Plexiglas® Acrylic Molding Resin

Extrusion

EQUIPMENT CONSIDERATIONS

The general specifications for extruders and the methods of heating, cooling, and controlling are the same for PLEXIGLAS resins as for most other plastics.

The following specific comments can be added:

Barrel/Screw

Nitrided steel barrels and screws should not be used. Their tendency to give trace contamination caused by abrasion can be objectionable in processing clear and translucent colors. Xaloy barrels and hard-tipped (Stellite or flame-hardened) flight lands are recommended.

Chrome plating of screws is not necessary for satisfactory processing, but is recommended because it makes cleaning the screw easier and provides corrosion- and abrasion-resistant surfaces.

The screw is normally operated in the "neutral" condition, that is, without internal cooling. The neutral condition is the simplest and usually the preferred method of operation. Water, or other controlled temperature coolants, should never be circulated through the *entire length* of the screw. In some cases, applying water cooling to a *limited section* in the feed end may be advantageous. Since limiting the range of circulation is difficult when a screw is already bored through most of its length, the cooling bore, when feasible, should be limited to a distance four times the screw diameter downstream from the start of the helix.

The need for limited screw cooling is usually apparent in an operation in which an obvious decrease occurs in the rate of feed intake to the screw (if this can be observed) and the motor load and machine output rate drop substantially as the run progresses. Such behavior results from polymer adhering to the screw channel surface to form a blockage that rotates with the screw and prevents or slows the rate of transport. The blockage usually occurs within the first few turns of the helix downstream from the feed opening.

Zoned screw cooling should not be applied when a serious block occurs, because the blockage may then be reinforced. If an evident need for zoned cooling exists, the flow of cooling water should begin before machine startup while the channel is open, provided that the length of cooling is limited to the distance stipulated above. Using a moderate flow rate for the coolant should keep the exit temperature of the water around 100°F (38°C).

Breaker Plates and Screens

In general, use a breaker plate with nominal screening (20/40 or 20/40/60 mesh packs are typical). Additional screens can be helpful when the die offers low resistance to flow and the screw has limited mixing or homogenizing ability.

PLEXIGLAS resins exhibit unusually good thermal stability, particularly in areas from which air is excluded. Degradation in slow flow areas should be of little concern in most applications.

Dies

Many different commercial sheet dies have been used successfully to extrude PLEXIGLAS resins. These include the "straight manifold" types, often termed T dies, and a variety of "coathanger style" modifications of the T die. All have adjustable die lip openings and may also have adjustable choke bars.

It is essential to provide dies with an effective and properly balanced heating system having adequate, sensitive controls, especially when the die is divided into heat zones, as in the usual sheet die.

When an extrudate with minimal die lines must be produced, the finish of the die lip is important, particularly in the area at and just ahead of the point where the melt leaves the lip surface. Irregularities in the die lip surfaces in this area, whether caused by mechanical imperfections or corrosion damage, can produce die lines.

Serious rapid corrosion can occur at the die lip discharge if the lips are low-grade steel and especially if moisture has not been effectively removed from the melt and escapes at this point. A good grade of alloy tool steel is certainly preferable when the die must produce good quality extrudate over a prolonged period. Although chrome plating of the die flow surfaces is not necessary, this practice offers several benefits:

1. Plating promotes the release of polymer deposits in cleanup operations and makes physical damage less likely.
2. Inspecting and judging the condition of the land areas become easier.
3. Some protection against corrosion results.

Streamlining the interior flow surfaces of dies has a favorable effect on the ease of purging when frequent changes are made in flow grade or color. Because PLEXIGLAS resins possess excellent thermal stability under the conditions normally occurring in dies, streamlining to prevent polymer degradation is not necessary. This stability also permits deckling of sheet dies in producing sheet narrower than the die. Excessive deckling should not be used, however, since it may form a heavy bead on the edge of the sheet.

Drive Horsepower Requirements

The estimated horsepower required for extruding PLEXIGLAS resins can be obtained from the following relationship:

$$\mathbf{H.P. = 0.14Q}$$

where Q is the actual or expected output rate in lb/hour. The constant 0.14 in the equation is a conservative value that covers most cases of high productivity in which relatively high melt temperatures develop and the screw supplies most of the total power requirement. In estimating cases with low productivity, the constant can be set at 0.10.

It is important to understand that the value of horsepower derived from the equation is the power delivered to the screw and is not necessarily the rated horsepower of the drive motor. When the equation indicates that the rated power of the drive motor should be adequate, but excessive motor current loads are nevertheless noted during operation, the problem arises from the type of speed control device in use and from the percentage of shaft speed at full output at which the machine is running. With any speed control device having constant torque characteristics, the rated motor horsepower can appear at the output shaft only when the machine runs at full speed. At reduced speed, when the drive motor is drawing the full rated motor current, the percentage of rated power available at the output shaft is the percentage of full speed at which the shaft is turning. In such a case, if the power requirement exceeds the amount available, the drive motor exceeds its rated current draw.

Speed control devices, such as the "eddy current clutch" and the"SCR-DC" type (those having armature control and constant field excitation), are in the constant torque category and are subject to the above limitations. Devices using mechanical variation for speed control, motor-generator sets driving DC motors, and SCR-DC devices which the upper portion of the speed range is provided by "field weakening" can supply the rated power over a wider range of output shaft speeds.

When the above problems occur with constant torque systems and marginal limitations cannot be resolved by adjusting the operating conditions, a change in the speed control system that allows the unit to operate closer to its maximum output speed must be considered. The gear ratio in the extruder gear reducer can be changed if gear change options are available. Before making such a change, however, it should be recognized that the gear reducer may become overloaded if adequate safety factors have not been provided in the original specifications of the equipment.

Melt Pumps

Melt pumps are used to give more stable output to improve yield and product quality. They can also increase output rates.

Profile Design

In profile extrusion, the process stability and the output rate are decisive for maintaining the shape and giving close dimensional tolerances. Optimum extrusion conditions must be established early in the extrusion procedure and held constant while various modifications in the die are made.

Figure 7 shows the design of a typical profile. The die construction of Figure 8 is a three-part assembly that provides consideration for low-cost machining, operation, and additional modifications. Nominal streamlining is provided on the internal flow channels with 1/16-inch minimum radii on corners and breaking of all sharp edges. The internal surfaces should have an extremely smooth machine finish and the die lands a ground and polished finish. Conventional strip heaters are mounted on the exterior of the die body with electrical connection to give multi-zone temperature control. The long flow channel and backup manifold afford a more uniform flow distribution. The length-to-opening ratio of the land used with the die is in the range of 10-12:1 and insures good reproduction in surface quality and shape retention.

FIGURE 7. PART DESIGN PROFILE SHAPE EXTRUSION
(FOR PRISMATIC LIGHTING FIXTURE)

