UNIVERSAL DYNAMICS, INC.

SYSTEM ENGINEERING WORLDWIDE

PLA SOLUTIONS

FOR

PLA SHEET EXTRUSION SYSTEMS

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INTRODUCTION

The needs of the PLA sheet extrusion operation is inclusive of many elements to insure high quality production. This document is intended to outline those items that support the operation of the extrusion machine and downstream takeoff equipment. Once an extruder is selected, the support equipment is not limited to only the process dryer or material handling equipment to enable peak performance. The ease of setup for material changes, access to operate and maintain the equipment and the planning for expansion are all part of the support system for the principle machinery. Over the past years, many users of extrusion lines have been changing from base resins, such as polypropylene and styrene, to one or more of the PET grades to gain or maintain their market position.

We are now in the position to welcome the introduction of a revolutionary new material to the sheet extrusion business in the form of PLA (Polylactic Acid) resin. The introduction of a crop grown feed stock in the form of corn presents a new set of opportunities and challenges to these markets. As PLA resin becomes more widely distributed and used for different products, both new and existing extrusion systems will be set up to run this new resin. Since all resins have specific needs and process operation parameters, we will try to present information that will assist the user in the application of bulk material handling, crystallization, and process drying technology of this material. While many existing plants can use PLA with little or no modification, there will be operating techniques that are different from PET and other sheet packaging materials. For those plants currently using PET resins, the process dryer and crystallizer are known elements of their process. For those using styrene or other non hygroscopic resins, the drying of the resin will be a new part of their process.

Most of the information developed and presented within this brochure is based on our experience with NatureWorks®[1] PLA resin. NatureWorks®[1] PLA is part of an ongoing development project that is a venture of Cargill Incorporated. Together they are bringing to the marketplace a packaging resin that is non-petroleum based with commercial quantities currently available for sheet line production.

Some of the topics that we will cover in this document include the importance of raw material handling and delivery layout, handling of regrind scrap material, proper crystallizing, blending and drying of the feed stock. Facility related items that we will cover are the use of mezzanine deck structures to support material handling equipment above the main floor and facilitating gravity feed from deck mounted bins. The proper selection of components, such as water towers and scrap grinders are not usually identified as directly affecting the operation of the extruder but can certainly detract when not operating at the required level of performance.

Control and operator interfaces for all machine systems are the most visibly changing component of the sheet extrusion system today. From the crude DC power systems of the early extruders to the touch screen HMI (Human Machine Interface) of the current day, the control system can provide as much information as needed to understand the proper operation of the system, as well as control the process. Process knowledge coupled with process understanding brings improvements that can be demonstrated to all interested parties. The control system is the key to process knowledge and data collection. Another feature of a good control system is the ease of duplicating past system performance with as little losses as possible. Memory of system configuration as well as what adjustments were made to get peak performance is a prime value of a control system.

Keep in mind, we are presenting only an overview of the supporting systems that are used with a PLA sheet extrusion system. There will always be new and different devices that can enhance a production system. By combining new ideas with a high performance existing system, it will be easy to evaluate changes and decide when they have made a positive contribution to the process.

[1] NatureWorks LLC, a company fully owned by Cargill Incorporated

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Raw Material Receiving and Storage

The purchase, receiving and storage of the PLA resin is the beginning, from a process perspective, of where proper handling techniques will first have an impact on the end quality of the product.

Virgin PLA resin, as manufactured by NatureWorks®[1], is crystallized and dried to 400-ppm moisture level prior to leaving the production plant at this time. This resin is packaged in boxes with moisture resistant foil liners to maintain the low moisture level. If the PLA is received in undamaged boxes and liners, the drying requirements are minimal but still necessary. In addition, if the foil liner has been opened, drying will be required. The resin is crystallized to promote efficient drying. Uncrystallized PLA becomes sticky and clumps when its temperature reaches 140º F. This is PLA's glass transition temperature (Tg); the point at which the amorphous pellet begins to soften. Regrind or recycled PLA may or may not be crystallized. Flake from clear thermoformed parts, trim scrap, or cast sheet, is highly amorphous. Flake from oriented film or oriented sheet will be a mixture of crystalline and amorphous fractions while that from fibers will be highly crystalline. Check with your resin supplier to verify the condition of the resin that will be delivered to your facility so the process can be planned accordingly.

Material Delivery Systems

Unlike PET delivery systems where rail car and bulk tank truck delivery are common today, the PLA material is currently shipped in gaylord boxes or super sack packaging. In the future, as relative needs change, bulk truck and eventually railcar shipment will be phased in as required. The virgin pellet can be stored in conventional silo storage similar to other pelletized resins. While it is best to use the resin directly from the delivery container, it can be conveyed to a "Day use bin" as a convenience to facilitate continuous operation.

Please note, when handling the reground material that is still amorphous from the extrusion line, it can not be treated the same as virgin crystalline pellets. The particle shape and chemical status will influence bin design as well as ambient temperature control. If an outdoor storage silo is filled with amorphous regrind, it may easily reach temperatures during the summer months that will exceed the glass transition temperature and proceed to stick together as it crystallizes. The thin cross section of most sheet regrind may layer and compress to the point that it will no longer free flow even at lower temperatures.

Handling Resin During Delivery- Rail Car Unloader

Rail car delivery of pelletized resin will require a "Rail Car Unloader" pneumatic conveying system. The bottom of the car will have multiple ports where a vacuum conveying hose can be connected to remove material by suction. Once in transit, the resin will be carried to a storage tank by transfer of a pressurized pneumatic conveying system. This entails a separation point in the line from the rail car so that a rotary airlock feeder valve will pass the pellet resin into the positive pressure line from the suction line coming from the railcar. The purpose of the airlock is to separate the different pressures, but still feed the resin from one side of the system to the other. A cyclone will be placed above the airlock to terminate the end of the

[1] NatureWorks® LLC, a company fully owned by Cargill Incorporated

vacuum line, and the airlock will be located so its bottom discharges into the pressure conveying line. While this may seem somewhat complicated it provides a number of important advantages.

- All of the conveying apparatus will be located at ground level
- The only part of the delivery system above ground are the conveying lines
- Use of a standard 4" OD conveying line for the storage tank fill allows use of the same lines for tank truck delivery
- Where two or more materials are used, a separate pipe for each material is installed on the storage tanks

The primary reason for use of a standard vacuum/pressure rail car unloader is the benefit of having all components of the conveying system at ground level during inclement weather or for operation after dark.

Sizing the Rail Car Unloader

The selection of a rail car unloader is dependant on several key items. Most important of those is the unloading rate or pounds per hour handled through the system. If a 240,000 pound capacity rail car must be unloaded in less than 12 hours, then an unloader capable of at least 20,000 pounds per hour should be specified. Secondly, the rate of material consumed by the plant on a daily basis should be handled in one or two shifts of unloader operation. It is best to work with less than a 24 hour per day loading rate calculation to allow some cushion for maintenance and lack of peak performance should filters become loaded or rate adjustments be incorrect. For most extrusion systems at least one or more storage tanks will be used, and one or possibly two rail car unloader systems will be employed. This will allow the rail cars to be unloaded in less time than is allotted by the rail company without incurring extra car holding charges and will provide enough resin in storage, allowing a few hour lead-way until the next scheduled delivery.

Truck Delivery Systems

Where rail car delivery is not an option, the next best choice is usually tank truck delivery. The modern tanker will hold between 40,000 and 60,000 pounds of resin, and will be transferred from the truck to the storage silo by an on-board pneumatic conveying blower. The road tractor engine using a power take off shaft typically drives this blower. When the truck arrives, a flexible hose is connected to the discharge piping under the tank, and from there to the storage silo pipe. The silo pipe will go vertically up the tank and make a 180 degree turn to point down into the silo. A vent on the lid of the silo will release the air used in conveying.

