PVC Gels

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The following two questions were submitted by Robert P. Skribiski, Electrolyzed Chemicals Corp., Burlington, Mass. The answers were provided by Dr. Imrich Klein, Scientific Process and Research Inc.

Question One:

During the extrusion of clear PVC at high throughputs large gels are intermittently formed in the extrudate. The gels will disappear if the screw speed is reduced from 180 to 150 RPM and barrel temperatures increased 15° F. The following questions arise:

a. Is the feed screw too deep in the feed or metering section?

b. Could the flutes of the Maddock mixer in the meter section be too deep?

c. Is this a wear problem?

Answer to Question One:

The symptoms described in the question clearly indicate that we are confronted with a melting problem. The gels represent PVC which has not melted under high shear conditions in the melt film which separates the solid bed from the barrel. The gels are essentially softened plastic the temperature of which is usually lower than that of the rest of the extrudate.

The rate at which melting occurs depends on the screw speed and production rate. Lowering the screw speed will also lower the output or production rate. At rower production rates melting will improve and will often be adequate to yield a completely molten extrudate.

This is therefore a typical screw design problem. A proper screw design must insure that melting is completed at a desired screw speed and production rate before the plastic reaches the die. A proper screw design must take into consideration the flow and thermal properties of the plastic as well as its frictional properties.

Of course the possibility exists that the melting problem is only a symptom and not the primary cause of the gels. For example, if solids conveying problems exist, very low pressures will occur at the point where melt formation begins, the melt, which under normal conditions forms a film on the barrel surface, now penetrates the voids in the loosely packed solid bed. This increase in the bulk density of the solid bed will cause a loss contact between the solid bed and the barrel In the absence of contact between the barrel and the solid bed no melting can occur until further downstream where contact is reestablished due to the decreased depth of the channel. The inadequate solids conveying has the effect of starve-feeding the rest of the screw and causing a shortening of the melting zone in the extruder.

The solids conveying problem can often be eliminated by carefully controlling the screw and barrel temperatures in the vicinity of the hopper. Since the problem is intermittent, it may be remedied by maintaining a more constant feed stock temperature. In other cases more drastic steps are needed, that is redesigning the solids conveying zone of the screw. In any case, full analysis would require coefficient of friction data on the screw and barrel surfaces as a function of surface velocity, surface temperature and pressure which can now be accurately measured.

The fluted section itself is unlikely to be the cause of the problem. It may, however, aggravate the problem if it is located too early and is exposed to a very high solids content which tends to plug the inlet flutes and render the device ineffective. One should therefore first determine the primary cause, that is the reason for the high solids content which reaches the fluted section.

Computer simulations of extruders teach us that the melting performance of PVC is, unlike polyolefins largely unaffected by screw wear. So the problem may be slightly aggravated by excessive screw wear but can not be fully caused by it. A computer simulation of the run will naturally reveal the true reason(s) of the problem.

Plate-out

Question Two:

Is there any way to eliminate plate out of filters during the extrusion of polyolefins containing 30-50% flame retardants, radiopacifiers etc.? The plating out of filters causes problems such as die and mandrel "halo", large filler specks in the extrudate build up of a plate-out on the feed screw, plugged screens etc. Is this problem caused by compounding, extrusions, or tooling?

Answer to Question Two:

The large filler specks in the extrudate seem to indicate that we are confronted with a compounding problem. The compounding operation should be looked at more closely. If any lack of compound homogeneity can be detected, this will confirm the suspicion. On the other hand, a special screw design will be instrumental in making the compound more uniform during the actual processing operation. Accordingly, even a compounding problem can often be remedied by proper screw design.

The Parting Line We all are familiar with the unwanted defects caused by flow lines, weld lines, parting lines, and whatever term we may use to describe the effect of temporary interruption of polymer melt flow by physical obstructions.

Considerable analytical design and effort have been expended to predict this effect and to lessen the resulting mechanical weakness in finished products. (See Ref. 1 and 2). Despite this earlier work we continue to find defects in pipes, bottles, film and injection molded parts originating from such flow obstructions.

In many instances it is necessary and sometimes unavoidable to have streamlined connecting members in dies and molds that temporarily interrupt polymer flow. On a molecular level the somewhat oriented and stressed molecules in flow are separated from each other, flow along each side of the flow obstruction, to be reunited at the trailing edge.

