

Injection Molding Guide for Ingeo™ Biopolymer

This information is intended for use only as a guide for the injection molding of Ingeo biopolymer. It will consist of generalized concerns for safety, process conditions, and tooling.

Since injection molding covers a wide arena of applications and polymers, an experimental approach using Ingeo at your facility will have to be completed to determine what tooling and mode of operation will work best.

Testing of the molded Ingeo products is also recommended in order to make sure it meets customer requirements.

1.0 Safety and Handling Precautions

All safety precautions normally followed in the handling and processing of melted thermoplastics should be followed for Ingeo Biopolymer resins.

As with most thermoplastics, melt processing and the variability of those conditions may result in minor decomposition. Lactide, a non-hazardous gaseous irritant, is a minor by-product of Ingeo melt processing. Appropriate air testing should be completed to ensure an acceptable Threshold Limit Value (TLV) of less than 5 mg/m³ is maintained. The use of process area point source remediation measures such as monomer fume hoods or exhausts near melt processing equipment are typically recommended.

Molten Ingeo is lower viscosity and sticks more readily to cloth, metal, brass and wood compared to other molten thermoplastics. Be prepared for this when cleaning die faces, purging equipment, collecting molten patties, and emptying purge containers. Unlike polyolefins, molten Ingeo will not release as cleanly from a gloved hand so use caution when grabbing any stream or patty.

Ingeo is considered non-hazardous according to DOT (US Department of Transportation) shipping regulations. When handling Ingeo resin at room temperature avoid direct skin and eye contact along with conditions that promote dust formation. For further information, consult the appropriate MSDS for the Ingeo grade being processed.

As with any melted thermoplastic waste, melted Ingeo waste should be allowed to cool before being placed into any waste container to minimize fire risks.

2.0 Pellet Storage and Blending Recommendation

Ingeo resins should be stored in an environment designed to minimize moisture uptake. Product should also be stored in a cool place at temperatures below 122°F (50°C).

Product that is delivered in cartons or super sacks should be kept sealed until ready for loading into the blending and/or drying system. Bulk resin that is stored in closed silos and hoppers for extended periods (more than 6 hrs) should be kept purged with dry air or nitrogen to minimize moisture gain. In the case of outside storage, if the product is supplied in boxes or other non-bulk containers, the unopened container should be brought into the extrusion production area and allowed to equilibrate for a minimum of 24 hours before opening to prevent excessive condensation.

3.0 Resin Properties

Ingeo Injection Molding Grades are specifically made for Injection Molding applications. Typical properties are shown in the table below.

Resin Property	Nominal Value
Specific Gravity	1.24
RV	2.5 - 3.3
Melt Temperature, °F (°C)	293-311 (145 – 155)

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Glass Transition Temperature, °F (°C)	131-136 (55 – 58)
Crystallization Temperature, °F (°C)	203– 248 (95 – 120)
Thermal Conductivity, BTU/ ft-hr-°F (cal / cm-sec-°C)	Amorphous 0.075 (3.1 x 10-4) Crystalline 0.11 (4.5 x 10-4)
Specific Heat, BTU/ lb °F (cal / g °C)	Below Tg 0.29 (0.29) Above Tg 0.51 (0.51)

4.0 Drying

Ingeo resins can be successfully dried using most standard drying systems. Recommended conditions are provided for standard desiccant based column dryers. For other drying system designs, additional information can be provided upon request.

To prevent equipment corrosion, it is not recommended to dry or store hot Ingeo resin in carbon steel vessels (see Section 2.0).

In-line drying is essential for Ingeo resins. It is recommended that Ingeo should be dried to a maximum of 250 ppm of moisture as measured by a Karl Fischer method. A moisture level lower than 250 ppm will help keep the melt viscosity stable over time at elevated temperatures. Processes that have unusually long residence times or result in melt temperatures greater than 240°C should only extrude Ingeo at moisture levels less than 50 ppm for maximum retention of molecular weight and physical properties. Material is supplied in foil-lined containers dried to less than 400 PPM as measured by NatureWorks LLC's internal method. The resin should not be exposed to atmospheric conditions after drying. Keep the package sealed until ready to use and promptly dry and reseal any unused material. The drying table below can be used to estimate the drying time needed for Ingeo. Air or nitrogen based desiccant drying systems can be used at the recommended temperatures. Typical Ingeo drying conditions are shown in the table below.

