“Improved Foam Extrusion Output Rates through the Use of Unique Flight Channel Geometry”

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Abstract

This paper presents the basis of a patented screw design that provides significantly improved output rates for polymeric foam extrusion. Higher foam cooling screw productivity involves higher melt velocity and diminished residence time. Through the use of a unique geometrical construct, the normal flow pattern of melt in the cooling screw system is disrupted and agitated. A novel venting technique is used to promote elongational flow and vortex development. The resulting cross channel flow disrupts the melt temperature field and increases the heat transfer rate substantially. In addition to increased throughput one obtains a polymer melt discharge to the die that is more homogeneous and thermally stable than that from a conventional foam extruder cooling screw.

Considerations

In order to understand how melt bed temperature stratification develops, one has to understand the flow patterns that occur in extruder screws, the rheological and thermal properties of the polymer, and how these properties interact with the conventional flow patterns inside the extruder. Effective cooling of the polymer melt requires low viscous heat generation and a large heat flux from the polymer melt. Heat removal from the polymer melt can be improved by applying special screw geometries.

Flow Patterns in Extruders

When the melting process has been completed the extruder acts as a simple melt pump. The mechanism of melt conveying is viscous drag. The relative motion between the screw and the barrel causes a drag flow. The drag flow rate, therefore, is directly proportional to the screw speed. The actual flow rate is a combination of the drag flow, the pressure flow, and the leakage flow.

The pressure flow is determined by the pressure gradient along the length of the melt conveying section. When pressure increases along the length of the melt conveying zone (positive pressure gradient), the pressure flow will reduce the total flow rate. When pressure reduces along the length of the melt conveying zone (negative pressure gradient), the pressure flow will increase the total flow rate. Down-channel velocity profiles for different values of the pressure gradient are shown in Figure1.

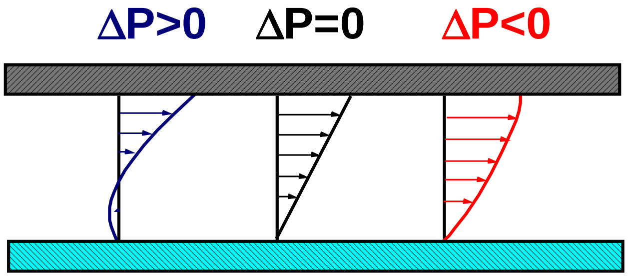


Figure 1. Down-channel polymer melt velocity profiles for three pressure conditions.

The cross-channel velocities are shown in Figure 2. In the top 1/3 of the channel the polymer melt flows to the left toward the leading side of the flight. In the bottom 2/3 of the channel the melt flows to the right toward the trailing side of the channel.

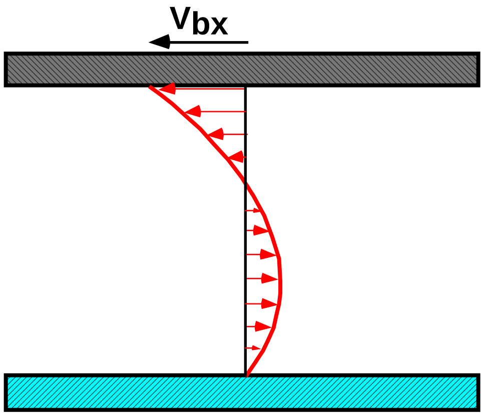


Figure 2. Cross-channel polymer melt velocity profile.

Mixing in single screw extruders is usually analyzed by considering the two main velocity components in the screw channel (1). These are the velocity in the direction of the channel (z-direction) and in the cross-channel direction (x-direction), see Figure 3.

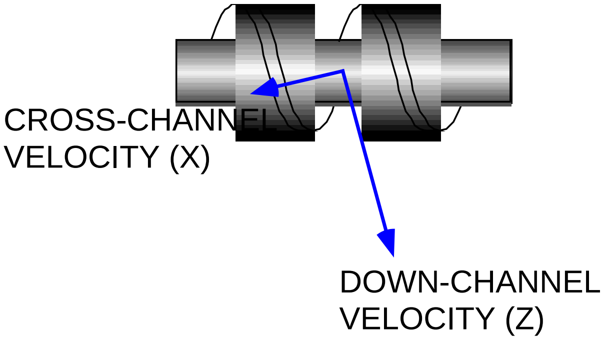


Figure 3. The two main flow components in a single screw extruder.

There is also a velocity component in the third direction (y-direction) parallel to the flight flank. This velocity component is usually very small and, therefore, is neglected in most analyses. If we look at a fluid element as it flows along the screw channel it will follow a helical path as shown in Figure 4, which shows the screw channel unrolled onto a flat plane. This velocity pattern results from the combination of the down-channel velocities shown in Figure 1 and the cross-channel velocities shown in Figure 2.

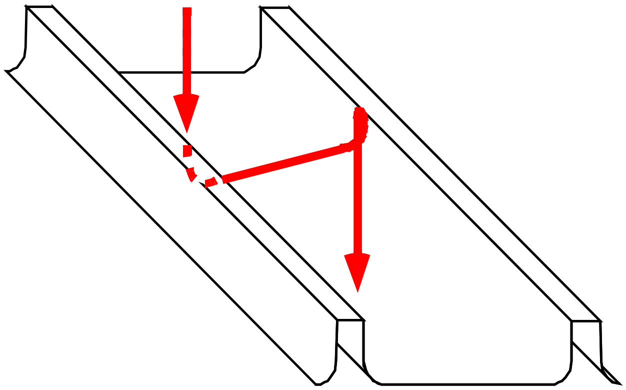


Figure 4. The helical flow path of the polymer along the unrolled screw channel.

