Development of BioBased Packaging via Twin Screw Extrusion

Next Generation Bio-Based Chemicals

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Twin Screw Extrusion (TSE) Process Sequence

- **Pellets**
- **Powders/Fillers**
- **Liquids**
- **Fibers**

**TSE**
- Feed
- Melt
- Mix
- Devolatilize
- Pump

**Size & Cool**
- Air
- Water
- Rolls
- Conveyors

**Finish**
- Pellets then/or...
- Sheet/film
- Tube/profile
- Filament/fiber
- Adhesive coat
- Injection mold

**Processing PLA on TSE’s**
- Temperature sensitive
- Moisture/melt = hydrolysis
- Shear sensitive
- Torque limited
HSEI TSE w/ LIW Feeders

- TSE’s are starve fed, feeders set the rate, screw rpm is independent
- Keep PLA in sealed cartons before processing
- Stainless steel metals for stagnant flow areas
- Pay attention to shutdown/purging protocols
- Heated water and other pelletizer mods to augment crystallization
Rotating screws impart shear and energy into materials being processed.
Barrel Section Temperature Control

- Internal cartridge heaters for electric heating
- Longitudinal cooling bores for liquid cooling
Barrel Cooling Schematic

- Inlet #1
- Inlet #2
- Quick disconnect
- Needle valve
- Coax valve
Co-rotating TSE design

Melt & mix
Solids conveying

More mixing
Convey

Pump/discharge
Vent
Mix and seal
Modified shaft design
More splines and asymmetrical geometry
Smaller diameter shaft can transmit more torque
Test #1

ZSE-27 rate tests

PLA NatureWorks 2002D

ZSE-27 HP
• 27 mm screw dia.
• 4.5 mm flight depth
• 10.3 cc/dia. free vol.

ZSE-27 MAXX
• 28.3 mm screw dia.
• 5.7 mm flight depth
• 14.3 cc/dia. free vol.

40 to 1 L/D process section
Screws centerline = 23 mm
1280 screws RPM
50 HP AC motor
Same temperature profile
Screw designs: ZSE-27 HP vs MAXX

Tests used open end discharge, less than 100 psi pressure
Process Comparison - ZSE 27

Rate Comparison - MAXX vs HP

PLA- NatureWorks 2002D: what’s the residence time?
PLA- NatureWorks 2002D: 20, 10 & 5 seconds
ZSE-75 MAXX Underwater pelletizer front-end

RT for 800 kgs/hr = 4 seconds
ZSE-75 MAXX Sheet system front-end

RT for 800 kgs/hr = 91 seconds
Temperature rise during pressure generation

\[ \Delta T (°C) = \Delta P \text{ (bar) } / 2 \ (\pm 50\%) \]

- 40 Bar (580 PSI) Pressure results in a 20°C melt temperature rise (40/2)
- Restrictive front-end designs may adversely affect the product
- RPM, discharge screw elements & materials play a role in Tm
**Gear Pump Front End**

300 bar pressure differential possible

**DISCHARGE:**

Anything that requires pressure generation

**INLET:**

TSE & coarse filtration (maybe)

- 200 bar
- 25 bar
Gear pump before screen changer & pelletizer
Direct Extrusion Process Sequence

- Eliminates heat/shear history (less MW loss)
- Saves conversion cost associated w/ pelletization
- Feeds high percentage of reclaim
Pressure profile in a TSE

- Pressurize die or gear pump inlet
- Add filler downstream after melting
- Feed PLA, & additives
Test #2
Direct extrusion of PLA/filler > sheet

- NatureWorks™ PLA 2003D with 15 & 25% CaC03 (Specialty Minerals EM Force™)
- 2 Loss-in-weight metering feeders
- ZSE-27 MAXX, 1.66/1 OD/ID @40/1 L/D
- Side stuffer @barrel position #5; vent in #4 (atm.); #7 (atm.) and #9 (vacuum)
- Gear pump and 250 mm wide flex-lip die
- 3-roll stack with puller and winder
Summary

• Process developed @ 140 rpm
• Zones: 170-190 deg. C
• 20 kgs/hr @ 60% motor load
• GP inlet pressure approx. 20 bar
• Melt temperature 185 deg. C
• Die gap @ 1 mm for ½ mm thick sheet

• Result: dispersed product w/ good dimensional stability, seems like candidate for scale-up tests

• Mechanicals: increased impact properties 10 -20 times compared to neat PLA (normalized Gardiner Impact MFE, 0.06 to 0.6 -1.14)
Impact Test Comparisons

![Impact Test Comparisons Graph](image)
Test #3
Undried PLA test/run conditions

- 1500 PPM moisture for PLA pellets and 2000 to 5000 PPM for sheet edge reclaim (50% pellets, 50% reclaim)
- Process developed @ 250 rpm on ZSE-50 MAXX & 200 kgs/hr @ 70% motor load
- Screw design for early atmospheric vent, 2 vacuum vents and minimal shear, Zones: 180-190 deg. C
- GP inlet pressure: approx. 25 bar, Melt temp. 180 deg. C
- 760 mm wide flex-lip sheet die and downstream roll stack
- Result: MW loss in 5 to 10% range
- Scale-up: volumetric scale to 4000 kgs/hr. on ZSE-140...2000+ kgs/hr more likely. Direct extrusion viable for this formulation.
Process Section for undried PLA

Devol efficiencies = RT @ vents, size melt pool, surface renewal, vacuum level
Vacuum pump schematic
Molecular Weight – dried vs. undried

- Dried PLA
- Undried PLA
Foam extrusion from TSE

PLA w/ additives
**Discharge element comparison**
Single Screw Pump/ Cooling Extruder
Davis-Standard tandem foam system
Some questions before jumping...

- Pelletization or direct extrusion?
- What are the critical boundary conditions?
- What's the method to heat/cool the barrels?
- What's the free volume?
- What's the torque rating?
- What's the TSE screw rpm and why?
- Twin screw extrusion systems don’t need to be redesigned, merely “tweaked” for success

New technologies are available for success