

# **EQUIPMENT AND PROCESSING CONSIDERATIONS FOR EXTRUDING BIO-RESINS**

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## **ABSTRACT**

With the addition of many new bio-resins and the push by consumers and end users for green products, changeover to sustainable products will eventually occur. How ready is your equipment and process for this change? This paper will outline a step by step approach from the resin supply through the winder to determine the considerations, changes and compromises that may need to take place to effectively move forward on the path of sustainability. Positives and negatives of potential changes with regards to both new and current products will be examined to help the converter choose the best path forward for their needs. Infrared scan data will be examined from a plant running PLA to see some of the challenges of this type of polymer.

## **DISCUSSION – MACHINE AUDIT**

Webster defines audit as "a formal examination and verification of accounts." If we take this definition and expand it to only continuous extrusion processes, it may look something like "a formal examination review and recommendation for improvement of a plant or specific piece of equipment."<sup>1</sup> In this case, the improvements need to be targeted to allow for the successful processing of bio-resins. A thorough understanding of the existing equipment and its limitations will be necessary. Some plants may even want to bring in an outside source to conduct the audit for a more open, unbiased analysis. Either way, this paper will provide guidance of the changes needed to process bio-resins.

### **Deciding on a Product Mix**

Before the audit can be done, the converter needs to decide what the line will be doing. Is the line going to run bio-resins a day a month or more like 50% of the time? If the amount of time to run bio-resins ends up being significant, it will be easier to dedicate an existing or new line to these products and make changes that will not have to be a compromise. Where this isn't possible, the converter will still have to decide what changes make the most sense for the product mix. Bio-resin processing does not mix well with conventional olefin processing due to significant differences in melt point, thermal stability and other processing requirements discussed in this paper.

## Resin Handling

The resin handling system for the line makes a good starting point for the audit. Many of bio-resins available are currently being produced by the box and in small lots. It is expected these resins will be available by rail car in the future.

If you only run from silos, you will need to access how the new material will to be stored. Is there a spare silo available for the new resin? It's not too early to plan on getting one in place for the future or clearing out or cleaning an existing one. Keep in mind that any hygroscopic resin that would be stored in a closed silo for more than 6 hours should either be purged with dry air or nitrogen to minimize moisture gain.

For present use, is there a staging area that boxed resins can be run from? You will need a vacuum receiver and wand if you are intending on running from boxes. If the boxes are going to be stored outside, the boxes will need to be moved to the machine location for 24 hours<sup>2</sup> before opening the box to minimize excessive condensation.

Operators will need to be made aware, through instruction or training, of the special care that needs to be taken in the handling of sealed bags or boxes of pre-dried resin.

## Resin Drying

Bio-resins, specifically PLA, reaction polymers (PET based) or PHA, are very hygroscopic. Hygroscopic materials will absorb water, even from the air. In-line drying is essential for PLA, PHA and other hygroscopic resins. If nylons or polyesters are currently processed on your line, you will already have drying equipment. If not, you will need to consider a desiccant dryer. Even if you do have existing drying equipment, you may want a dedicated system to dry these resins as they are very sensitive to cross contamination, have lower melting points and are less thermally stable. If you intend on running multiple resins in the dryer, you will need to account for time spent cleaning the system of pellets and dust before loading the bio-resins and changing resins back and forth.

PLA should be dried to less than 250 ppm of moisture as measured by a Karl Fischer method<sup>3</sup>. If the moisture is higher, the PLA will degrade during the extrusion process. Further, if the PLA is exposed to unusually long residence time or extrudate temperatures higher than 204°C (465°F), the moisture level should be less than 50 ppm<sup>4</sup>. Trials yielded better results with as low a moisture level as possible.

It is true that suppliers of PLA provide the material pre-dried in foil liners. However, I have personally measured moisture content in several boxes of PLA from different manufacturers or lots and each one was different. These resins do pick up moisture very quickly. It is not worth taking the chance of having processing difficulties with something as simple to correct as moisture.