At the top of the channel the fluid elements travel in the direction of the barrel, while at the bottom of the channel the fluid elements travel across the channel. The position of a fluid element in the upper portion of the channel corresponds to a complimentary position in the lower portion of the channel. The cross-channel deformation of a rectangular fluid element is shown in Figure 5.

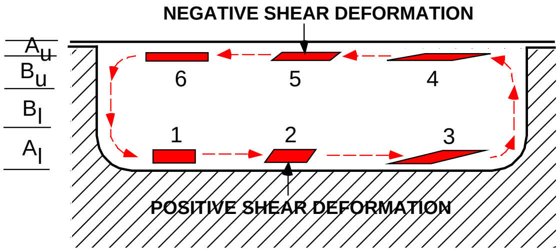


Figure 5. The shear deformation by cross-channel flow in different regions of the channel.

Interestingly, the shearing in the lower region A (A_l) is in positive direction, while the shearing in the upper region A (A_u) is in the negative direction. This means that the mixing that occurs in the lower portion of the channel is counteracted by the mixing in opposite direction in the upper portion of the channel. In fact, there is a demixing action going on as a result of the exposure to positive and negative shear rates!

The situation is quite different in region B. Here the shearing in the lower part of region B is in the same direction as in the upper part. As a result, the mixing in the upper portion of region B enhances the mixing in the lower portion of region B. Therefore, there are no demixing effects occurring in region B, the inner recirculating region, only in region A, the outer recirculating region.

Melt Temperatures

It is often assumed that the temperature of the polymer melt in the screw channel is the same as the barrel temperature. However, this is usually a bad assumption. In most cases, the melt temperatures at a particular cross section of the screw channel vary substantially from one point to another. There are two main reasons for this situation. The first is the high viscosity of polymer melts; this causes considerable viscous heat generation. The second reason is the low thermal conductivity of polymer melts. The typical thermal conductivity of a polymer melt is about two orders of magnitude lower than steel. Typical values of the thermal conductivity of polystyrene and polyethylene compared to steel are shown in Table 1.

Material	***Thermal Conductivity*** *[J/ms°C]*
Steel	45
Polystyrene	0.12
Polyethylene	0.24

Table 1. Thermal conductivity values of steel, polystyrene, and polyethylene materials.

The low thermal conductivity entails that in conductive heating or cooling of polymers, large temperature differences will occur in the material. Also, it can take a long time for temperature differences in a polymer to disappear by conduction. For instance, in a thick extruded product it can take over an hour, sometimes days, for the product to cool down uniformly to room temperature. Unfortunately, it is very difficult to measure the actual melt temperatures in the screw channel. In order to measure the temperature of the material in the screw channel, one needs to have a temperature probe immersed in the material. However, due to the rotation of the screw an immersion probe through the barrel will be sheared off by the flight within one screw rotation. Immersing a probe through the screw is possible but relatively difficult.

Melt Temperature Measurement

It is possible to measure the temperature of the melt at the end of the screw. If the temperature probe at the end of the screw is properly immersed, it is found that the melt temperature can deviate considerably from the barrel temperature. Even though it is very difficult to measure the stock temperatures in the screw channel, it is possible to calculate the stock temperatures. This involves solving the equation of motion and the energy equation together with a constitutive equation for the polymer. Solution of these equations requires the use of numerical techniques; the most commonly used are finite difference analysis (FDA) and finite element analysis (FEA). The latter has become quite popular because of its ability to be used with a wide range of channel geometries.

Finite Element Analysis

One FEA program that was developed specifically for the analysis of polymer melt flow in extruders is REEFlow® [1]; the results presented are generated using this software. To determine the temperatures in the screw channel, the velocities have to be calculated as well because the temperatures change as the velocities change. The velocities can be represented by arrows (vector plot) or they can be represented by a color contour plot. Figure 6 shows a vector plot of the velocities in a 38 mm (1.50") screw of a HDPE melt with a screw speed of 100 rpm. The melt index of the HDPE is 0.2 (condition C), which means that it is a relatively high viscosity material.

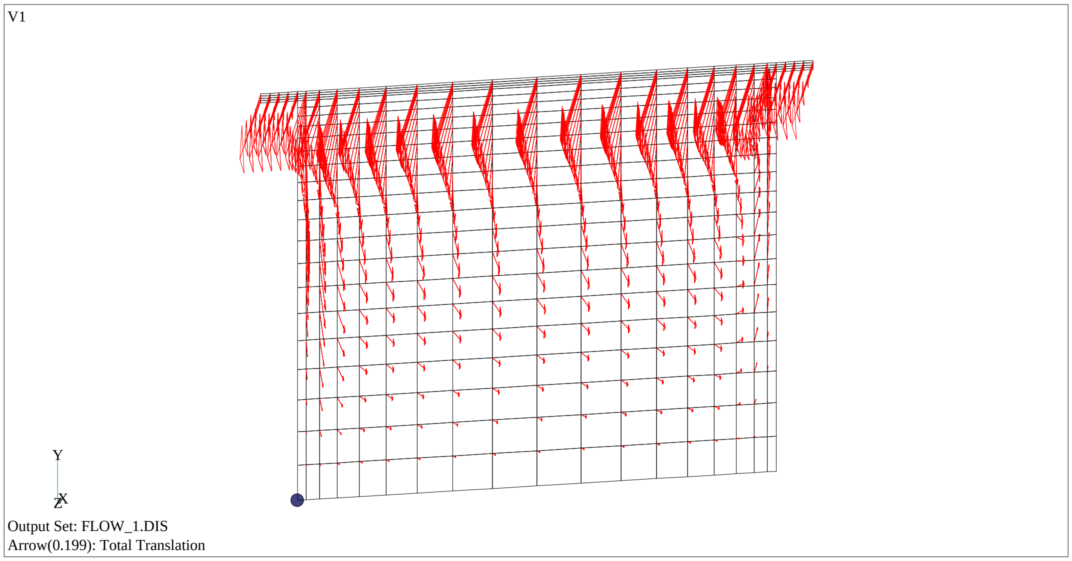


Figure 6. Vector plot of the polymer velocity in the screw channel.

