Polymer Single Screw Extrusion with Metered Feeding

Krzysztof Jan Wilczyński

Polymer Processing Institute, Warsaw University of Technology,
02-524 Warsaw, Narbutta 85, Poland, a.lewandowski@wip.pw.edu.pl

The state-of-the-art is presented for composite modeling of single screw extrusion of polymeric materials. The flood mode of feeding and metered mode of feeding are considered. A new inverse approach of composite modeling for metered fed single screw extrusion is discussed. Some experimental and theoretical results of the study are presented. The polymer melting behaviour and degree of filling of the screw channel during the process, as well as the pressure and temperature development are discussed.

Keywords and phrases: Polymeric Materials, Single Screw Extrusion, Composite Modeling, Metered Feeding, Polymer Melting.

Introduction

Extruders in the polymer industry come in many different designs, and they are divided into single screw and multi screw extruders.

The single screw extruder is the most important type of extruder used in the polymer industry. Its advantages are relatively low cost and straightforward design. Its main disadvantages are rather poor transport, melting and mixing capabilities. The single screw extruders are usually flood fed.

The twin screw extruder has established a solid position in the polymer industry over the past 30 years. Main areas of application for twin screw extruders are profile extrusion with counter-rotating machines, and specialty operations with co-rotating machines which are used for compounding, blending, chemical reactions etc. These machines offer several advantages over single screw extruders, better transport, melting and mixing capabilities. Their main disadvantages are rather high cost and not so straightforward design. The twin screw extruders are usually metered fed. In metered feeding the material is metered into the machine with a feeder, so the bottom section of the hopper is not fully filled with material.

Taking into account advantages of twin screw machines over single screw machines which may, to some extent, result from the mode of material feeding, a conception of applying of the metered mode of feeding for single screw extrusion (Fig. 1) has been recently discussed [1–8].

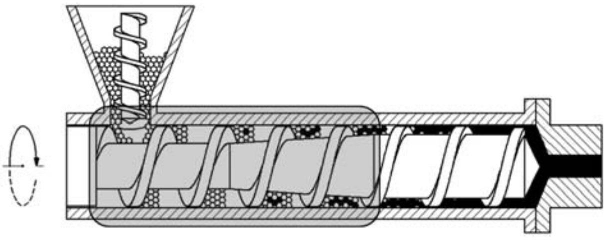

Fig. 1. Metered fed single screw extrusion.

It was concluded that the metered fed extrusion has several advantages over the flood fed extrusion. The pressure built up along the screw is lower than in flood feeding, and therefore there is less chance of agglomeration, what results in improved mixing action [1–4]. Another benefit is related to the melting action which is faster than in flood feeding, since the pellets are not compacted into a dense solid bed, and the polymer particles maintain their individuality as melting progresses [5–8].

Generally, with metered feeding single screw extruders can be used for more demanding operations than with flood feeding, although there are some disadvantages. The extruder throughput is obviously reduced below its full capacity, and the operation is more complicated, because an external device is necessary to feed the material into the machine

The conclusions are schematically presented in Fig. 2.

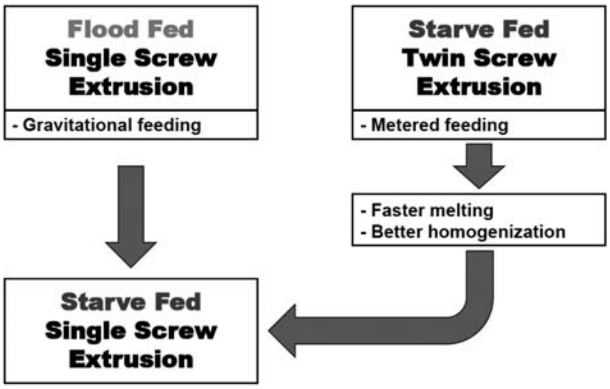

Fig. 2. A conception of applying of the metered mode of feeding for single screw extrusion.

The studies on metered fed extrusion were mainly focused on mixing and melting capabilities [1–8], with little attention to the modeling of the process. Some efforts have generally been done through minor modifications to the equations applied to flood fed extrusion [7, 9]. There is not any composite model of metering, melting and solid conveying for a starve fed single screw extrusion process.