Typical Ingeo Raw Material Drying Conditions

Drying Parameter	Typical Settings	
	Amorphous	Crystalline
Residence Time (hours)	4	2
Air Temperature °F (°C)	113 (45)	194 (90)
Air Dew Point °F (°C)	- 40 (-40)	- 40 (-40)
Air Flow Rate, CFM/lb resin (m ³ / hr - kg resin)	> 0.5 (1.85)	> 0.5 (1.85)

Typical desiccant dryer regeneration temperatures exceed the melt point of Ingeo resins. To prevent issues with pellet bridging, sticking or melting, the drying system should be verified to ensure temperature control is adequate during operation as well as during regeneration cycles since valve leakage is common in many systems. Installation of a water-cooled after-cooler may be necessary to prevent the drying air temperature from exceeding the recommended set point when drying amorphous materials. Ingeo is a semi-crystalline product that can come in either amorphous or crystalline form and can be dried accordingly as per the table above.

5.0 Melt Processing

Prior to introducing Ingeo into any melt processing system, the system should be properly cleaned and purged to prevent any polymer cross contamination. Insure that the feeding & blending equipment is thoroughly cleaned & free from dust and contamination and all metal magnates have been wiped clean. Insure that all hang-up areas such as elbows transitions and slide gates have all previously run dust and granules completely removed. The purging procedures below are recommended for optimal removal of other polymers.

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5.1 Ingeo Purging Procedure

Following PET, PA, HDPE, or other higher melting polymers in your system

1. Purge with low MFR (<1) PP at normal polymer operating temperatures. Purge 10-30 minutes or as necessary. Let system empty as much as possible. Clean hopper and convey lines from pellets and residual polymer dust.
2. Introduce a high melt flow PP (5 - 8 MFR) and change to normal Ingeo operating temperatures.
3. Purge 10-30 minutes as necessary. Let system empty as much as possible.
4. Alternatively, you can purge with a high flow PETG (similar to Eastman copolymer 6763) or acrylic. Then reduce temperatures to Ingeo conditions.
5. Stop injection molder and completely clean all hoppers, elbow, slide gates, dryers, hopper loaders bins, hopper loader filters and material conveying lines of residual polymer. Load Ingeo into material handling system.
6. Transition to Ingeo and purge until melt is clear of any contamination.
7. At the completion of the run, purge all Ingeo from the extrusion system, using a moderate to low melt index PP, immediately after completion of the production run.

Notes:

1. It is critical that all drying and conveying/receiving systems be free of all incumbent polymer and is vacuumed to ensure that there is no remaining polymer dust, before adding Ingeo. Some polymers will not melt at Ingeo operating temperatures and will block screens, if it is present in the system.
2. The brand of PP used for purging is unimportant, as long as it does not thermally cross-link.

5.2 Injection Mold Machine Recommendations

Ingeo injection molding resin grades will injection mold on most conventional equipment but there could be some limitations if the screw design has a high compression ratio. Compression ratios of 2.5-3 should be adequate for Ingeo. Typical molding conditions are listed below.

Zone	Barrel Temperature Setting, °F (°C)
Feed throat	70 (20)
Feed Section	330 (165)
Compression Section	380 (195)
Metering Section	390-450 (200-230)
Hot Runner	400-450 (205-230)
Nozzle Tips	400-450 (205-230)
Mold	77 (25)
Screw Speed	50-100 rpm
Back Pressure	150-200 psi
Mold Shrinkage	0.004 in/in +/- 0.001