The top surface of Figure 6 is the barrel surface, the left boundary is the pushing flight flank, the bottom surface is the root of the screw, and the right boundary is the trailing flight flank. Figure 6 shows that the magnitude of the velocity vectors changes from the bottom of the channel to the barrel surface. The highest velocities occur at the barrel surface. It should be remembered that the velocities are calculated assuming that the barrel is moving relative to a stationary screw. As a result, all the velocity values on the screw surface are zero. Figure 6 also shows that the direction of the velocities changes as we move from the top of the channel to the bottom of the channel. This was shown experimentally by Mohr, et al. [5].

The color contour plot as shown in Figure 7, depicts the melt bed temperatures when the barrel is maintained at 175°C (347^0 F) and the screw surface is thermally insulated. The highest temperatures occur in the center region of the melt channel. This is surprising, because the highest shear rate and the viscous heat generation are the highest in the flight clearance region. The highest temperatures occur in the center region of the channel and not in the flight clearance because of convective and conductive heat transfer.

When the melt temperatures are higher than the barrel, there will be conductive heat transfer from the melt to the barrel. The heat transfer in the flight clearance is very efficient because the thickness of the melt film in the clearance is very small; thus, heat will be removed efficiently from the flight clearance. The heat transfer in the center region of the channel is inefficient because the thickness of the melt film is larger; the center region is much further removed from the barrel. As a result, the heat transfer from the center region is much less efficient than in the flight clearance.

The above discussion explains why the melt temperatures in the center region are higher than in the flight clearance even though the viscous heat generation in the clearance region is higher than in the center region. This is not always the case, however; it depends on the screw geometry, screw speed, barrel temperature, polymer melt viscosity, and the thermal properties of the polymer. When the polymer melt viscosity is high (low melt index) it is quite common that the actual melt temperatures are substantially higher than the barrel temperature and the highest temperatures typically occur in the center region of the channel; this is particularly true at high screw speeds.

As a result of the viscous heat generation and the inefficient heat transfer, the melt temperatures in the screw channel can be quite non-uniform - temperature differences as much as 50 degrees C (122^0 F) are possible! Clearly, such large melt temperature variations can cause problems in the extruded product, such as dimensional variation and product distortion, surface imperfections, non-uniform frozen-in stresses in the product, etc. It is critical, therefore, to minimize the non-uniformities in melt temperature as much as possible. The most efficient method of doing this is by incorporating one or more distributive mixing sections along the extruder screw.

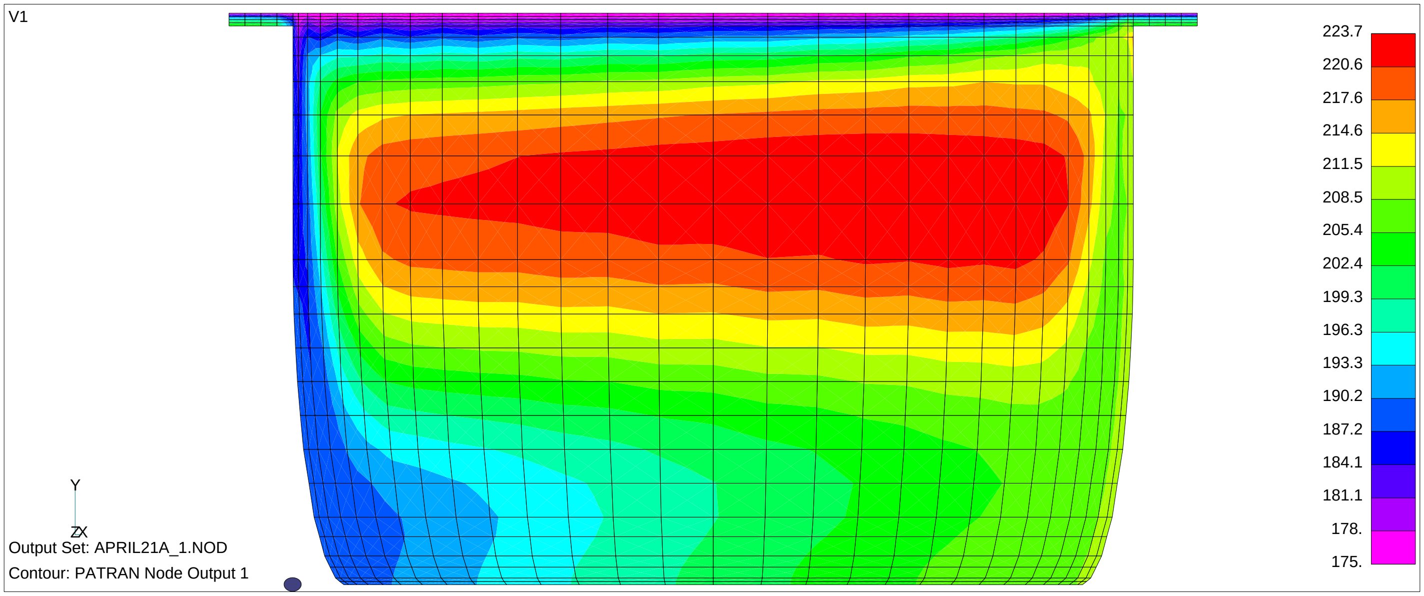


Figure 7. Color contour plot of the melt temperatures in the screw channel.

