Changeover in a Transfer Line: Numerical Modeling and Experimental Validation

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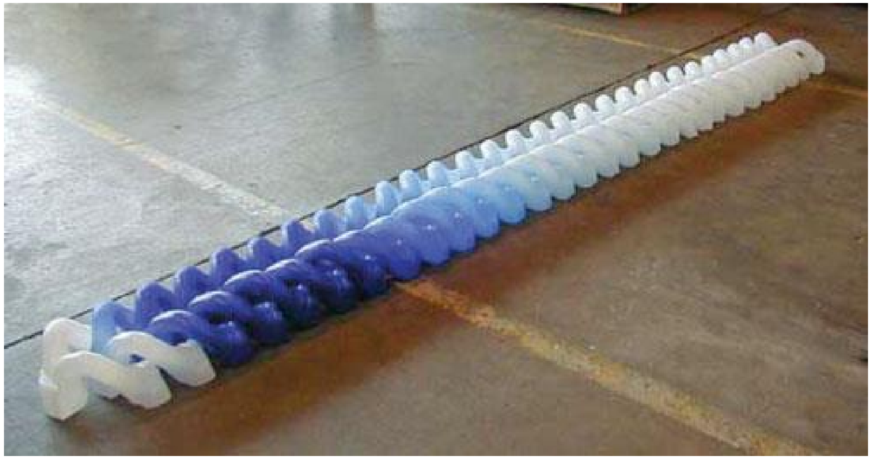
Resin Changeover

- In industry, a broad range of polyolefin products are often processed in the same equipment with multiple changeovers daily.
- Changing the resins in processing equipment: material waste and production down time.
- Run the products in an optimized sequence and streamline a flow path to reduce the changeover costs.

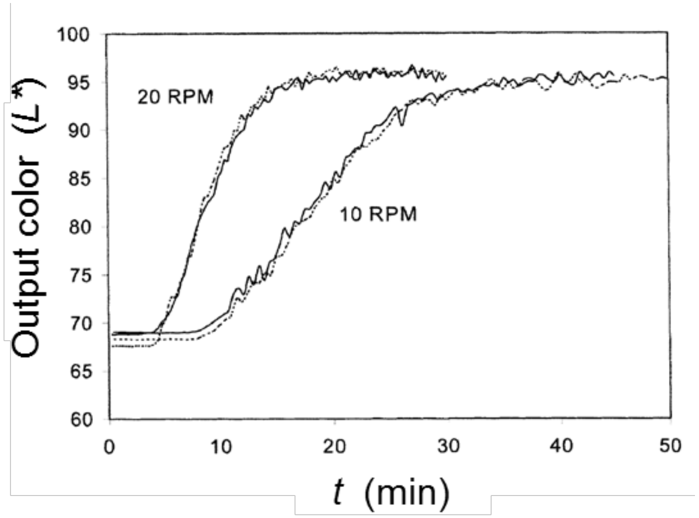
Plastics Machinery Magazine, Aug 2015



Plastics Technology, Sep 2010

Changeover Time in Transfer Line

- Changeover Time: Time to change from one steady state to another, transient
- Product changeover, purging etc.
- Much expertise and knowhow but not many academic studies and reports



"Purging a high viscosity resin with low viscosity resin takes more time"

But Why?

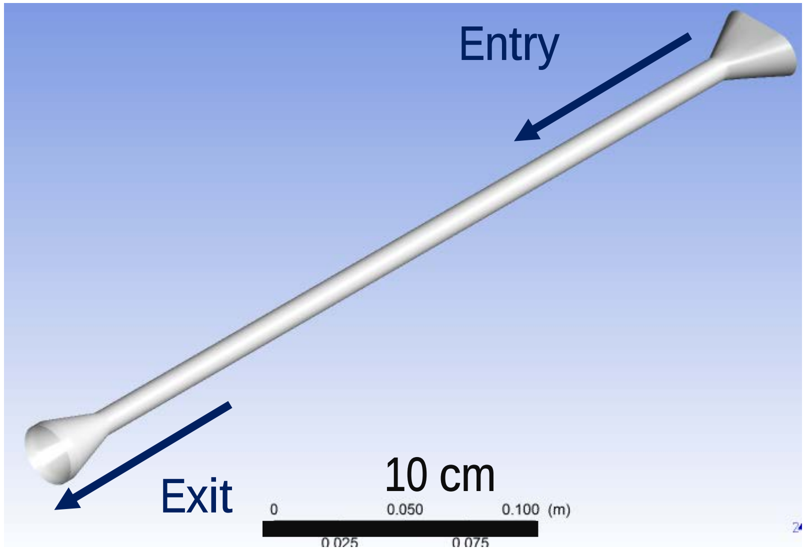
Gilmor et al., *Polym. Eng. Sci.*, 43(2): 356 (2003)

Objectives

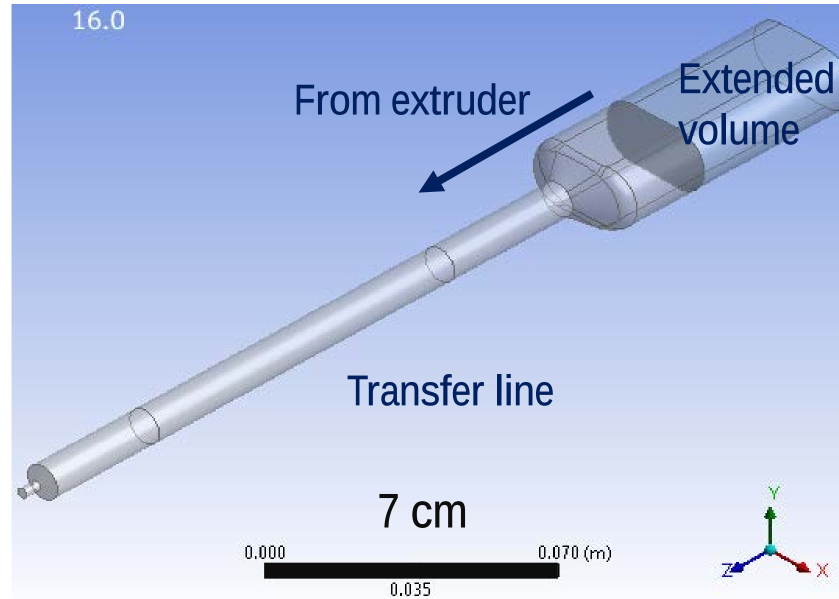
- Determine the fundamentals of polyolefin resin changeover from a transfer line via numerical modeling and experimental measurements
  - Influence of polyolefin resin properties and resin sequence.

