All about Plasticizing Screws

Part 2 of the Series Deals with Basic Methods for Evaluating a Screw Geometry

Once the basic layout of a plasticizing unit has been determined and the appropriate injection unit has been selected, the development of the screw geometry enters its decisive phase. To be able to carry out the practical test in a resource-saving manner, the designers use simulation tools to assess the screw geometry. What is important here is explained using a 3-zone screw as an example.

The screw geometry is finely optimized in several calculation steps until the desired result is achieved. Subsequently, test screws are manufactured in original size and tested in practical tests with various material types

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The basic design of a plasticizing unit and the correct choice of the injection unit were discussed in the first part of this series. The way to determine the required screw diameter on the basis of the shot volume was also explained. By applying the formula for the mean residence time, the utilization rate and the thermal material load can be estimated; the latter needs to be kept low to achieve high end product quality. The maximum injection pressure and the available screw torque are additional key variables for successful injection molding production.

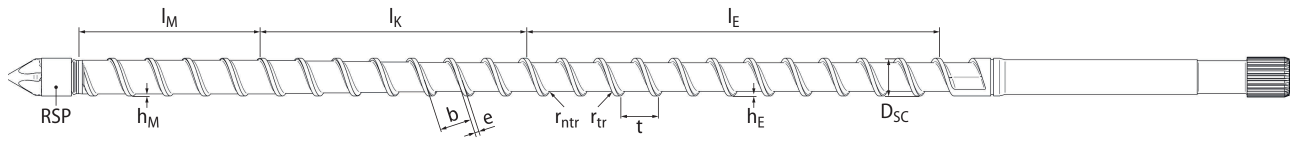
These considerations (see ***Kunststoffe*** *international* 10/2020, pp. 27-29) form the basis for the choice of the barrel-and-screw combination and also the starting point for further optimizations. In the second part of this series of articles, the basic methods for simulative assessment of the geometry of a given screw are presented – using the example of a 3-zone screw.

Before All Experiments Comes the Simulation

The first question to be answered is what objectives should be pursued in developing a screw geometry. Often the goal can be clearly defined, such as increasing the flow rate, reducing the melt temperature, improving the quality of the blend, etc. The requirements become more complex as soon as the desired results are only indirectly linked to the screw geometry, or when they can be attributed to several causes, for example, when it is desired to reduce the formation of plaques, or when the wear behavior and conveying stability need to be improved.

Such multiple demands on screw aggregates often conflict with each other. Careful balancing of the layout is necessary to resolve such conflicts between several different objectives.

It has become common practice to optimize the geometry of a screw by way of simulation before the first tests are carried out with real experimental



D_{SC} = External screw diameter
L/D = Screw length in relation to the screw outer diameter
l_E = Length of feed zone
l_K = Length of compression zone
l_M = Length of metering zone
h_E = Flight depth of feed zone
h_M = Flight depth of metering zone
b = Flight width
i = Number of screw flights
t = Flight pitch
e = Width of screw thread
RSP = Ring check valve
r_{tr} = Radius of driving flank base
r_{ntr} = Radius of passive flank base

Fig. 1. Schematic diagram of a 3-zone screw with number of screw flights i = 1 Source: [2], C. Gornik; graphic: © Hanser

screws. With PSI/REX, Wittmann Battenfeld GmbH, Kottingbrunn, Austria, has a special software at its disposal for calculating the screw design. This software is ultra-modern and subject to continuous updates by targeted research carried out at Paderborn University, Germany.

While using the computer to calculate the screw geometry, the geometry can be varied extremely flexibly, and the resulting change can be immediately visualized on the screen. By running systematically through a pre-defined series of tests, it is possible to analyze the emerging trends. Finally, the results of all calculations are combined and compared. From the sum of this information, the corresponding screw geometry is developed and further optimized down to the last detail – until the desired result comes into view.

Experimental Screws in Original Size

Only then are experimental screws produced in original size and used in practical tests. Depending on the complexity of the task, several different experimental screws may be used to approach the objective from various angles. If these tests prove successful, the optimization process is completed. Where there is still room for improvement, the development loop is re-run.