Another critical issue is the residence time of fluid elements in different regions of the channel. The residence time can be calculated from the velocity profiles and the channel geometry. High local velocities result in short residence times and low velocities result in long residence times. As a result, the residence times close to the screw and barrel surface are quite long as shown in the next Figure.

The residence time, t, as a function of the dimensionless normal distance, y, is shown in Figure 8 where y =0 represents the screw surface and y =1 represents the barrel surface. The residence time reaches a minimum at y = 2/3, this corresponds to the point where the cross-channel velocity is zero (see Figure 2). The residence time increases towards the screw and barrel surface and reaches infinity at y = 0 (screw root) and y = 1 (barrel). For good mixing it is important to exchange material from the center region of the channel with material close to the barrel wall.

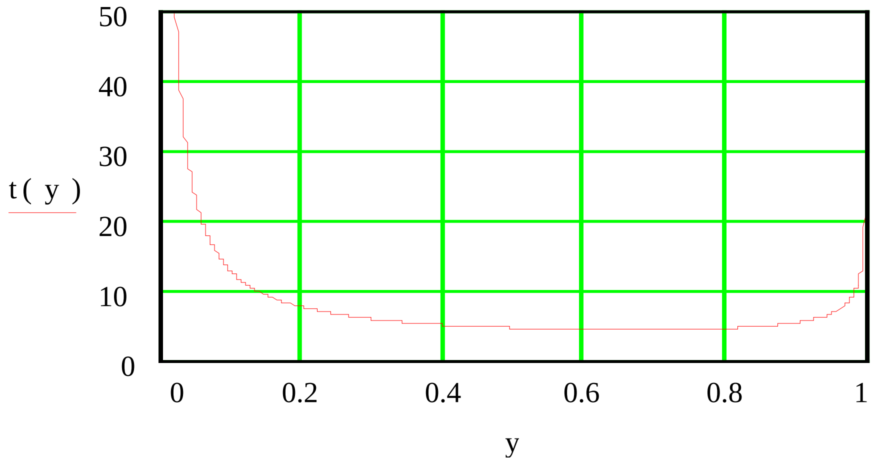


Figure 8. Residence time versus normal distance (dimensionless).

Cooling the Polymer Melt

Clearly, the polymer melt can only be cooled if the heat transfer away from the polymer melt is greater than the viscous dissipation in the melt. Effective cooling therefore requires a high level of heat removal from the polymer melt and a low level of viscous dissipation. If the melt viscosity is described with a power law equation, the viscous dissipation can be written as:

$$q_v = m\dot{\gamma}^{1+n} = m\left(\frac{\pi DN}{H}\right)^{1+n} \qquad (1)$$

where D is the barrel diameter [m], N the screw rotational speed [sec^{-1}], H the depth of the screw channel [m], m the polymer melt consistency index [Pa.sec^{n}], and n the polymer melt power law index [dimensionless].

Expression (1) shows very clearly the main screw design variable that controls viscous dissipation: the channel depth H. By increasing the depth of the channel the shear rate is reduced and thus too the viscous dissipation. It is important therefore to make the channel depth of a cooling screw quite large. It is also important for the screw to have multiple flights to enhance surface renewal and reduce the size of the high temperature region in the center of the channel as shown in Figure 7.

By equating the viscous dissipation to the heat transfer from the polymer melt an expression for the fully developed melt temperature can be derived [3]:

$$T_e = T_0 - \frac{1}{a_T}\ln\left(\frac{q_c}{q_{v0}}\right) \qquad (2)$$

where a_T is the temperature coefficient of the polymer melt viscosity [°C^{-1}], q_c is the heat conducted away from the polymer melt [W/m^3] and q_{v0} is the viscous dissipation [W/m^3] in the polymer melt at the reference temperature T_0

Figure 9 shows how the melt temperature rise depends on the consistency index and the conductive heat flux away from the polymer melt. Two heat flux values are shown: 10,000 and 100,000 W/m^3. With a high conductive heat flux and low consistency index the melt temperature rise can be negative. In other words, the melt will be cooled.

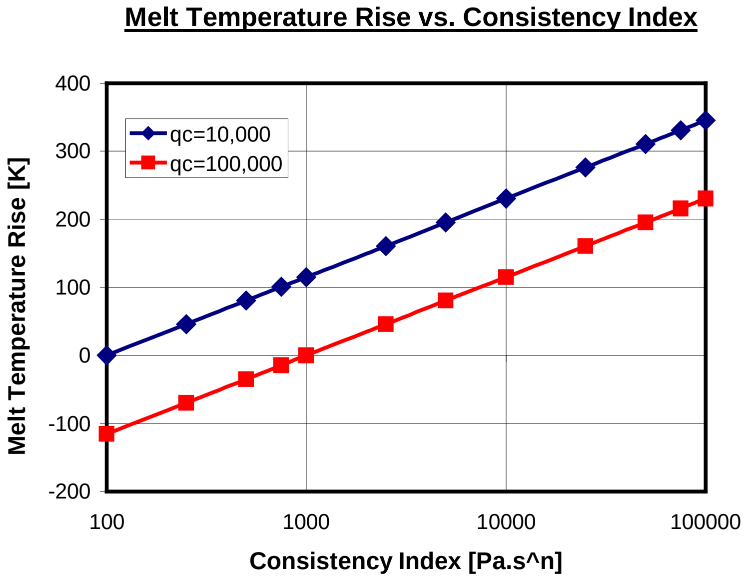


Figure 9. Equilibrium melt temperature rise versus consistency index.

