

TWIN SCREW EXTRUDER SYSTEM DESIGN & CASE STUDIES FOR PLA, PHA & TPS

Leistritz Extrusion **Bioplastics** Twin Screw Workshop, May 16, 2023

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Leistritz Extrusion: www.leistriz-extrusion.com



Introduction

- Screw Elements
 - Types
 - Nomenclature
- Element Functionalities
- Design Considerations
- Feeders
- Case Studies



Screw element types



1. Conveying

Flighted, Used for: Feeding, Pumping



2. Mixing

Great Variety of Geometries, Dispersive and Distributive Mixing



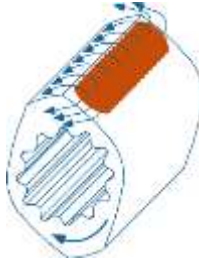
3. Zoning

*Restrictive Mixers and Flighted Elements;
Separates unit operations*

Common terminology

- **Pitch** (geometrical quantity) influences the chamber volume and residence time.
- **Chamber volume** describes the available volume in the screw flight.
- **Self-cleaning** becomes possible by the “Erdmenger profile” of the screws and is ideal for conveying elements.
- **Residence time** is the time it takes material to first exit the TSE.
- **Residence time distribution** is the total time it takes for all particles of material to exit the TSE.
- **Conveying effect** describes the element’s ability to push the material forward. The more flights there are, the smaller the pitches are. And the smaller the pitch is, the stronger the conveying effect.

Element mixing comparison

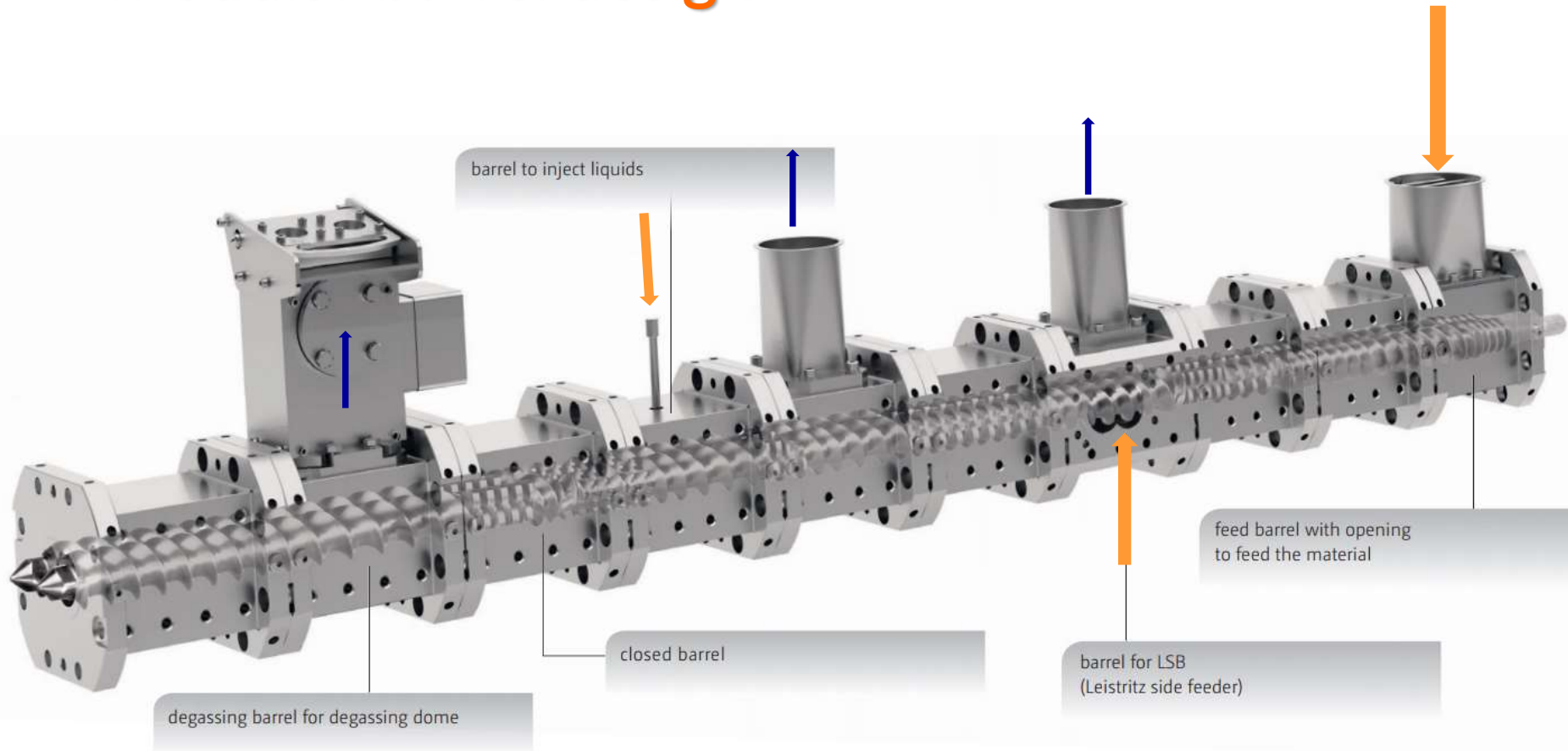
Distributive		Dispersive	
	<u>Narrow Disc:</u> Melt divisions and distributive mixing		<u>Wide Disc:</u> Increased elongational acceleration and dispersive mixing
	<u>GFM:</u> Sharp geometry minimizes energy to make divisions, material can leak back around interruptions in the flight		<u>KB 90°:</u> Very high dispersion, very high residence time
Combination			
	<u>KB 30°:</u> More distribution, some dispersion low residence time		<u>KB 60°:</u> More dispersion, some distribution higher residence time