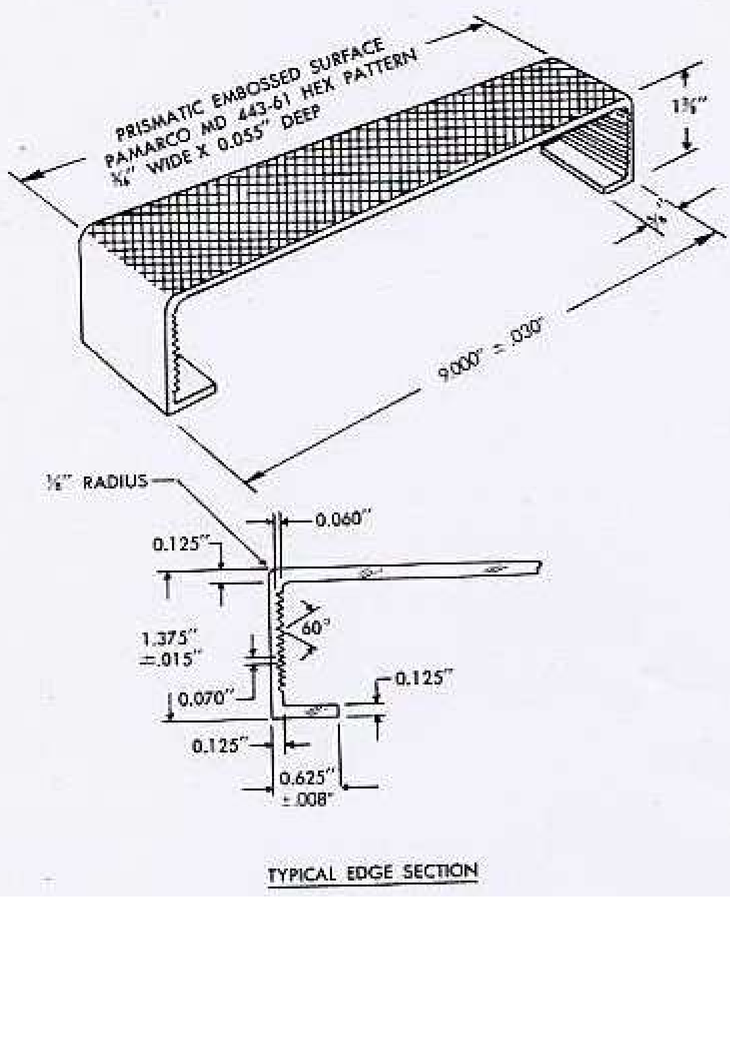
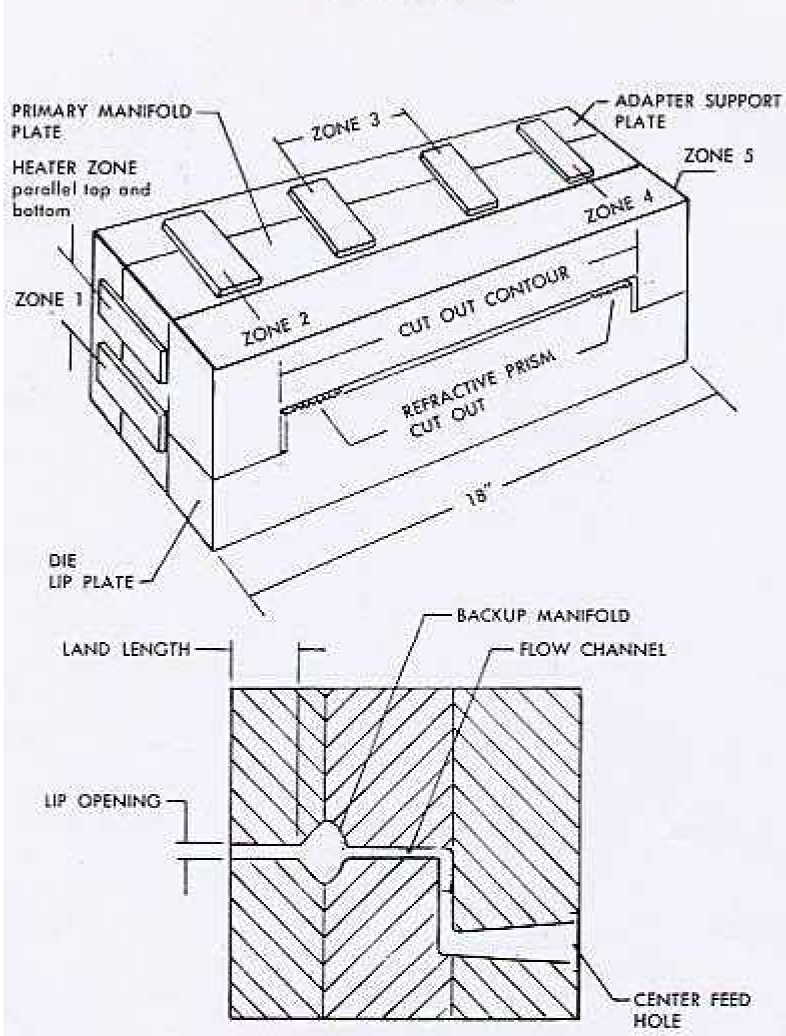


FIGURE 8. PROFILE DIE ASSEMBLY



The required modifications of the die can be most conveniently made on the lip plate. The changes consist of machining to alter the cutout contour and lip opening to adjust the flow distribution to give the final dimensions of the shape. Figure 9 shows typical recut procedures and basic data. The final cutting of the die must be associated with a fixed set of operation conditions that reflect a good level of extruder performance and process stability. In addition, the formulation of the extrusion resin must be kept constant to insure the same melt flow and extrusion characteristics.

Trial and error is the only practical approach to the final die dimensions. The amount of work can be minimized if oversizing allowance factors are known and the die is originally sized so the corrections involve removal of metal. To obtain reliable oversizing factors, feedback data must be developed systematically. In the method shown in figure9, the cutout contour is held flat except for specified sharp corners, and oversizing factors are begun at about five percent for thickness dimensions and 10 percent for lineal dimensions based on the part design specifications. In further trials, the extrudate thickness profiles and nip bead impressions should be measured. From these data, geometrical extrapolations can be plotted for the respective curvature and lip opening. In this example, three die cuts were needed to produce the correct shape and size and uniform flow distribution. The final oversizing allowance factors resulted in average values of 1-0 percent for thickness and 20 percent for lineal dimension.

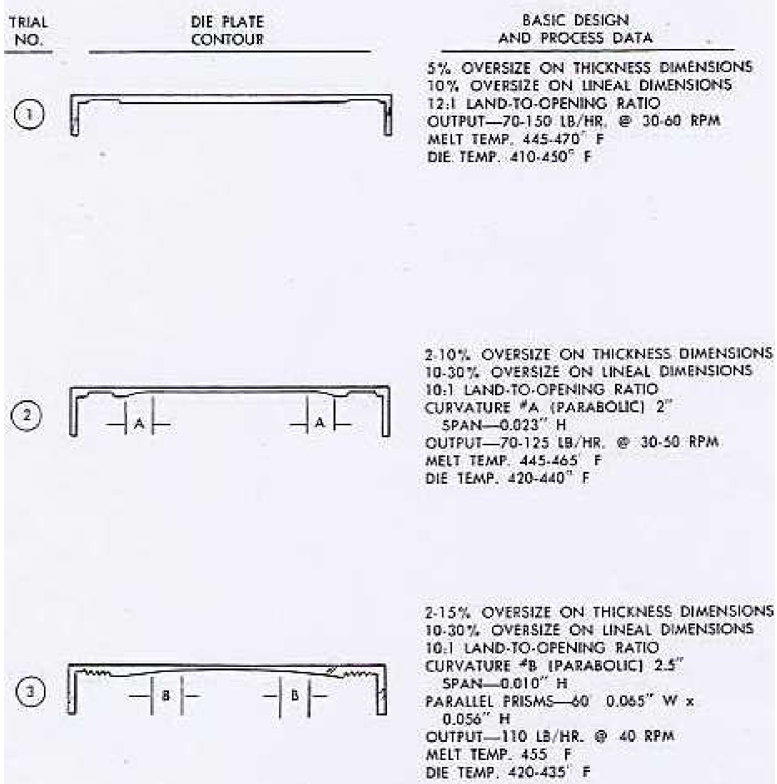


FIGURE 9. PROFILE DIE MODIFICATIONS

Schematic of 'Try and Cut' Procedures for Producing Shape Extrusion for Given Part Dimensions

It is important to note that die swelling of acrylic extrudates is normally very small and can usually be ignored in design work. The drawdown of the extrudate is mainly responsible for oversizing requirements in the die dimensions. Drawdown is normally not uniform across wide extrudates, and much higher drawdown occurs at the edges than in center portions. Studies with a profile die have shown the drawdown can be as much as 30 percent oat the edges and as little as 10 percent for center areas.

Figure 10 gives a schematic representation of a typical embossing reproduction on a profile surface. The extrudate is fed through a horizontal straight-through take-off for nip roll engagement. The overhanging extremities of the hot extrudates are supported on cooled sizing fixtures. To achieve the optimum embossed quality, uniform flow distribution must be provided with a full rolling bank on the order of 1/16 to 1/8 inch. To maintain good pattern alignment and definition, careful regulation and close synchronization of the line speeds between the embosser and the pull units are required.

Figure 10 also shows the essentials of techniques used in cooling and sizing profiles. After it leaves the embossing roll nip, the warm extrudate can be post-shaped by means of a series of plate fixtures conduction-cooled with water and sized to the contour and dimensions of the finished part. The movable plate fixtures are mounted on an adjustable bed assembly and spaced 3 to 5 inches apart along a bed length of 6 feet. In cooling extrudates from 430°F to below 200°F at line speeds up to 4 feet per minute, bed lengths of 4 to 6 feet are usually required with an additional equivalent length for air cooling on a roller conveyor prior to puller and cutting operations. If the extrudate temperatures or line speeds are higher than these, longer beds and closer spacing of the cooling fixtures should be provided with adjustable assembly fixtures.