Pneumatic Conveying Principles

The use of a blower to move granular pellet material through a piping system is referred to as a pneumatic conveying system. The air is moved through the pipe, and a regulated amount of material is introduced into the pipe. At the destination, there is a separator to drop the solid material from the air stream, and release the air from the piping system. In the plastic resin handling

Pneumatic Conveying Principles *- continued*

systems that we are using, these systems operate in a dilute phase range, where a relatively small level of material is used compared to the amount of air used for the transportation means. In design of these systems there is a preferred range of material velocity in the system to maximize throughput and not cause damage to the material or piping system. On the low end, 3,000 feet per minute will move most plastic resins, with 5,000 feet per minute being the preferred maximum speed. These values are calculated by dividing the CFM (Cubic Feet per Minute) of air moved through the pipe by the square foot cross section of the pipe. The low number is the slow end of getting the resin to move with the high end limited by the degradation of the resin.

Degradation to Resin During Handling

It is very possible to degrade the pellet resin during pneumatic conveying by using conveying line velocities that are too high. The PLA resin will form streamers or “Angle Hair” on the inside of the piping system. This typically occurs in the elbow, and immediately following the elbows where the pellets are forced into the pipe walls at high speeds. It is possible to generate these streamers when handling the resin at the plant where it is produced, during the unloading of the rail car or truck, as well as in the plant material handling systems. One of the significant opportunities to create this problem is during the tank truck unloading process. The driver of the truck will manually manage the truck blower and valve setting to get a workable conveying setup for unloading the truck. When working with the typical 4” conveying line that is used with truck delivery, it is possible to unload a 40,000 pound load in less than one hour if the blower speed and pressure are set high enough. On the other hand, this will generate fines and streamers every time it operates in this configuration. A more reasonable rate to unload a tank truck would be about 20,000 pounds per hour to limit the material velocity to 5,000 feet per minute or less. This means that a blower curve or performance chart will be needed to set the blower at about 415 CFM to stay at or below the 5,000 feet per minute maximum velocity. One benefit of the fixed rail car unloader is the blower speed is established by the drive ratio from an electric motor, and is not subject to adjustment by an operator.

In addition to regulating the speed of the resin during conveying, using internally “Roughened” or “Scored” tubing for the conveying pipe will also minimize fines production. By having a rough internal surface, any tendency a smooth surface would have to accumulate a film of resin, streamer or Angle Hair is defeated. Conveying velocity must still be no higher than 5,000 feet per minute.

Silo Storage Systems

Typical outdoor storage solutions for PLA raw materials will be done in vertical cylinder silos. These vessels are normally sized to hold at least one transport (Railcar or truck load) carrier of resin. The selection of silo type begins with the choice of bolted or welded construction. Where an inexpensive solution is desired, the bolted tank with ease of shipment in a number of small crates is the most economical approach. These vessels consist of a number of panels approximately 8 feet tall which makes up each “Ring” or band of the tank. The installer will assemble the ground level ring on the foundation, and then install scaffolding up the tank, and hoist each new ring into place, and then repeat the process however many times are required to reach the total height of the silo. Care during installation is important since placing gaskets, panel thickness selection and uniform bolt tightness will impact the final quality of the vessel. Most tanks of this type are mild carbon steel construction, and will be coated both internally and externally with an epoxy finish. The other selection in storage silos is the all welded

Silo Storage Systems *- Continued*

vessel. These tanks are shop fabricated and fully welded as a finished unit before shipment. As a result, delivery distance and travel route restrictions can impact delivery time and cost. Since these tanks will typically travel over public roads, the maximum limit of 12 foot in diameter will limit the capacity compared to larger diameters readily available in bolted tanks. The welded tank can be made of aluminum, stainless steel, or mild steel. Construction of non-ferrous metals will allow the use of a vessel without the need for internal rust proof coatings. Welded tanks have fewer concerns with leaks and other site assembly issues than field erected bolted tanks. For this reason, they are preferred over the bolted tank where a premium storage solution is desired.

Some operators have used agricultural grain storage bins for plastic resins with success. Keep in mind, the intended use of the equipment when employing vessels not designed for the materials to be stored may not be optimal. One of the most critical aspects of large storage vessel design and safety is using the correct apparent bulk density of the material to be stored when calculating the structural requirements for the bin. Should the bin have marginal strength, it may deform or even collapse if an overload or upset condition occurs. It is important to have a bin suitable for all fill levels and all expected material characteristics. Unexpected bulk density changes, flow patterns, or total load can cause even a well designed vessel to experience failure.

There are a number of special circumstances that should not be overlooked when designing bulk resin storage. The first is the geographic area where the facility is located. Depending on location, seismic disturbances can add significant loads to the resin loads. When working with a new location for tank storage, reference to a seismic zone chart will enable the engineers to select the proper tank design for the installation. Just because earthquakes are not noticeable in the local area does not necessarily mean that there is no seismic activity. Secondly, if there are high wind loads in the area, they will affect tank design as well. A partially empty tank can be subject to distortion where the same tank when full will be completely stable. Additionally, there can be flow patterns that develop in the tank that will cause intermittent movement of the resin during continuous discharge. These flow anomalies can cause physical damage should large masses of pellets fall inside the tank, to noise or "Yelping" during discharge. While noises are generally not dangerous structurally, they can be very annoying in populated areas.

Mechanical contractors familiar with tank erection will usually do the installation of storage vessels. The first element to be considered is the foundation. All vessels must be placed on a stable base to insure structural integrity of the tank. The use of large poured concrete monolithic blocks for silo foundations is the best approach. The bases are designed to have about the same mass as the loaded vessels. The foundation must secure the vessel adequately during all fill level conditions, as well as weather and seismic activity. To secure the vessel to the base, special bolts are placed in the concrete during the pour, or drilled and placed in epoxy glue after the foundation is cured. These bolts form the only link between the vessel and the base.

Silo Storage Systems *- Continued*

Once the foundation is ready, a crew will want the bolted tank parts adjacent to the pad, and access to get the stage and lift equipment to the site. The bolted tank is then erected one ring at a time, and the panels lifted by hand into place. Once the cylinder is done, the top deck will be placed, again, one panel at a time. When the tank is done, all of the accessories will be installed. These can include the access ladder, deck safety railing, fill pipes, level controls and monitor devices. If there are any scratches in the tank, they will be touched up before the crew leaves. At this point, the bolted tank is ready for use.