Geometries and Computational Conditions

Transfer line Geometry A



Geometry B



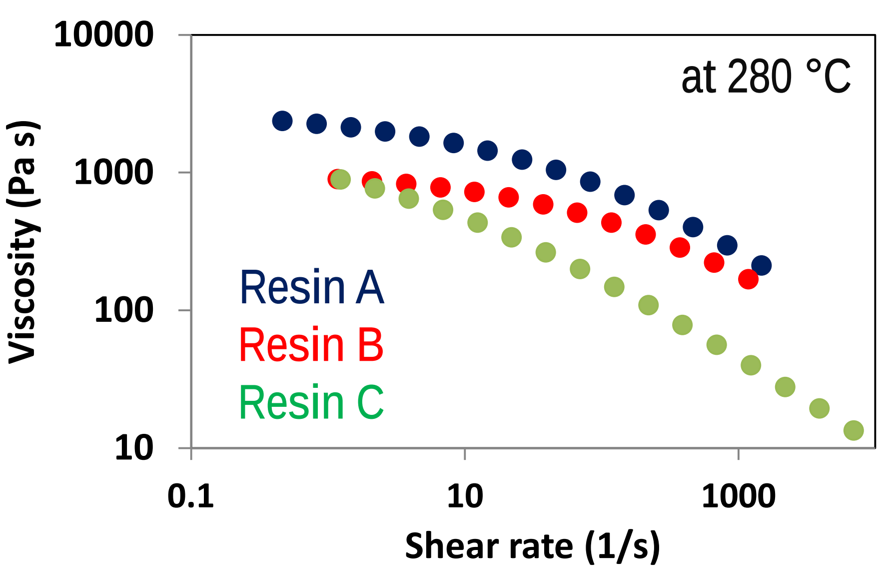
- Finite Element Models using ANSYS Fluent, isothermal transient flow model based on Volume-of-Fluid method.
- Inlet of geometries extended: a fully developed inlet flow and changeover time distribution from the extruder.
- 100,000 mesh elements on a quadrant of the geometry, plane of symmetry.
- Flow rate: 0.5 – 5 kg/h (max shear rate: 10 – 100 /s)

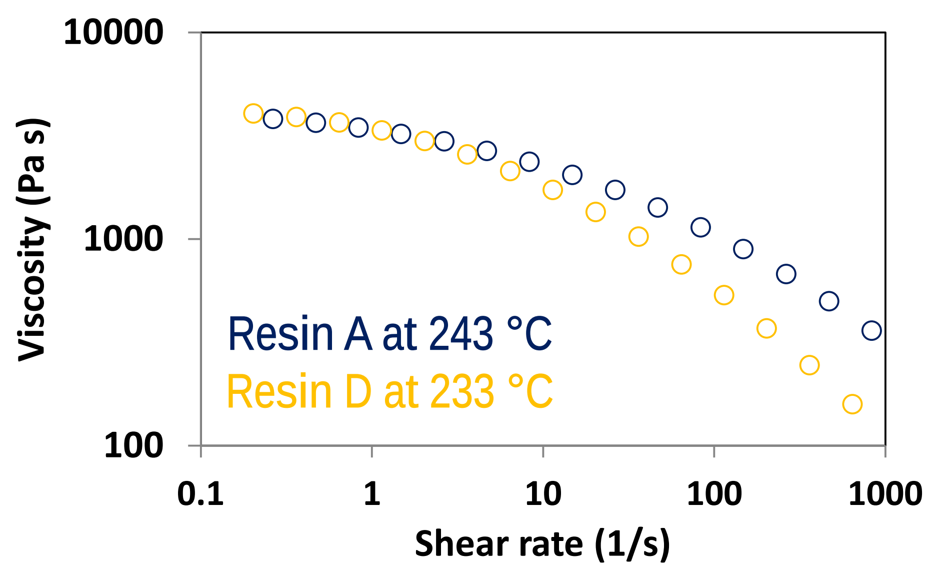
Materials and Rheology

- LLDPE, LDPE and PS
- Isothermal viscous rheology models: shear thinning based on Cross model

Material	Resin	I2	ρ (g/cm³)
Resin A	LLDPE	1.0	0.920
Resin B	LLDPE	2.3	0.917
Resin C	LDPE	1.9	0.919
Resin D	PS	1.5	1.04