Design Considerations

- Main Feed
- Melting
- Side Feed
- Injecting
- Mixing
- Venting
- Pumping

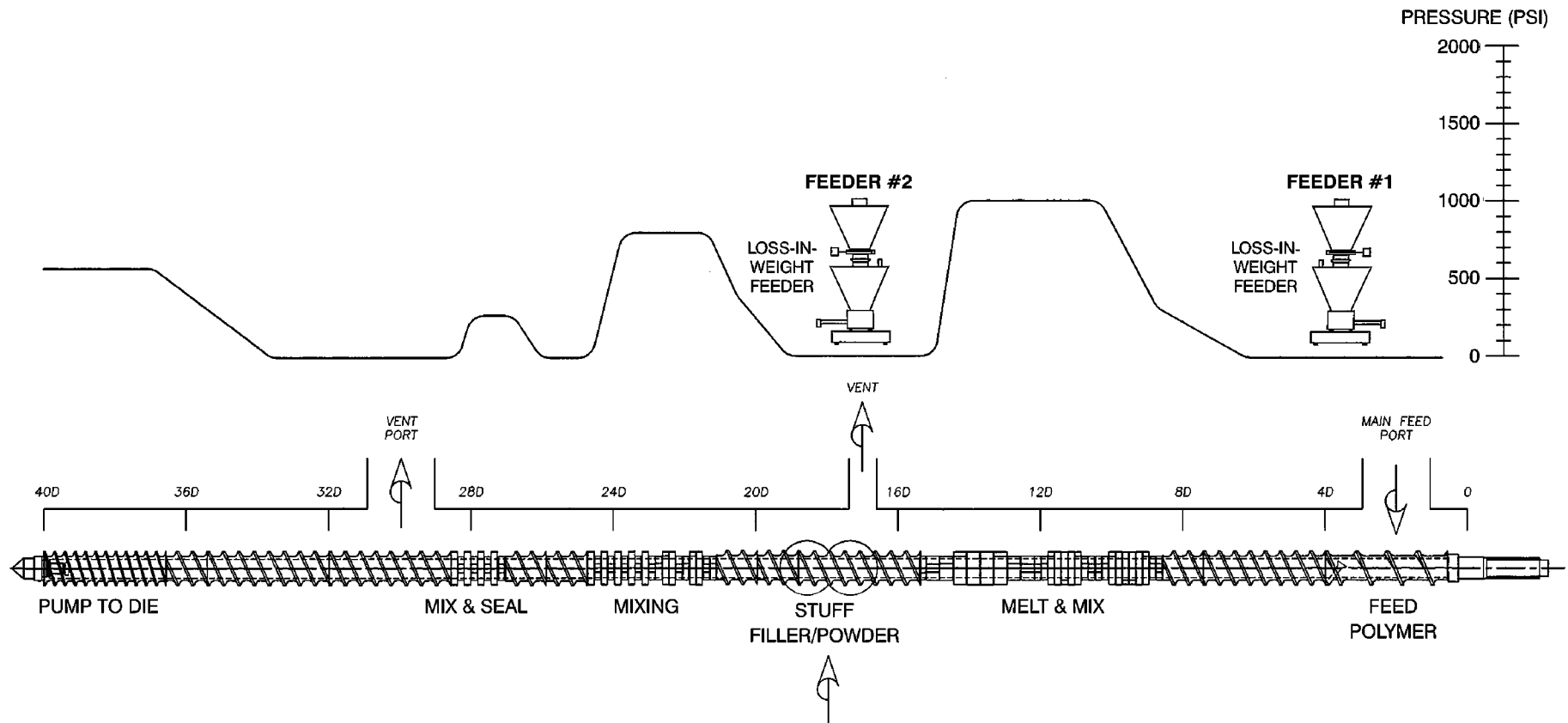


Modular barrel design



- More unit operations or residence time needed = Longer machine

Example controlled pressure gradient in TSE



Summary Questions to consider before designing a screw

- What is the objective?
 - HME, ASD, wet or melt granulation, transdermal, profile, co-extrusion, etc.
- What is being processed?
 - Solids: powder, pellet, flake? Premix or split feed? Bulk Density? Flowability? MFI?
 - Liquid: miscibility? how viscous?
 - What are the percentages of each?
 - Will you be able to feed everything in the Main Feed, or will it need to be separated?
 - If separate: All in one side stuffer/inj.? Or several?
- What is the *melting* point of the material?
 - What does and does not melt in the formulation?
 - If it does not melt, does it solubilize? If yes, how quickly/at what temperature?
- Will there be degradation (thermal or any other pathways) or shear sensitivity issues with any of the materials?
- Does surface moisture or humidity have an impact on the process?
 - Will vacuum be needed to remove volatiles or will an atmospheric vent be ok?
 - Do any of the materials need to be dried prior to processing?
- Will particles need to be dispersed? Or distributed?
- Downstream objectives?
 - Strands, sheet/film, profiles, fibers, etc.

Feeding systems

Solid and Liquid Feeders



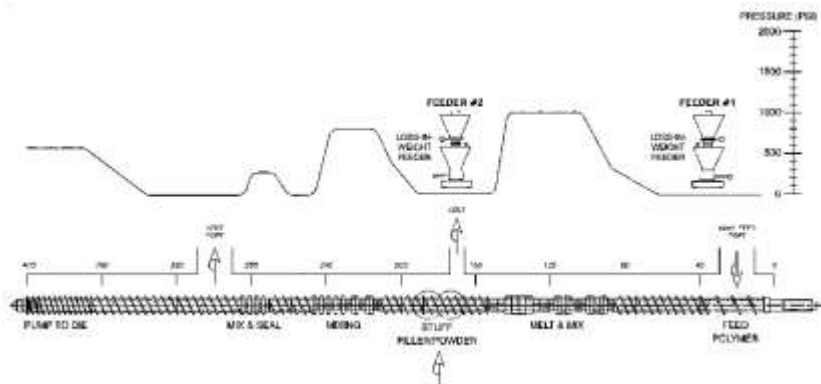
Twin screw extruders are Typically starve-fed, not flood fed

Single screw extruders:

- SSE are flood fed, hopper sits over screw, rpm determines rate
- SSE are high pressure machines used mainly for pumping

Twin screw extruders:

- Feeders set rate for a TSE, the screw rpm is independent
- TSE screw rpm up to 1200 is used to optimize compounding efficiencies
- Pressure gradient is controlled in TSE, and 0 psi for much of the process
- The 0 pressure regions in TSE facilitates sequential process operations



What influences feeder selection?

Solid material feeders

- Volumetric or gravimetric
- Output rate
- Closed or open construction
- Material conservation (friction)
- Cleaning
- Flow characteristics
 - - bridging
 - - sticky
 - - flooding
 - - hard or easy flowing
 - - particle size distribution
- Accuracy
- Price

Liquid material feeders

- Volumetric or gravimetric
- Output rate
- Closed or open construction
- Cleaning
- Viscosity
- Pressure at area of injection
- Accuracy
- Price

Feeders set rate

Ex: 75% polymer + 20% filler + 5% plasticizer = % mixing in 1st



Volumetric vs. gravimetric

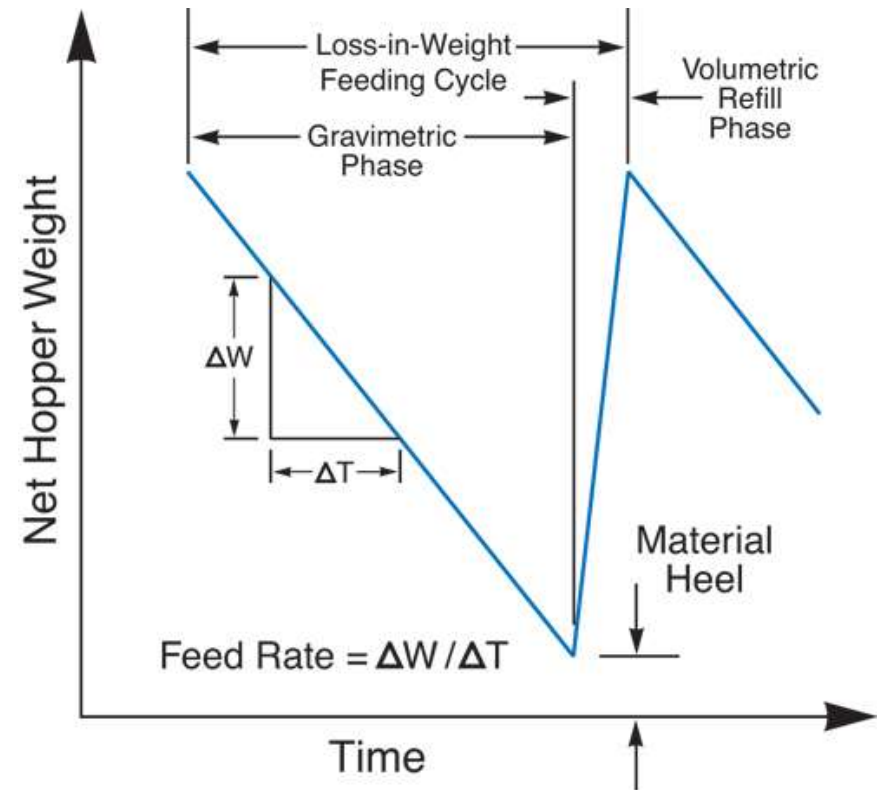
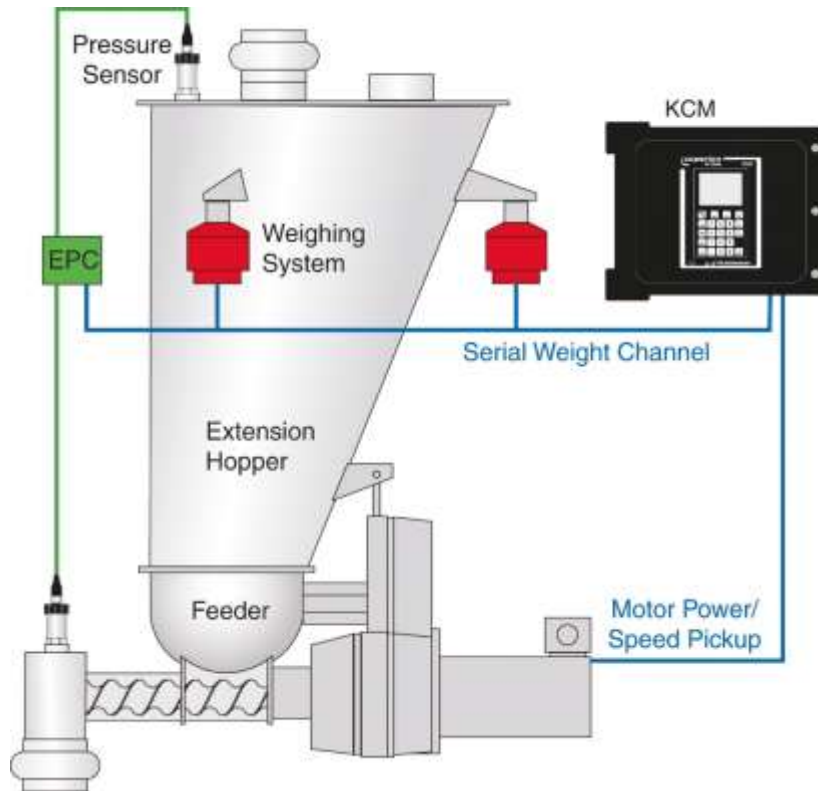
Volumetric Feeders:

- Do not control mass flow
- Operate by delivering a certain volume of material per time
- Assumes linear volumetric displacement versus feed

Gravimetric (Loss in Weight) Feeders:

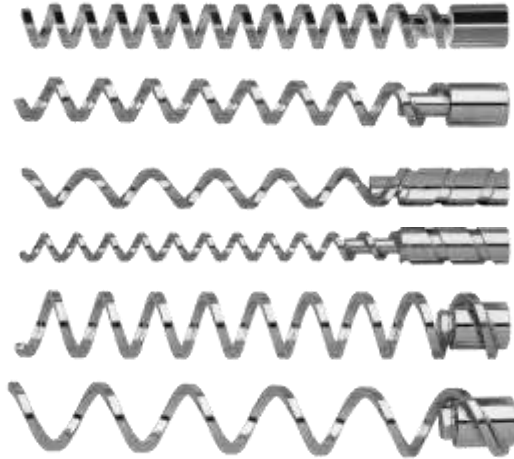
- Controls mass flow
- Adjusts feeder speed to achieve and maintain the desired setpoint
- Ideal for continuous operations