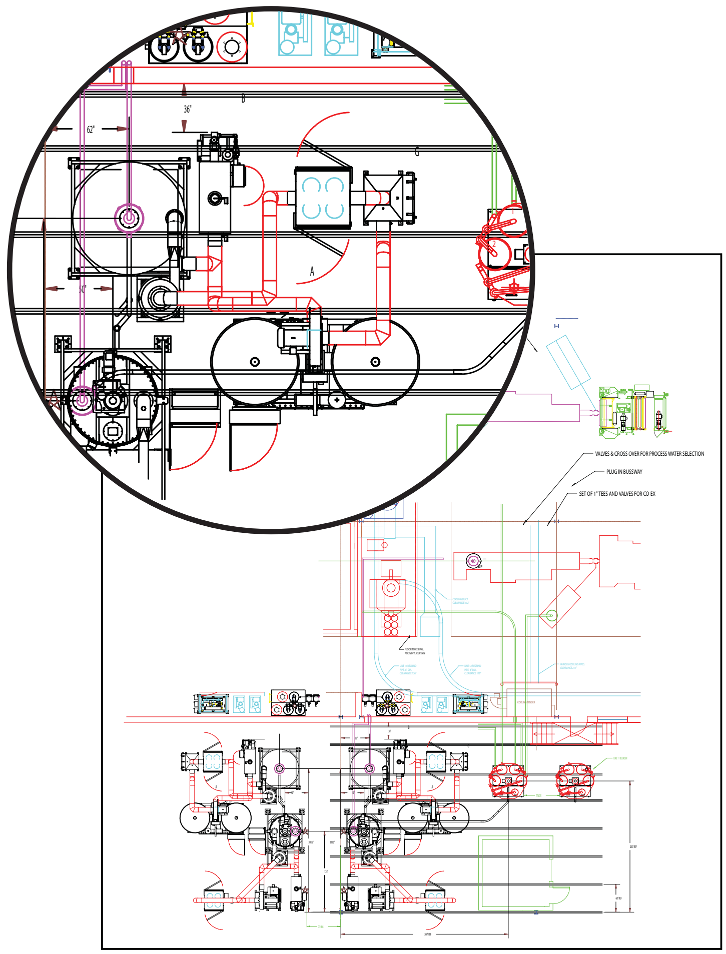
For installation of a welded vessel, more equipment is required at the erection point to spot and lift the vessel. When delivered, the vessel will be on a special trailer made to hold the silo in transit. These trailers can self unload the tank wherever it needs to place the vessel for installation.   When the foundation is ready, a crane capable of lifting the tank fully clear of the ground while hanging vertically will be required. The crew will usually install most of the optional equipment on the vessel while it is still on the ground before lifting it into place. When ready to lift, the riggers will attach cables to the lift points, and raise the tank to vertical and then swing it over the foundation. Lowering the vessel, and bolting to the foundation will complete the major part of the welded tank installation. Both welded and bolted vessels will need grouting at the foundation and connection of the conveying equipment to finish the installation. After the first rain, the tank should be checked for leaks in the storage part of the vessel as well as the enclosed skirt below the internal discharge cone. All leaks must be fixed because water that gets into the material will contaminate the resin with unwanted water or stop resin flow if the water freezes during cold temperatures. A silo that freezes during the winter will probably not flow again until spring thaw. If the lower area of the vessel leaks, accelerated rusting of the lower part of the vessel will occur from standing water under the cone.

When PLA resins are intended for silo storage, the use of a Silo Dehumidifier is an important option for an untreated vessel. Due to the chemical makeup of PLA resins, high ambient air moisture or elevated temperatures during storage will cause reduction of the resin into bio components, rendering the resin useless. A dehumidifier, connected to recirculate dry air through the head space in the tank, will avoid unnecessary regain of water or the possible need to increase the drying requirements for a saturated resin.

Plant Layout

In the business of PLA sheet extrusion, as much as a poor layout can detract from operations, a good plant layout can enhance the operation of the facility. When selecting the equipment needed for a sheet extrusion plant, organization of the available floor space is as important as the purchase of the machinery itself. At the beginning of the process, location of the material delivery and storage is a good first step. The selection for material delivery site, and where the extruder is placed inside the facility should be closely coordinated so transfer of the raw material will be within a reasonable distance. In this general area, allocating room for the material preparation equipment is the next point of interest. When placing the extruder close to the material source, the dryer, crystallizer, grinder and blending equipment should be located in the immediate area if at all possible. By grouping these machines near the extruder, all of the operator interface points for preparing and running the line are close at hand.

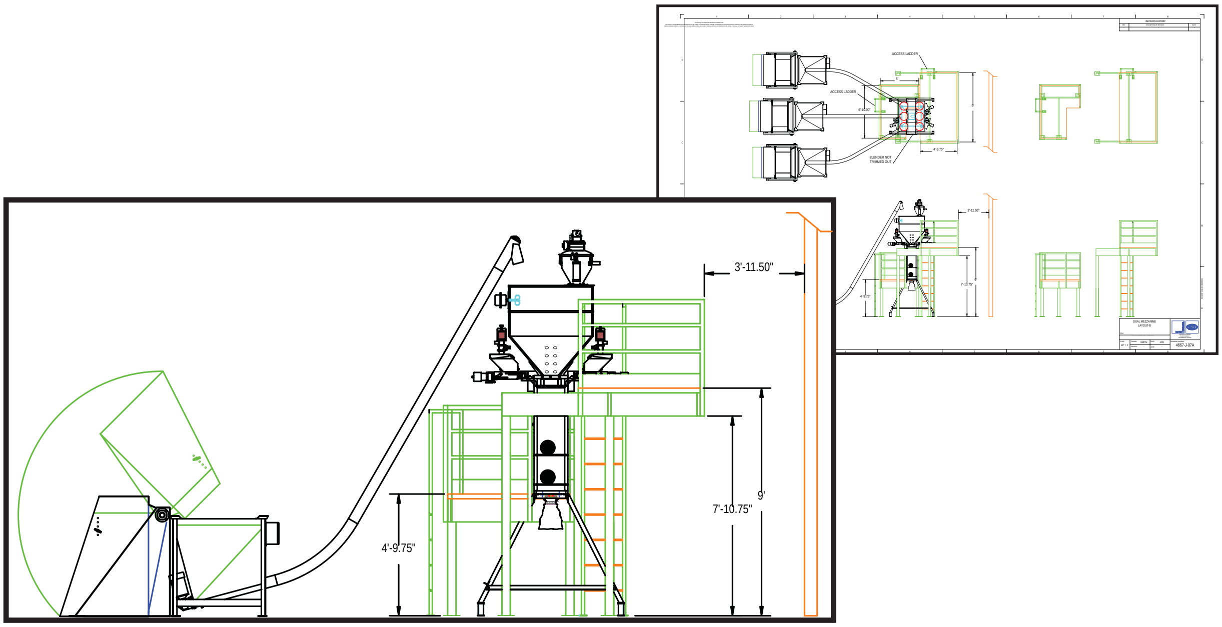
A building plan drawing and scale insert drawings of each machine to be used is the starting point for equipment layout. General placement of each system should allow for operator and maintenance access as well as aisle space wide enough for fork truck operation. Since the crystallizer and drying hoppers are relatively tall, check beam clearance height in the building to be certain they can be placed where desired. If there is a ceiling height issue, then another part of the facility may house the tall equipment, and transfer to the extruder throat. Should this happen, limit straight line distance between conveying points to about 300 linear feet to enable vacuum conveying with conventional equipment. If transfer lines are to exceed 500 linear feet, then pressure conveying should be considered. Keep in mind that vacuum conveying is preferable due to less dust and is simpler than pressure systems. Should the building not have any area with enough vertical height available, adding a pit below the floor level, or a penthouse on the roof will enable installation of suitable processing vessels. While some adjustments can be made in the height of standard equipment, expectations of a 5 or 10 foot reduction from a vessel is simply not realistic.