Shear viscosity

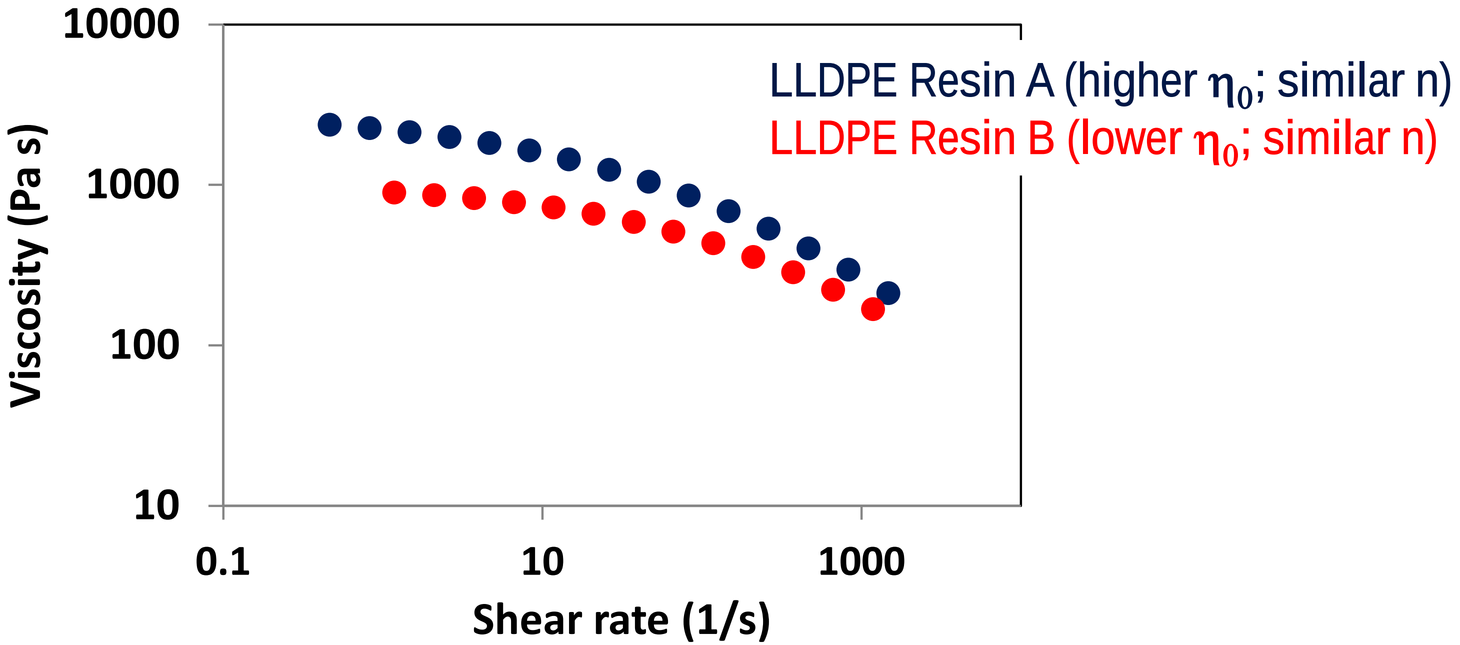




Transient flow modeling: Effect of viscosity

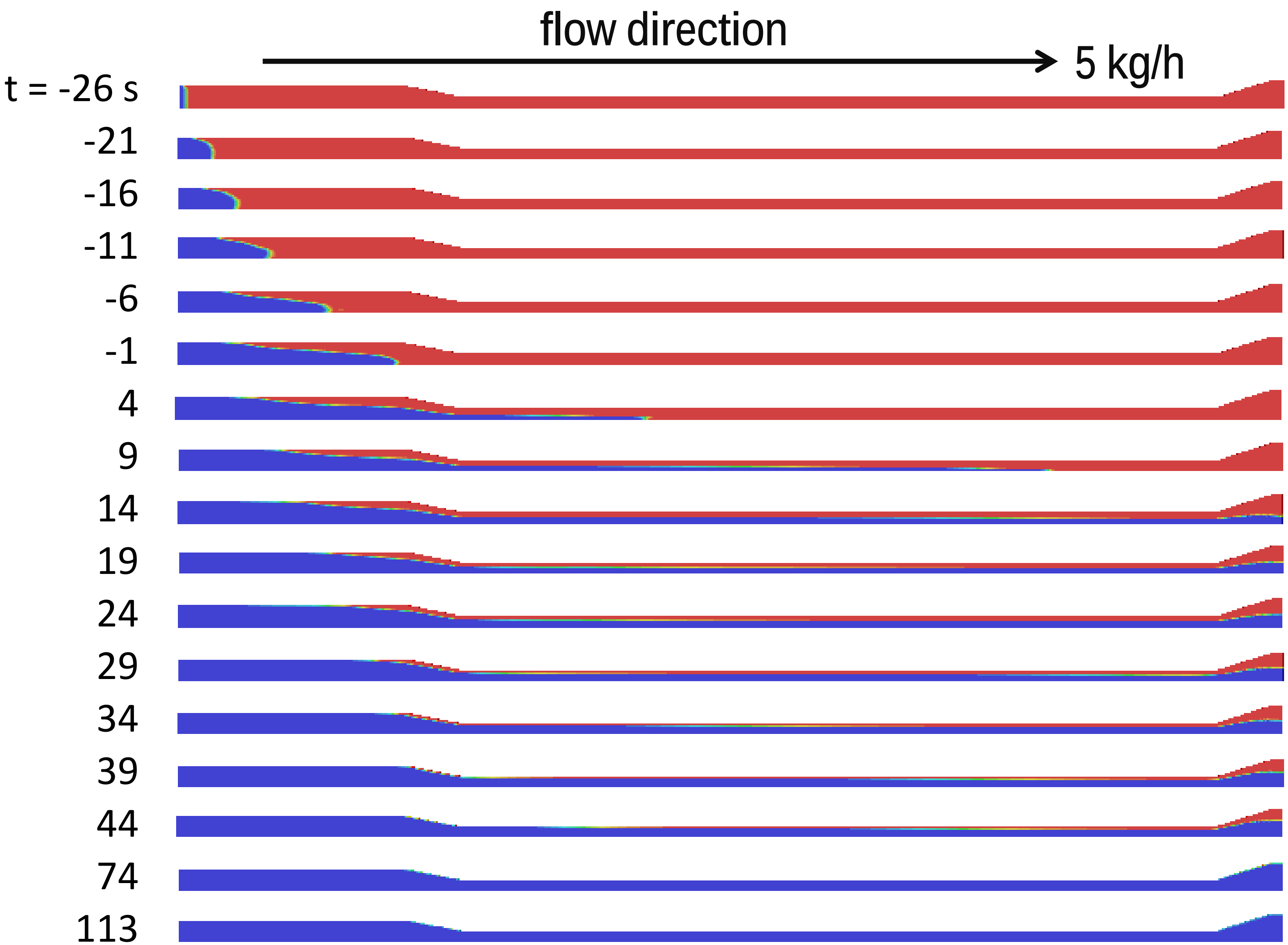
- Determine the changeover time between resins with different zero-shear viscosity (and no viscosity cross-over in shear rate range of interest).
  - Ex) LLDPE resins with two different melt indices