Loss-in-weight (LIW) feeder

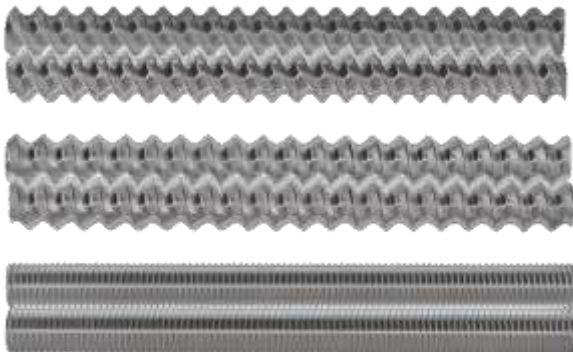


Material characteristics: Screw Selection

- Spiral Screws: Powders and granules with normal flow characteristics



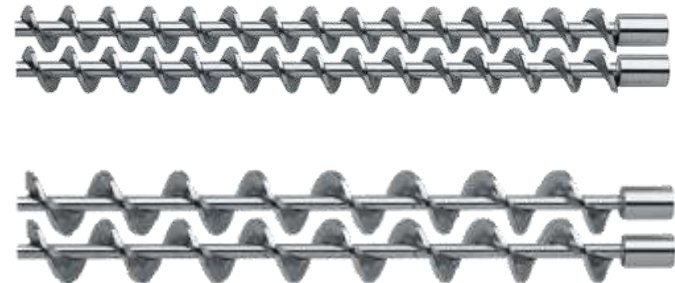
- Twin Concave Screws: Extremely floodable or poorly flowing powders



- Blade Screws: Slightly floodable powders

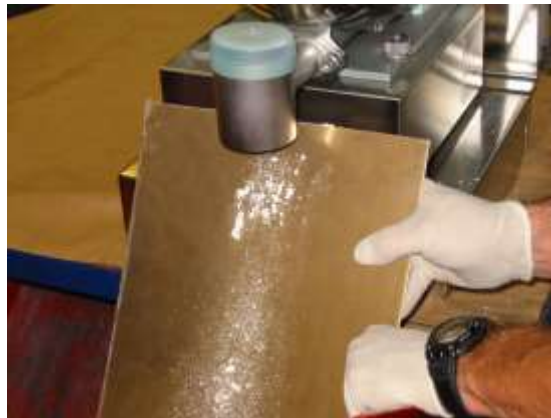


- Twin Blade Screws: for ingredients with normal to slightly floodable characteristics, also for granules and poorly flowing ingredients



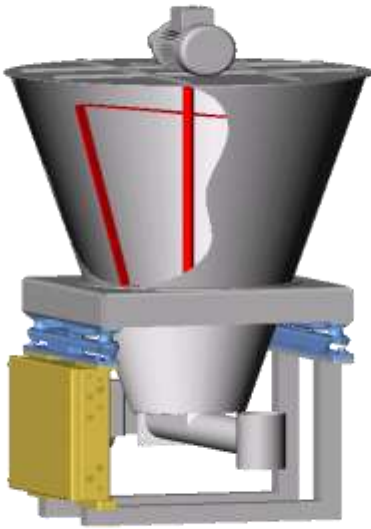
Hopper flow aids

- Agitators
- Flexible Liners
- Bin vibrators
- Air Injectors
- Coatings



Hopper Agitation

- Agitators – Internal
 - Eliminates bridging & rat holing
 - Promotes flow
 - Possible segregation

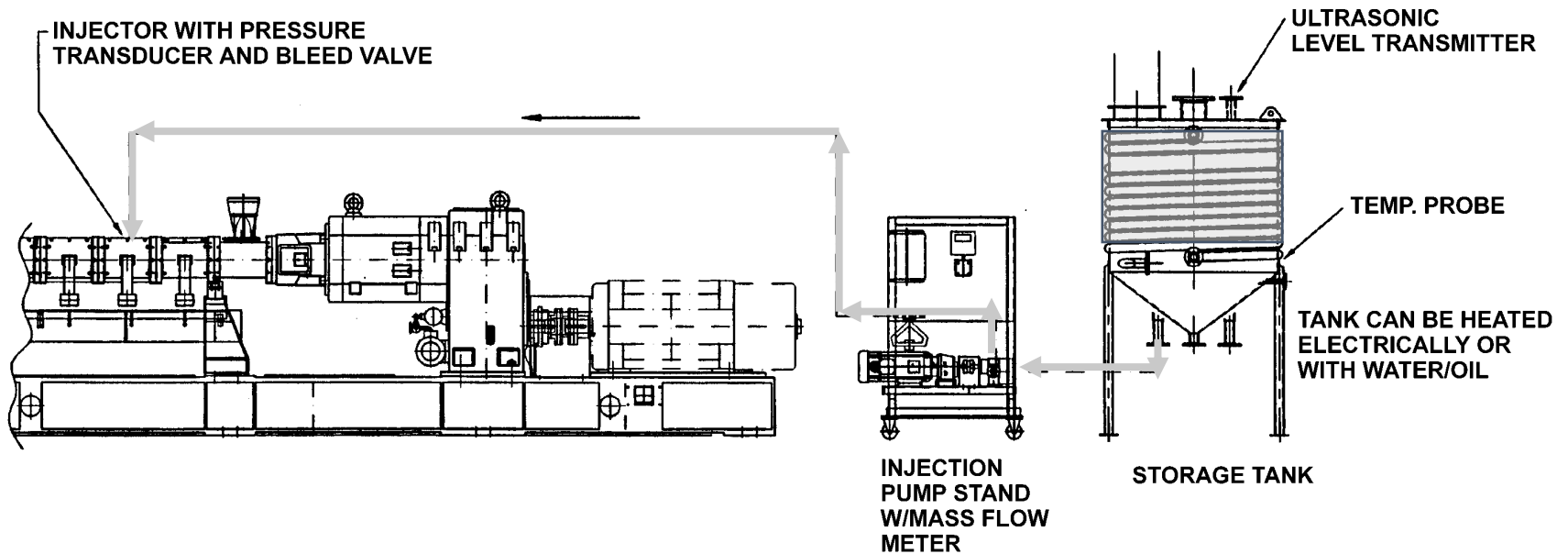


Hopper Agitation

- Agitators – External
 - No product contact
 - Minimal segregation
 - Chemical compatibility?



Typical liquid feedstream



Liquid systems

Most common types of liquid pumps:

- Piston pump
 - Low viscosity: 1 – 2000 cps
 - Low to high pressure region: 0 – 3,000 psi
 - Can be partially heated
- Diaphragm pump
 - Low viscosity: 1 – 2000 cps
 - Low to high pressure region: 0 – 3,000 psi
 - Can be partially heated
- Gear Pump
 - Low to medium viscosity: 1 – 20,000 cps
 - Low pressure region: 0 – 100 psi
 - Can be heated
- Peristaltic Pump
 - Low to medium viscosity: 1 – 20,000 cps
 - Low pressure region: 0 – 100 psi
 - Cannot be heated
- Screw or Drum Pumps
 - Medium to high Viscosity: 20,000 – 500,000 cps
 - Low to high pressure region: 0 – 3,000 psi
 - Can be partially heated
- Liquid can/should be heated to decrease viscosity depending on type of pump being used.
- A heated hose at the outlet of a pump can help with processing.
- Pump size will depend on the rate required.