The heat removal from the polymer melt can be made more efficient by applying special screw geometries. Jim Fogarty (BSc-ChemEng. WPI '61) of Plastic Engineering Associates, Inc., Boca Raton, FL [4], has developed a novel, patented cooling screw design, which accelerates heat removal, promotes improved homogeneity and thus increases production efficiencies significantly.

Turbo–Cool ™ Foam Extrusion Screw

Turbo-Cool^{TM} Screw – Hardware Considerations

From the discussion above, effective cooling of the polymer melt requires low viscous dissipation and a large heat flux from the polymer melt. Clearly, the non-uniform temperature profile and the non- uniform residence time in the typical melt channel are detrimental to both end product quality and total extrusion throughput rate.

A new concept in screw flight design, now in commercial production, significantly increases total extrusion throughput rate by disrupting the normal melt bed flow patterns. The *Turbo-Cool*^{TM} foam screw design relies upon a series of new flight geometries, which promote cross channel flow. Three such geometries are depicted below in Figures 10, 11 & 12;

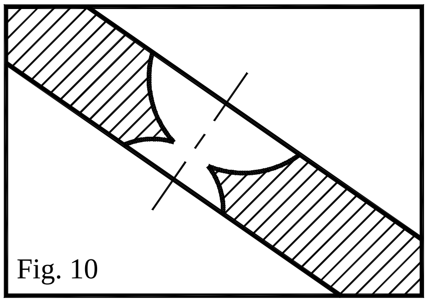


Fig. 10

FLIGHT GEOMETRY "A"

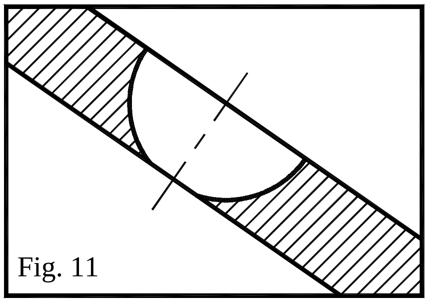
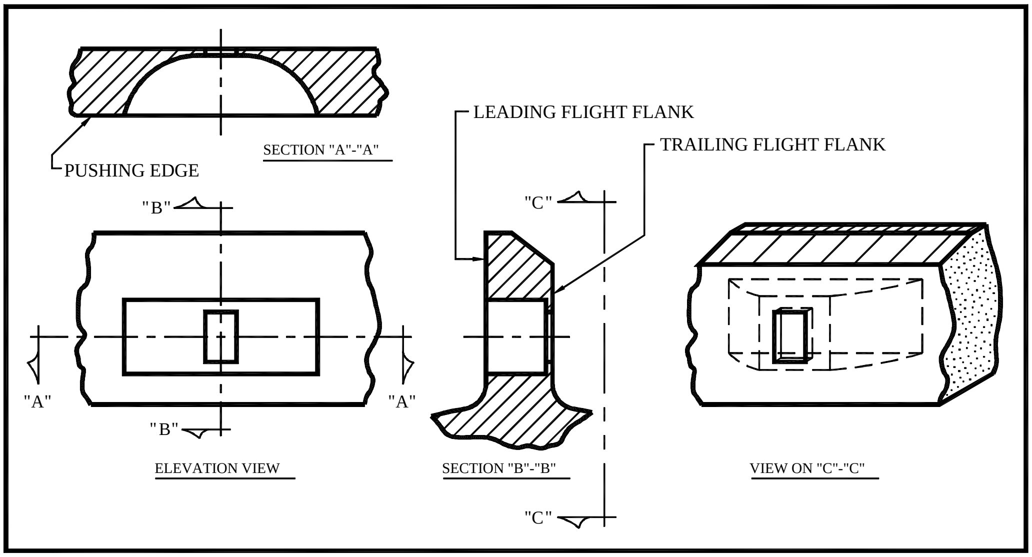


Fig. 11

FLIGHT GEOMETRY "B"



FLIGHT GEOMETRY "C" - PREFERRED

Figure 12. Preferred screw flight circulation channel geometry.

High temperature melt from the center region of the current helictical flow channel (Figures 7 & 17), is moved to the outer recirculating region of the previous helictical flow channel via the new screw flight geometry. At the same time, low temperature melt close to the barrel wall of the current helictical flow channel is transferred to the inner recirculating region of the previous helictical flow channel. The melt temperature of the layer in contact with the barrel is increased, thus reducing the power consumption of the screw. The overall end result is improved heat transfer, more uniform melt bed temperature and the ability to increase substantially the throughput rate.

Note Figures 17 & 18 which are photographs of a typical 6.00” (152mm) diameter production *Turbo-Cool*^{TM} screw. These photographs clearly show evidence of the desired cross channel flow between adjacent screw flights.