Shear viscosity at 280 °C



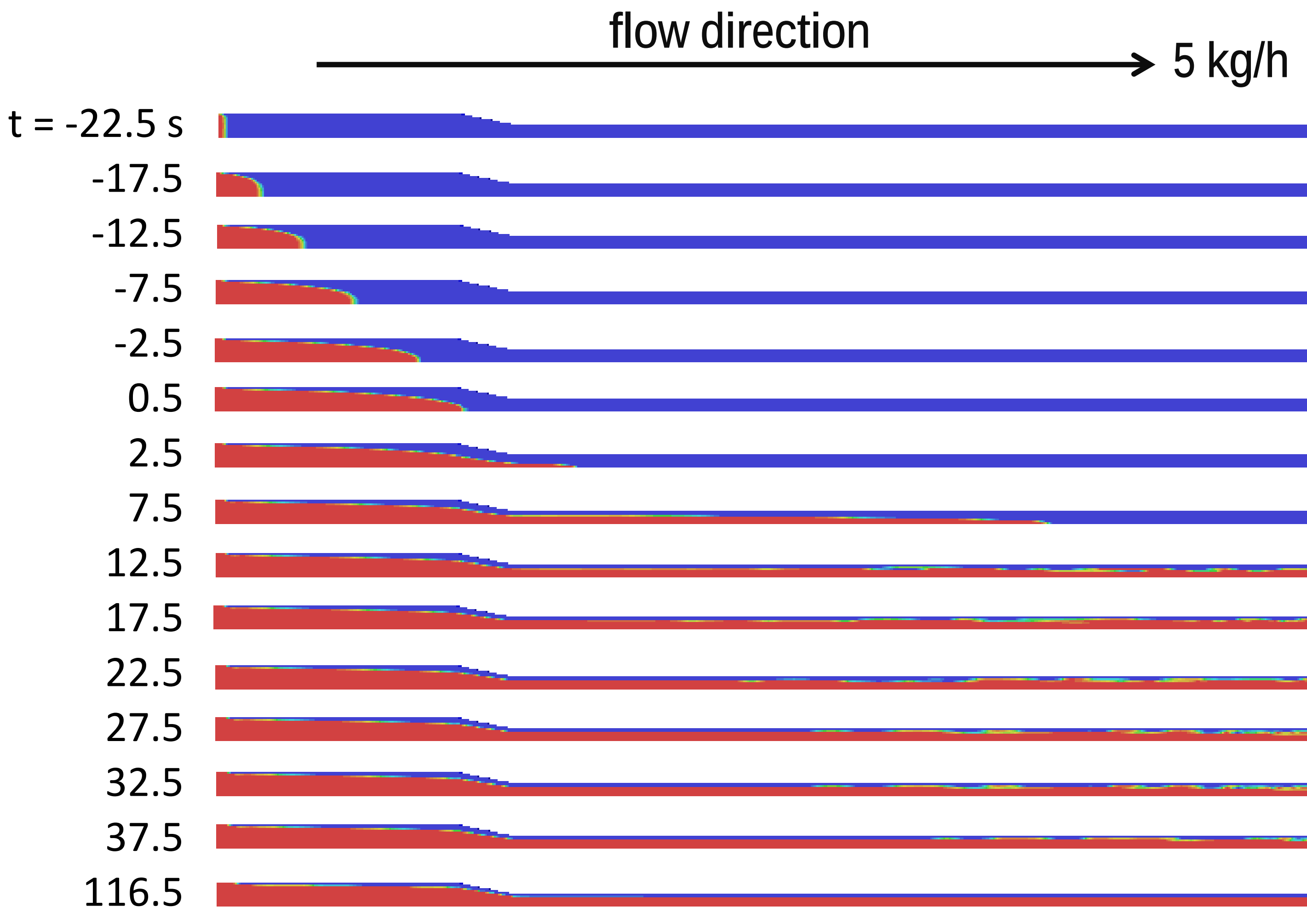
2.3 MI Resin B to 1 MI Resin A

Transfer line Geometry A



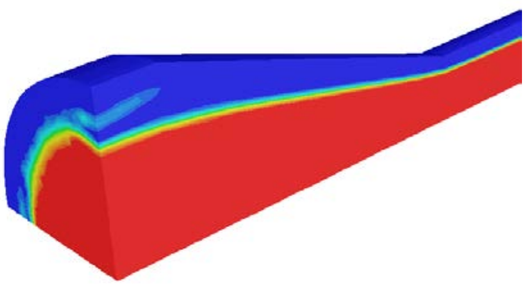
1 MI Resin A to 2.3 MI Resin B

Transfer line Geometry A



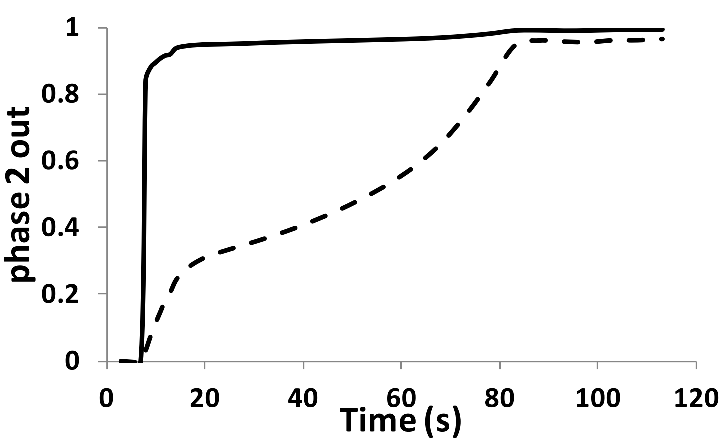
Changeover time: Effect of viscosity

- Flow channel was filled with phase 1, and phase 2 was introduced from inlet at t = 0.
- Time to achieve 97% conversion to phase 2 at transfer line outlet.

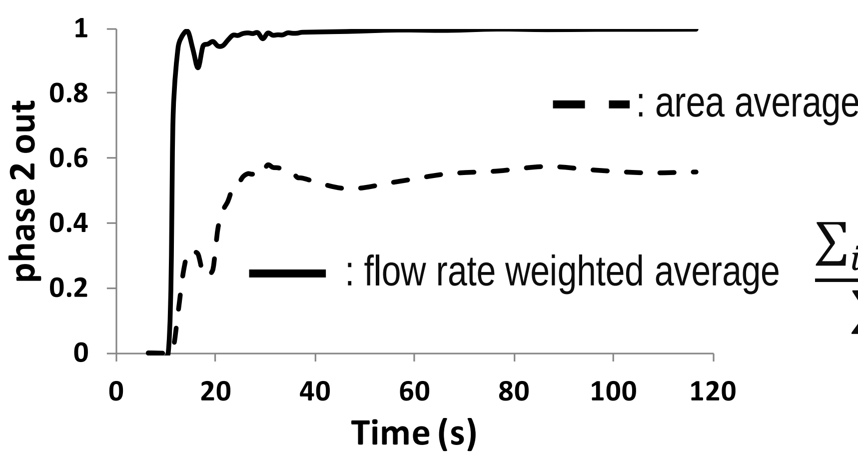


	Flow rate weighted avg	Area average
Resin B to Resin A	67 s	120 s
Resin A to Resin B	23 s	very long time

Resin B to Resin A



Resin A to Resin B



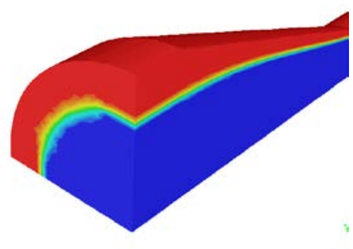
$$\frac{\sum_i \alpha_{i,2} A_i}{\sum_i A_i}$$

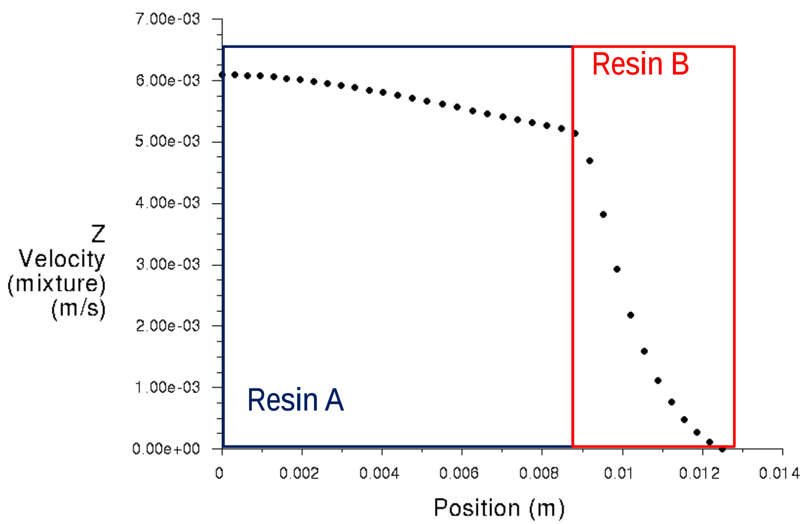
$$\frac{\sum_i \alpha_{i,2}\rho_i v_i A_i}{\sum_i \rho_i v_i A_i}$$

Velocity profiles

Resin B to Resin A

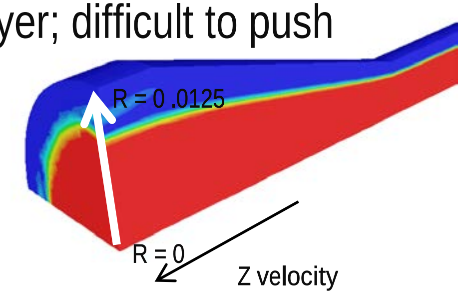
- High viscosity core encapsulated by relatively fast flowing low viscosity boundary layer.
- Plug flow pushing mobile boundary layer for complete removal.

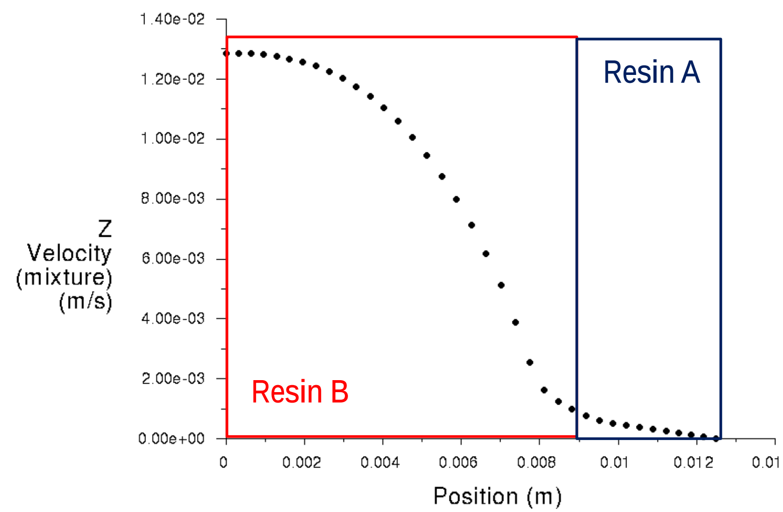




Resin A to Resin B

- Faster moving low viscosity core encapsulated by sluggish high viscosity boundary layer.
- Parabolic drag flow over an almost stationary boundary layer; difficult to push out old material.