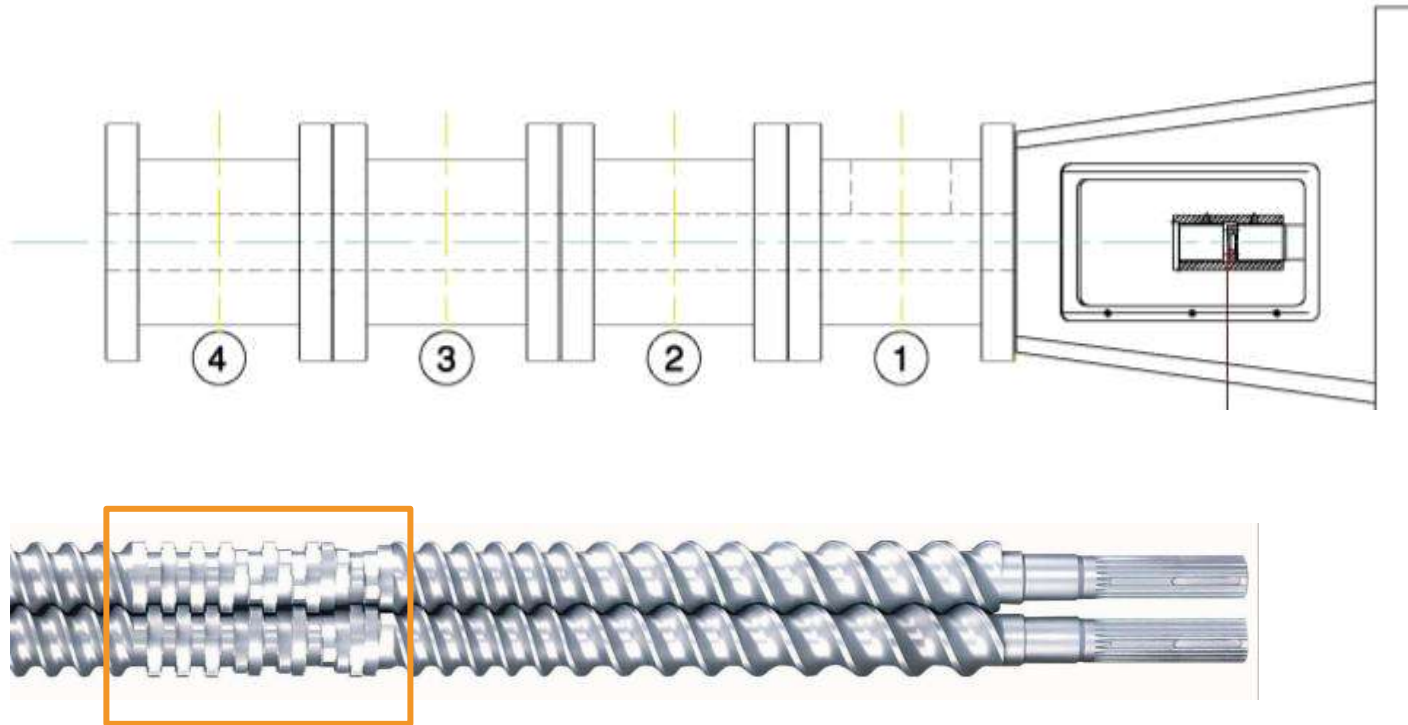


Liquid systems - Injection nozzle

Flow rate	1 cP (water)	34.6 cP (vegetable oil)	88 cP (SAE 10 oil)	820 cP (Glycerine)	1561 cP (SAE 50 oil)	17,640 cP (SAE 70 oil)
0-5 g/min	0.006"	0.008"	0.010"	0.012"	0.014"	0.016"
5-15 g/min	0.016"	0.018"	0.020"	0.022"	0.024"	0.026"
0.2-3 Kg/hr	0.020"	0.022"	0.024"	0.026"	0.028"	0.030"
3-10 Kg/hr	0.036"	0.038"	0.040"	0.042"	0.044"	0.046"
10-40 Kg/hr	0.062"	0.064"	0.068"	0.071"	0.075"	0.078"
40-100 Kg/hr	0.120"	0.125"	0.130"	0.136"	0.140"	0.160"
100-200 Kg/hr	0.160"	0.168"	0.178"	0.190"	0.220"	0.250"
200-300 Kg/hr	0.188"	0.210"	0.240"	0.280"	0.310"	0.340"
300-400 Kg/hr	0.225"	0.280"	0.375"	0.440"	0.500"	0.625"

Melting zone impacts melt temperature

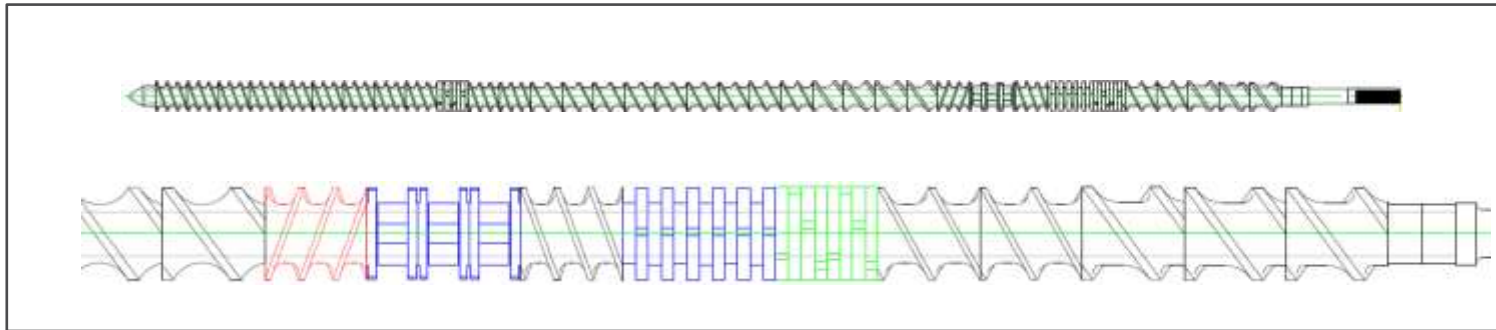
Tests comparing different melt zones for <1 MFI & 10 MFI PP



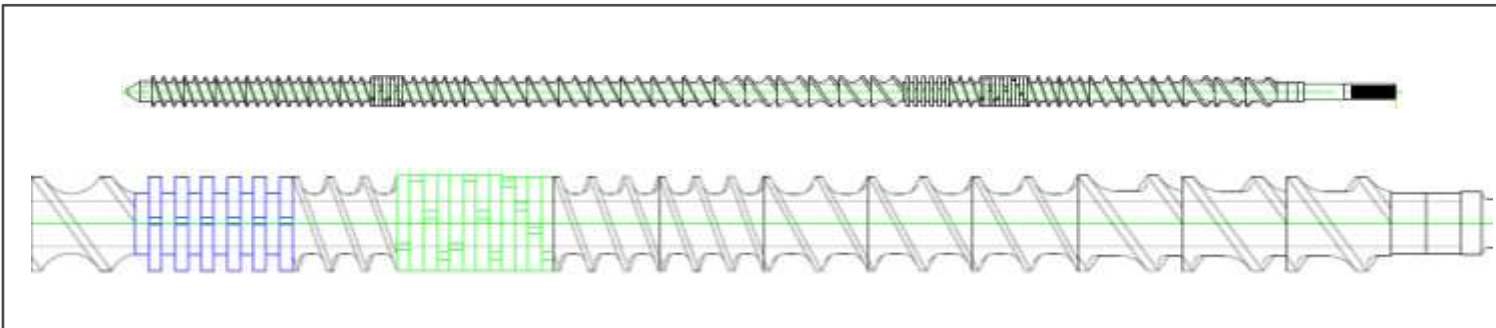
Melt temperature study

ZSE-27 MAXX melt zone designs + 1 mixing element

- Aggressive melting zone



- Extended (Mild) melting zone



Melt temperature study

Comparison of different melt zones

Machinery setup:

- ZSE 27 MAXX @ 40:1 L/D
- 28.3 mm diameter screws
- 1.66 OD/ID ratio
- Discharge adapter

Processing conditions:

- 400, 600, 1000 rpm
- Max rate at 85% torque
- <1 MFI PP & 10 MFI PP
- Open discharge to keep pressure to a minimum

Melt temp. measured by flush temperature & immersion probes*

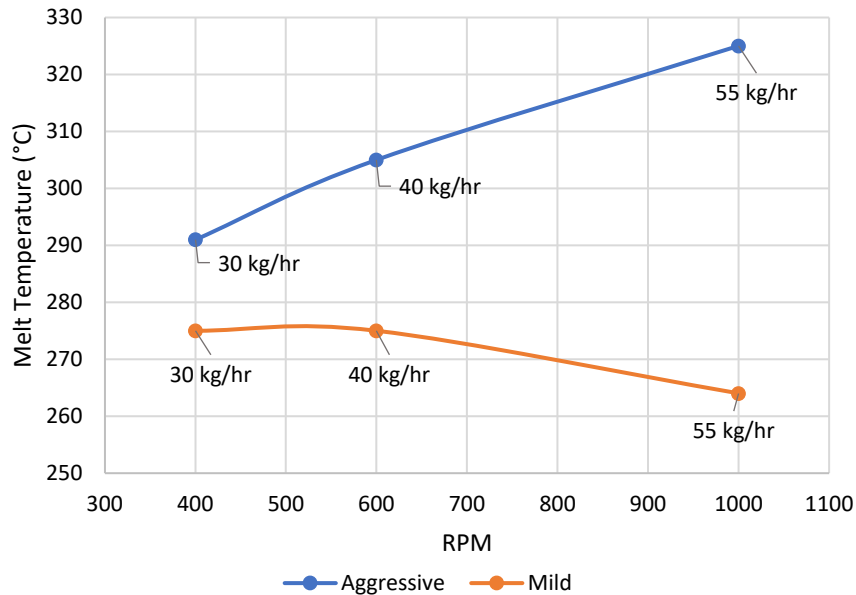
Temperature Setpoints (°C)										
ZONE 10	ZONE 9	ZONE 8	ZONE 7	ZONE 6	ZONE 5	ZONE 4	ZONE 3	ZONE 2	ZONE 1	ZONE 0
Swing Gate	Solid	Vent (atm.)	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Main Feed
233	233	233	233	244	244	255	266	266	255	COLD
160	160	160	160	160	170	170	180	180	180	COLD