The inlet of the flight circulation channel (Figure 12) is on the leading flank (pushing edge) of the flight. The discharge of the channel is as depicted on View “C-C”. Note that the inlet of the flight circulation channel is quite large (2x to 10x) as compared to the purposefully shaped *discharge orifice*, in order to promote elongational flow and vortices due to flow instabilities. It has been found that the scooping effect of the curved sidewalls is critical in achieving effective heat transfer from the polymer melt.

The polymer melt is subjected to elongational flow as it flows through the flight circulation channel. In the process, the polymer melt will be stretched. As the melt exits from the flight circulation channel, there will be some degree of elastic recovery of the material. This will tend to expand the leakage stream. The acceleration of the polymer melt flowing through the flight circulation channel is important in achieving efficient redistribution of the polymer melt.

The inlet area of the flight circulation channel takes up approximately 15% of the area of the pushing screw flank. The discharge area takes up about 4% of the area of the trailing screw flank. As a result there is about a 4:1 reduction in cross sectional area of the flight circulation channel.

The geometry of the opposing wall pairs (Figures 13 & 15) of the flight circulation channel is intended to promote flow instabilities [6~9].

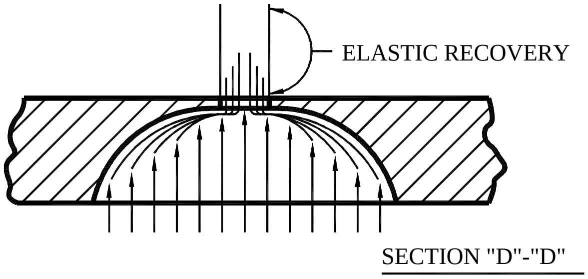
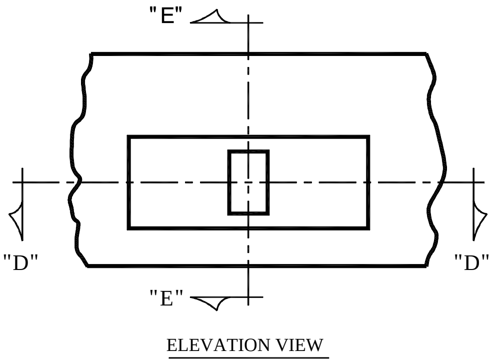


Figure 13. Inlet velocity profile of the flight circulation channel – plan view.



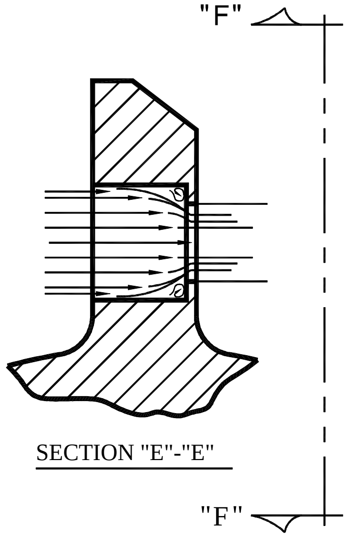
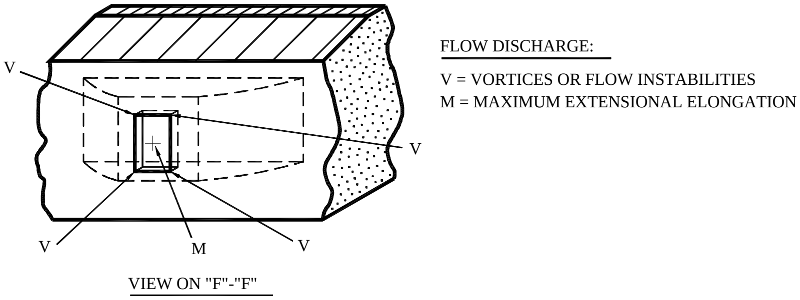


Figure 14. Front elevation view – Flight circulation channel.

Figure 15. Inlet velocity profile of the flight circulation channel – Section E-E



FLOW DISCHARGE:

V = VORTICES OR FLOW INSTABILITIES
M = MAXIMUM EXTENSIONAL ELONGATION

Figure 16. Flow discharge opening on the trailing flank of the screw flight.

Figure 17. 6.00” *Turbo-Cool*^{TM} Production Feed Screw.

Figures 17 & 18 below depict flow marks on the root of the screw, indicating strong cross channel flow that is created by the presence of the flight circulation channels in the screw flights.