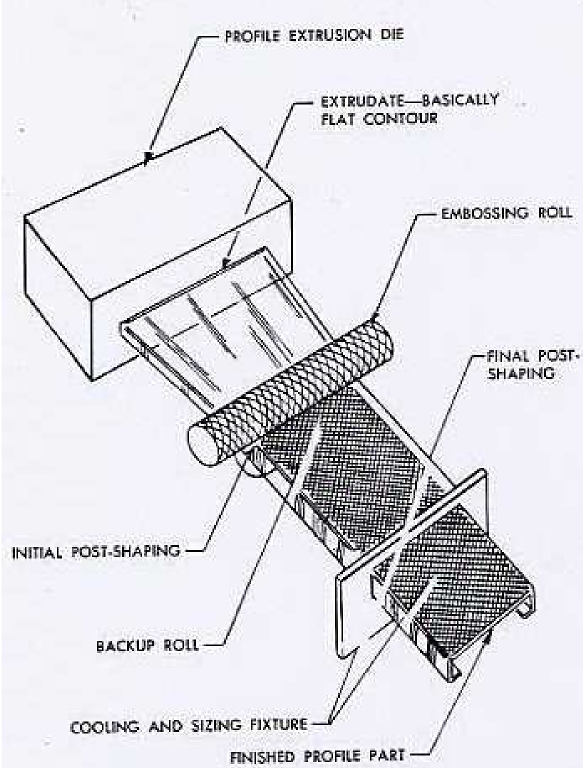
Figure 10 illustrates the fold-down method for shaping the extrudate and shaping it downward and below the mating fixtures. This sort of post-shaping starts at the nip of the rolls and is completed within 2 or 3 successive sets of angled features.

Final shaping and cooling complete the production of the part. To give support during the fold-down, adjustable external fixtures are set up outside of the extrudate in the same plane as the internal sizing plate. This procedure maintains the shape closely.

Screw Design

FIGURE 10. PROFILE TAKE-OFF ASSEMBLY

(FOLD-DOWN METHOD)



A wide variety of screw designs may be used to process PLEXIGLAS resins. A plasticizing extruder is required to receive and transport discreet solid particles of feed, heat and melt them into a viscoelastic melt, and pressurize the melt to force it through an attached die. It is not surprising; therefore, that screw design can be important in imposing limits on the process and its efficiency and productivity. Some general statements can provide an understanding of how screw design affects productivity:

Successful operation requires the screw to provide constant melt temperature and melt pressure at the delivery end. Constancy of the melt conditions strongly affects the uniformity of the flow rate and consequently the dimensional uniformity of the sheet or profile shape.

In adjusting the screw speed and other operating conditions to increase output, the rate obtained by departing from constancy defines the acceptable maximum process rate for a given screw in a particular situation. A breakdown in uniformity most often appears as a variation in melt temperature exceeding acceptable limits, but reliable information on changes in melt temperature is difficult to obtain in commercial machinery because the melt thermocouple probe is easily damaged.

Most extruders are now equipped with a device for measuring head pressure. These devices are quite rugged and provide useful information on the stability of extruder output. Assigning an acceptable maximum output rate to a particular screw design is often arbitrary, because the only indicators usually available to operators are the ease of controlling the process and the efficiency or yield at which the process can be sustained. Nevertheless, for any given screw diameter, the screw design has substantial effect on the maximum acceptable output rate. This assumes that the available horsepower and range of screw speeds do not limit the process.

If a variety of screw designs are characterized and arranged in the order of increasing maximum acceptable rate, short screws (low L/D ratio) with relatively shallow metering channels appear at the low end of the range and long screws with relatively deep metering channels at the high end assuming the die does not restrict flow. In addition to variations in screw length and channel depth in the metering section, options of adding shearing or mixing devices and of using two or more stages can also be adopted to extend output capacities. These changes in design can be considered steps toward improving the uniformity of plastification achieved in the extruder.

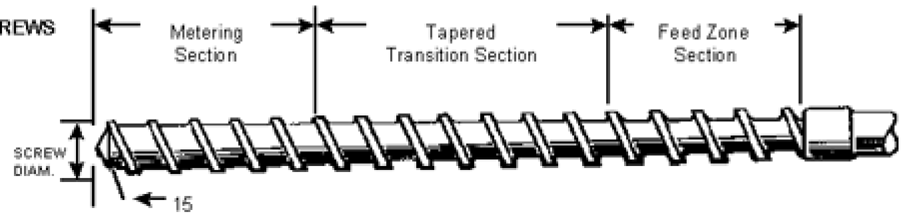
Before selecting or modifying a screw design, consideration should be given to the possible effects on the melt temperature in a particular process. When making rods or other products having a heavy section, in which cooling the extrudate is a major concern, design changes that increase the melt temperature should be avoided. In making complicated profiles, the increased productivity must more than compensate for the losses in yield that arise from difficulties in sizing and in cooling a less viscous extrudate. A favorable climate for improving productivity by modifying screw design is afforded by the production of flat sheet and similar applications in which simple dies and setup and improved handling techniques can better cope with the effects of increases in temperature and rate.

The above comments indicate that no single design is appropriate for all processes and applications and explain why a variety of screw designs has been used in extruding PLEXIGLAS resins.

The following Table III presents typical screw designs for single-stage and two-stage machines in the more commonly used diameters. The designs utilize a pitch equal to the diameter of the screw. These designs are intended only to be guides; minor changes in design can be made without causing difficulties, but excessively long or shallow metering zones increase the shear exerted by the screw and increase the melt temperature. In designing two-stage screws, a proper balance must be maintained between the first- and second-stage metering sections to prevent flooding the vent.

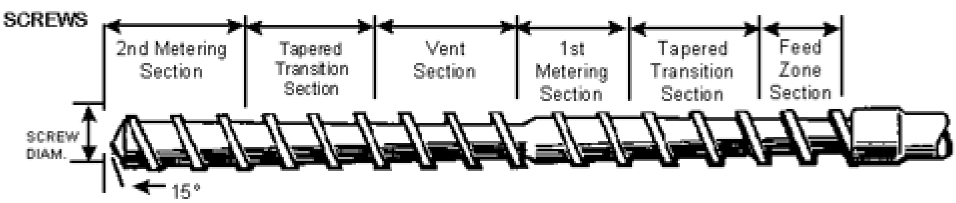
TYPICAL SCREW GEOMETRY FOR EXTRUSION OF PLEXIGLAS ACRYLIC RESINS

SINGLE-STAGE SCREWS



Screw Diameter	2½"		3½"		4½"		6"	
L/D Ratio	24:1		24:1		24:1		24:1	
Dimensions:	Depth	No. of Turns	Depth	No. of Turns	Depth	No. of Turns	Depth	No. of Turns
Feed Section	.375"	6	.510"	6	.600"	6	.650"	6
Transition Section	–	10	–	10	–	10	–	10
Metering Section	.125"	8	.170"	8	.225"	8	.250"	8

TWO-STAGE SCREWS



Screw Diameter	2½"			3½"			4½"			6"		
L/D Ratio		24:1	30:1		24:1	30:1		24:1	30:1		24:1	30:1
Dimensions:	**Depth**	**No. of Turns**		**Depth**	**No. of Turns**		**Depth**	**No. of Turns**		**Depth**	**No. of Turns**	
First Stage												
Feed Section	.375"	5.5	6.5	.510"	5.5	6.5	.600"	5.5	6.5	.650"	5.5	6.5
Transition Section	← To fit extruder →											
Metering Section	.125"	5	6	.200"	5	6	.225"	5	6	.250"	5	6
Second Stage												
Feed Section	.400"	5	5	.600"	5	5	.675"	5	5	.750"	5	5
Transition Section	← To fit extruder →											
Metering Section	.180"	4	5	.280"	4	5	.350"	4	5	.370"	4	5

Static Mixers

Static mixers are frequently inserted between the extruder and the die to provide mixing. They do not contribute to shear mixing, which only the screw can do. Tests have shown that static mixers are effective in coloring PLEXIGLAS resins with color concentrates in the extruder. They also promote greater uniformity in the melt temperature of the extrudate presented to the die and may conceivably permit higher output rates without instability. When properly designed, installed, and temperature-controlled, these units produce only a small drop in pressure. A static mixer should run at stock temperature and should neither heat nor cool the melt.

TAKE-OFF, COOLING, AND SIZING SYSTEMS

Plain and Embossed Sheet. The usual system for handling and cooling extruded acrylic sheet as it leaves the die is a three-roll polishing stack. Three-roll stacks can produce plain and embossed sheet. For flat sheet, the rolls should have a mirror-like chrome finish. The center roll is held in a fixed position, and the movable top and bottom rolls are held against adjustable stops by means of pressurized cylinders. Pressures of at least 100 pounds per lineal inch should be available.

The polishing stack should be parallel to and level with the travel of the sheet and pull the plastic straight from the die lips. The rolls should be as close to the lips as possible to minimize the sagging of the melt. Rolls should be kept clean and care must be taken never to mar the surfaces, because an imperfection on the rolls would appear as a defect on the finished sheet. Each roll should be equipped with its own temperature control. The center roll should be about 10°F below the temperature at which the sheet begins to stick to the metal. Roll surface temperatures above 220°F will cause sticking.