Each resin manufacturer has recommended drying temperatures and times. These should always be considered a minimum requirement to meet or exceed. In general, 2-4 hours at 90°C (194°F) with -40°C (-40°F) dewpoint air is sufficient. Note that drying temperatures are lower than those for typical nylon or polyester resins which may require longer dwell times.

### Extruder Drive, Gear In and Screw Design

Bio-resins consume more torque than the standard olefin resins that they replace. If you do not currently run a stiff, torque demanding polymer (e.g. LLDPE, PET,...) on your machine, you may not have enough hp to effectively process Bio-Resins. The extruder drive is closely tied in with the screw design and gear in so different designs will require different torque to function.

Table 1 compares requirements of Bio-Resins (such as PLA or PHA) with LDPE for example, a 6" extrusion coating extruder. Keep in mind that the values in the table are based on a dedicated design for each resin.

Resin	Bio-Resins	LDPE
Horsepower required	373 kW (500 hp)	298 kW (400 hp)
Maximum screw speed	100 rpm	225 rpm
Maximum output	1136-1364 kg/h (2500-3000 pph)	818-1091 kg/hr (1800-2400 pph)
Melt Temperature	220-240°C (428-465°F)	316-327°C (600-620°F)
Screw Type	Barrier with single mixer	Single flighted with two mixers
Screw depth (relative)	Deep	Shallow

Table 1 – Extrusion Coating Processing Comparison

This table shows how dramatic the differences are between these resins if the extruder is designed for LDPE or simple polyolefins. It is possible to run bio-resins at a very slow speed for trial purposes, but not practical for full production. The high shear stress in olefin type screws causes degradation in bio-polymers.

Some big decisions need to be made at this point. Can the line be dedicated to one product or the other? If so, the proper changes will need to be made. In order to change to bio-resin exclusively some or all of the following will need to be done:

1. Larger motor and drive
2. New gearbox with higher ratio
3. New screw

If both products need to be run, there are a few different directions that can be taken. If the line has multiple extruders, one station can be for LDPE and the other can be for bio-resins. If that is not possible, there are two other scenarios. The first would be an additional extruder, dedicated for the bio-resins. Included in this would be:

1. New extruder, downstream, heat control & drive
2. Mounting structure to fit into existing extruder arrangement
3. New or modified feed block

The other scenario would be modifications to the existing extruder with a screw changeover needed between changes of LDPE or bio-resin. This would include:

1. Larger motor and drive (would need high amount of field weakening)
2. New gearbox
3. New screw

The drive would need to be field weakened enough to be able to run high speed for LDPE but still have enough torque for the low speed bio-resins. There would be significant change over time to change screws. This would be the most difficult of the different scenarios to justify.

Consideration could be given to providing a change gearbox for the two different ratios. These were quite common twenty years ago but have gradually disappeared due to field weakening for DC motors or the lower speed torque availability for AC motors. It is difficult to find this type of box anymore and not recommended.

Deciding what to do with the drive end and screw of the extruder will be the most difficult and costly decision to make.

### Barrel Heating and Cooling

The heating and cooling for a standard extruder will usually work for bio-resins. The key to this area is that the cooling must work properly. Bio-resins will utilize more cooling than heating when running at steady state. If the cooling system is not functioning properly, the bio-resins will overheat and degrade. The machine audit list should include a check of this system, including the cooling efficiency.

The temperature profile for the bio-resin is going to depend on the type of screw used and the connected horsepower to the system. If there is enough horsepower, a standard profile can be used. If it looks like horsepower may run short, a reverse profile will keep the melt temperature low and reduce the motor load. Keep in mind that too much high temperature residence time causes degradation for these polymers.

### Feed Cylinder

A water cooled feed section is required for bio-resins. With lower melting points, it is easier to initiate premature melting and cause a melt block or bridge. Check the feed cylinder to determine that there is adequate water flow to keep the feed section at 45°C (113°F) or lower. Keep in mind that older feed sections may be fouled and need cleaning. Keeping the feed section cool isn't as critical for polyethylene extrusion.