Model Case for the Optimization fo the Screw Geometry

Next, the parameters of a standard 3-zone geometry shall be discussed, and their influence on the manufacturing process shall be illustrated by an example. In order to give a full description of such a geometry in terms of process technology, the following parameters must be known (**Fig. 1**).

From the number of geometry parameters for only a relatively simple standard 3-zone screw, it is already apparent that there is basically a multitude of possible variants even for this type of screw. In the case of more complex geometries, such as those found in barrier screws, screws with shearing and mixing sections or shearing/mixing screws, the number of geometry parameters is many times higher. Starting basically from the recommendations available in the relevant professional literature [1], the optimization of the geometry for a screw with a diameter of 50 mm (DSC) is calculated below as an example.

It is assumed that the length of the feed zone is 50 % of the total length of the screw and the lengths of the compression zone and metering zone should each be 25 % of its total length. We set the feed zone depth at 0.1 D, i.e. 5 mm. The flight depth ratio between the feed zone and the metering zone should be 2. The L/D ratio is assumed to be 22.

A variety of different calculations can be performed for a screw with these predefined parameters. The present discussion focuses on the melt throughput, the pressure curve or pressure build-up capacity and the melting process.

Basic Assumptions and Throughput Behavior

Further assumptions include the metering stroke of 85 mm and the cycle time of 35 s. The back pressure is set at 80 bar. To simulate moderate and realistic metering conditions for the material polystyrene (grade:PS 454N; manufacturer:

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Note

Part 1 of the series was devoted to the basic design of a plasticizing unit and the correct choice of injection unit and was published in ***Kunststoffe*** *international* (issue 10/2020, p. 27–29). In the 3rd part of this series of articles, the calculation results will be analyzed, and first steps towards optimization of the geometry will be outlined. It will appear in one of the next issues.

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Styrolution), a circumferential screw speed of 300 mm/s is assumed. The barrel temperature profile is slightly rising from the filling opening to the antechamber. All calculations are carried out for the 50 mm screw position (**Figs. 2 and 3**).

For the previously selected cycle parameters, the average metering performance is calculated at about 12.49 g/s for the present screw geometry. This means that the machine transports 12.49 g/s in the metering phase and thus takes about 12.7 s to plasticize 158 g of material. With a residual cooling time of more than 12.7 s, the machine can start a new metering stroke on time. But if plasticizing takes longer than the residual cooling time, the timing of metering impacts the total cycle time and thus reduces productivity.

The total output of 16,25 kg/h determines the amount of material consumption in the course of production. Since the screw does not dose during most of the cycle time, this output falls below the figure suggested by the average metering performance. The total output is the decisive parameter in dimensioning auxiliary equipment (dryers, material loaders, etc.).