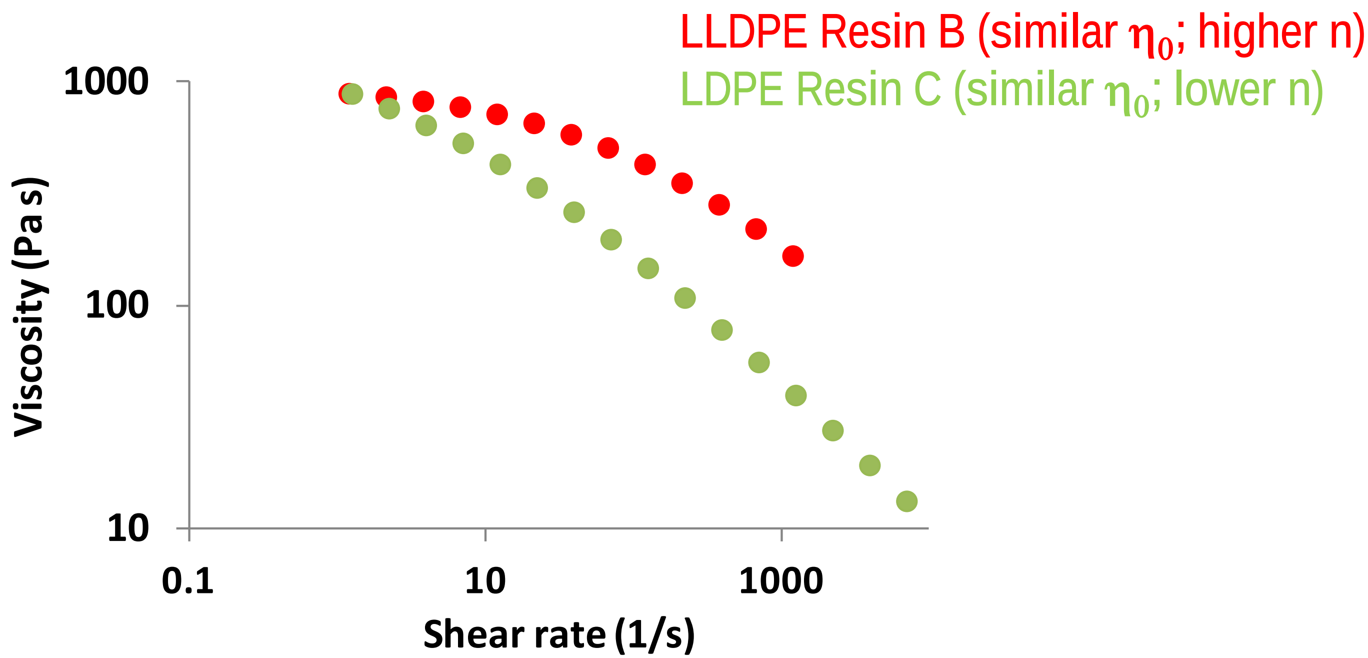


Transient flow modeling: Effect of shear thinning

- Determine the changeover time between resins with different shear thinning (and melt strength) character.