Typical roll temperatures for smooth flat sheet range from 160°F to 220°F. The most downstream roll should be the hottest. Higher temperatures on the top roll "polish" the sheet resulting in excellent surface finish.

Excessive temperatures on the bottom roll may allow the pull rolls to stretch the sheet and produce severe orientation. The rubber pull rolls should exert constant tension on the sheet. The tension should be kept at the lowest level required to insure the proper travel of the sheet through the take-off system. Excessive tension, which is the main cause of excessive orientation in the machine direction, should not be used to control the thickness or width of the sheet. Speed control for the polishing and pull rolls should be applied by separate synchronized controls and a variable differential.

Embossed or patterned sheet can be made on a three-roll stack by replacing the smooth center roll with an embossing roll. The operation is otherwise identical to that used for flat sheet. A three-roll stack is superior to a two-roll stack for embossing, because it gives patterns with better definition. The three-roll stack also provides greater cooling and thereby can hold the pattern straight in both directions more easily, an important factor for giving patterns with good optical quality. A two-roll stack usually requires additional cooling to freeze the pattern onto the sheet.

The temperatures of embossing rolls must be controlled precisely to insure control of the cooling operation. The temperatures for embossing are slightly lower than for polished sheet. They are set in the range of 100-190°F for three-roll stacks and 90-150°F for two-roll operation. The actual temperatures depend to some extent on the nature of the pattern.

The extrudate may be cut to length with a traveling saw. The width of the sheet can be sized with slitting saws or by scoring the sheet near the three-roll stack and breaking off the edges at the end of the line. To reduce the possibility of scratching during handling, the finished sheet should be masked or interleafed with tissue or polyethylene film as soon as possible. Masking with polypropylene can be done on line by unwinding the film around the pull rolls.

Valving Devices

A valve arrangement installed between the extruder and the die may be used to regulate the head pressure (usually defined as the melt pressure at the screw tip). The head pressure can significantly influence the melt temperature developed by the screw. A valve can, therefore, be used to raise the melt temperature or to maintain a constant melt temperature (or head pressure) when other factors, such as screen clogging, may affect the head pressure.

Valving devices are usually helpful or beneficial when high productivity is feasible and required. A valve is particularly advantageous in a two-stage vented extruder to control the inventory of melt in the second stage. Adequate inventory in the second stage improves output stability.

Valving should not be attempted unless operable, dependable pressure gauges are used to register the head pressure. The valve is often in a highly restricted position and its adjustment is quite sensitive. The temperatures of the valve element and the die have an effect on the head pressure and should be measured accurately and controlled to help maintain process stability.

A process in which substantial valve restriction is employed *should not be shut down without relieving the restriction.* Failure to do this could subject the equipment to severe damage during a subsequent startup.

Valves used to regulate the head pressure are usually plug or gate types that produce flow separation around a portion of the restricting element. When a flow stream is separated and rejoined, operational problems are likely to occur.

PROCESSING CONDITIONS

Extruder barrel zone temperature settings vary with circumstances, machine, and screw designs. The following table lists ranges of temperatures applicable to commonly used PLEXIGLAS V-Series formulations. When suitable operating temperatures have been established for a particular formulation, the changes suitable for another formulation can be approximated from the relative differences shown in the table.

The most important temperature, and the one usually most difficult to establish without actual experience in the equipment, is the rear zone. Because this temperature affects the frictional forces in the feed area, it has a strong influence on the dry solids conveying rate and is therefore important in determining the motor load and process rate. The temperature setting for the rear zone must be kept in a range in keeping with the melting, transport, and pumping functions of later zones. Within these limits (and the input power limits), a consistent relationship exists whereby *reducing* the rear zone temperature *increases* the motor load and process rate (output/rpm) and vice versa. (Note that screw speed (rpm) is the primary determining factor for process rate and that regulating the rear zone temperature has only a contributory effect on the screw speed at which a given output is obtained. This setting can influence motor overload in constant torque drives, as discussed above.) The temperature of the rear zone should be given primary attention, particularly in a first run, and should be adjusted to provide a permissible steady motor load and minimum variation on head pressure.

ANNEALING PARTS MOLDED OF PLEXIGLAS® ACRYLIC RESIN

Annealing is recommended to insure optimum quality and maximum useful service life from parts molded of Plexiglas acrylic resin. The primary benefits of annealing Plexiglas parts are improved resistance to external stresses (mechanical or chemical) and greater dimensional stability at elevated service temperatures.

Annealing is the process of heating a molded part for a period of time at a temperature near, but below, it’s softening point. After heating the part, slow, uniform cooling will cause stress relaxation without distortion of shape. The ultimate goal of annealing is to redistribute and reduce the stresses in the part generated by the injection molding process. Annealing does not *completely eliminate* molded-in stresses in a well-molded part, and can only partly relieve the internal stresses in a poorly-molded part.

SELECTING THE BEST ANNEALING CYCLES FOR YOUR PLEXIGLAS MOLDED PARTS

(This procedure is only intended to establish a suitable temperature and time period for annealing your parts. To achieve the maximum benefits from annealing, also follow the suggestions listed below the table.)

1. Place several carefully measured, as-molded parts in the annealing oven at the higher temperature from the table below for the specific grade from which the parts were molded.
2. Heat-treat them for the length of time indicated for the maximum applicable part thickness.
3. Remove the parts form the oven and let them stand for several hours at room temperature before remeasuring their dimensions.
4. If the dimensional change following this heat treatment proves no greater than 1%, or the maximum permissible change for your specific application, the parts may be properly annealed with these conditions. In certain cases, even additional heating time may be required to further relieve internal stresses.
5. If the dimensional change exceeds 1% (or maximum permissible), repeat the test at the lower temperature and time indicated in the table. If unacceptable dimensional changes continue to occur, this is positive evidence the part is poorly molded and requires improvement of molding conditions.

Maximum Thickness (inches)	Plexiglas V825, V826		Plexiglas V052, V045, V044, V920, DR, MI7, HFI10, HFI7, SG10, SG7		Plexiglas VM, VS, VH		Maximum Cooling Rate (°C/Hour)
	95°C	90°C	85°C	80°C	75°C	70°C	
0.060 to 0.150	2.5	7.5	2.5	7.5	1.5	7.5	40
0.151 to 0.375	3	8	3	8	2	8	20
0.376 to 0.750	4	9	4	9	3	9	10
0.751 to 1.125	5	10	5	10	4	10	8
1.126 to 1.500	8	13	8	13	7	13	5

SUGGESTIONS FOR MAXIMIZING ANNEALING EFFECTIVENESS

1. Annealing should be performed in forced circulating air ovens with the parts supported so they are not under stress. Air should circulate freely around each part.
2. Slow-cooling will produce the best annealing after heating. Strictly observe the maximum recommended cooling rates from the table. Annealed parts should not be removed from the oven until the temperature reaches 50°C.
3. If practical, parts should be annealed after all fabrication is complete, including cementing, machining, polishing, and decorating. If crazing occurs when unannealed parts are cemented or decorated, this may be remedied by annealing the parts both before and after these operations.

Die Temperatures

As with most thermoplastics, PLEXIGLAS resin extrudates tend to exhibit increased gloss with increasing die temperatures. With formulations having melt flow rate values greater than four, the variation in gloss is relatively small over the usual operation range. As a result, the die temperatures can be chosen to provide the best compromise between any of the following objectives.

1. To optimize the flow distribution from the die, a worthwhile aim with "non-adjustable" profile dies.

2. To regulate or influence the head pressure.
3. To suppress surface defects.

Drying

Excessive moisture will cause surface defects. Plexiglas acrylic resins are packaged in specially constructed containers at low moisture levels and can frequently be used with no additional drying. Critical jobs or old material may require drying.

Absorbed moisture in Plexiglas acrylic resins does not effect the physical properties of extruded sheet or profile. However, excessive moisture will cause surface defects or bubbles in thick parts. These defects can be overcome by drying the molding resins in warm air circulating ovens, vacuum dryers, or hopper dryers. If drying trays are used, the layer of molding resins should be no more than one inch deep. Moisture levels should be 0.05 percent or less for demanding jobs. Non-critical jobs may tolerate as much as 0.1 percent moisture in the resin.