* All data shown, unless otherwise noted, is measured with the immersion probe

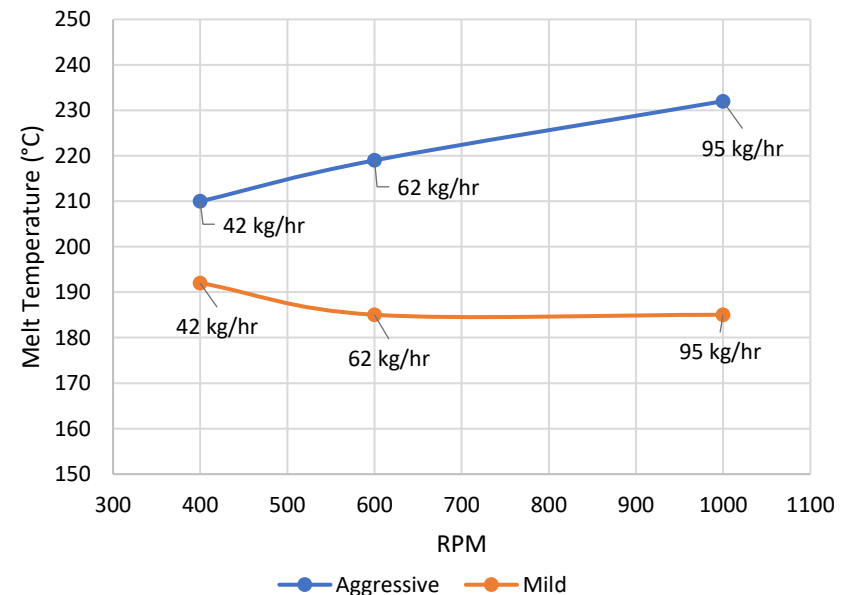
Melt temperature study

Higher melt temperature with aggressive design (reverse elements and wide disk/neutral KB's)