### Screw Root Cooling

The feed section of the screw should be bored for cooling. Screw cooling should be used for bio-resins to prevent feed blockage and premature melting. Most screws are cored and supplied with screw cooling. Extruders running polyethylene may or may not be using the screw cooling. In this case, screw cooling will not hurt a typical olefin resin

so it is better to have it installed and running, regardless of what product is being made. The screw should be bored to the end of the feed section.

### Downstream

Downstream needs to be evaluated for residence time and polymer hang up concerns (especially a compromise system that will be running bio-resins at reduced output). Bio-resins do not fare well with long residence time. If the pipes are very long, now may be the time to consider a new more streamlined set. Machine tooling and Cad make it easy to produce compound angles which can greatly reduce length.

Polymer flow surfaces should be examined in the audit. If there are any major areas of redesign to eliminate stagnation, consideration should be given to changing construction to stainless steel to minimize corrosion. The screen changer and valve should be examined to see how much flow divergence and residence time is occurring in these sections.

A countersink inlet and outlet of the breaker plate will work well for bio-resins. Keep in mind that you will not want to use tight screens (150 mesh or higher), due to excessive shear heating of the bio-resin.

Another piece of equipment that may be helpful in processing these bio-resins is a static mixer towards the end of the feed pipe run. This mixer will provide additional additive distribution as well as melt temperature homogeneity. However, the static mixer may not be a good idea for the other products on the line.

Do you have a method of evaluating temperature variation (position and time dependant) in the feed pipe? You will want the opportunity to be able to determine the temperature across the melt stream to allow for better troubleshooting. The line can be run with a more "robust" thermocouple most of the time. An adjustable one can be used for process evaluation only.

### Forming Die

The die on the line may have a short final land and internal deckles. The forming step needs to consider the differences between the visco-elastic processing characteristics of the bio-resins and typical materials produced. For example, one of the problems seen with bio-resins is draw resonance at high output. The bio-resins tend to be lower melt strength resins as compared to standard polyethylene resins. This can cause edge stability problems, more neck in and draw resonance.

A longer land die tends to stabilize the polymer before it leaves the die. It is not necessary to buy a new die, just for the land length. A short land die can be run but may be speed limited. Keep in mind that the die gap may need adjustment as will the air gap, compared to your standard extrusion coating resins.

Another option to stabilize the melt curtain and increase processing speeds would be the addition of edge encapsulation. This would be similar to what is done when running low melt strength PET. This option would involve either an edge encapsulation die or

feedblock. An additional extruder would be needed for the edge material. Also, a suitable material that bonds to PLA and is stable will also be required.

The die can be an area of long residence time for bio-resins. It is a good idea to run the die slightly colder (5-10°C) than the rest of the process. Build up of degraded bio-resins is likely around die deckles. It is a good idea to purge the deckles areas well during down time.

Does your die have lip heaters? These would generally not be recommended for bio-resins as they could cause degradation. However, it is a good tool to have if you are experience bond issues and need a little more heat in the resin.

### Case Study – Draw Resonance Phenomenon

As mentioned above in the die section, the lower melt strength of the bio-resin can cause draw resonance type problems at higher output. This phenomenon was documented on an extrusion coating machine with a Raytek Infrared scanner. Figure 1 shows a scan at a slower speed. Note that the curtain looks uniform in the machine direction from the top to the bottom of the picture.