The substantial increase in stress produced by elongational flow in flow elements or molecules close to the wall of the flow obstruction causes alignment of all involved molecules in the direction of flow. The effect, because of the relatively high local viscosity and the short residence time, is mostly irreversible. Visible to the naked eye— and, if not, by observation in polarized light— is a sharply defined line which upon testing under impact or tensile loads proves to be weaker than adjacent areas.

Considering the problem through the eyes of the design or processing engineer he will have five different means to partially or totally solve it. One variable is time. Even at the typically high viscosities of polymer melts molecules have a considerable degree of freedom to move around. Given enough time a certain amount of interdiffusion of elongated flow element will occur accompanied by a corresponding increase in mechanical strength at the parting line.

An increase in temperature will similarly increase molecular motion by lowering viscosity, bringing about a partial improvement. Increasing substantially the resistance to flow downstream from the obstruction will have a "healing" effect. Introducing mixing elements downstream, or division of partial steams that are reunited in different geometric planes, will effective wash Out the effect of a flow obstruction. Finally, complete elimination of flow obstructions as achieved in a spiral blown film die virtually eliminates the problem.

A combination of increasing downstream pressure, temperature and residence time will understandably show an aggregate effect equivalent to the sum of the partial effects. In any event the effect produced by increased pressure is difficult to assess by itself because of heat rise by viscous dissipation encountered with many polymer melts. To illustrate this combined effect Figure 1 shows the results of a controlled experiment where the severity of a weld line was evaluated as a function of increased downstream pressure by closing the die gap in successive steps. Extrusion rate and residence time were kept constant.

The particular set of experimental conditions resulted in a weld line that was thicker than film thickness in adjacent areas. The relative increase in weld line thickness was measured as a function of die gap. To emphasize the effect a short residence time was achieved by placing a 50 mm diameter flow obstruction within 15 cm from the die exit.

Apart from the very localized effect of a weld line we have to be concerned about a reduction in flow volume in the vicinity of the flow obstruction. Under assumption of negligible pressure drop from leading to trailing edge of the flow obstruction Pearson has shown that this volume reduction is linearly proportional to the slope of the log. Shear rate/log. Shear stress curve, or, in other words, is proportional to the degree of deviation from newtonian behavior. The table below shows Pearson's tabulation of calculated volumes for three different hypothetical polymers with slopes n 1, 2, and 3 where

n = logQ2-log Q1/ log P2-log P1

and

Q equals throughput, and P equals die pressure.

Another experiment one might conduct is to extrude a polymer with a large "n" and a high viscosity through a bottom fed blown film die or a typical pipe die. At a given rate of extrusion at the lowest temperature possible the resulting web will not reunite to form a tube. Depending on the number of "spider legs" there will be a corresponding number of stripes coming out of the die. As the rate is increased temperature and pressure increase and at a given point autohesion can occur because of the increased mobility of the molecules. Starting extrusion at a higher melt temperature will obviously cause knitting or rewelding at a lower rate.

Extending our findings to the technology of heat sealing we can now see the intimate relationship between heat seal and weld line strength as a function of pressure, time, and temperature.