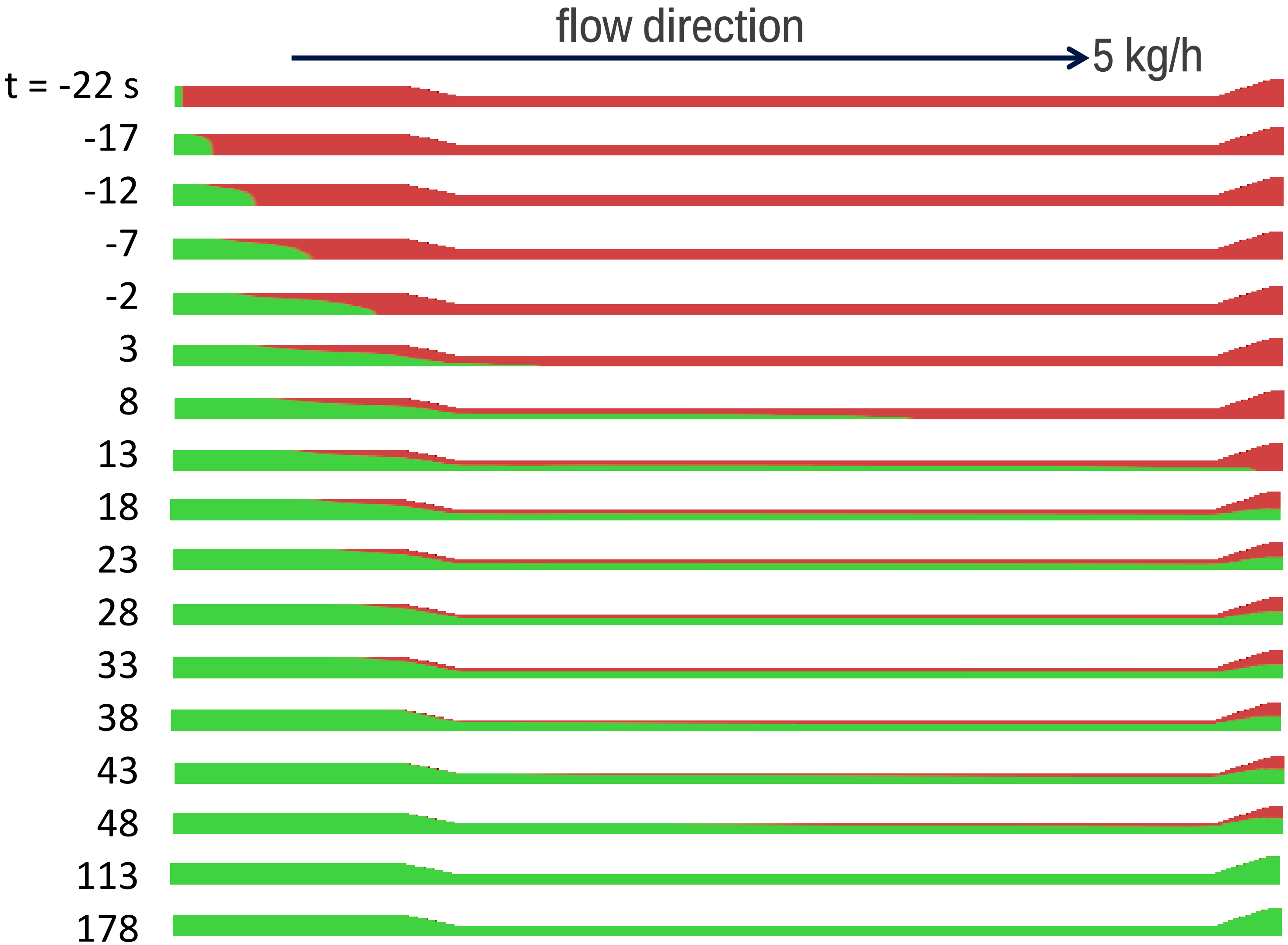
- Ex) LDPE vs. LLDPE

Shear viscosity at 280 °C



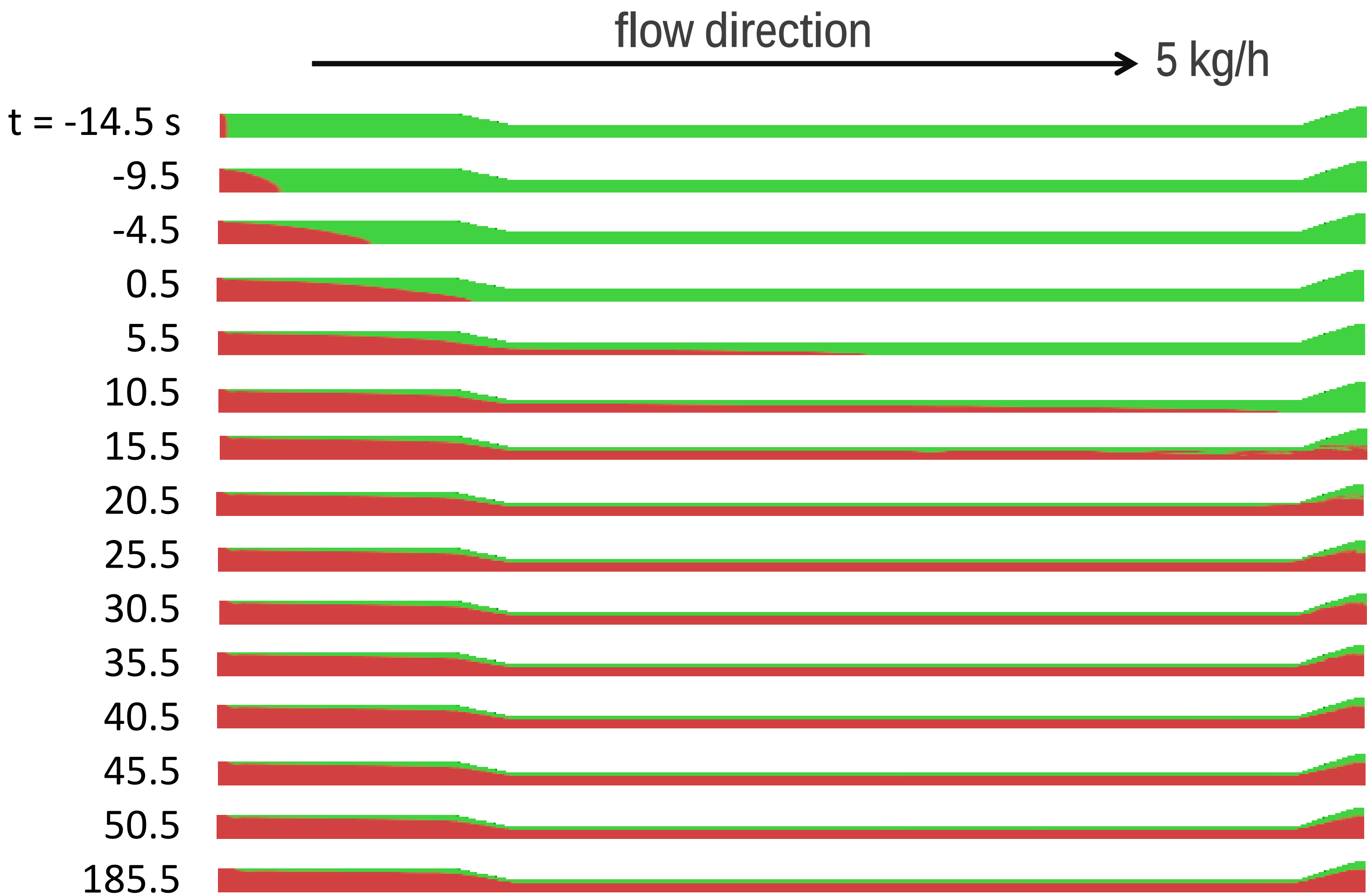
LLDPE Resin B to LDPE Resin C

Transfer line Geometry A



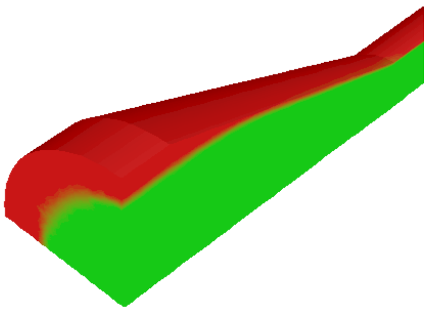
LDPE Resin C to LLDPE Resin B

Transfer line Geometry A



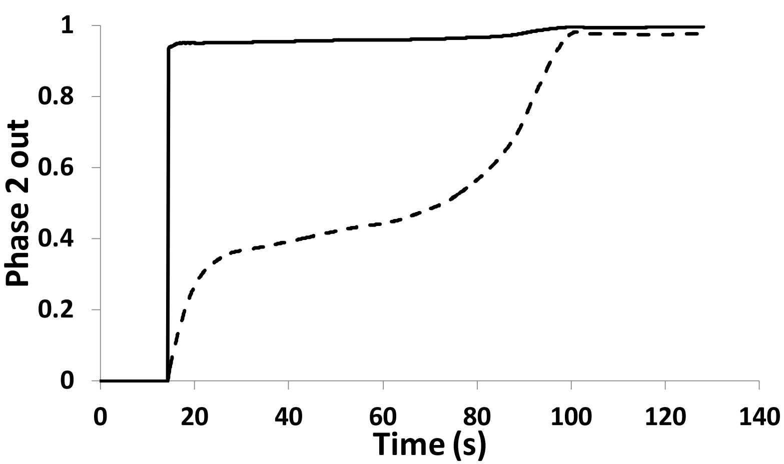
Changeover time: Effect of Shear Thinning

- Resins with different shear thinning behavior (melt strength), ex. LDPE and LLDPE.
- Changeover time for two resins displaying different shear thinning character.

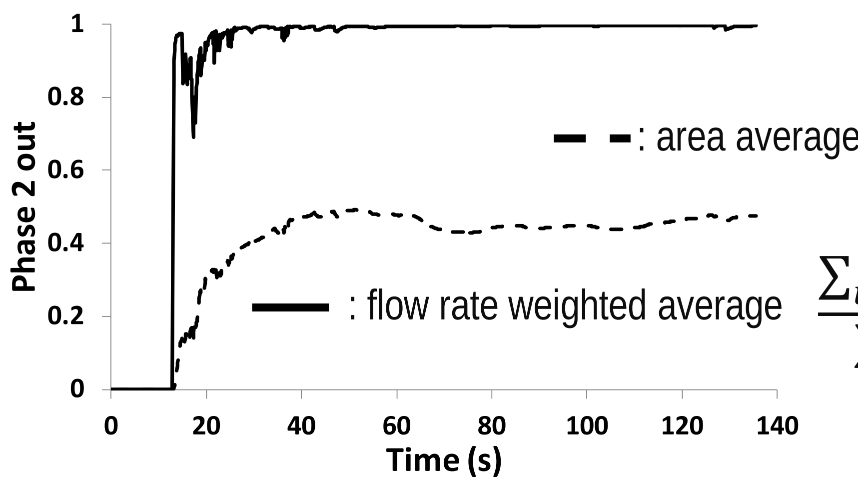


	Flow rate weighted avg	Area average
Resin B to Resin C	85 s	99 s
Resin C to Resin B	26 s	very long time