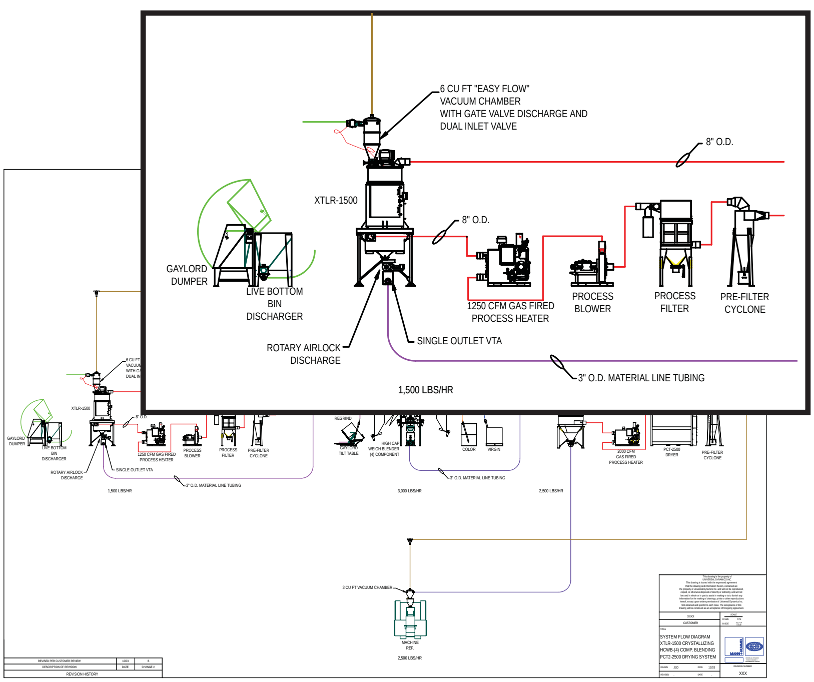


One feature that is often overlooked in layout of sheet extrusion systems is the use of a mezzanine deck to place parts of the material preparation system above the main floor. This will conserve valuable space on the operating floor, and will allow room for the crystallizer, blender and dryer systems near the extruder throat. Another feature of the mezzanine is the capability to mount the drying and crystallizing vessels through the

Plant Layout - *Continued*

deck to enhance access for maintenance and clean out. A second benefit is only using one set of support legs for the deck and equipment to further reduce the clutter on the operating floor.





In the planning stages of the system, a full set of schematic layout and floor plan drawings provided by UDI will enable the user to anticipate most layout related issues and solve them before they become full scale problems. From years of experience with installations, a complete set of installation drawings and schematics can make a new system installation go smoother than trying to decide what to do when the equipment arrives from the supplier. As part of the total job package, installation drawings are provided for each system to enable subcontractors a complete package of information for both bid and install.

Plant Material Handling System

Part of every plastic extrusion system is a raw material handling system to bring feed stock to the throat of the extruder. In dealing with PLA, there are several items that need attention beyond the normal pneumatic conveying system. First, whenever possible, use vacuum conveying for the conveying inside the facility. The benefit of a vacuum system is that should any leaks develop over time, all that will happen is a small amount of room air will be drawn into the conveying line. If anything leaks on a pressure conveying system, any dust in the system will eventually come through the leaks, and deposit in the plant. The use of a vacuum system for all of the in-plant conveying eliminates this potential housekeeping problem. The next issue to address is the use of a properly engineered conveying power unit to move the air through the system. While many people believe that virgin pellets are dust free, in real life there is always some level of fines in a material handling system, and management of the system to minimize generation of fines is a top priority. Our approach to this issue is the use of carefully controlled airflow through the system. This is done by selection of the proper positive displacement blower, and then operating it at the correct RPM to generate a specific airflow. Once this device is selected, it is applied to a single conveying tube diameter, and as a result develops a specific resin velocity in the system. By limiting the maximum velocity to 5,000 feet per minute (F/M), degradation of the material while pneumatic conveying is minimized. The other end of the scale in vacuum conveying is preserving enough velocity at the pickup end of the system to get reliable intake of the resin at the feed end of the system. About 3,500 F/M pickup velocity will insure trouble free operation of a PLA conveying system.

Another problem that can arise from excessive conveying velocity in the PLA resin is “Smearing” on the interior walls of the conveying tube, eventually stripping off and becoming “Angle Hair” or “Streamers”. Since the conveying system is expected to handle granular regrind or pelletized resins, the creation of hair balls in the system due to excessive line velocity should be avoided. When a mass of streamers come to rest in a drying hopper, they will eventually block the discharge of the vessel. Draining the vessel, removing the blockage, and refilling with new material is the only way to fix this problem.

Plant Material Handling System - *Continued*

Since there will always be some level of fines in the system, the vacuum power unit should be protected with both a pre filter cyclone, and a protective cartridge filter. Each of these devices have a quick release catch can to accumulate fines during operation. At the beginning of operation for a new system, monitoring the amount of material removed from the catch cans on a regular basis will allow the operator to determine a suitable interval for emptying the catch cans. One of the simplest ways to impair the operation of a pneumatic conveying system is to attempt to continue to operate with clogged filters. Rather than fixing the problem, many operators will begin to adjust load times and resin pickup devices. None of these adjustments are a substitute for properly maintained filtration.

Other considerations involved in pneumatic conveying is the selection of receiver filtration. Wherever possible, use a pellet screen separator rather than a filter bag or cartridge; this will limit the amount of maintenance time spent on the top of the equipment. While a pellet screen may pass a small amount of fines through the element, not having a daily or weekly cleaning operation on top of a dryer or crystallizer is well worth the additional dust collected by the pre filter cyclone.

When handling dry PLA the possibility of exposure to room air and the consequences of regaining water in the resin is another concern. While there are various points of view on this subject, from not needing to protect the dry resin, to use of a closed loop of dry air for conveying at all times, we recommend a dry air conveying system where the dry resin is moved to the extruder. Anytime after the main dryer has prepared the resin, use of dry air protects the material from water regain. These systems are easy to install since the dryer can supply a small bleed of dry air to a plenum that will provide the conveying air. Once in operation, there is very little air exchange, and the dry air conveying system requires very little new dry air to protect the resin.

When one conveying power pack blower is used for both dry and room air conveying, the addition of a segregation valve to the discharge of the blower will preserve the integrity of the drying system. This valve will allow the blower to discharge the room air back into the room, while moving dry resin and preserving the closed loop of dry air. Another feature to consider when conveying dry resin is to purge the material conveying line after each load of material. This prevents any quantity of resin from sitting in a conveying line where is more likely to lose temperature and regain water than if cleared from the line. This can be accomplished by adding an air or material control valve at the material pickup point, allowing the conveyor to still move air after the source of material is cut off. This will purge the line, and remove the bulk of the resin that was in transit. One of the best policies in running a PLA extrusion system is to protect the dry resin as effectively as possible once it leaves the bottom of the drying hopper.

Process Water Cooling

In addition to the equipment, the PLA sheet extrusion process requires a process water cooling system to operate the extruder and process dryer properly. The extruder will have a water cooled feed throat section as well as cooling for the hydraulic systems on the machine. These items, along with the return air cooling coils of the dryers, can be operated on a tower water utility. The finishing rolls that catch the hot resin will require chilled water to achieve an adequate rate of cooling for the sheet stock. These requirements form the basis of the plant utility cooling water needs.

A tower water system can provide cooling water at about 80ºF readily. In this type of cooler, water is recirculated through an atmospheric cooling tower similar to those used at electrical power plants. Although much smaller in size, an industrial tower water system consists of the same elements as a larger one. The tower assembly sprays water through a series of baffles to allow evaporative cooling of the water. As a result, about 3% of the water volume in the system will be lost to evaporation and will require makeup water from the facility water supply. Once the water has been cooled in the tower, it is brought up to pressure in a centrifugal pump. The pump discharge is connected to the distribution piping system and plumbed to the individual use points.

At each device using the cooling water, shutoff valves and appropriate disconnect devices should be used to enable any one item to be isolated from the distribution system. Parallel to the supply water pipe will be a second pipe to return the used water to the cooling tower where the loop starts over. Tower water systems may require the use of additives to control corrosion and limit scale buildup. Since the evaporative tower is open to the elements, a biocide is normally used to prevent the growth of mold and any other microbes that will live in a warm, dark, wet areas. These controls are important to maintain a trouble free water cooling system.