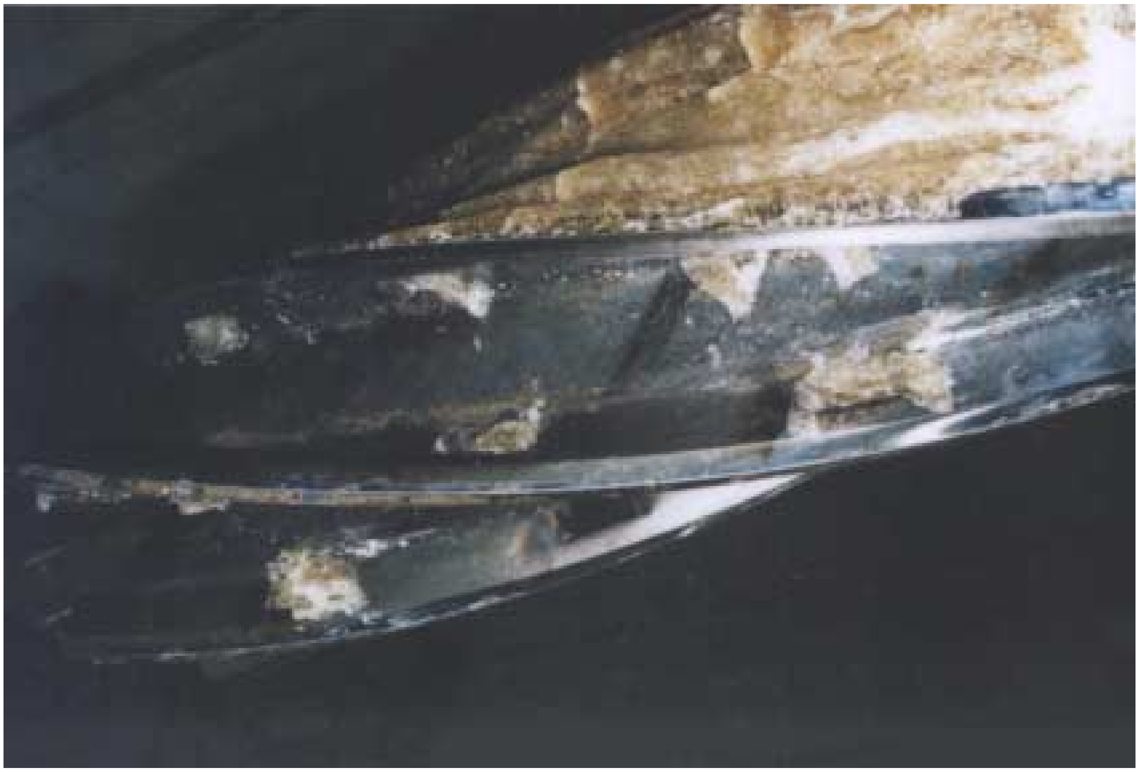


Figure 18. 6.00” (152.4mm) Diameter *Turbo-Cool*^{TM} Production Feed Screw.

Production Data

Case #		**"A"**		**"B"**	
End Product		**1" ~ 4" p/s plank. (25mm ~ 100mm)**		**0.060"-0.200" p/s sheet (1.5mm~5mm) for food containers.**	
Tandem Size		4 ½" – 6" 114mm x 152mm		4 ½" – 6" 114mm x 152mm	
		Conventional	***Turbo-Cool^{TM}***	**Conventional**	***Turbo-Cool^{TM}***
System Output	**Lb/hr**	**1,417**	**2,070**	**1,015**	**1,481**
	(Kg/hr)	(643)	(939)	(461)	(672)
	% Increase	——	**↑ 46.1%**	——	**↑ 45.9%**
Screw Speed (rev/min)		**15.5**	**21.4**	**18.5**	**17.3**
Secondary Barrel ΔP	**psi**	**1,990**	**1,510**	**1,800**	**1,700**
(Inlet – discharge)	(bar)	(137)	(104)	(124)	(117)
Secondary Inlet Temp ^{0} F		**435^0 F**	**437^0 F**	**417^0 F**	**427^0 F**
(^{0} C)		(224)	(225)	(214)	(219)
Secondary Outlet Temp		**258^0 F**	**255^0 F**	**285^0 F**	**287^0 F**
(^{0} C)		(126)	(124)	(141)	(142)
Secondary Drive Power (horsepower / lb / hr)		**0.0323**	**0.0308**	**0.0494**	**0.0406**
Throughput Efficiency (lbs / hr / in^2 of barrel bore area)		**0.423**	**0.618**	**0.288**	**0.420**

Figure 19. Production Data table – Observed Results using Turbo-Cool^{TM} technology.

Observed Power Savings

The *Turbo-Cool*^{TM} Screw production data to date on extruder drive motor power consumption per unit of throughput yields a 10% to 20% savings over the consumption with conventional cooling screws. This savings is due to two factors. The first is that the fixed power consumption due to inherent motor and power transmission elements (gear reducer, belts, etc) is diminished on a unit basis as the throughput rate increases. The second and more significant factor is that the residence time of the more power consumptive viscous melt is reduced at the barrel surface.

The additional energy that is not required over a conventional cooling screw on a per unit basis for melt cooling (chilled water) results in additional cost savings. The magnitude of which is often near to that of the drive motor power savings.

Economic Benefits

The principal financial benefit of the use of the *Turbo-Cool*^{TM} screw technology is the significant increase in marginal profit as derived from the revenue generated from added sales. This paper has presented a series of data that illustrate an average 46% production improvement in two individual cases of polystyrene foam production (Figure 19). Some other *Turbo-Cool*^{TM} users have enjoyed a 20% to as high as 60% improvement in output over their conventional process.

Depending upon the end product markets and the corresponding profit margin per unit output, an average net present value (NPV) [14] to a typical polystyrene food-packaging user in North America is approximately \$300,000 to \$3,000,000 per tandem system for a five year operating time period when sales are successfully increased. In the case of plank production, gross margins are higher, therefore the NPV values are even greater. Five (5) years is selected as the shortest relevant time horizon for this capital investment lifespan analysis and the corresponding decision criterion. Five years is considered an overly conservative basis for this analysis and thus acceptable for many financial managers. Extrusion hardware typically has a long physical lifespan in excess of the five-year time frame.

Many large organizations use the Net Present Value (NPV) model [14] for capital investment selection criteria. NPV is used to calculate the total net worth of a long-lived capital project over a relative time frame of lifespan. The project’s total value (all cash inflows), net of all costs, including all capital investments (\$,£,¥,etc) is then expressed in terms of time zero financial units. The NPV method should allow a manager to value and grade dissimilar alternative capital investment prospects in terms of each project’s total financial impact upon the firm. In theory, the highest positive NPV project(s) should receive the allocation of a firm’s limited investment capital. Naturally, strategic imperatives may alter the decision making model away from the mathematically pure answer of selecting the project(s) with the highest positive NPV.