The main task of this research is to develop a composite model for starve fed single screw extrusion process. The model should be able to predict the polymer melting behaviour, pressure and temperature development as well as filling of the screw channel.

Experimental

A Metalchem T45 single screw extruder was used for experimentation (Fig. 3). The extruder was equipped with a three-sectional conventional screw, as well as with a mixing screw Various polymeric materials were investigated, e.g. Polystyrene (BASF PS 158K) has been used in the study. It was fed at different rates and screw speeds. To investigate a polymer behavior along the screws "Screw Pulling-out Technique" was used. Pressure and temperature measurements were also done. Some results of experiments are shown in Figs. 4–7.

We observed that the filled length increases with the flow rate at a fixed screw speed, and it decreases with the screw speed at a fixed flow rate. The experimental observations were consistent with our previous study [10].

Inspection of the extruded samples leads to the conclusion that the contiguous melting mechanism is not the case for the starve fed extrusion. More likely dissipative mechanism might be responsible for melting, especially for small starving. For higher starvation conduction may be responsible for melting.

It is also clearly seen that pressure drastically decreases with an increase of starving for both conventional and mixing screw.

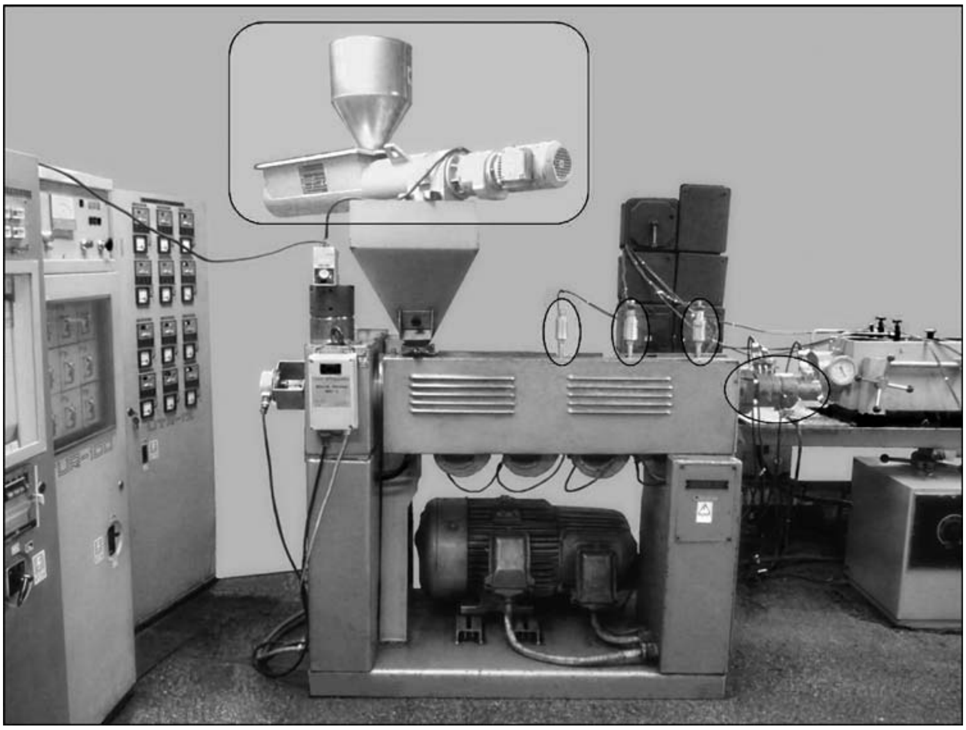

Fig. 3. Single screw extrusion experimental stand.

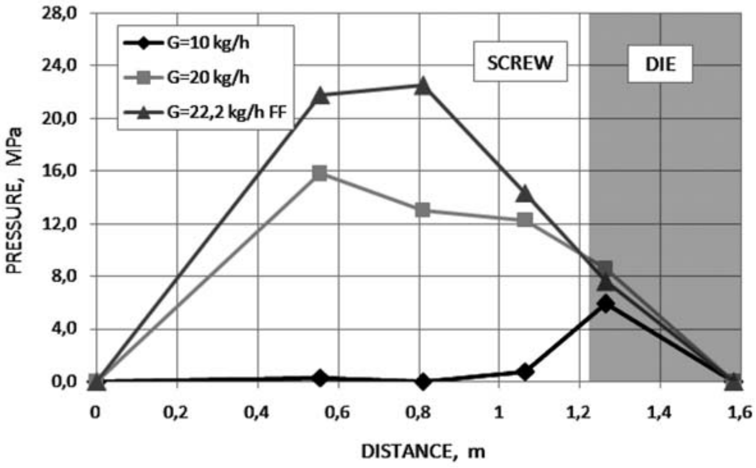

Fig. 4. Pressure profile for PS, N = 50 rpm (conventional screw)