To achieve the best possible drying performance, dehumidified or desiccant drying systems are needed. Dew points in these systems of -20°F to -40°F (-29°C to -40°C) are recommended. Dew points above 0°F (-18°C) are unsatisfactory. A drying time of four hours is recommended for all Plexiglas resins. Recommended drying temperatures are listed below:

PLEXIGLAS Resin Grade	**Hopper Dryers**	**Shallow Trays**
V825, V826	190°F (88°C)	200°F (93°C)
V052i, V045i, V052, V045, V044	180°F (82°C)	190°F (88°C)
SG-0, SG7, Solarkote H, HFI7, HFI10, VOD, V920	175°F (80°C)	190°F (88°C)
VM, VH	165°F (74°C)	85°F (85°C)
VS	150°F (65°C)	170°F (77°C)
Solarkote A, Frosted, Granite, DR, MI7	180°F (82°C)	190°F (88°C)

A two-stage vented extruder can remove a moderate amount of water from a feed of untried resins and leave no evidence of moisture defects. In the range of moisture contents that this type of machine can handle, however, the behavior of the polymer in the extruder may vary with the moisture content enough to alter flow characteristics through the die. Parts extruded from feed materials exposed to humid conditions will almost certainly have unacceptable appearance and performance. Drying equipment should therefore be provided in two-stage vented processing, even though the drying requirements may be less strict than in corresponding single-stage operation.

Extruders having double vents are available. Tests have shown that such machines have a much greater capacity for removing moisture than those with single vents and may in some cases eliminate the need for pre-drying.

Feeding Extruders

Though extruders vary in their sensitivity to changes in input feed temperatures, some reaction to all such changes should be anticipated with any machine. In the case of PLEXIGLAS resins, a rise in feed temperature increases the output rate under a given set of operating conditions. A constant output rate requires a constant feed temperature.

Problems caused by variations in processing conditions are most likely to occur when hot dried resins are fed to a large uninsulated and unheated feed hopper or when the material is not loaded automatically by a level sensing device. In such cases, when the hopper is likely to become filled completely with hot feed and is then left to run low before refilling, an obvious condition for promoting changes in feed temperature develops. The ideal feed hopper should be small with quite steep walls to minimize adsorption of moisture and changes in feed temperature.

Vacuum loaders and compressed air loaders utilize the movement of air to fluidize and transport resins from one station to another. Vacuum loaders have the advantage of conveying under negative pressure with respect to the surroundings. The possibility of fine particles escaping into the surrounding area is thereby reduced. This resistance to escape is particularly beneficial in maintaining cleanliness with a feed of regrind. Using compressed air presents the risk of contaminating the feed with oil unless special oil-free compressors are employed.

Though aluminum tubing is often used to convey plastic resins, it should be restricted to straight runs only. Curved sections should have sweep bend curvature and be made of stainless steel to prevent contamination. In very demanding applications, the exclusive use of stainless steel tubing is well advised.

Mechanical transfer devices, such as some form of screw or helical conveyor, are sometimes used. The design and materials of construction of such devices must be considered carefully with regard to the possibility of abrasion.

Whatever transfer device is selected, it should permit convenient adjustment to maintain the required feed levels at the various stations. In charging a hopper drier, holding the level constant stabilizes the drying time. When transfer devices are used to unload a drier and feed an extruder hopper, they should provide a relatively constant level in the hopper. This is necessary for a stable output rate and minimum variation in feed temperature.

Hopper driers are sometimes mounted directly on the extruder to provide gravity flow of the hot feed into the extruder feed throat and to remove the need for a transfer device. Direct mounting often causes difficulties, however, because the volatile materials given off from the back of the screw cannot vent. Material fed by gravity from the hopper drier should proceed through a small open hopper to allow venting of the feed area. A more convenient arrangement, frequently needed because of limited head room, is to mount the hopper drier on the floor, and use a transfer device to feed the extruder hopper. Separation of the hopper drier from an extruder can increase the efficiency of scheduling and carrying out cleanup operations on the drier and the extruder. This separation also provides flexibility in supplying several extruders from a single drier if the drying capacity is adequate.

Material Handling

Introduction

Altuglas International manufacturing facilities are continuously reviewing and looking for ways to further improve the cleanliness and quality of our Plexiglas resins. This section provides details on resin handling systems designed to keep the resin as clean as when produced. How the resin is handled once it arrives is critical in keeping contamination rejects to a minimum. Housekeeping and proper system design, coupled with good filtration of air used in conveying the resin are all part of producing a quality finished product.

This section discusses various handling systems. There are many companies today which can offer various types of conveying systems, depending on the customer's needs/concerns. Surprisingly, few system suppliers recognize how critical resin cleanliness is to the customer. Often the system supplier will quote "food grade" handling system which falls well short of the cleanliness required. Many times the system includes galvanized storage bins, or other components which cause acrylic discolorations. Filtration of air for conveying often falls short of the standards we maintain in our production facilities. This section is designed to provide some basic guidelines to building a resin handling system that will keep the resin clean.

Pressure Transfer Systems

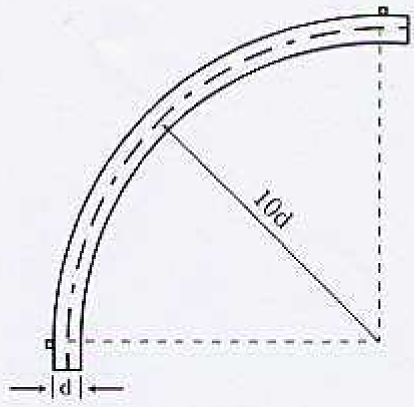
Stainless Steel 304 or 304L grades are recommended in conveying and storage systems for acrylic resins. See Figure 1.

Star Valves (constructed from 304 and / or 316 stainless steel)

A rotary star valve is used to introduce the pellets to the conveying line. This valve is vented so the pressure from the conveying line will be relieved, allowing pellets to fall into the conveying stream. Star valves should be specifically designed to handle pellets. This usually means the rotor ends are closed versus open as used for most powder systems.

Conveying Lines and Pipes (Figures 1-4)

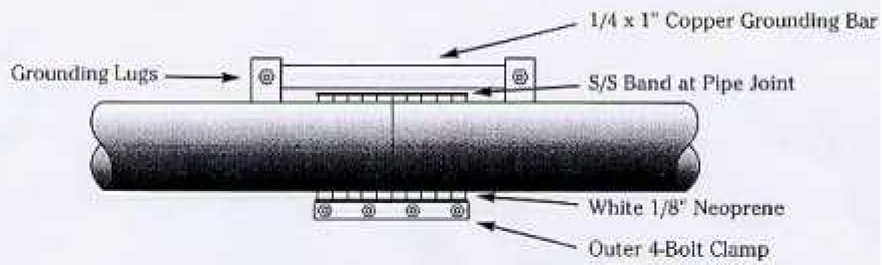
Figure 1 - Pipe Bend



Conveying Lines and Pipes

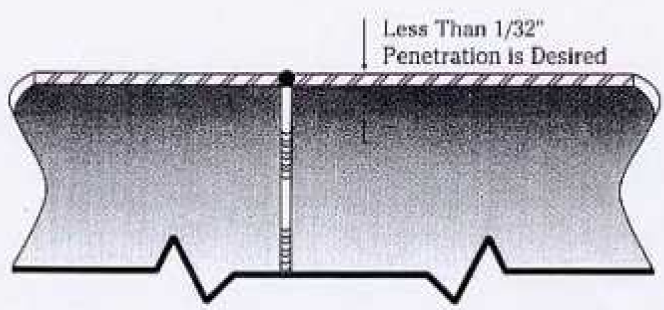
Material:	304 or 304L
	Schedule 10
Radius of bends:	10 X pipe diameter

Figure 2 - Morris Coupling



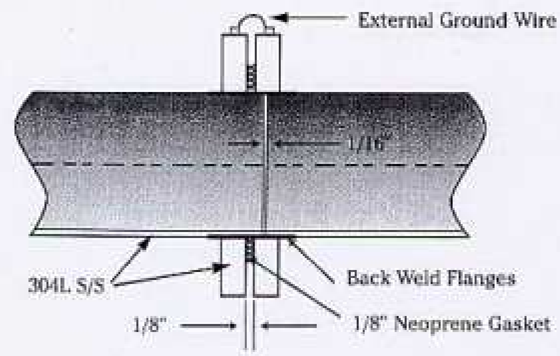
Pipe connection: 1) Morris coupling clamp; this type of connection requires grounding wires or bars over each coupling and proper maintenance of pipe alignment.

Figure 3 - Weld Joint



2)Welding of pipe; this procedure requires TIG (tungsten inert gas) welding to keep the internal bead as small as possible.

Figure 4 - Flanged Joint



3) Flanged connections: this procedure requires centering the flange on the pipe and securing it by back welding. Also, a male / female flange placement can reduce misalignment.
Note: When the flange is bolted tight, the pipe is compressed to a metal fit and the 1/8" gasket is compressed to 1/16".