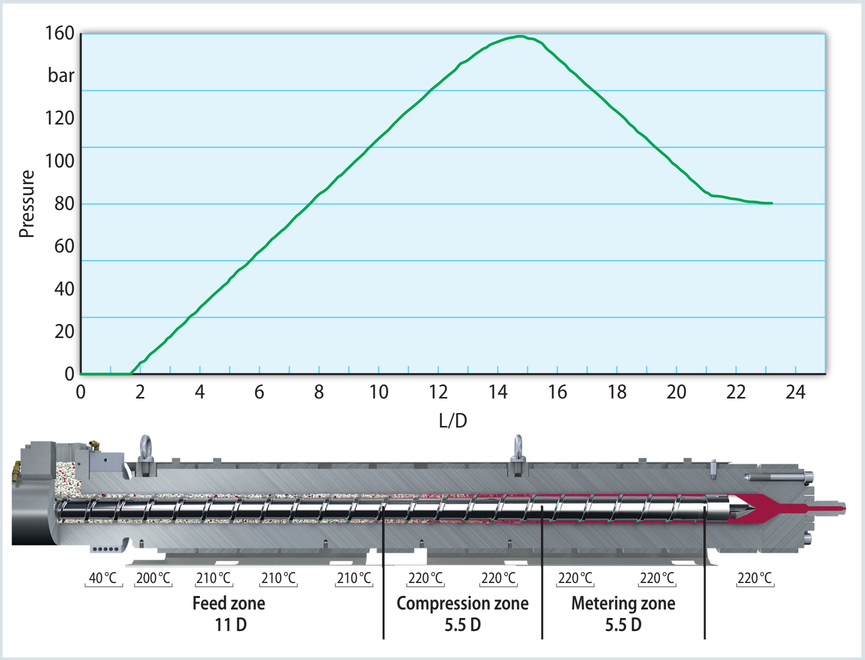

Fig. 2. Pressure curve along the screw at 50 mm stroke position Source: Wittmann Battenfeld; graphic: © Hanser

Pressure Build-up Capacity and Melting Process Curves

During the metering phase, the pressure inside the screw channel increases from the feed opening to the back pressure in the antechamber. Depending on the screw geometry, there may be one or more pressure peaks in between.

Figure 2 shows the pressure curve over the screw length. In this particular case, the pressure curve begins to rise at about L/D = 2 and reaches the peak pressure of about 160 bar at about L/D = 14.25. In the last zone of the screw, the metering zone, the pressure drops continuously up to the check valve.

The melting process (MP) is visualized via two curves (**Fig. 3**): the solid bed width (green) is shown for the corresponding screw channel section, and the proportion of molten material (red) during the metering process. In addition, the development of these two parameters towards the end of the cycle is illustrated (in orange and beige).

From the results, it can be concluded that this melting process promises good melting of the material, since the proportion of melt has already reached 100 % at about L/D = 8 (proportion of melt MP = 1). In other words, the solid bed width has been reduced to 0.

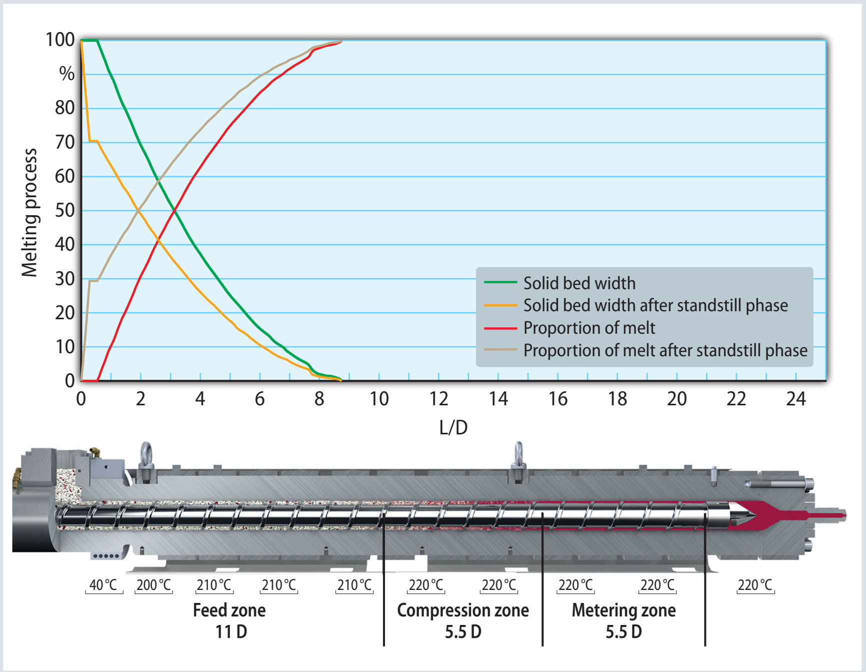

Fig. 3. Melting process curves for the screw at stroke position 50 mm towards the end of the cycle

Source: Wittmann Battenfeld; graphic: © Hanser

Conclusion

It can be seen that even with a "simple" 3-zone screw, the designer has a large number of geometric parameters at his disposal to achieve the development goal. With the simulation software, the actual experimental effort can be reduced significantly. However, the results of the simulation cannot replace the practical experiments, since not all boundary conditions can be considered or are known. In a closed environment they show trends and possible need for action. ■