Fig. 5. Effect of flow rate for PS, N = 50 rpm (conventional screw)

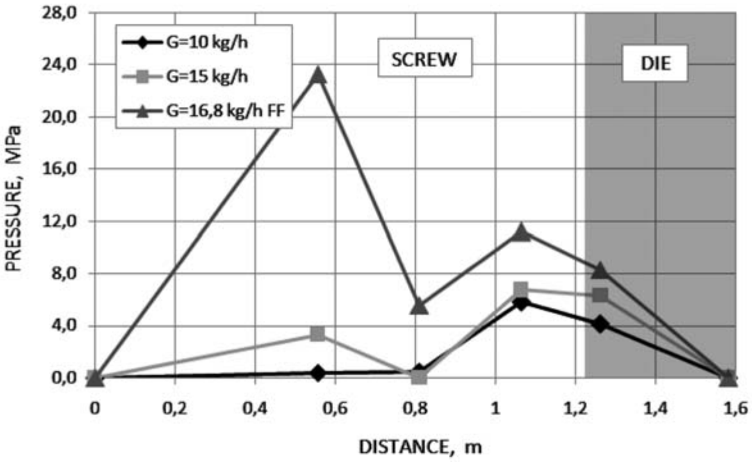

Fig. 6. Pressure profile for PS, N = 50 rpm (mixing screw)

Fig. 7. Effect of flow rate for PS, N = 50 rpm (mixing screw)

Metered Fed Single Screw Extrusion Modeling

The Single Screw Extrusion Model SSEM simulates an operation of the extruder-die system for flood fed single screw extrusion process. The model describes solid conveying, melting, and melt conveying in the plasticating unit, as well as a melt flow through the die. The model predicts: extrusion output, melting behaviour of the polymer, and pressure as well as temperature profiles. This model might be extended to the starve fed mode, replacing the contiguous solid melting model CSM through the dispersive solid melting model DSM (Fig. 8).

In polymer processing, the mathematical models are generally deterministic, transport based, either steady (continuous process) or unsteady (cyclic process), and distributed or locally lumped parameters.

For engineering design of screw processing machines lumped parameter models may generally suffice. The main goal of the engineering designs is to predict the pressure and mean melt temperature profile along the machine for a given screw geometry as a function of the operating parameters: screw speed, barrel temperature profiles etc. In the models, the screw channel is usually divided into short axial segments, where the inlet temperature and pressure are known from the calculation in the previous segment. Within each segment local parameters are assumed to be constant. The details of the mechanical and energy computations within each segment can vary complexity.

The lumped parameter model approach becomes particularly useful when dealing with the plasticating processes, where in addition to melt flow, we are faced with the steps of solids handling and melting. A fundamental idea of the lumped parameter modeling is shown in Fig. 9.

The modeling of the starve fed single screw extrusion process has to involve the fact that as the machine is starved, the machine output is known. Using the die geometry, a presumed exit temperature may be used to compute the pressure at

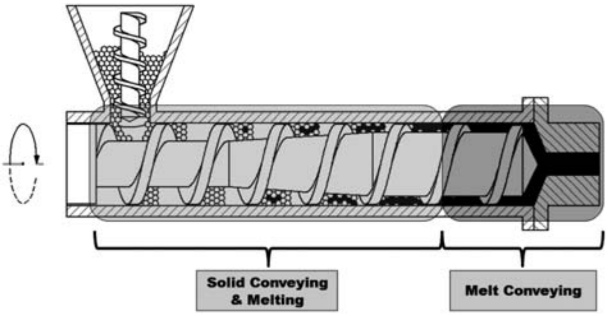

Fig. 8. Composite modeling for single screw extrusion.