When pellets are being fed to the star valve from a silo, a knife gate valve (non-lubricated) is placed in the line a few feet above the star valve. This allows isolation of the star valve for repair and can be used to throttle flow of pellets to the star valve.

Blowers and Conveying Air Filters

For dilute phase (higher volume / velocity) transfer, "Roots" blowers are recommended; usually RCS616 Whispair or smaller, depending on the desired rate of transfer. The heavier a dilute phase transfer system can be loaded without plugging, the more desirable. This will minimize pellet degradation.

The air used to convey the pellets must be free from contamination. For best results, two HEPA filters are recommended, and are essential for critical applications. The first filter housing contains a rough filter and a HEPA (High Efficiency Particle Accumulator) 99.97% efficient at 0.3 microns and is connected via stainless steel piping to the intake of the carbon steel blower. The second filter is a canister type filter with a HEPA element, also 99.97% efficient at 0.3 microns. This filter is located between the discharge of the blower and the pellet entry point into the air stream. All connection piping is 304 stainless steel. A differential pressure gauge (DPG) may be connected across this second filter to aid in determining when to change the element. See Figure 6

Figure 5 - Conveying Air Filters

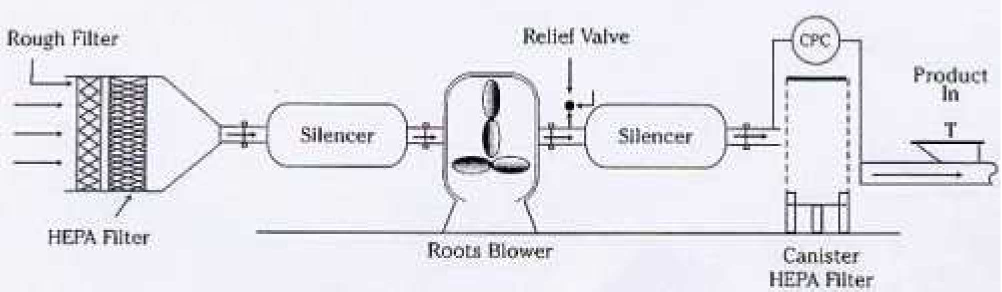
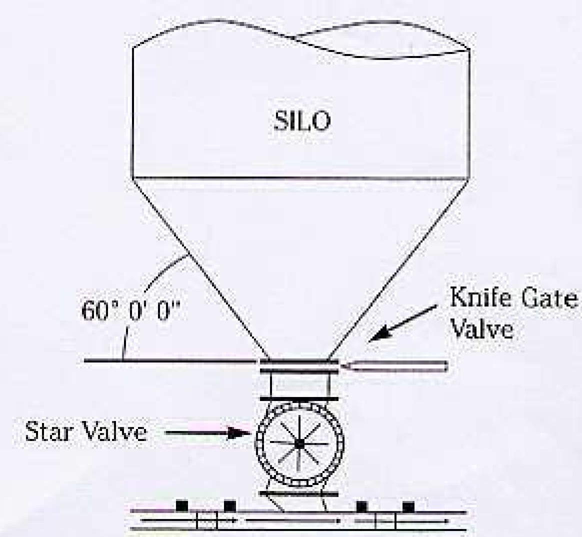


Figure 6 - Silo storage



Flex Lines

On occasion it may be necessary to use flex lines to direct product to various locations. An all stainless steel dry bulk conveying flex line is required. A single direction flex line designed for product flow only in one direction provides minimal degradation of pellets.

Hose fittings for these flex lines should be stainless steel. "Evertite" and "Sprout-Waldron" connectors are recommended. These connectors should have a minimal number of square edges. If a gasket is used it should be arranged so pellets cannot wear or abrade parts of the gasket material into the air and pellet stream.

Use of flex lines and connectors should be kept to a minimum to keep the conveying systems as efficient as possible.

Vacuum Transfer Systems

Piping and conveying lines for vacuum conveying systems should also be of 304 or 304L stainless steels. In some instances, aluminum piping has been used for straight runs of pipe as a cost savings. However, aluminum elbows and fittings can be abraded by acrylic resin which results in aluminum specs in finish molded parts.

Distributor Boxes

Vacuum systems usually pull pellets from a silo using a distributor box on the bottom of the silo outlet to introduce pellets into the air stream. Distributors or collector boxes should have an air tight connection to the silo and all conveying air should be filtered, preferably with HEPA filters.

A knife gate valve above the distributor box is recommended to facilitate collector box changes, additions or repairs. Rotary or star valves may also be used.

Pellet Loaders

There are many pellet loaders available. These are recommended to have stainless steel components that contact the material. Many of these loaders use soft or elastomer seats to seal and pull vacuum. These seats need to be tough, durable and unexposed to pellet flow. However, these seats will still wear and are a possible cause of foreign particle contamination.

Another source of contamination comes from airborne particles, as most loaders are open to room air when they are not loading. These foreign particles can contain insects, dirt, metal flakes, and fines from other non-compatible resins. This may cause streaking, clouding, or other undesirable finished part rejects. The air entering the loader needs to be filtered to preserve the cleanliness of the acrylic and reduce reject rates.

Flex Lines

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Use of flex lines and connectors should be kept to a minimum to keep the conveying systems as efficient as possible.

Resin Storage Systems

Silo Storage Tanks

All parts of the silo which come in contact with, or are exposed to the product should be stainless steel. Exterior supports and brackets may be painted carbon steel. CAUTION! Do not attempt to weld a galvanized or zinc rich coated steel to stainless steel. The zinc will cause "cracking" in the heat affected zone of the weld in the stainless steel component.

The outlet cone at the bottom of the silo should have a 60° angle to assure total emptying of the silo. If the silo or hopper is square or rectangular, the corner angles should not be less than 60°. Refer to Figure 6

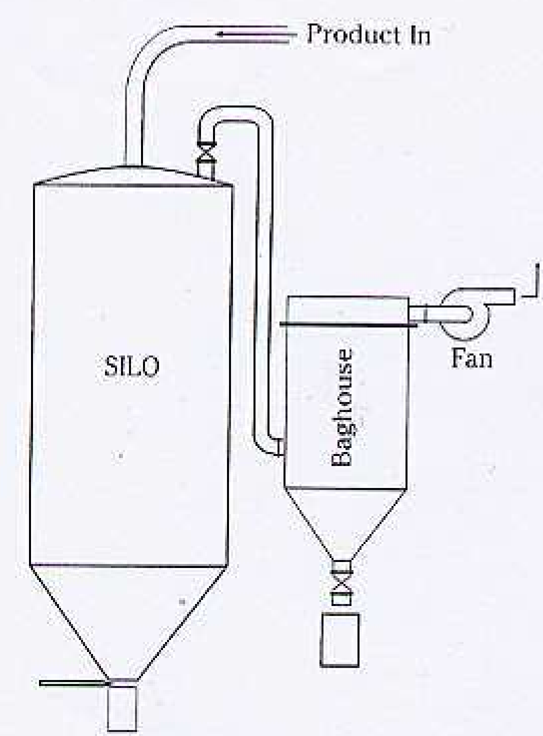
Silo Accessories

The fill line to a silo must enter directly into the center of the top, in the vertical direction. A second nozzle on the top of the tank must be vented to a fan and baghouse (see Figure 7) or bin vent.

A cyclone or decelerator (discussed later) may also be used to top load a silo with the vent from the cyclone going to the baghouse.

The baghouse and fan are normally interlocked so the they operate when product is transferred into the silo. Also, no transfer can take place until the baghouse and fan are started. The baghouse and fan can be carbon steel construction.

Figure 7 - Silo Accessories



Silo Dryer

Cyclone

A cyclone (constructed from stainless steel) can be used when it is necessary to load the product into the silo in a "softer" manner or when a vent nozzle to a baghouse is not available. The cyclone will slow the pellet velocity and let the gravity fall into the silo, bin or hopper. A top view and a front view of a typical cyclone are shown in Figures 8 and 9.

When the air and pellets enter tangentially, the inertia of the pellets cause them to slide against the outer wall. This slows the product and removes it from the high velocity air, allowing it to drop by gravity into the silo. The air exits out the top center to a baghouse to capture any products fines. If the cyclone is feeding product into an open vessel, or one that cannot contain the pressure or vacuum, a star valve may need to be installed at the bottom of the cyclone.