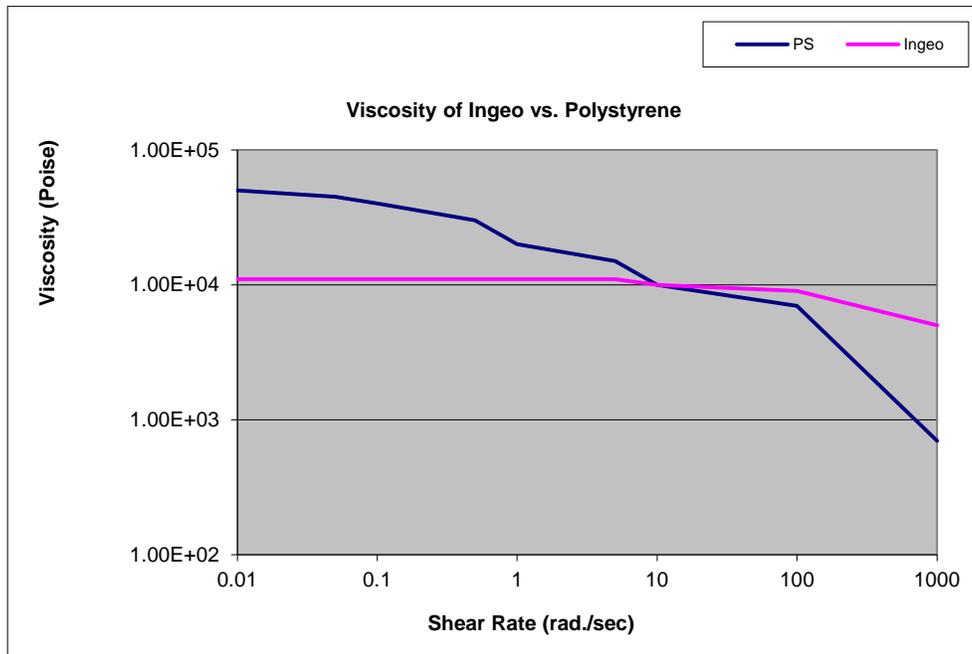
(Please note that these are recommended starting conditions and may need to be optimized)

Since Ingeo has a lower glass transition temperature (~58°C) than PS or PET, it might take a little longer to set up in the mold. Finding an optimum mold temperature is recommended in order to get the best quality parts and the shortest cooling times. Plate-out of lactide can occur over time if injection speeds are too low, and/or mold temperature is too cold.

Hot runners are also acceptable for the injection molding of Ingeo.

Another concern is that Ingeo shear-thins slower and to a lesser extent than resins like PS, PE, and PP. Because of this, filling of the mold is a concern especially for thin-walled products like drinking cups. It might be possible to overcome this issue by experimentation and finding the right melt temperature and injection speed necessary to fill the part. Usually, one will have to raise the melt temperature, which can have an adverse effect on the cooling time of the part while in the mold.

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5.3 Mold/Tooling Recommendations

Stainless steel that is hardened is best especially for molds running full production. It has been found that thermal gates and valve gates are acceptable. A hot-runner system designed for PET and PS can be used for Ingeo since the mold shrinkage of Ingeo is low (0.004 in/in), running on PS or PET tooling is recommended over resins such as polyethylene or polypropylene.

5.4 Additives

Colorants and slip agents can be added as a masterbatch at 15-30-wt% in Ingeo by dry blending with the neat resin in the required amount and adding the blend to the injection molder. The additions of colorants have been successfully done using liquid injection technology as well. Since Ingeo is not compatible with most incumbent materials, it is important that all additive masterbatches use Ingeo as the carrier. Some potential additives are inappropriate for extrusion with Ingeo because they are hygroscopic or hydrated salts (e.g. calcium carbonate), or zinc stearate that would lead to severe Ingeo molecular weight degradation and property loss.

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Safety and Handling Considerations

Safety Data Sheets (SDS) for Ingeo biopolymers are available from NatureWorks. SDS's are provided to help customers satisfy their own handling, safety, and disposal needs, and those that may be required by locally applicable health and safety regulations. SDS's are updated regularly; therefore, please request and review the most current SDS's before handling or using any product.

