently of the bulk material and the rheological/thermodynamic characteristics of the material.

The new extruder concept offers greater flexibility in processing different raw materials/raw material mixtures than today's usual degassing extruders. This flexibility makes economic advantages possible, which compensate for the higher capital outlays of the more complex construction method in a justifiable timeframe due to the throughput increase. This CoAx extruder can be used particularly favorably in the area of the production of products with secondary raw materials. As further applications the processing of polymers/mixtures to be degassed should be mentioned. ■

### REFERENCES


1 Wortberg, J.; Rahal, H: Einschneckenextruder mit schnelldrehenden Schnecken, VDI-Verlag, Düsseldorf 2004, pp. 65–84
2 Michels, R.: Verbesserung der Verarbeitungsbandbreite und der Leistungsfähigkeit von Einschneckenextrudern, Dissertation, Universität Duisburg-Essen 2005
3 Dalhoff, W.: Systematische Extruderkonstruktion, Habilitationsschrift, Otto-Krauskopf-Verlag, Mainz 1974
4 Schenkel, G.: Kunststoff-Extrudertechnik, Carl Hanser Verlag, München 1963
5 Knödler, W.; Wortberg, J.: Getriebemotor, Gebrauchsmusterschrift DE 20206979, Anmeldungstag: 02.05.2002
6 Kaczmarek, D.: Feststoffförderung und alternative Plastifizierung bei der Extrusion, Dissertation, Universität Duisburg-Essen 2004


### THE AUTHORS


PROF. DR.-ING. JOHANNES WORTBERG, born in 1951, has the Chair for Construction and Plastics Machines in the Institute for Product Engineering (IPE) at the University of Duisburg-Essen, Germany; johannes.wortberg@uni-due.de

DIPL.-ING. HASSAN RAHAL, born in 1971, studied mechanical engineering at the Technical University of Imenau, Germany, and was Research Assistent at the IPE.

DR.-ING. ROBERT MICHELS, born in 1967, works as a Project Manager at ETA Kunststofftechnologie GmbH, Troisdorf Spich, Germany.