For the finishing rolls that cool the hot resin, chilled water at about 60ºF is used to remove the thermal energy in the melted resin. In order to depress the temperature of cooling water below what is available with evaporative cooling methods, a refrigerant based chilling system is employed. These systems will use common refrigerants to remove energy from a circulating water system and will typically transfer the excess heat to the tower water system. A chilled water system will employ a refrigerant compressor, a air or water cooled condenser for removing the excess energy from the refrigerant, and an evaporator heat exchanger to cool the circulating water. Construction of a chilled water system will usually employ a single frame to hold the refrigerant system along with the heat exchangers and water circulating pumps. Most packaged systems will have a redundant water pump available for circulating water to avoid system loss due to a pump failure. This is important since loss of circulating water in either cooling system can have the water in the equipment boil and released as steam.

Both tower and chilled water systems require a reservoir tank to equalize the system operating pressure. This tank is sized based on the total gallons recirculated in the system and will have a makeup valve and overflow pipe to manage the water volume in the system. In tower water systems, water conditioners are necessary and must be monitored and adjusted based on the amount of makeup water introduced into the system. On chilled water systems the water is trapped in a closed loop so losses are minimal. Proper water condition is still required, but is not subject to the changes of a continuous makeup dilution.

Scrap Recovery

In a sheet extrusion operation the use of a thermoformer is the next step in production of most final products. In the thermoformer process the hot sheet is pulled over a male mold, and once cool, the part is trimmed from the original sheet. The residual sheet without the parts is typically referred to as a “Skeleton” or “Web” from the thermoformer. Since all of the resin is valuable, these skeletons are fed into a scrap granulator to grind them into a usable form. As “Regrind” they can be introduced into the system as a blend with virgin pellet resin, and crystallized, dried and re-extruded. In the selection of a grinder, the size of the chip coming from the grinder is as important to the successful operation of the crystallizer and dryer, as it is to the extruder. The grinder will control the chip size by the selection of a “Screen” element that is part of the grinding chamber. The screen will have a specified opening such as 5/16 or 3/8 inch hole. These openings will control the size of the resin leaving the grinder so that it will be a uniform, free flowing supply of resin. At present, we recommend using only a 3/8” screen size to minimize fines generation in the grinder. In addition, the grinder should be equipped with a material handling fan to extract the ground resin and to allow maximum, practical air flow through the grinder cutting chamber. Use of a high flow fan should be implemented or the flow of an existing fan should be increased to produce more air through the grinder. Since PLA will soften at very low temperatures, the grinder can easily develop heat if the material smears in the cutting chamber instead of a clean, quick cut. It is also important that the grinder knives be kept sharp and properly gapped. All these specifications are more pertinent to PLA than other resins, including PET.

A second source of scrap is the edge trip from the extruded sheet. To make a uniform width roll of sheet stock, a edge trim knife is employed on each side of the sheet as it comes from the finishing rolls. This will usually remove a narrow strip of stock as it passes the knife. These two ribbons of material will be fed back to a puller feed roller on top of a small edge trim granulator. This unit is located near the downstream end of the extrusion line and is placed so as not to interfere with the handling of the finished rolls of sheet. The edge trim granulator will feed its regrind back to meet the regrind from the web, and then to a blender to be incorporated into the next pass through the extruder.

Provisions are also necessary for grinding whole sheet if there is a defect in the roll coming from the extruder. While this is not expected in a normal operation, on occasion when a roll is not acceptable, it will be ground and fed back into the system. Depending on the reason for a roll rejection, it can be used like any other regrind, or if the relative viscosity is damaged in the extruder, it can only be used at a limited addition to a new run of sheet. Careful management of the regrind system is necessary because contaminated or low RV resin can not be returned to the system without special consideration. Since normal operation of a thermoforming sheet line generates 40 to 50% scrap, losses in the handling of regrind are a significant economic problem.

Blending Operations

The operation of a PLA sheet line system generates significant levels of reground scrap, the re-introduction of these scrap materials is critical to making quality sheet and for economic success. When operating a mono line system where only one extruder is providing resin to the die, the amount of scrap to be re-fed into the system will usually be about 40 to 50% of the total throughput. The accuracy and consistency of the blended PLA feedstock will insure proper processing downstream. Depending on the product being made, the blender will need to provide a consistent mixture of virgin pellet materials with one or more regrind streams. The blender will also be used to introduce colorants and other process additives as required.

By use of a gravimetric blender, the accuracy and repeatability of the mix is simple to produce and monitor. The typical gravimetric blender will keep track of the accuracy of each material that it feeds as well as the total rate blended per hour. While there are two basic types of gravimetric blending machines, the most widely used one for PLA sheet line work is the gain in weight system. These machines use a hopper mounted on a single scale to receive a dose of each feed stock material in sequence. At the completion of a batch, the scale hopper is discharged into a mixer where all of the components are blended before discharge from the unit.

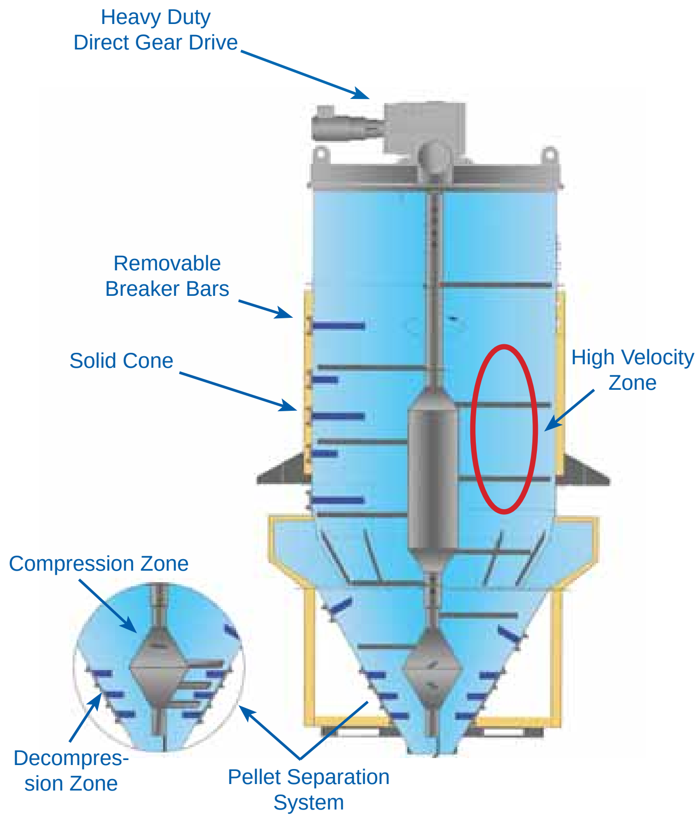
A blender of this type is good for .25% accuracy of the scale capacity for all materials. These blenders produce a reliable mix without the complexity of a loss in weight type system.

The loss in weight gravimetric blender consists of an individual hopper and scale for each material to be fed into the blend. As the material is removed from the blender, all of the feed systems discharge a uniform stream of resin in the required proportions. This system weighs each resin as it is fed, and tracks the accuracy of the component and blend as a result. While the loss in weight blenders can provide a well blended resin, the costs are several times higher than the gain in weight blenders, and consequently are not used in a typical operation.

PLA Crystallizer Operations

When processing PLA resins, the feedstock for the extruder must be dry before entering the melt phase. Lack of drying will degrade the RV and cause loss of mechanical properties of the finished product. As a prelude to drying, PLA resins are crystallized to allow conventional hopper driers to operate properly.

PLA crystallization is required to move from an amorphous state each time it is melted, and then after cooling, to a crystalline state as the temperature is increased above the “Glass Transition” temperature. Glass transition is the temperature that will begin to make the amorphous material change to crystalline. PLA resins will crystallize when raised to 190ºF - 212ºF as a final temperature exiting the vessel. During this change of state, the resin particles become surface tacky to the extent that they will agglomerate in a non agitated vessel, and block the flow through the system. The use of a crystallizer enables the resin to reach and pass through the glass transition stage, and by use of gentle agitation, avoids agglomeration that would prevent the flow of material through the system.