Melt Temperature at Same Rates, <1 MFI



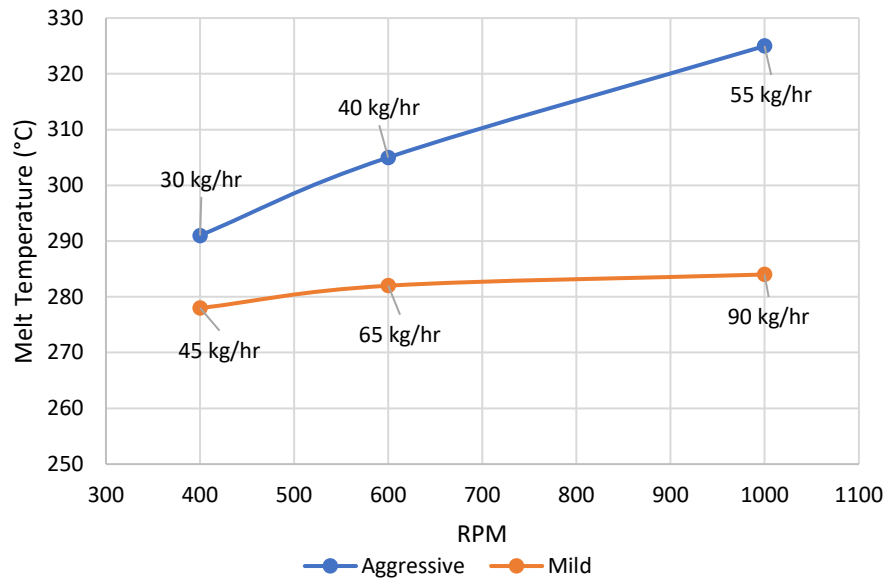
Melt Temperature at Same Rates, 10 MFI



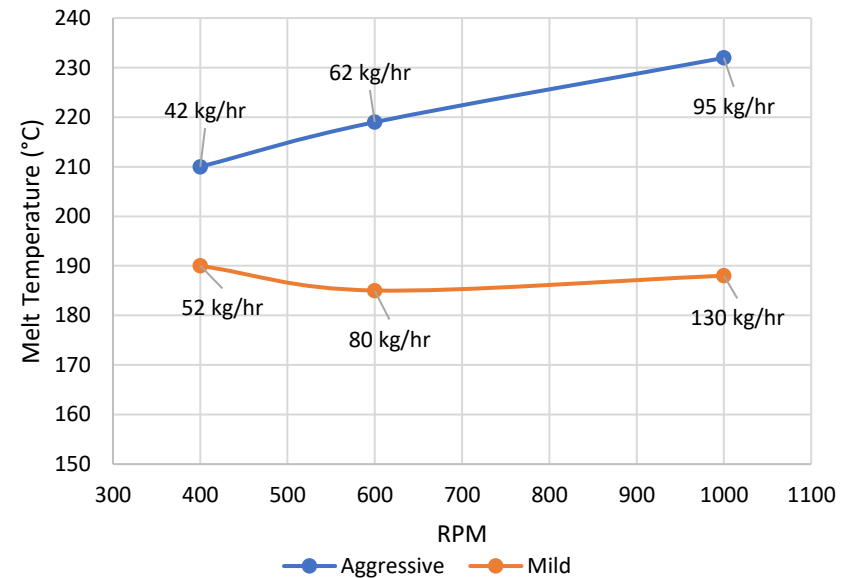
Melt temperature study

Aggressive screw = higher melt temps & less rate

Melt Temperature at Maximum Rates, <1 MFI

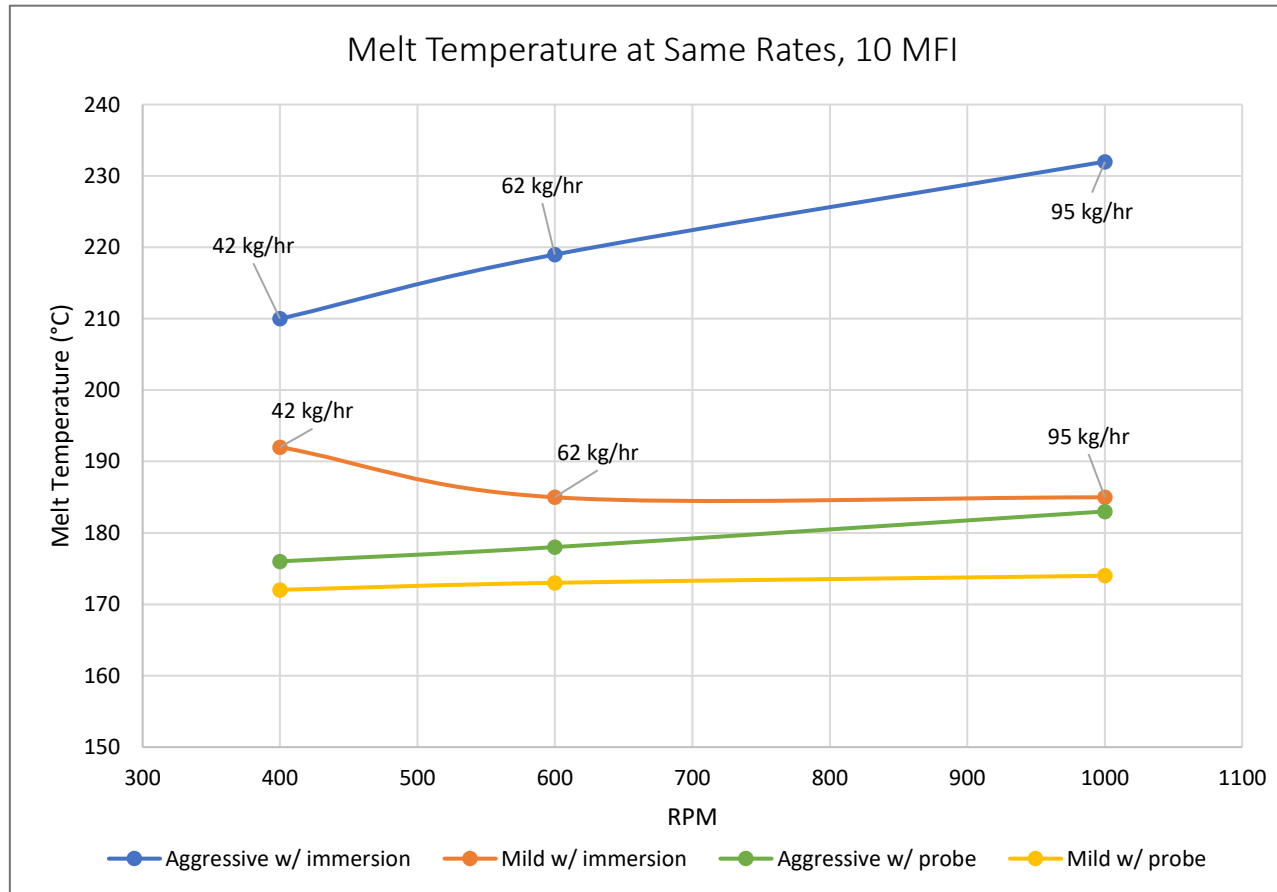


Melt Temperature at Maximum Rates, <1 MFI



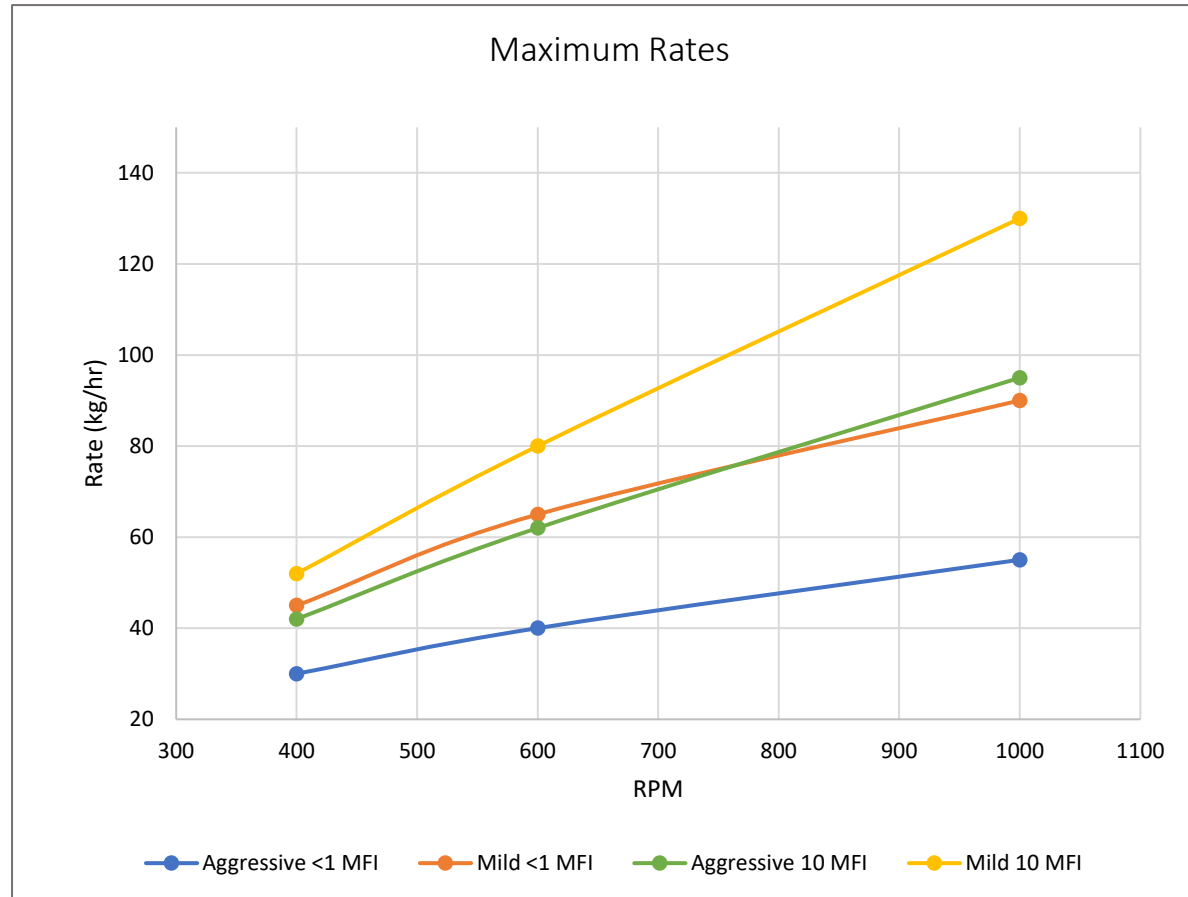
Melt temperature study

Higher temperature values with immersion probe vs. flush probe for all conditions



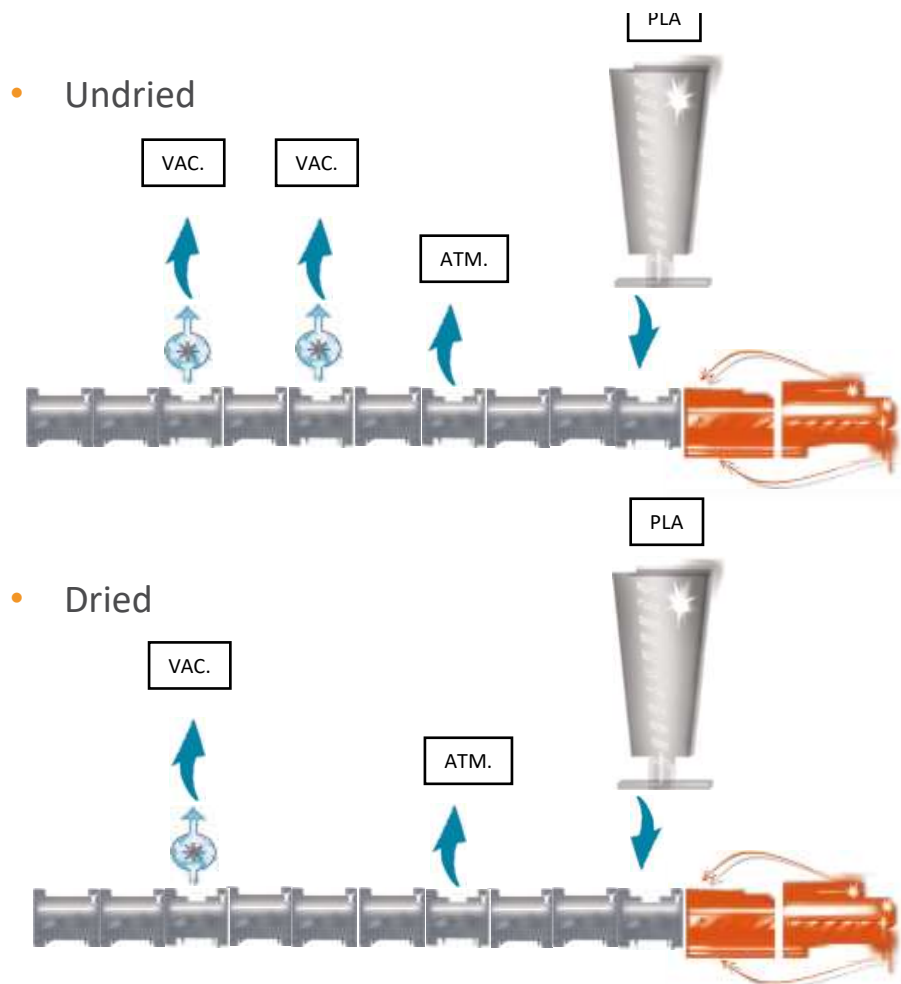
Melt temperature study

Aggressive screw = higher melt temps & less rate
Lower viscosity allowed for higher maximum rates



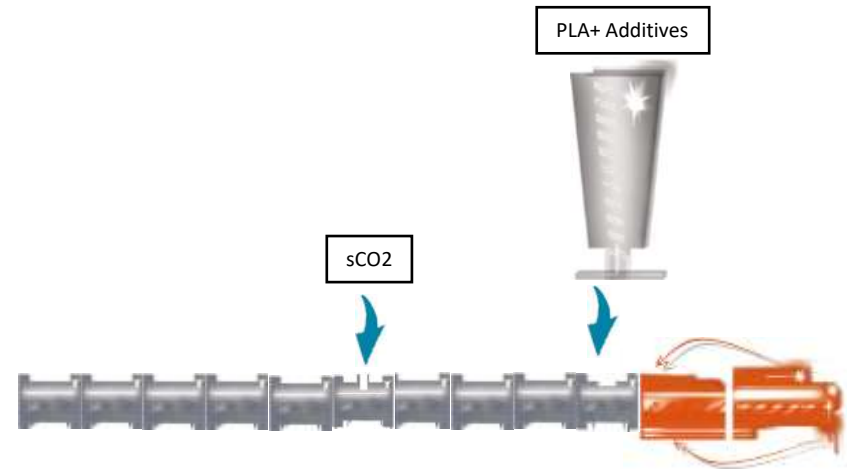
PLA Processing

- Drying Pros
 - Less risk of hydrolysis and property loss
 - More processing flexibility
 - Fewer steps
- Drying Cons
 - Another step pre-processing
 - Additional equipment & space
 - Drying Times
 - Additional energy consumption