Resin B to Resin C



Resin C to Resin B



$$\frac{\sum_i \alpha_{i,2} A_i}{\sum_i A_i}$$

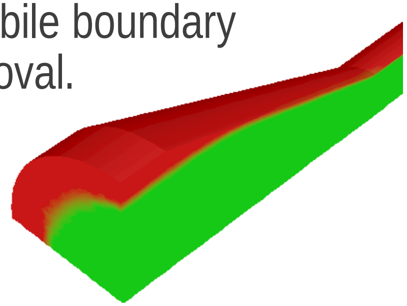
$$\frac{\sum_i \alpha_{i,2} \rho_i v_i A_i}{\sum_i \rho_i v_i A_i}$$

Velocity profiles

Resin B to Resin C

- Lower viscosity & high shear thinning core encapsulated by relatively fast flowing higher viscosity & lower shear thinning boundary layer.

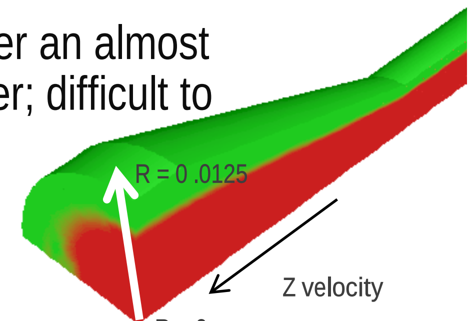
- Plug flow pushing mobile boundary layer for complete removal.

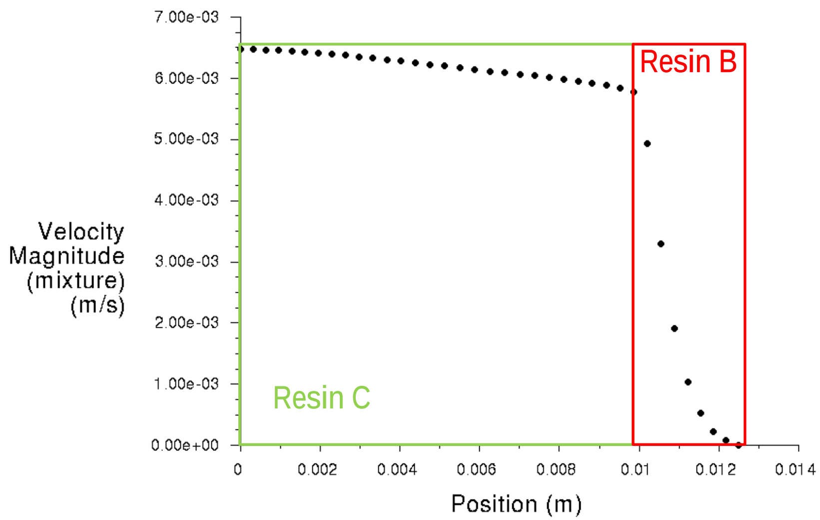


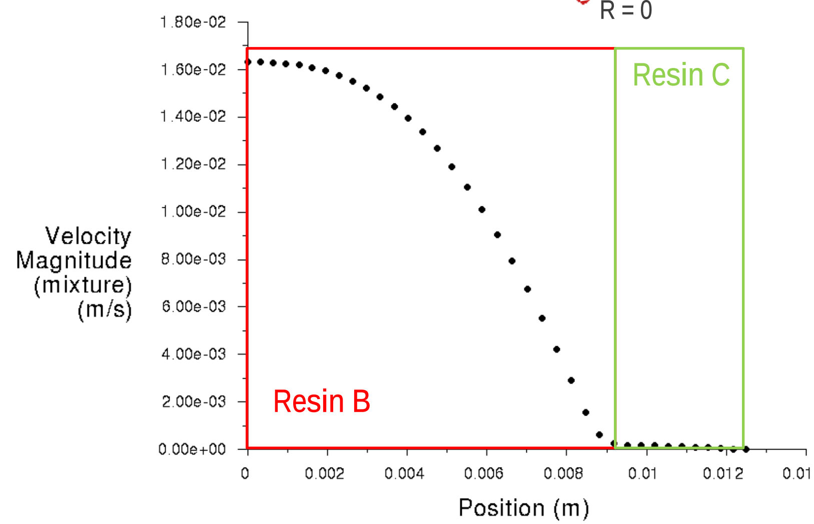
Resin C to Resin B

- Faster moving higher viscosity & lower shear thinning core encapsulated by sluggish lower viscosity & higher shear thinning boundary layer.

- Parabolic drag flow over an almost stationary boundary layer; difficult to push out old material.



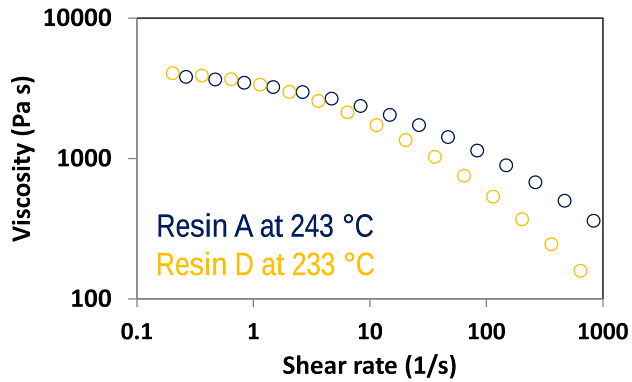


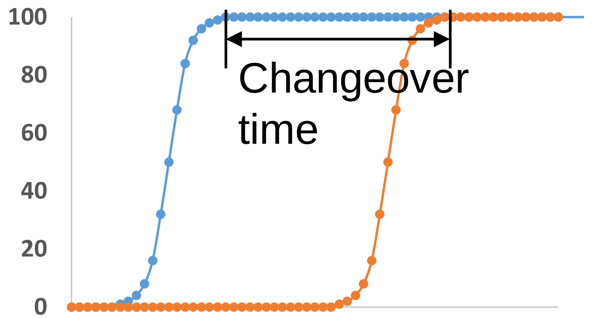


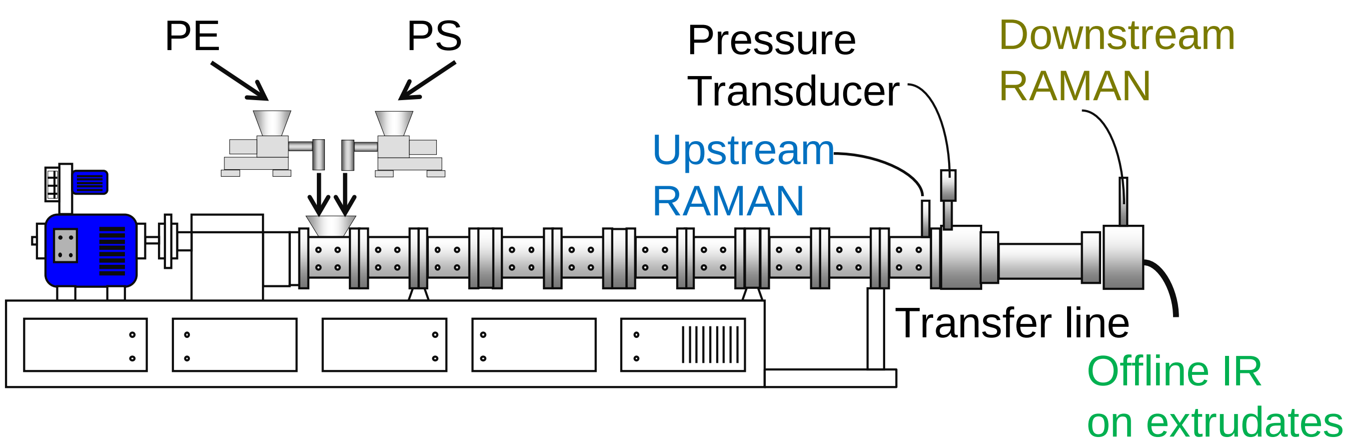
NOTE: The trends wrt viscosity are opposite to those seen in the previous case!