Theory of Operation

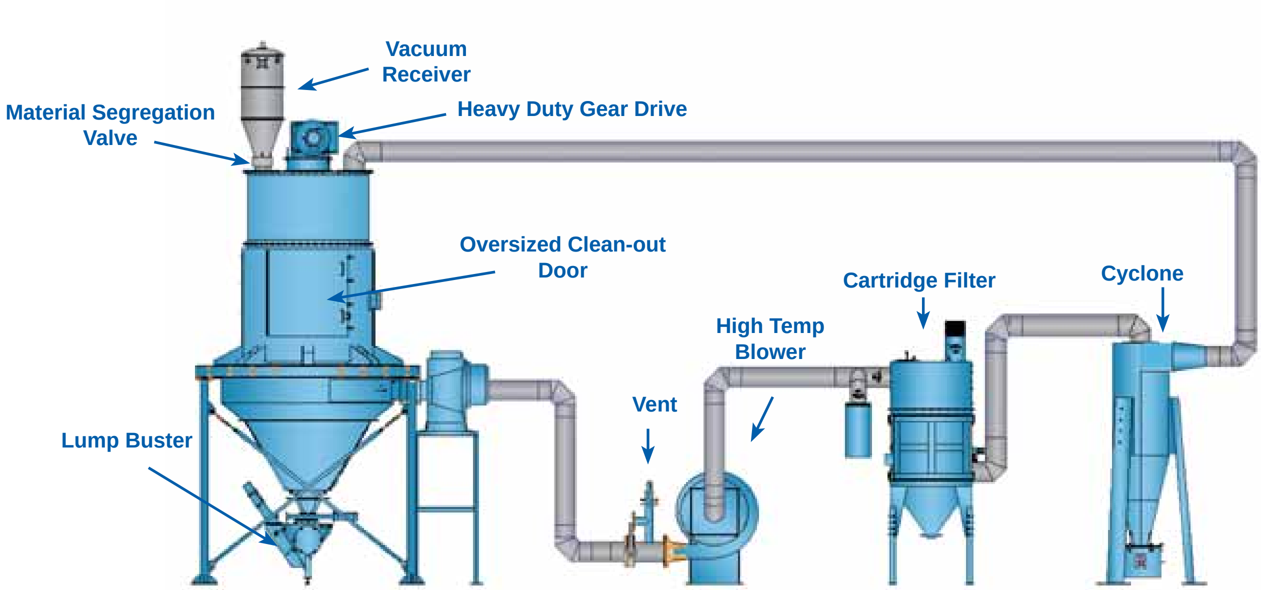
A crystallizer performs a relatively simple process in treating the PLA resin. Any amorphous resin will be raised in temperature using hot air for enough time to pass through the glass transition state. As the material becomes surface tacky the agitation of the resin will separate the clumps of agglomerated resin. The material regains its hard surface once it passes from the glass transition condition and can be dried and handled easily. Note that processing through this system is intended to produce adequate surface crystallization to enable further processing. The crystallization process will continue in the internal mass of the pellet as long as the temperature is high enough to facilitate the reaction. Our goal of this process is to achieve enough surface conversion to regain a particle that will not stick to other particles. Once through this stage, the resin is suitable for transfer to a process drying unit prior to extrusion.

Detailed Sequence of Operation

The Universal Dynamics, Inc. Crystallizer System combines the necessary temperature management of the resin as it passes through the vessel plus gentle mechanical agitation to insure free flowing processed material. Under typical conditions, the resin entering the vessel will be at room temperature. A vacuum loading system will convey the PLA resin from a storage source up to the top of the crystallizer hopper. This loading chamber will have a positive seal valve dump as well as a material inlet valve that can isolate the chamber from the rest of the system. When conveying resin into the chamber the dump valve will be closed, and the material inlet valve will be open. The chamber will fill on a dwell time basis, and when full, will be discharged trough the dump valve. The opening of the dump valve is simultaneous with the closing of the material inlet valve. This allows the vacuum in the chamber to be equalized with the pressure in the upper portion of the hopper so the load of material will freely discharge from the chamber. In operation of the crystallizer, it is important to

Detailed Sequence of Operation *- Continued*

maintain the airflow and temperature profile in the system as such that the loading chamber and lid area of the crystallizer do not exceed the glass transition temperature, thereby allowing the feed material to stick to the vacuum chamber and eventually blocking the resin flow. It is not necessary for this temperature to be exact but it must be considered when selecting an airflow and processing temperature. The crystallizer is loaded to cover a high-level control switch installed in the sidewall of the vessel. The location of this switch allows for adequate space above the material control level for the process air to disengage from the material and exit the vessel carrying the least amount of fines. The control of the crystallizer level is maintained by activation of the “Load Enabled” function of the control which will call for material to be loaded into the vessel whenever the high-level switch is uncovered.



Once the material is at the high level control, the continuous operation of the system will develop three distinct temperature process zones within the crystallizer hopper. At the top of the vessel, the material that has just been loaded into the system will be begin to heat up as the hot air moves through the vessel. As material is drawn from the hopper, the material will progress through the vessel by gravity in mass flow. Mass flow is the state where all of the material will be treated equally at the same time in a continuous process vessel. As the resin is heated in the crystallizer, the transition from amorphous structure begins. Within the first 6 to 12 inches from the controlled high-level the resin will enter the glass transition state. It will become surface tacky and will visibly stick together. By looking through the sight glass openings in the upper portion of the vessel, the operator should be able to observe this part of the process. If there is too much heat and/or airflow, the resin can stick to the vacuum chamber feeding in the raw material. On the other hand, if there are some visible clumps of resin on the exposed top surface of material in the vessel, this tells the operator that there is adequate heat and airflow for proper processing of the resin. As the material drops to approximately the middle of the straight side of the vessel between the cone and high-level control, it should be fully surface crystalline, and be broken apart by the mechanical agitation of the stirring bars. If there are clumps of resin visible in the sight glass openings at the bottom of the straight side of the vessel where it meets the cone, the resin is not being properly treated in the “Process Zone” described previously. As the resin moves down through the vessel, all of the clumps should have disintegrated as the material moves out of the main body cylinder and into the conic area prior to discharge. Should large clumps of resin reach the lower portions, of the cone, it is possible to progressively block the discharge of

Detailed Sequence of Operation *- Continued*

the crystallizer until it will no longer flow material. At this point, removing the equipment under the discharge flange of the cone, and manually clearing the opening will be required.

One great benefit of processing clear PLA resin is that the transition from amorphous to crystalline is accompanied by a change from clear transparent resin to an opaque white color. This distinction will aid the crystallizer operator in learning the effect of the crystallization temperature and airflow adjustments to achieve the best operation of the system. By observing the change in color in the upper third of the hopper, the operator will have visual confirmation that the chemical reaction is progressing. When the resin reaches the lower sight glass on the vessel, the resin should appear to be completely white and should not show any clear material at this level. Should clear resin appear in the lower sight glass, the resin has not been correctly processed and will most likely agglomerate in the drying hopper causing a blockage.

The discharge of a crystallizer is important in two respects. The draw through the system from a down steam device should not exceed the available process rate. Use of a material flow regulator is appropriate for this situation. Additionally, the air pressure in the lower portion of the crystallizer vessel is normally much higher than room air pressure, such that it will eject material from a conventional vacuum take off adapter. The use of a charge box VTA with knife gate valve will solve both of the afore mentioned concerns. Two separate devices control the valve. The first being the output relay that will allow "Downstream Enable". This feature is part of the control logic that prevents untreated material from being discharged from the crystallizer. Also, a high-level bin switch is provided in the box under the valve to stop it from opening if the material is not being taken from the box at a high enough rate to keep the VTA clear of standing material.