Figure 8- Cyclone (Top View)

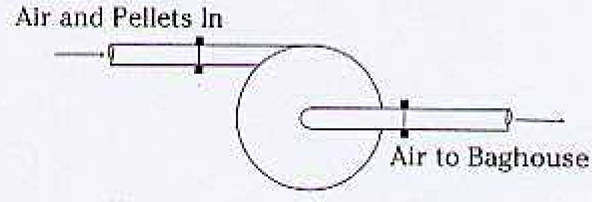
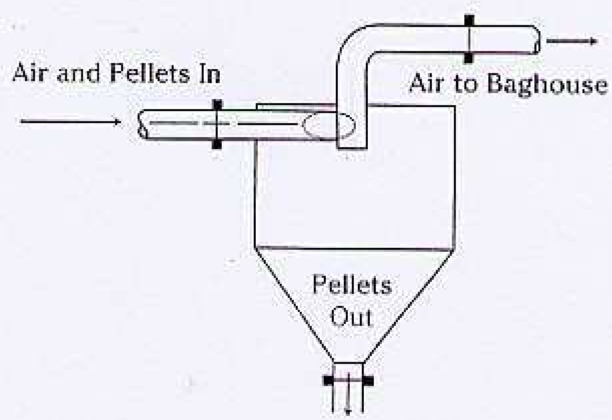


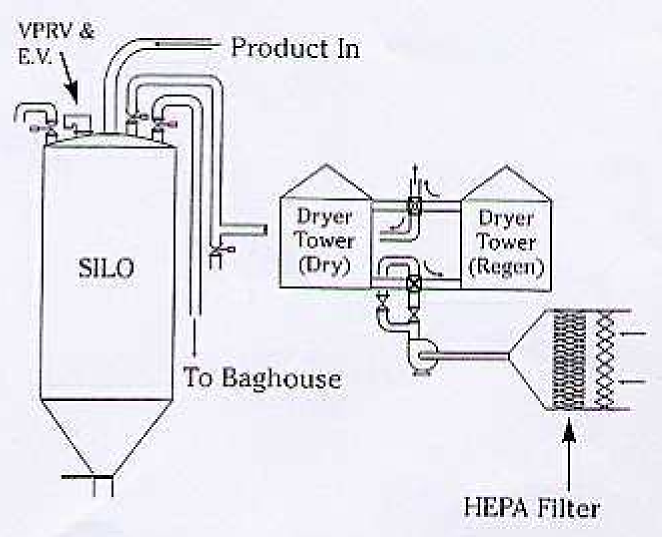
Figure 9- Cyclone (Front View)



Silo Dryer

A dryer is used on each silo to dry the air in the silo above the product. Dryers are typically twin-tower, with one supplying dry air to the silo while the other tower is regenerating. The air is also filtered with HEPA filters to prevent any foreign particle contamination. The air is then blown in on one side of the top of the silo, and allowed to exit on the other side of the top. Valves are typically interlocked to close when the silo is being filled and the dry air is directed to the outside for this period of time. Refer to Figure 10.

Figure 10 - Drying



Silo Vents

Each silo should be equipped with an emergency vacuum/pressure relief valve (E.V. and VPRV) to prevent over-pressure or vacuum damage to the silo. Acrylic dust is potentially explosive so emergency venting is required. Because of space limitation on the roof of the silos, sometimes this emergency vent and VPRV can be incorporated into the manhole cover.

Silo Level Indicators

There are several systems on the market for silo level indication. However, reliability for use on pellets has historically been a problem. The most reliable system has been and still is dropping a weighted tape measure in the top manhole and measuring the outage. Care must be taken to insure that no dirt or foreign particles fall into the silo while the level reading is being taken.

An ultrasonic indicator system works reasonably well as long as each silo has a totally separate system.

Another reasonably accurate method of determining the level of material is to mount the silo load cells.

Remember, all components exposed to the product need to be stainless steel.

Flex Lines

On occasion it may be necessary to use flex lines to direct product to various locations. An all stainless steel dry bulk conveying flex line is required. A single direction flex line designed for product flow only in one direction provides minimal degradation of pellets.

Hose fitting for these flex lines should be stainless steel. "Evertite" and "Sprout-Waldron" connectors are recommended. These connectors should have a minimal number of square edges. If a gasket is used it should be arranged so pellets cannot wear or abrade parts of the gasket material into the air and pellet stream.

Use of flex lines and connectors should be kept to a minimum to keep the conveying systems as efficient as possible.

Grounding

Acrylic dust, as with most polymeric dusts, can accumulate and coat the walls of conveying systems can be potentially explosive. Mechanical grounding using copper wires or bars across every gasket or mechanical joint must be used. The copper wires and bars are uninsulated to have clear visibility of any broken wire or grounding connections. (See Figure 11)

Continuity of the entire system and of any component of the system to ground should have a total resistance of less than 5 ohms. This should drain off any static electricity, or potential to create a spark.

Individual grounding of each component (silos, roots blower, motor, etc.) is also required. All individual parts of the conveying and storage system must be bonded to each other by copper conductors.

When a bulk load truck or railcar is to be loaded or unloaded it should also be grounded. (See Figure 12)

Figure 11 - Grounding

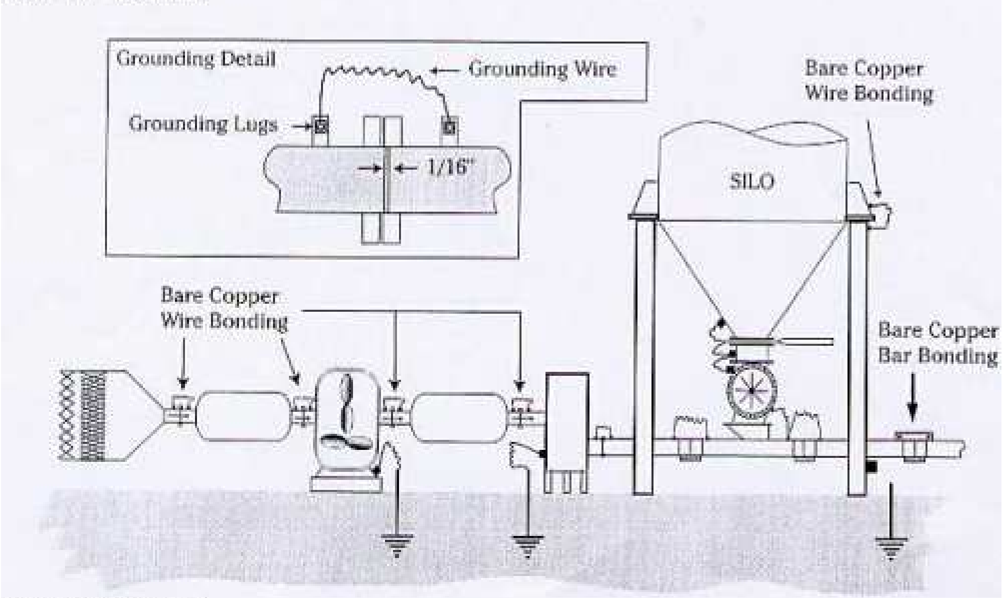
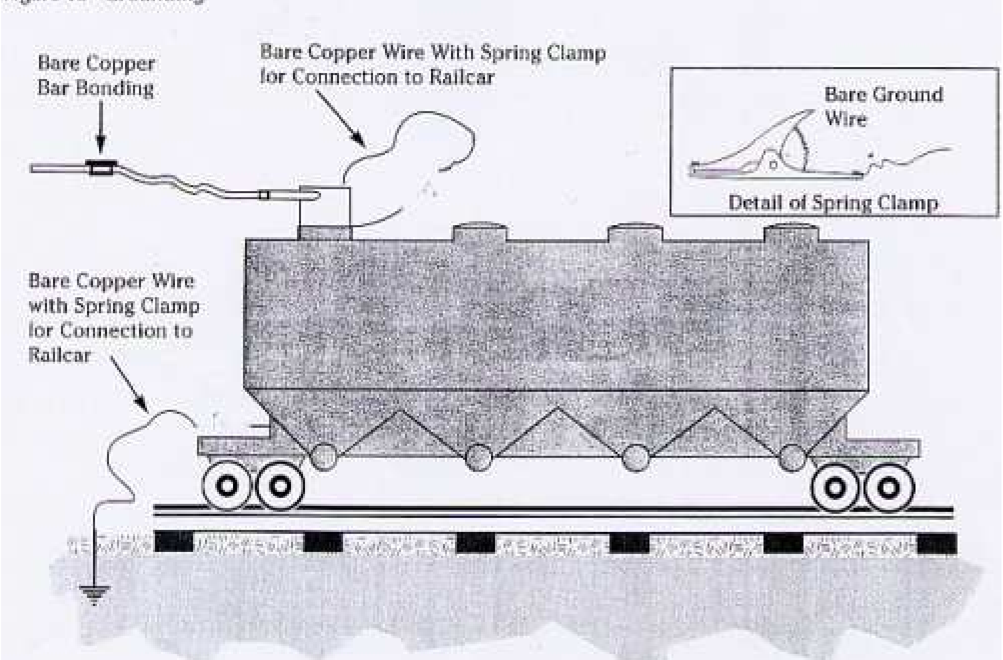


Figure 12 - Grounding



Melt Temperatures

In operating extruders at relatively low productivity, a direct correlation can be expected between the melt temperature developed at the screw discharge and the barrel temperatures in the equipment, especially in machines of small diameter. Because of the effects of the screw design factors discussed earlier, the influence of the barrel temperatures on melt temperature decreases with increasing productivity. Other factors, such as screw speed, head pressure, and polymer viscosity assume the major role in determining the melt temperature.