Changeover Experiments

- Determine the changeover time experimentally, and validate numerical modeling results.
- Three measurement locations
- Changeover between PE (Resin A) and PS (Resin D)

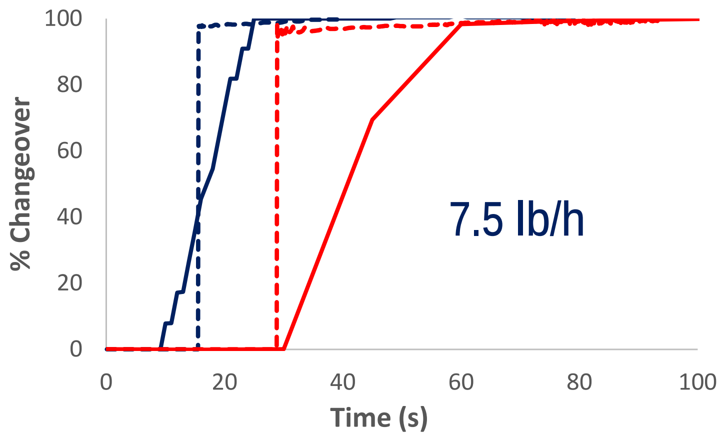




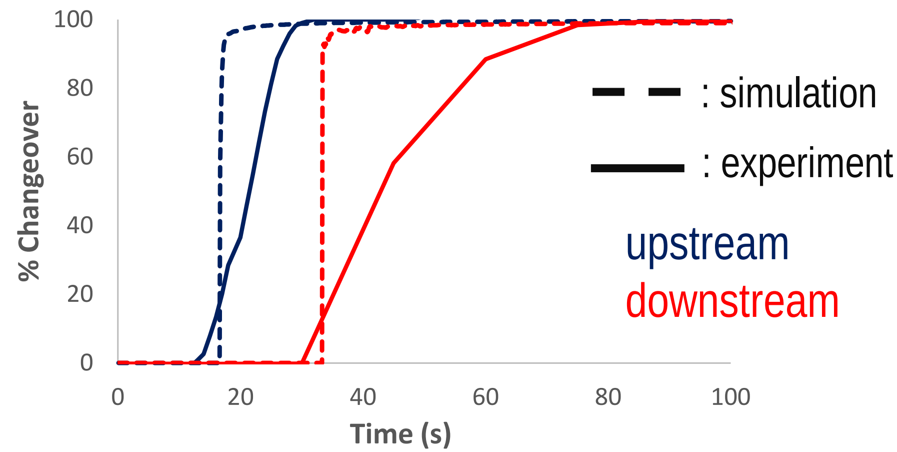


Experiments vs Simulation

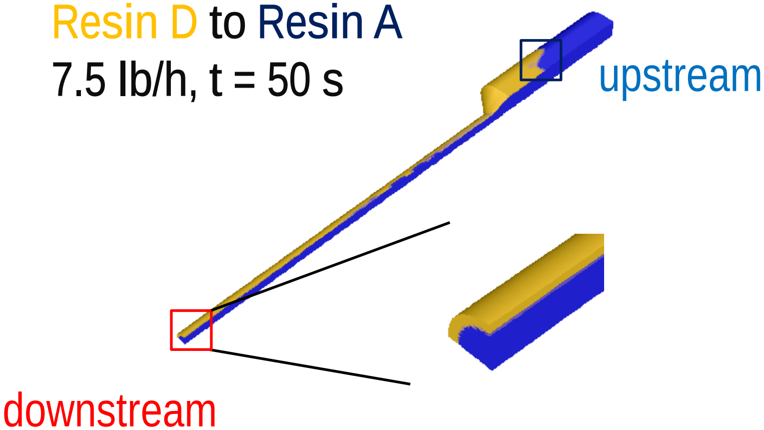
Resin D (PS) to Resin A (PE)



Resin A (PE) to Resin D (PS)



Resin D to Resin A
7.5 lb/h, t = 50 s



- Onset of changeover: reasonable agreement between experimental and simulation.
- Slope
  - Experimental: gradual change (phase mixing)
  - Simulation: sudden jump (pure A to B in plug flow)

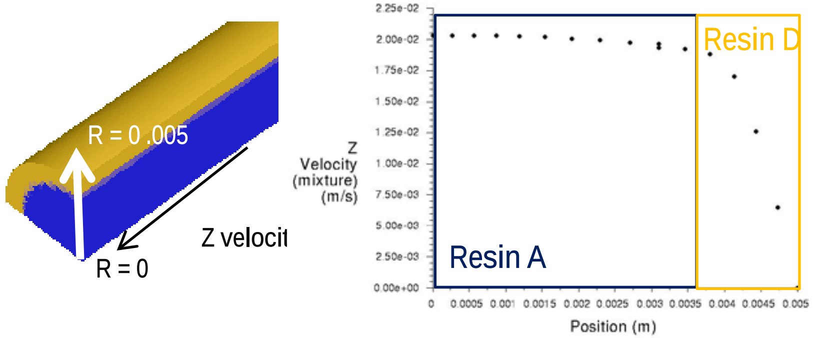
Changeover time summary

Time to 99% changeover

Changeover time (s)	Experimental		Simulation (flow rate weighted)	
Flowrate (kg/h)	1.7	3.4	1.7	3.4
Resin D to Resin A	> 115	50	161	36
Resin A to Resin D	> 56	60	83	65

- Good agreement between experiment and simulation
- Faster changeover at higher rates
- Resin sequencing for a shorter changeover time depends on flowrate

Resin D to Resin A, 7.5 lb/h, t = 50 s



Summary

- A unique series of numerical simulations were conducted to determine the effect of resin properties and sequence on changeover from a transfer line.
- The numerical results indicate faster area-weighted changeover for
  - Low viscosity to high viscosity than the opposite order
    - ➢ *High to low viscosity: high viscosity resin forms stationary boundary layer*
  - Less shear thinning to more shear thinning (high melt strength) than the opposite order
    - ➢ *More shear thinning to less thinning: More shear thinning resin forms sluggish skin layer*
- Good agreement between changeover experiments and numerical results
- Important to understand the rheology and resin sequencing for the changeover from a transfer line
  - Sequence for shortest changeover time may be flowrate dependent
- Optimize these factors to minimize the changeover times for the polymer processing equipment to reduce production time and cost.