The following comments apply only to Ingeo biopolymers; additives and processing aids used in fabrication and other materials used in finishing steps have their own safe-use profile and must be investigated separately.

Hazards and Handling Precautions

Ingeo biopolymers have a very low degree of toxicity and, under normal conditions of use, should pose no unusual problems from incidental ingestion or eye and skin contact. However, caution is advised when handling, storing, using, or disposing of these resins, and good housekeeping and controlling of dusts are necessary for safe handling of product. Pellets or beads may present a slipping hazard.

No other precautions other than clean, body-covering clothing should be needed for handling Ingeo biopolymers. Use gloves with insulation for thermal protection when exposure to the melt is localized. Workers should be protected from the possibility of contact with molten resin during fabrication.

Handling and fabrication of resins can result in the generation of vapors and dusts that may cause irritation to eyes and the upper respiratory tract. In dusty atmospheres, use an approved dust respirator.

Good general ventilation of the polymer processing area is recommended. At temperatures exceeding the polymer melt temperature (typically 175°C), polymer can release fumes, which may contain fragments of the polymer, creating a potential to irritate eyes and mucous membranes. Good general ventilation should be sufficient for most conditions. Local exhaust ventilation is recommended for melt operations. Use safety glasses (or goggles) to prevent exposure to particles, which could cause mechanical injury to the eye. If vapor exposure causes eye discomfort, improve localized fume exhausting methods or use a full-face respirator.

The primary thermal decomposition product of PLA is acetaldehyde, a material also produced during the thermal degradation of PET. Thermal decomposition products also include carbon monoxide and hexanal, all of which exist as gases at normal room conditions. These species are

highly flammable, easily ignited by spark or flame, and can also auto ignite. For polyesters such as PLA, thermal decomposition producing flammable vapors containing acetaldehyde and carbon monoxide can occur in almost any process equipment maintaining PLA at high temperature over longer residence times than typically experienced in extruders, fiber spinning lines, injection molding machines, accumulators, pipe lines and adapters. As a rough guideline based upon some practical experience, significant decomposition of PLA will occur if polymer residues are held at temperatures above the melting point for prolonged periods, e.g., in excess of 24 hours at 175°C, although this will vary significantly with temperature.

Combustibility

Ingeo biopolymers will burn. Clear to white smoke is produced when product burns. Toxic fumes are released under conditions of incomplete combustion. Do not permit dust to accumulate. Dust layers can be ignited by spontaneous combustion or other ignition sources. When suspended in air, dust can pose an explosion hazard. Firefighters should wear positive-pressure, self-contained breathing apparatuses and full protective equipment. Water or water fog is the preferred extinguishing medium. Foam, alcohol-resistant foam, carbon dioxide or dry chemicals may also be used. Soak thoroughly with water to cool and prevent re-ignition.

Disposal

DO NOT DUMP INTO ANY SEWERS, ON THE GROUND, OR INTO ANY BODY OF WATER. For unused or uncontaminated material, the preferred option is to recycle into the process otherwise, send to an incinerator or other thermal destruction device. For used or contaminated material, the disposal options remain the same, although additional evaluation is required. Disposal must be in compliance with Federal, State/Provincial, and local laws and regulations.

Environmental Concerns

Generally speaking, lost pellets, while undesirable, are benign in terms of their physical environmental impact, but if ingested by wildlife, they may mechanically cause adverse effects. Spills should be minimized, and they should be cleaned up when they happen. Plastics should not be discarded into the environment.

Product Stewardship

NatureWorks has a fundamental duty to all those that use our products, and for the environment in which we live. This duty is the basis for our Product Stewardship philosophy, by which we assess the health and

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environmental information on our products and their intended use, and then take appropriate steps to protect the environment and the health of our employees and the public.

Customer Notice

NatureWorks encourages its customers and potential users of its products to review their applications from the

standpoint of human health and environmental quality. To help ensure our products are not used in ways for which they were not intended or tested, our personnel will assist customers in dealing with ecological and product safety considerations. Your sales representative can arrange the proper contacts. NatureWorks literature should be consulted prior to the use of the company's products.

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