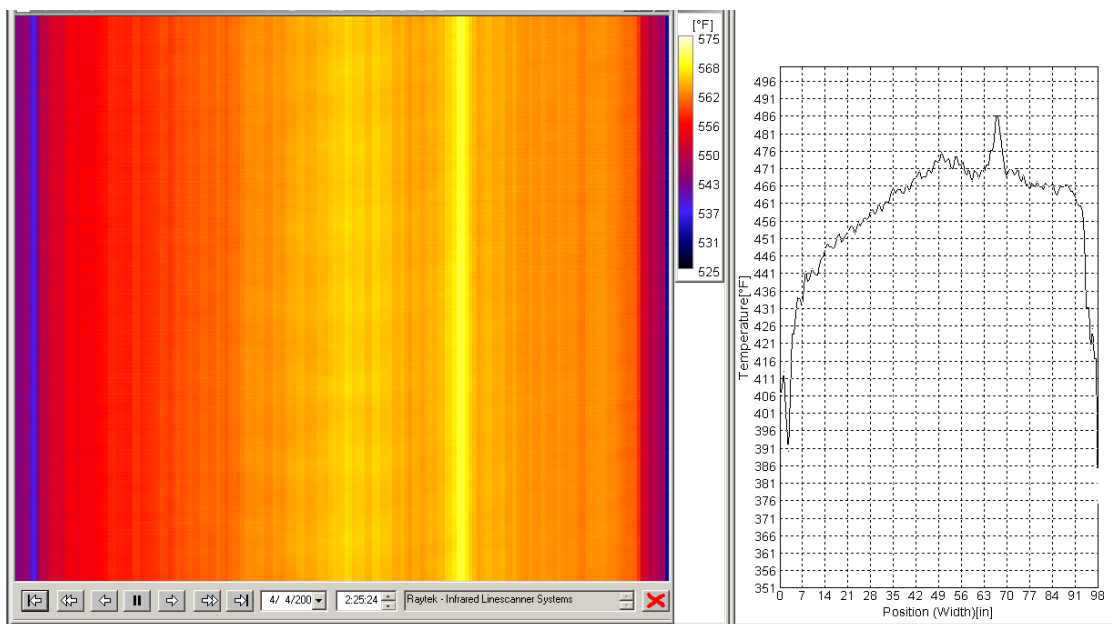


FIGURE 1

Figure 2 is a scan of the same bio-resin at a faster speed. Note the unevenness in the machine direction that looks like waves on the scan. This was also very apparent in the finished product as well. Thermal waves on the scan correspond to thickness waves in the product. Primary cause was degradation of the material through the extrusion process due to residual moisture, high screw shear stress, long residence time and

overheating. Die gap, die to nip height or die type can be changed to try to reduce or eliminate this problem.