Operation of the crystallizer using all recommended practices does not guarantee trouble free processing under all possible conditions. One such circumstance is the development of rock hard clumps of PLA resin in the crystallizing vessel. These agglomerations are far beyond the ability of any normal lump reduction device that is less than a grinder to break them apart. These lumps are most likely generated by the exothermic reaction during the crystallization process. The temperatures for crystallization of PLA are so low that the additional energy of crystallization may contribute to the formation of these lumps during process flow interruptions. In cases where the extruder has stopped for times in excess of one or two hours and internal crystallizer temperatures have exceeded the air inlet temperature by 50ºF, these conditions may further these formations.

To address this issue, we recommend the use of a knife gate valve on the crystallizer discharge with a "Lump Catcher" gate that has a clear window for observation of any accumulation of clumps so they may be manually removed by the operator. In the past, use of a rotary airlock feeder below the crystallizer was common to charge a conveying line. If any of these hard clumps are caught in the pinch point of the airlock, they are likely to stop its rotation. The current recommendation is to use a charge box under the knife gate valve and drop the needed volume of resin to fill the take away conveying chamber. This will purge the conveying line with the use of a short valve open time and an extended convey/purge time to clear the resin from the charge box.

Starting the Crystallizer

The previous description of operation is achieved during steady, continuous process operation. Starting the agitated vessel crystallizer is a separate operation that is critical to long term uninterrupted operation of the system. The process of starting the system is dependant on a supply of pre crystallized resin that is loaded into the

Starting the Crystallizer *- Continued*

hopper before loading any untreated material. This material may be retained from the end of a previous run, or left in the machine at the end of the last operating period. The successful operation of the PLA crystallizer is dependant on a mixture of crystalline pellet combined with the amorphous reground flake. We recommend starting with approximately 25 to 30% regrind by weight, and increasing the amount of regrind to 50 to 60%. At this writing, use of more than 75% regrind is based on trial operation and verification by the operator. Since most mono extruder sheet line systems will typically generate 50% scrap, this should be satisfactory in the long run operation of this equipment. When previously treated material is not available, use of virgin pellet material will allow the system to be started since all new resin is pre crystallized pellet PLA. Again if there is any question about a clear resin being crystallized, the opaque white color of the resin will be evidence of a crystallized material. Once the vessel is filled at least half the straight side of the hopper (To the high-level switch), untreated material can be loaded for the balance of the initial filling. It is easiest to start a system where the initial load of material is all pre crystallized, however, were there is a shortage of material to be used to start the crystallizer, starting with at least a half full hopper with treated material will work. By using the automatic “Cold Start” feature of the control system, the control will fill the vessel to the high-level switch, and enable the blower, heater and agitator. The logic sequence will then preheat the vessel using a preset minimum time and then compare the vessel air outlet temperature with the preset “Release Temperature”. Once the outlet air exceeds this temperature, or the maximum timer expires, the cold start feature will allow material to be withdrawn from the system after a successful initial startup. Any attempt to start a crystallizer with all amorphous material will result in total obstruction of the vessel that will not be broken down by the agitator. This system relies on a specific process treatment of the amorphous resin in the upper portion of the crystallizer hopper. If untreated resin reaches the lower portion of the vessel, the process has been compromised and must be cleanout and restarted.

Temperature Management

The crystallizer operates properly when the airflow and process temperature selected apply adequate energy to the process to cause crystallization of the resin. In selecting operating parameters, the combination of airflow and temperature must impart a minimum required level of energy to cause the change in state from amorphous to crystalline. If the power applied is inadequate, then eventually untreated material will pass through the system. If excessive amounts of power are applied, then some will be wasted, as well as possibly causing problems with the in feed hopper overheating and tacking material before it is in the main vessel.

When selecting airflow, the minimum airflow can be estimated by the planned throughput rate. A good starting point for airflow is to divide the process rate in pounds per hour (PPH) by two to give the CFM needed. The formula to get the actual requirement follows: KWH = PPH x (Specific heat of PLA) x 100ºF (Temperature change of material) / 3412. Once given the required KWH use, the next formula is for airflow: CFM = (KWH x 3000) / 80ºF (Temperature change of air through the hopper). Though these formulas make certain assumptions about temperature changes that will be required and the specific heat of the material, they do provide a starting point the will insure an adequate volume of air to process the material.

Selection for the temperature of the process air entering the crystallizer is simple, start with the lowest temperature that will convert the resin from amorphous material to a crystalline state. Watching the hopper air outlet temperature and increasing the setpoint until the outlet temperature is above the inlet resin temperature will verify this selection. It is critical when setting up the crystallizer that the adequate temperature and airflow is set to insure crystallization. If enough power to convert the resin from amorphous material is not applied, the downstream drying equipment will fail due to clumping of the resin. Once the system is in steady operation, record all of the airflow and temperature settings for future reference.

Process Drying System

Process drying of the PLA resin is the most critical stage of the raw material preparation. It is at this point in the system that all of the available water carried by the resin is removed. In order to make good sheet material, the standard for process drying is to reach the 250PPM or less water content. This can only be accomplished with the application of the specified temperature, corresponding exposure time and air quality. If any of the required factors to dry and then maintain the dryness of the resin is neglected, substandard production will ensue. Should the product not meet specifications, then regrinding and feeding back into a properly operating system will then make an acceptable product. With PLA, improper drying will degrade the finished product. At the outset of PLA resin manufacturing, NatureWoks® LLC, developed a series of tests that illustrated the need for proper drying of the PLA resin. These tests resulted in a chart that illustrated an acceptable time and temperature exposure for resin drying. Since the PLA sheet forms the basis for the mechanical properties of the finished product, any fault in processing that consumes or damages the RV available in the raw material is undesirable. Producers exercise great care in the preparation and extrusion of PLA since damage to the base resin is generally non-reversible.

The equipment to dry PLA consists of a dehumidifying hopper dryer with low temperature process options. In drying PLA there are four principle factors. First, adequate airflow is necessary to carry thermal energy to the resin and provide enough air exchange to carry away all of the water. When selecting a PLA dryer, use one CFM per pound per hour of PLA to be dried to determine the preferred dryer size. While approximately one half CFM would sufficiently carry enough energy to the resin, the extra air insures uniform drying. At approximately one third CFM per pound per hour processed the capacity would be inadequate for the air to carry the required thermal energy to the resin. Since filters will not always be perfectly clean, it is better to have extra airflow than too little. The second element in drying PLA is the dryness or dewpoint of the air entering the process drying hopper. The industry standard is a –40ºF dewpoint. Dewpoint is defined as the temperature at which 100 percent relative humidity exists. So if we take a sample of dry air at –40ºF dewpoint, and reduce the actual temperature to –40ºF, then the sample will fog and water will begin to condense on surfaces. Since we never actually have a temperature as low as –40ºF, this is used as an absolute reference number, and not an indication of the air temperature. The reason a low dewpoint is desirable is to enable any water content of the resin to move immediately to vapor and be carried away on the process airflow. If the process air contains too much water, getting the water in the resin to change to a vapor would be much more difficult, if not impossible. Another use of dry air is that with a low dewpoint air supply, the air leaving the top of the drying hopper is still far dryer than the room air, and for this reason, a closed loop of dry air is recirculating in the system. The third aspect of PLA drying is temperature. The appropriate drying temperature for PLA is between 150ºF and 190ºF. We recommend using the lowest temperature that will give successful drying, usually in the 150ºF to 160ºF range. This will also limit softening or sticking of the material should it get too close to the tack point. It is important that airflow, dewpoint and temperature be at their best selection. If any of the three is deficient, one will not compensate for the other.