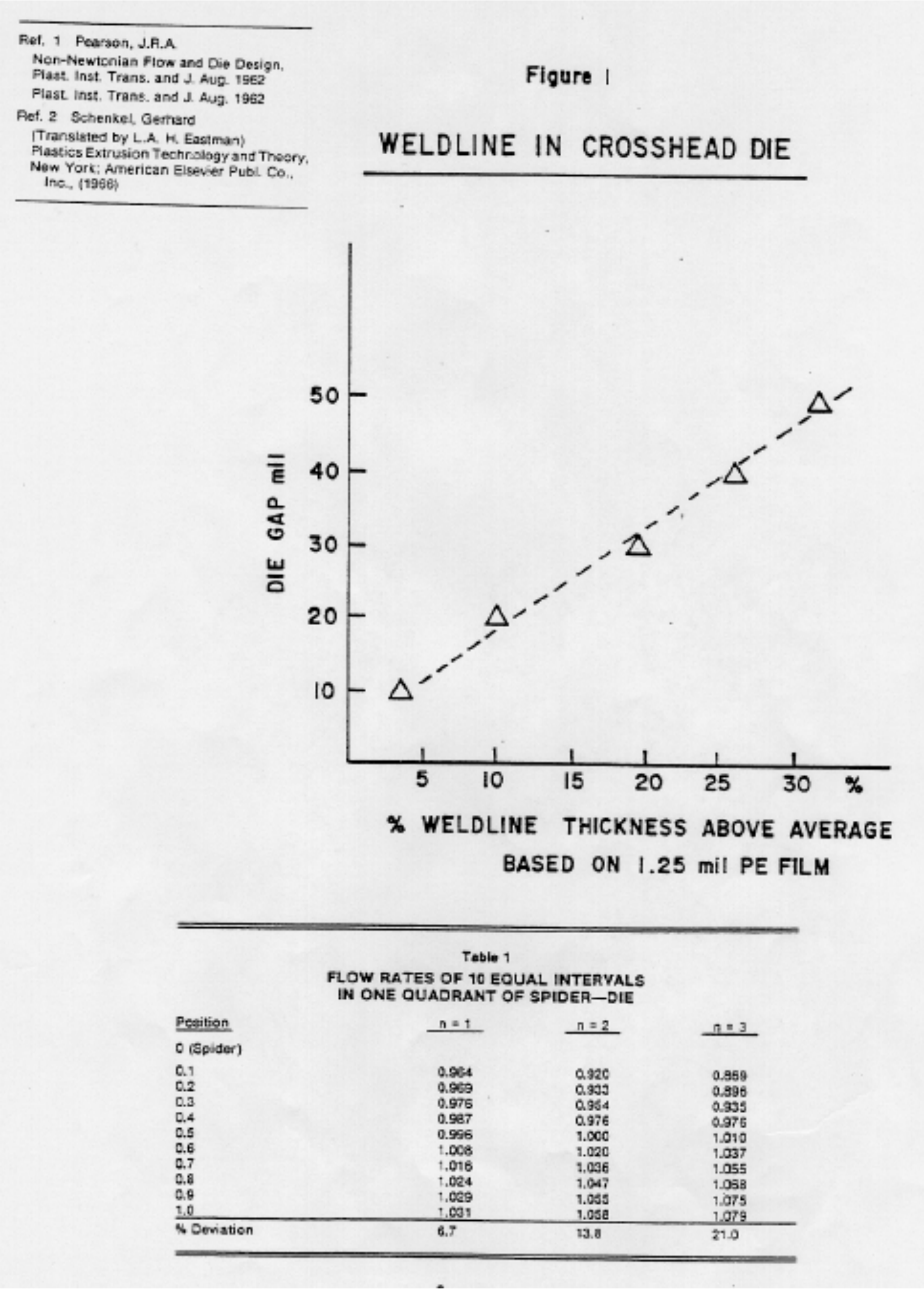
We also may infer the power of this relationship as tool to design flow systems with flow obstructions that have a minimum effect of product geometry and mechanical properties.

In any endeavor one should not overlook the possibility of converting a problem into an asset if viewed under a different light.

The problem at hand has indeed led to applications where the introduction of a weak line added substantial value to the product in question. One such example is the tear line used for making the opening of plastic bags easier. Another application makes use of a weld line as a "score line" for subsequent folding along the line.

There will be other examples coming to the readers mind as well as other stimuli for investigation.

(See Figure 1 below)



Ref. 1 Pearson, J.R.A.
Non-Newtonian Flow and Die Design,
Plast. Inst. Trans. and J. Aug. 1962
Plast. Inst. Trans. and J. Aug. 1962

Ref. 2 Schenkel, Gerhard
(Translated by L.A. H. Eastman)
Plastics Extrusion Technology and Theory,
New York; American Elsevier Publ. Co.,
Inc., (1966)

Figure 1

WELDLINE IN CROSSHEAD DIE

Table 1

FLOW RATES OF 10 EQUAL INTERVALS
IN ONE QUADRANT OF SPIDER—DIE

Position	n = 1	n = 2	n = 3
0 (Spider)			
0.1	0.964	0.920	0.859
0.2	0.969	0.933	0.896
0.3	0.976	0.954	0.935
0.4	0.987	0.976	0.975
0.5	0.996	1.000	1.010
0.6	1.008	1.020	1.037
0.7	1.016	1.036	1.055
0.8	1.024	1.047	1.058
0.9	1.029	1.055	1.075
1.0	1.031	1.058	1.079
% Deviation	6.7	13.8	21.0

See also:

- Gels
- Mixing myths
- On-line quality analysis
- Polymer filtration
- Sources of gels

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