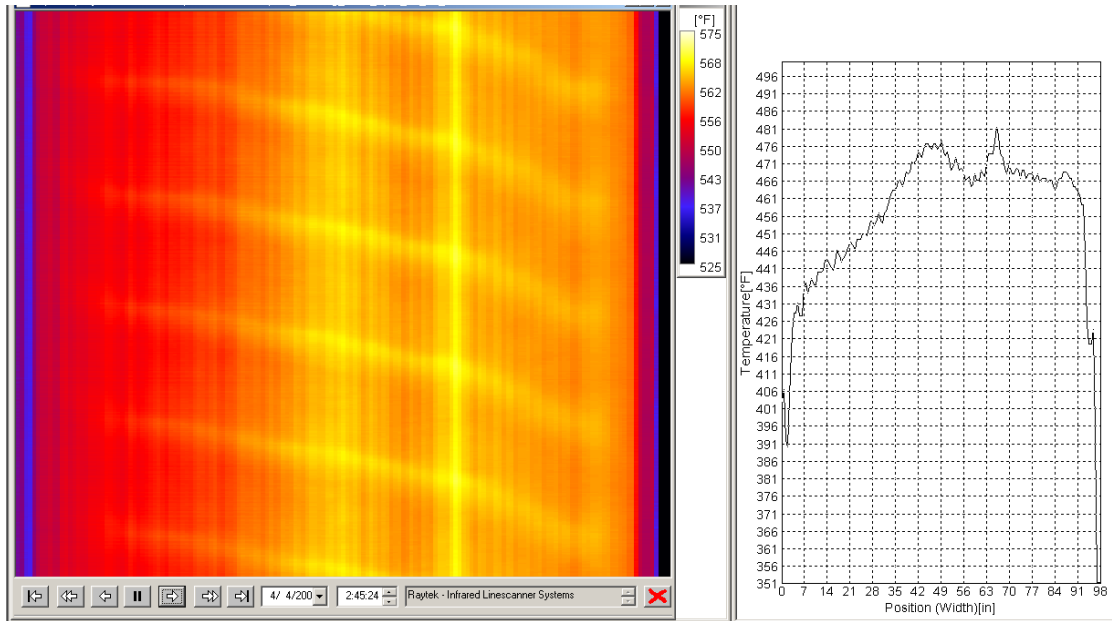


FIGURE 2

### Resin Changeover and Purging

Resin changeover can be challenging and time consuming when running bio-resins. These materials run at very low temperatures compared to the standard resins. Going from an olefin to a bio-resin is as follows: A high melt flow resin such as PP should be used as a transition resin to purge the existing resin at temperature. The temperature can be lowered to the bio-resin temperatures while purging. The bio-resin can be added when the system is clean. Going from the bio-resin to another resin requires a moderate to low melt index resin that processes well at 205-230°C (400-450°F). Keep in mind there needs to be adequate purge time for both the transition resins and the bio-resins. DuPont Disco Purge procedure will shorten transition time and conserve resin.

### Haul Off Equipment

There is not generally a requirement for significant changes in haul off equipment. The chill roll may not need to be run as cold as it needs to be for polyethylene due to lower melt temperatures for bio-resins. The nip pressure may need to be increased to promote a better bond with the bio-resin and substrate as raising melt temperature will not be possible. A radiant or IR heater in the air gap will reduce the cooling in the draw down zone, allowing an increase in bond and/or high line speeds.

## Slitters

Most bio-resins, especially PLA, are brittle. Drying will help these resins to be less brittle. However this brittleness, with higher coat weights especially, can present a challenge with edge trimming. What type of slitters are on your machine? Shear slitters work the best for bio-resins. Razor slitters may be able to be used on very light coat weights but will generally create a rough edge and possibly cause a web break. The bio-resins will also slit better if they are warm. If your edge trim is right after you extrude, you may be able to keep the product a little warmer to allow for better slitting.

If you do not have shear slitters, it may be worthwhile to invest in a pair of c-frame slitters, keeping in mind that these are adjustable on the fly but will need a drive. You can still use razors for the other products.

It is well worth checking into all of the bio-resins that are becoming available. New processing aids are being developed to address the brittleness and processability of these resins.

## Regrind Possibilities

Most bio-resins can be reground and reprocessed in the extruder. The regrind does not need additional drying if it is used immediately. The extrusion coating process usually doesn't involve regrind of any kind due to substrates used in the product. However if the product is overcoated, this could be something worth considering.

## Tension & Winding – Web Products

You can spend all your time and effort making a great looking product but if you overlook tension, you could have a product that doesn't wind well. The inherent brittleness and stiffness of these bio-resins means one thing, additional tension. The line tensions will have to be raised as compared to standard extrusion products. As part of the audit, the maximum line tension along with standard running tension should be noted. If the line is already running maximum tension, you may have some web handling issues to look for when running bio-resins. The tension control for the winder should be looked at during the audit. The machine should have good tension control at the winder as well as additional tension capacity for the bio-resins.

It is assumed that the line runs in tension and not speed or draw. Therefore, the tension control should be "better than 1% of the material breaking strength"<sup>5</sup>. The material breaking strength will vary for the bio-resins depending on its additive package. Also, "the cross machine tension should not vary more than 5% of set point at steady state and 10% during transitions"<sup>6</sup>. There is also a recommendation for machine direction variation. The "down web variation through a drive section should not span more than 10% during steady state running and 25% during speed changes"<sup>7</sup>. Keep in mind that the load cells will need to be sensitive enough to read the above variations. It would be best to check and correct tension control issues before running bio-resins.

## The Next Step

From the audit, the converter should have a list of equipment that needs to be changed, added to or modified. Some of these will be minor, others are major. From this list, a plan can be put in place so that when it comes time for using bio-resins, the converter will be ready with no hidden surprises.

## **SUMMARY**

Most bio-resins cannot be used on systems designed for polyolefin processing without changes. This paper gives a step by step approach to auditing the critical components of the line to enable the converter to add sustainable products to the product list without sacrificing current processing requirements.

## **REFERENCES**

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