The expression (3) NPV is given as;

NPV = [(-) initial capital investment] + (present value of the project’s revenues - present value of the projects costs).

All the cash flows are summed during the project's relevant lifespan for analysis and are discounted by the opportunity cost of capital (discount or hurdle rate) over time in order to arrive at a present-day net financial valuation for the project.

$$NPV = C_0 + \sum_{n=1}^{n} C_t \ / \ (1+r_t)^n \qquad (3)$$

C_0 = capital investment required at project inception (time n=0)
C_t = net cash inflows for each period of time (n)
r_t = opportunity cost of capital or hurdle rate
n = number of time periods (normally expressed as annual time units - years)

Many commodity polymeric foam markets, especially in North America, might be considered to be hyper-competitive [11]. Commercial success is often gained and sustained by using a generic competitive strategy of either; significant product differentiation, a targeted market focus (segmentation) and / or by gaining an overall cost leadership position [10].

Clearly, the use of the *Turbo-Cool*^{TM} feed screw can provide a user with a significant relative cost of production advantage when compared to the industry's standard cooling screw hardware. If the firm's generic competitive model is cost leadership [10], this new technology may afford the chance to disrupt the existing sales models in the market. In the alternative case of a first mover user, such firms should accumulate excess economic profits during their period of exclusive use. For these reasons, a new technical development like *Turbo-Cool*^{TM} is often referred to as a disruptive competitive force [12] or a technological discontinuity [13].

Existing *Turbo-Cool*^{TM} users do in fact report significantly lower total costs of production, which we believe arise from the following principal attributes of the new technology;

- **Significant tandem foam system throughput rate increases (25% to 70% to date).**
- **Modest capital cost required per unit of throughput gained.**
- **Lower direct costs of conversion due to higher labor and capital productivity.**
- **Total power cost savings, which average \$10 to \$15,000 per year for a typical 4.5"-6.0" tandem foam extrusion line.** (avg. power cost assumed to be US \$0.06 /Kilowatt hour)
- **Improved extrusion system output stability. (lower reject rates at extrusion)** (existing licensees report a range of from 65% to an 80% reduction in extrusion scrap)
- **Higher extrudate product quality and consistency. (lower finished product reject rates in both plank and thermoforming products)**
- **Short learning curve for conversion to *Turbo-Cool*^{TM} by plant operating staff.**

Ongoing Work

While the production results to date have been significant, further optimization is possible. In order to achieve additional throughput gains, the following additional flight circulation channel variables require additional study;

Channel orientation verses helix angle.

Compression ratios.

Spacing – channel to channel.

Channel size verses flight depth.

Helix angle.

Flight thickness.

Efforts are also currently underway to perform a complete 3-D analysis of the flow in the *Turbo-Cool*^{TM} screw using the boundary element method (BEM). Time constraints prevented the inclusion of the BEM analysis results in this paper. By the use of particle tracking, complete information on the three-dimensional flow patterns can be elucidated in static as well as in dynamic fashion. The results however will be presented at the Foam 2000 Conference in October of 2000.

References

1. “Polymer Mixing, A Self-Study Guide,” Chris Rauwendaal, Hanser Publishers, Munich, Germany (1998)
2. "Finite Element Analysis of Flow in Extruders," 52nd SPE ANTEC, 298-305, San Francisco, CA, Chris Rauwendaal and Jeff Anderson (1994)
3. “Estimating Fully Developed Melt Temperature in Extrusion,” 58th SPE ANTEC, 307-311, Orlando, FL, Chris Rauwendaal (2000)
4. U.S. Patent 6,015,227, Thermoplastic Foam Extrusion Screw with Circulation Channels, James Fogarty (1998)
5. “Flow Patterns in a Non-Newtonian Fluid in a Single Screw Extruder,” SPE Transactions, July, 113-120, W.D. Mohr, J.B. Clapp, and F.C. Starr (1961)
6. Melt Rheology and its role in Plastics Processing, J. Dealy, K. Wissbrun, Van Norstrand Reinhold, 332-336, 317-319 (1990)
7. Extrusion Dies for Plastics and Rubber 2nd rev. ed. , Walter Michaeli, Oxford University Press, 111-116, 68-74 (1992)
8. Polymer Extrusion 3rd rev. ed., Chris Rauwendaal, Hanser Publishers, Munich, Germany, 314-315 (1994)
9. Rheology in Polymer Processing, Chang Dae Han, Academic Press, 304-315 (1976)
10. Competitive Strategy-Techniques for Analyzing Industries and Competitors, Michael E. Porter, The Free Press, 34-46 (1980)
11. Hyper-Competitive Rivalries – Competing in Highly Dynamic Environments, Richard A. D’Aveni, Simon & Schuster Inc. 177, 221, 149-170, (1994)
12. “Meeting the Challenge of Disruptive Change”, Harvard Business Review, March-April 2000 66-76 Clayton M. Christensen, Michael Overdorf
13. Competitive Advantage-Creating and Sustaining Superior Performance, Michael E. Porter, MacMillan Inc., 190, 62-118 (1985)
14. Principles of Corporate Finance 4th rev. ed., Richard A. Brealey, Stewart C. Myers, McGraw-Hill, Inc 73-117 (1991)

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