For these reasons, a listing of melt temperatures in Table IV would be impractical. Melt temperatures in general approach the listed nominal front barrel temperatures in cases of low productivity and reach values 50 to 75° F higher at higher productivities.

Regrind

Regrind usage should be kept to 10 to 20 percent of virgin material for trouble-free processing. Handling the regrind like virgin material and reducing or eliminating fines enable the processor to use a high percentage of regrind, up to 100 percent, in a feed mixture. Uniform melt temperatures and output rates of reground Plexiglas acrylic resin depend on uniform particle size.

The use of regrind does not harm physical properties but care should be taken to avoid contamination and the development of excessive heat history which may effect part appearance. Regrind should not be allowed to accumulate since it will readily absorb moisture and is very difficult to dry adequately.

Start-up Conditions

Start-up Procedures. Before startup, set the temperature controls for each zone to give the predetermined temperatures and thoroughly heat the extruder and die. At the end of the preheating period, start the screw at slow speed while making sure to feed material slowly from the hopper. *Never run the screw dry.*

Continue running the screw at slow speed until a uniform extrusion is obtained at the die. If the pressure becomes too great, stop the run, determine the cause of the difficulty, and correct the faulty condition. When the flow of extrudate is satisfactory, increase the screw speed gradually and adjust the temperature settings to operating conditions.

In starting a partially loaded extruder that has cooled, the preheating period should be long enough to soften the plastic in the barrel and die so that it can flow and permit rotation of the screw without excessive resistance.

Shutdown Procedures. If the operation is stopped for any length of time, shut off the feed and immediately reduce the screw speed to a minimum. Run the screw at slow speed until material stops flowing from the die, then turn off the extruder and die heaters. When processing polymers that resist degradation, the extruder can be left in this condition for the next startup if a cleanout is not needed.

It is important to recognize that the "static" temperatures established at the barrel walls, screw surface, adapter, and die melt passages during heat up can be altered substantially by the shearing forces and frictional heat developed under "dynamic" operation. With the possible exception of the surface temperatures at the front and rear ends of the screw, these temperatures tend to increase as the machine enters its operating mode. A reduction in motor load and operating stresses in the equipment usually occurs as the machine approaches dynamic equilibrium, so that care must be exercised to prevent overloading and severe stressing of the equipment during startup.

If no previous information on the process is available, it is advisable to start with barrel temperatures set near the upper end of the ranges listed in the table below.

TYPICAL START-UP CONDITIONS FOR EXTRUDING PLEXIGLAS ACRYLIC RESINS

Barrel Temperature	**Frosted, Plexiglas DR, MI7**	**Plexiglas V044, V045, V825**	**Plexiglas V920**	**Plexiglas VM, VH**	**Plexiglas Granite**	**Solarkote A, Solarkote H**
Rear Zone	390-420°F.	360-470°F.	370-410°F.	320-410°F.	360-400°F.	390-420°F.
Center Zone	410-460°F.	400-480°F.	390-420°F.	340-420°F.	400-440°F.	400-460°F.
Front Zone	410-470°F.	400-480°F.	400-430°F.	350-420°F.	400-440°F.	400-470°F.
Die Temperature	410-450°F.	400-450°F.	380-410°F.	350-400°F.	400-440°F.	400-440°F.
Stock Temperature	470-510°F.	450-500°F.	450-500°F.	450-500°F.	430-500°F.	450-500°F.
Head Pressure	1800-5500 psi	1000-5500 psi	1000-5500 psi	1000-5500 psi	1500-2500 psi **NO SCREEN PACK**	1800-5500 psi
Polishing Roll Temperature	180-220°F.	170-210°F.	160-210°F.	160-200°F.	170-200°F.	175-220°F.
Screw Speed	40-80 rpm	40-80 rpm	40-80 rpm	40-80 rpm	50-70 rpm	50-100 rpm

Troubleshooting

TROUBLESHOOTING GUIDE

Defect

Die Lines	Rough or Dull Surface	Moisture Streaking	Pock Marks or Craters	Variation in Thickness or Shape	Curling and Warping	Chatter Marks	Fold – Over Marks	Entrapped Bubbles	Flow Marks	Melt Fracture Pattern	Poor Embossed Reproduction	Excessive Orientation	Suggested Remedy
						X							Check mounting and location of line equipment.
				X		X							Check polishing drive system.
X													Polish die to remove nicks.
X		X						X					Reduce die temperature.
	X									X		X	Increase die temperature.
X	X												Purge or clean die or extruder.
				X				X			X		Be sure temperature controllers are functioning properly.
				X			X		X	X			Reduce output rate.
X	X	X	X	X				X					Dry material more effectively.
X	X	X	X					X					Use a vented extruder.
				X									Adjust feed zone temperature.
				X					X				Increase barrel temperature in transition zone.
				X				X	X	X			Use proper screw design.
				X	X		X		X				Adjust die flow.
							X						Increase take-off speed.
												X	Reduce pressure of polishing roll.
X	X										X	X	Increase polishing or embossing roll temperature.
											X		Reduce polishing or embossing roll temperature.
X	X										X		Increase pressure of polishing or embossing roll.
					X						X	X	Regulate speed ratio between embosser and pull rolls.
	X									X		X	Increase stock temperature.
			X										Eliminate contamination.
					X								Adjust temperature differential between rolls.
X	X		X	X	X		X		X		X		Adjust bead at polishing rolls.
X								X					Reduce stock temperature.
	X		X										Use highly polished rolls.
										X		X	Reduce drawdown.
				X									Repair worn screw or barrel.

Health & Safety Precautions

All thermoplastic materials produce some gases or vapors at high temperatures; but no harmful concentrations of same should result if Plexiglas® acrylic resin is dried, molded, extruded, or reground in accordance with recommended techniques, processing conditions and temperatures in areas with adequate ventilation.

Heating Plexiglas resins above 350°F may release gases and vapors, including methyl methacrylate monomer (MMA). High concentrations of methyl methacrylate vapors can cause eye and respiratory irritation, headache and nausea. The American Conference of Government Industrial Hygienists (ACGIH) Air Contaminant Standard for methyl methacrylate places the maximum permissible exposure level at a time weighted average (TWA) of 100 ppm.

It is always good practice to provide local exhaust ventilation as close to the point of possible generation of vapors as practical. Suggestions for the design of exhaust ventilation systems are provided in Industrial Ventilation -- A Manual of Recommended

Practice, published by ACGIH (1988) and American National Standards Institute, Fundamentals Governing the Design and Operation of Local Exhaust Systems, Z9.2-1979.

Any dust produced by the cutting or regrinding of Plexiglas acrylic is considered "nuisance" dust, i.e., particles of little adverse effect on lungs that do not produce significant organic disease or toxic effect when exposures are kept under reasonable control. The current ACGIH Air Contaminant Standard for this type of dust places TWA exposure to total dust at 15 mg/m^3 and breathable dust at 5 mg/m^3. Worker exposure to dust can be controlled with adequate ventilation, vacuum dust removal at the point of generation or the use of suitable protective breathing devices.

Customer's dry coloring Plexiglas acrylic should determine and follow the Health and Safety Recommendations of their Colorant Suppliers for the safe managing of the concentrate systems.

Caution: Plexiglas acrylic resin is a combustible thermoplastic. In general, the same fire precautions that are observed in connection with the handling and use of any ordinary combustible material should be observed when handling, storing or using Plexiglas resin. The fire hazard of uses of Plexiglas resin can be kept at an acceptable level by complying with building codes and applicable Underwriter's Laboratories standards, and observing established principles of fire safety. Impact resistance is a factor of thickness. Avoid exposure to extreme heat or aromatic solvents.

For more information, to request literature or to place an order, please call our toll free customer service number: 1-800-523-1532.

Plexiglas® acrylic plastic is a combustible thermoplastic. Observe fire precautions appropriate for comparable forms of wood and paper. For building uses, check code approvals. Impact resistance is a factor of thickness. Avoid exposure to heat or aromatic solvents. Clean with soap and water. Avoid abrasives.

See MSDS for Health & Safety Considerations.
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