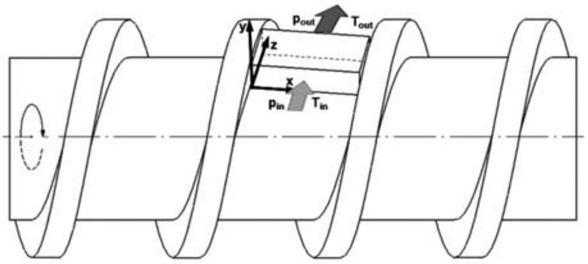

Fig. 9. Lumped parameter modeling for single screw extrusion: p — pressure, T — temperature, in — input values, out — output values.

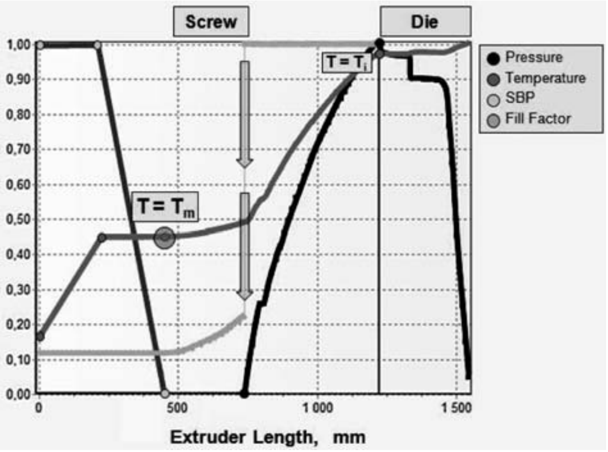

Fig. 10. Algorithm of modeling for starve fed single screw extrusion.

the screw end. Then we may use screw pumping characteristics to calculate pressure gradient back along the screw. If the pressure falls to zero, starvation develops, and the screw channel becomes not fully filled, and the fill factor may be calculated from the screw geometry. Then, we couple the fluid mechanical analysis with an energy balance, step by step, and the temperature profile may be calculated. At the position where melting is finished, the calculated temperature is compared to the melting point, and the computation is achieved when both temperatures are equal. Otherwise, the presumed exit temperature is modified and computations are iteratively repeated.

The algorithm of computations is shown in Fig. 10. We start calculation with solid bed profile prediction (blue line). When the material is fully melted (SBP = 0) we go the die, and we calculate the pressure drop (navy blue line). The pressure drop in the is equal to the pressure increase in the extruder. So we can calculate pressure gradient back along the screw. The pressure calculations are coupled with temperature computations (green line). When pressure drops to zero we calculate filling of the screw channel (red line). And finally, we are looking for convergence of the calculated temperature and melting point.

Conclusions

We observed for both polymers that the filled length increases with the flow rate at a fixed screw speed, and decreases with the screw speed at a fixed flow rate. The contiguous melting mechanism is not observed for starve fed mode. More likely dissipative mechanism might be responsible for melting for small starving, and conduction for higher starvation. The Single Screw Extrusion Model might be extended to the starve fed mode, replacing the contiguous solids melting model CSM through the dispersed solids melting model DSM. The modeling of the process has to involved the fact that as the machine is starved, the machine output is known, and different algorithm of calculation is necessary.

References

[1] Rauwendaal, Ch. *Polymer Extrusion*. Munich: Hanser, 2001.
[2] Thompson, M.R., G. Donoian, and J.P. Christiano. SPE ANTEC 57, 1999: 145.
[3] Elemans, P.H.M., and J.M. van Wunnik. SPE ANTEC 58, 2000: 265.
[4] Elemans, P.H.M. SPE ANTEC 58, 2000: 2582.
[5] Isherwood, D.P., R.N. Pieris, and J. Kassatly. *Trans. ASME* 106, 1984: 132.
[6] Strand, S.R., M.A. Spalding, and S.K. Hyun. *Plast. Eng.* 1992: 17.
[7] Strand, S.R., M.A. Spalding, and S.K. Hyun. SPE ANTEC 38, 1992: 2537.
[8] Thompson, M.R., G. Donoian, and J.P. Christiano. *Polym. Eng. Sci* 40, 2000: 2014.
[9] Jerman, R.E. SPE ANTEC 41, 1995: 279.
[10] Wilczyński, K.J., et al. PPS Annual Meeting 25, 2009: 7.