The fourth, and last, most important element of the drying process is the drying hopper. There are several functions preformed by this relatively simple appearing vessel. Size selection should be determined by desired holding or dwell time for the drying to take place. If the vessel is undersized, then undried resin will proceed to the extruder. If the vessel is grossly oversized then thermal damage is possible, particularly with higher drying temperatures. Once a proper sized vessel is selected, the performance of the vessel as a continuous process element comes into play. There are two items that are specific to the operation of a drying vessel. The first is mass flow, or the equal treatment of each pellet that enters the vessel. While this may seem a simple concept, getting a relatively short cylindrical vessel with a conic hopper bottom to not generate a funnel or center flow discharge is not an easy task. When dealing with a conic bottom vessel, the inherent tendency is for pellet material to go out the center outlet of the cone, leaving the area where the cone meets the cylinder and the wall of the cylinder stagnate. To avoid this condition, various flow control cones or other devices are placed in the lower part of the vessel to generate the desired mass flow condition. In most cases this will approximate mass flow, and a vessel that has 10 percent early and 15 percent late discharge of material on a time basis will be considered to be operating in mass flow. A vessel that is not in mass flow will easily pass some pellets in less than 25 percent of the predicted dwell time of the vessel and will hold some resin indefinitely. The next consideration in process hopper design is the distribution of the hot, dry air we discussed earlier. The best quality of dry air is only useful if it is distributed to each and every pellet being dried. With this in mind, air is introduced into the lower part of the drying hopper and air diffusers are utilized to equally move the air to all parts of the vessel. While distribution of air is usually straight forward, the method used can create back pressure on the air delivery that will restrict the volume of air if not accounted for in selection of the air mover for the dryer. Once a combination of all four elements required for proper drying are in place, then loading the vessel with crystalline resin, and proceeding to predry and then run the extrusion system will ensure successful production.

Two Stage Process Drying

In some cases the requirements of a particular system will not facilitate the proper placement of the process-drying hopper directly over the extruder throat. This may be due to lack of headroom over the extruder or the size of the hopper necessary for a higher throughput dryer that exceeds the elevations normally suited to the manufacturing process. When this occurs, the main drying hopper can be remote mounted, usually on a floor stand, and the dry material conveyed to a smaller hopper over the throat of the molding machine. The best approach to this question is to provide a 15 to 45 minute hopper size over the extruder with enough airflow to maintain the temperature of the resin at the throat. This will typically require .05 to .1 CFM/PPH airflow at this hopper in addition to the main drying vessel. Airflows at these levels will maintain the dryness of the resin, but will not change the temperature of the pellets.

System Datalogger

Part of every PLA sheet line system should be a Datalogger for the process dryer and Crystallizer. This small microprocessor package samples all of the process variables on the dryer and records them on a fixed time interval. By downloading these files from the Datalogger, it is possible to plot charts that enable the operator to verify correct machine operation. One of the most valuable uses of the Datalogger is to have periodic charts of a dryer to compare with the most recent operation, and through this method, troubleshoot the performance of the system. Review of the Datalogger information will enable scheduled maintenance to fix problems that may not be obvious in the routine maintenance of a dryer.

Several examples of proper dryer operation will also illustrate the operation of the equipment associated with the dryer. By checking the return air temperature on the drying hopper, it is easy to see if the material transfer system has been working properly. A check of the dryer inlet temperature usually will show the heat exchanger water supply consistency. In this example, should the return temperature be higher than normal or steadily increasing, the water supply could be intermittent or low pressure. The Datalogger will also indicate if both desiccant towers are working properly, and if there are any leaks inside the dehumidifier valves. These will show up in the charts as asymmetrical temperature profiles between the left and right towers of the dryer. Once an operator is familiar with the Datalogger, it is possible to anticipate most of the maintenance issues with the system. By knowing what condition the system is in, the problems can be addressed long before the process is adversely affected.

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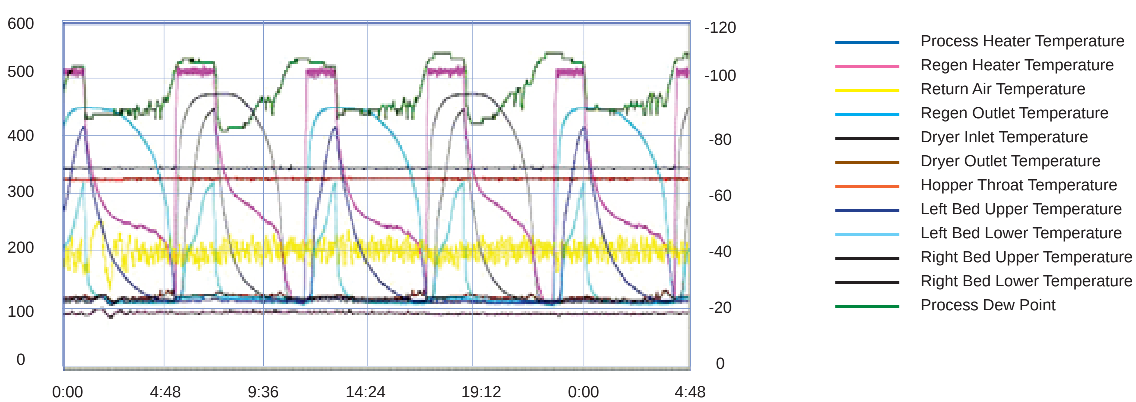

Converting PET Systems to Run PLA

For those operators that will be using existing PET lines to run PLA sheet, there are several simple changes that will enable successful operation. First, the temperatures used to dry and crystallize the PLA are much lower than any of the PET resins. On electrically heated equipment, setting the operating temperatures as instructed in the resin literature will insure proper processing. For those plants where gas heated equipment is in place, there are two simple changes to operate the system. The gas fired crystallizers that are normally operated in a closed loop airflow, will need to have the loop opened to use room air intake for the process air blower. This will enable the inlet air to the gas fired heater to be low enough so that a setpoint of 190ºF to 200ºF will operate without causing any alarms due to excess temperature situations. One way to open the loop can be just opening the door to the process filter. If there is enough air exchange, and the filter does not present too many fines entering the room, usually this will be adequate to manage the temperature at the correct range. If this is not practical, disconnect the blower intake duct and place a protective screen on the now open duct for the room air intake. The discharge of the system can be vented into the room or ducted outside. The normal use of a gas fired crystallizer in the closed loop connection is to maintain a 300ºF or higher temperature with minimal losses in energy. A single pass air system is satisfactory for use with a PLA operation because the PLA crystallizer is at low enough temperatures that energy consumption is significantly less than that of a PET operation.

The next step involves the process dryer. If the dryer has a gas fired process air heater, use the UDI code set point of 32ºF to disable the process air heater. This will allow the dryer to operate and produce dehumidified air while still in a closed loop air connection. The natural temperature balance in a system of this type will have the air discharge from the dehumidifier at 140ºF to 160ºF without any additional energy. This is due to the heat of compression of the process air blower, and the heat of adsorption of the desiccant. These two factors will add approximately 30ºF or more to the air in the drying loop. These measures are only required on a gas heated system, so where there are electric process heaters, adjust the set points to the specified temperatures and prepare to run the system.

In addition to the temperature controls indicated above, a very critical aspect of using existing equipment for trials or production of sheet is to clean out all traces of the PET that normally runs in the system. Since the PLA resin melts approximately 200ºF less than the PET resin, all of the fines left in the process vessels will come through the extruder as unmelted contaminates. If these specs are large enough, they may present problems with the finished product. For those plants where PLA will run on a regular or frequent basis, having segregated vessels for the two different resins will remarkably reduce resin change over and prevent contaminates from entering the PLA sheet stock. While this does involve additional equipment, the losses from production of PLA sheet stock with contaminates can quickly justify the additional vessels.

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