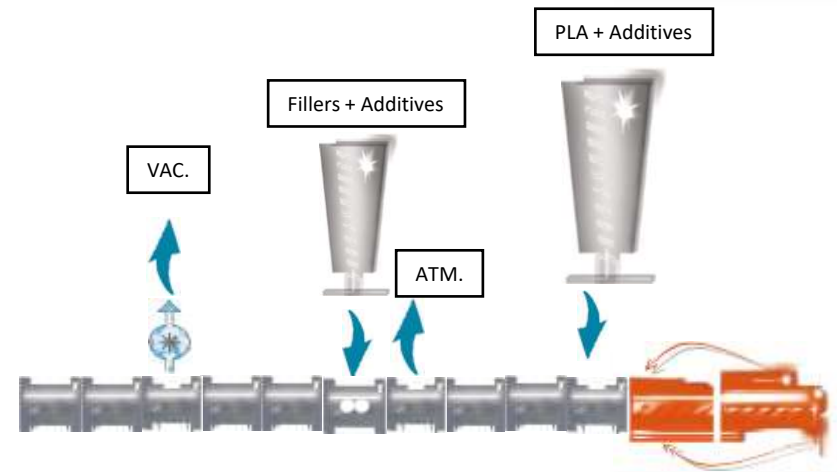


PLA Processing

- Foam
 - Dried
 - Strong Melt Seal before sCO₂ injection
 - Chain Extender
 - Reverse Temperature Profile
 - Low RPM
 - Die design is important (minimal land length)



- Compounding
 - Dried or undried
 - Downstream vent location determined by presence of Gear Pump (Barrel 8 vs. 9)
 - Direct to sheet/film/profiles possible
 - Dual purpose early vent
 - Back or Forward vent may be needed to assist in feeding fillers at high levels



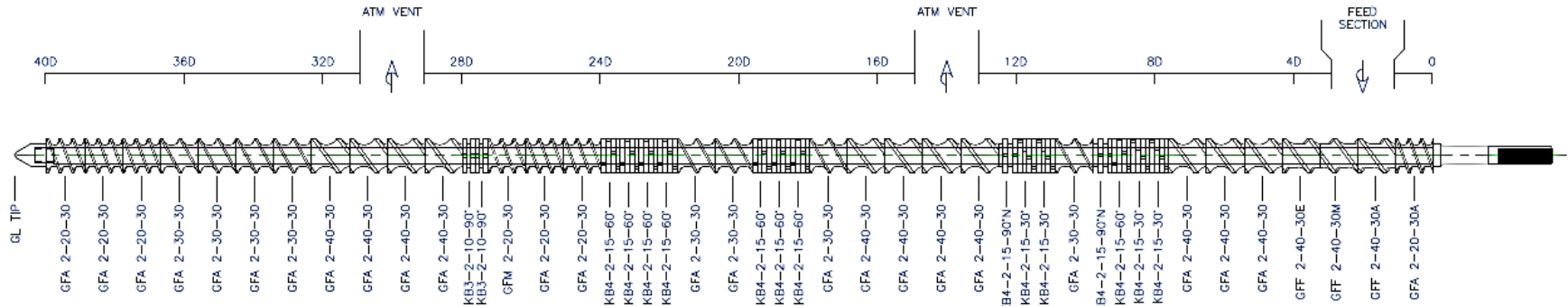
Melting efficiency for various pla resins

PLA NatureWorks 4032D

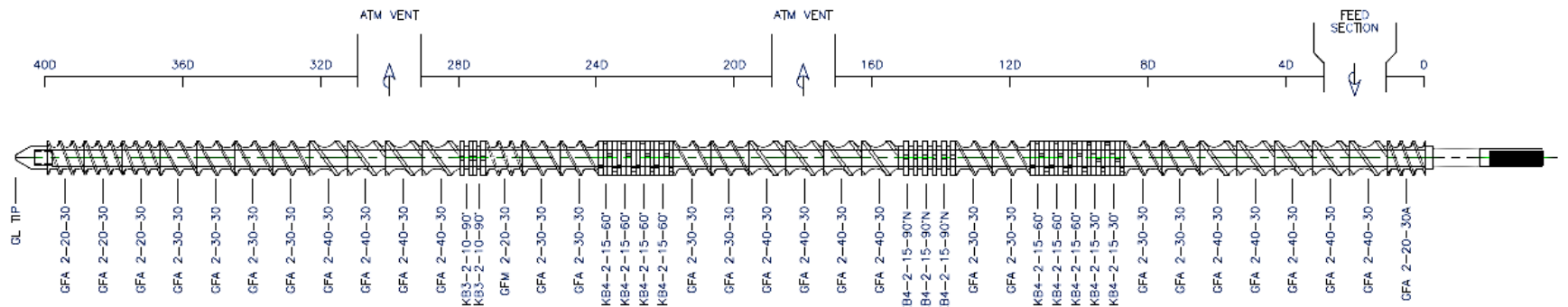
- Analyze PLA melting performance with and without lubricant
- Optimize set points and screw design to:
 - prevent crunching of pellets in melting region
 - Improve melting performance

Tests performed at 35 kgs/hr

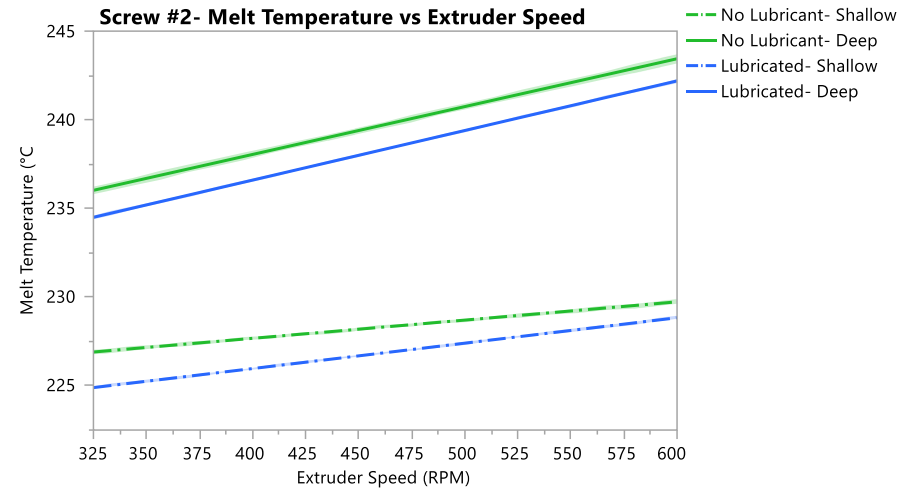
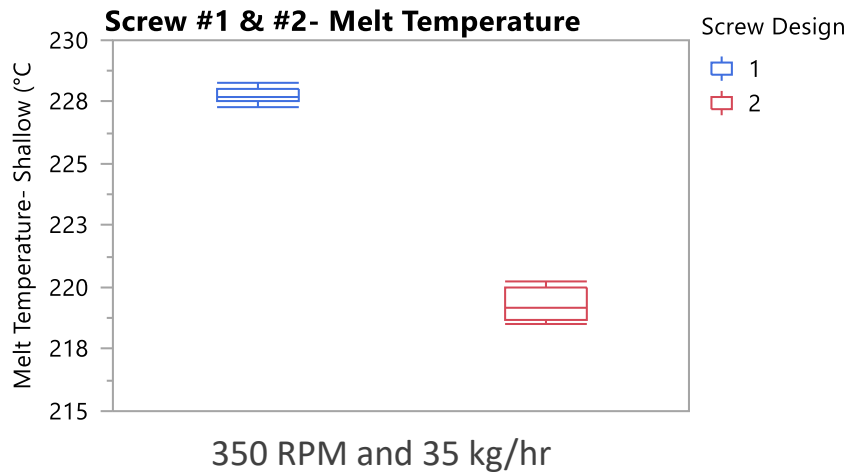
SCREW #1



SCREW #2



Melting efficiency for various pla resins

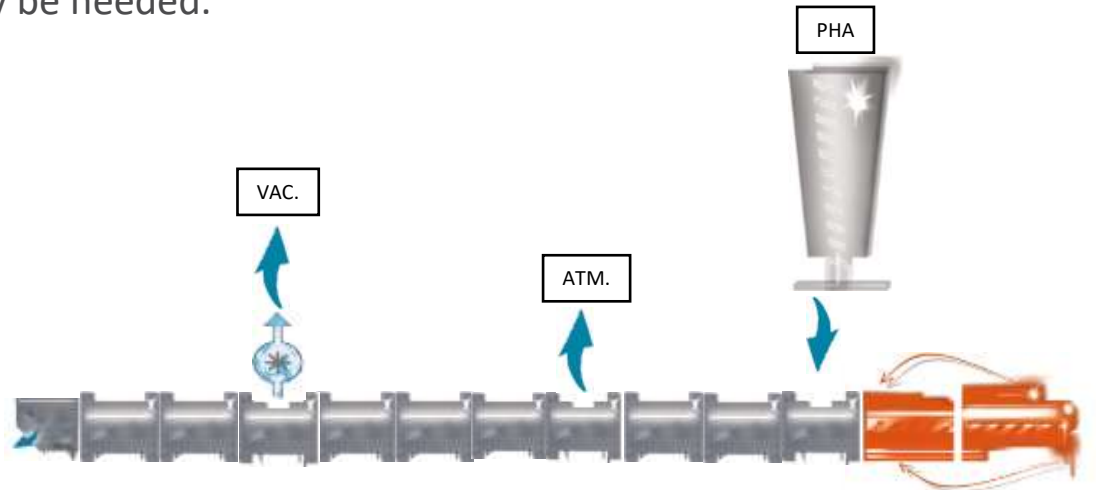


- Removed several kneading blocks
- Extended and modified melting zone
- Used a reverse profile by increasing barrel temperatures in melting zone to increase melting efficiency

	Zone 10	Zone 9	Zone 8	Zone 7	Zone 6	Zone 5	Zone 4	Zone 3	Zone 2	Zone 1
Screw 1	210	210	210	210	210	210	210	210	210	210
Screw 2	210	210	210	210	210	220	230	230	240	220

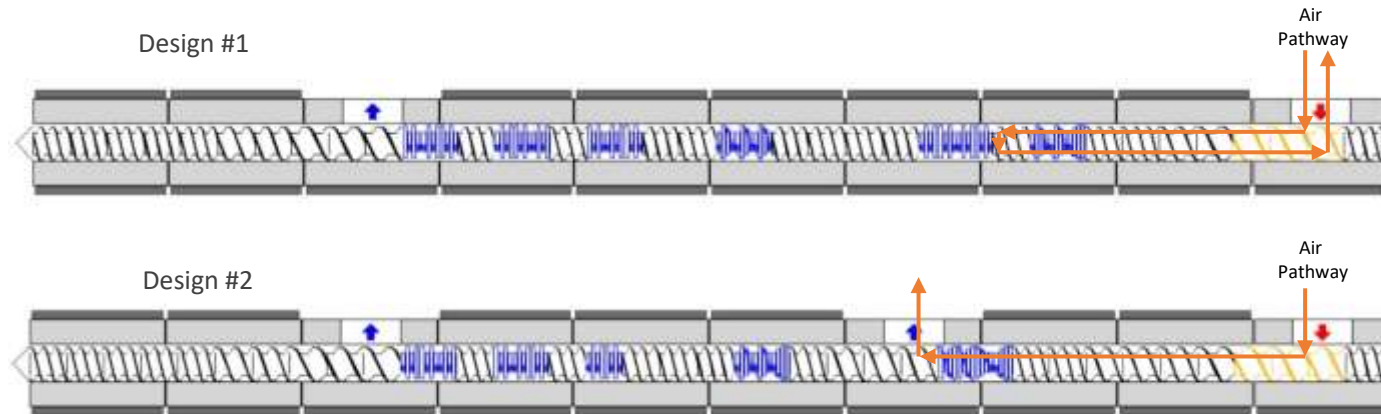
PHA Processing

- 40:1 L/D Process Design
- Early atm. vent to remove surface moisture and allow air to escape forward
- Temperature profile will depend on grade
- Low shear screw design
 - 90° Kneading Blocks are ok before the vacuum to create a seal
- Additional vacuum vent may be needed.



Feed zone comparison

Low bulk density powder PHA formulation



Achievable rate ZSE-27 MAXX:

- Design #1 = 12 kgs/hr @ 300 rpm = 1500 rev/kg*
- Design #2 = 62 kgs/hr @ 800 rpm = 776 rev/kg

*(back degassing caused melting in feed throat at higher rpms/rates)

Tips:

- Minimize drop distance to TSE feed throat
- Delay melt zone and include forward relief vent

PLA & PHA Processing Concerns

- Temperature setpoints
- Loss of molecular weight
 - Too much shear (related to screw design or rate vs. rpm)
 - Hydrolysis
 - Chain Extender
- Mechanical property reduction
- Efficiency of venting (atmospheric and vacuum)
- Pre-drying if possible

Starch

- Types
 - Corn
 - Potato
 - Cassava
 - Pea
 - Etc.
- End Uses
 - Packaging
 - Single Use
- Processes
 - Compounding
 - Thermoplastic Starch
 - Foam



Source: <https://www.naturalproductsinsider.com/ingredients/starch-stabilizer-solutions>

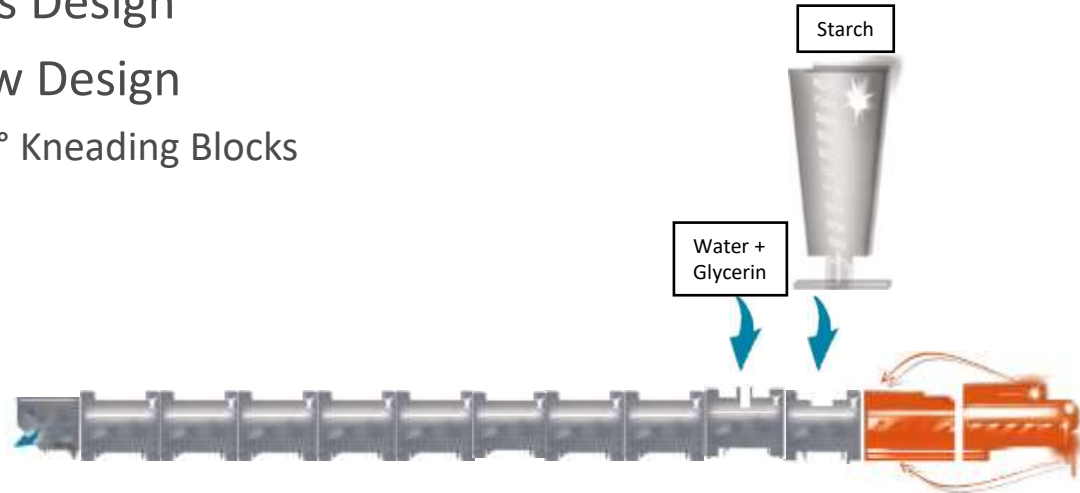
Foamed Starch

- Formulation
 - 90 - 93% Starch
 - 5 - 9% Water
 - 1 - 2% Glycerin



Foamed Starch

- 40:1 L/D Process Design
- Low Shear Screw Design
 - Only 30° and 60° Kneading Blocks



Temperature Profile °C										
Z#10	Z#9	Z#8	Z#7	Z#6	Z#5	Z#4	Z#3	Z#2	Z#1	Z#0
110	110	100	90	80	75	70	70	60	50	COLD

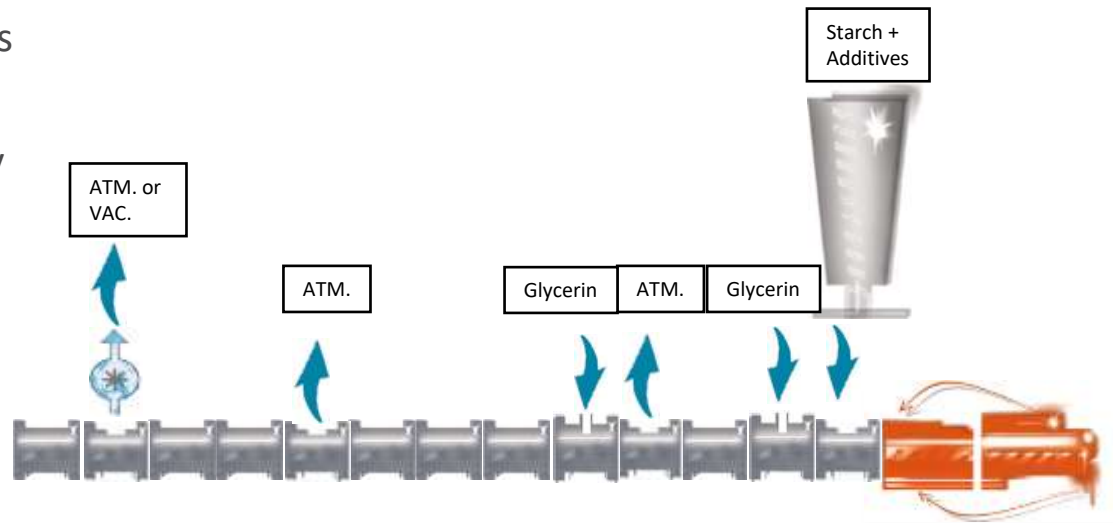
Thermoplastic Starch

- Formulation
 - 65 – 70 % Starch
 - 20 – 25 % Glycerin
 - 5 – 10 % Additives



Thermoplastic Starch

- 52:1 L/D Process Design
- Progressively stronger screw design
 - Zones 1 – 6, only 30° and 60° Kneading Blocks
 - Zones 7 – 11, 90° Kneading Blocks
- Removing moisture is critical
- Multiple injections may be necessary
- Pre-conditioning formulation and feeding as a slurry is possible



Temperature Profile °C

Z#13	Z#12	Z#11	Z#10	Z#9	Z#8	Z#7	Z#6	Z#5	Z#4	Z#3	Z#2	Z#1	Z#0
110	110	120	130	150	150	150	140	130	110	90	70	50	COLD

Starch Processing Concerns

- Careful startup and shutdown procedures
- Temperature setpoints too hot
- Water/glycerin pump blocks or loses rate
- Too much shear (high rpm or element choice)



THINK BIOPLASTICS!!!!

Contact Leistritz Extrusion today to receive the detailed case studies referenced in this presentation....

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Leistritz Extrusion: www.leistritz-extrusion.com

