COMSOL CONFERENCE 2016 BOSTON

COMSOL Simulation Application for Thermoplastics Viscosity Measurement

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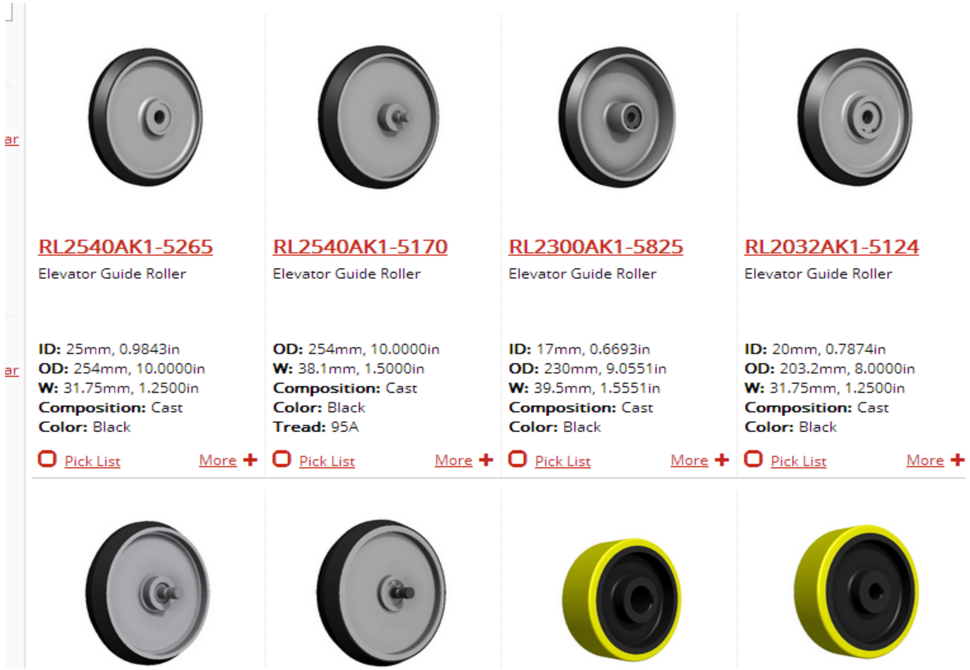
EHC CANADA, INC.

- **A world leader in the design and manufacture of escalator handrail products; and other products such as elevator lift belts, safety brushes, urethane rollers, and engineered polymer products**
- **EHC is a privately owned Canadian company with more than 20 service locations and 550 employees around the world**
- **EHC consumes 2MM kg of TPU**
- **EHC manufacturing facilities are ISO9001:2008 and ISO 14001:2004 certified**


DS3


RL2540AK1-5265
Elevator Guide Roller
ID: 25mm, 0.9843in
OD: 254mm, 10.0000in
W: 31.75mm, 1.2500in
Composition: Cast
Color: Black
Pick List
More
RL2540AK1-5170
Elevator Guide Roller
OD: 254mm, 10.0000in
W: 38.1mm, 1.5000in
Composition: Cast
Color: Black
Tread: 95A
Pick List
More
RL2300AK1-5825
Elevator Guide Roller
ID: 17mm, 0.6693in
OD: 230mm, 9.0551in
W: 39.5mm, 1.5551in
Composition: Cast
Color: Black
Pick List
More
RL2032AK1-5124
Elevator Guide Roller
ID: 20mm, 0.7874in
OD: 203.2mm, 8.0000in
W: 31.75mm, 1.2500in
Composition: Cast
Color: Black
Pick List
More

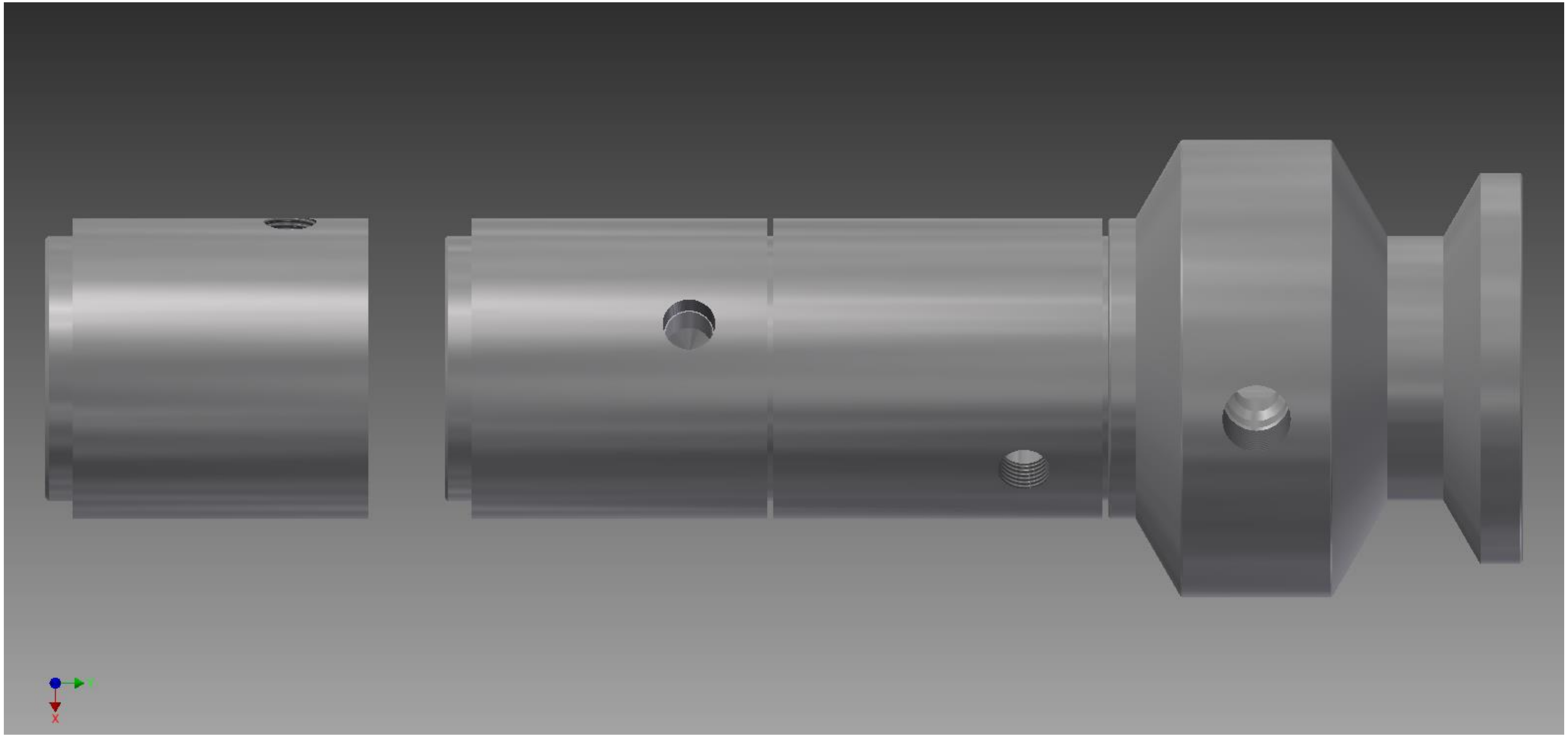
Outline

- **Background: importance of viscosity**
- **Customized rheometers**
- **Current method**
- **COMSOL application on viscosity measurement**
- **Some results**
- **Future work**

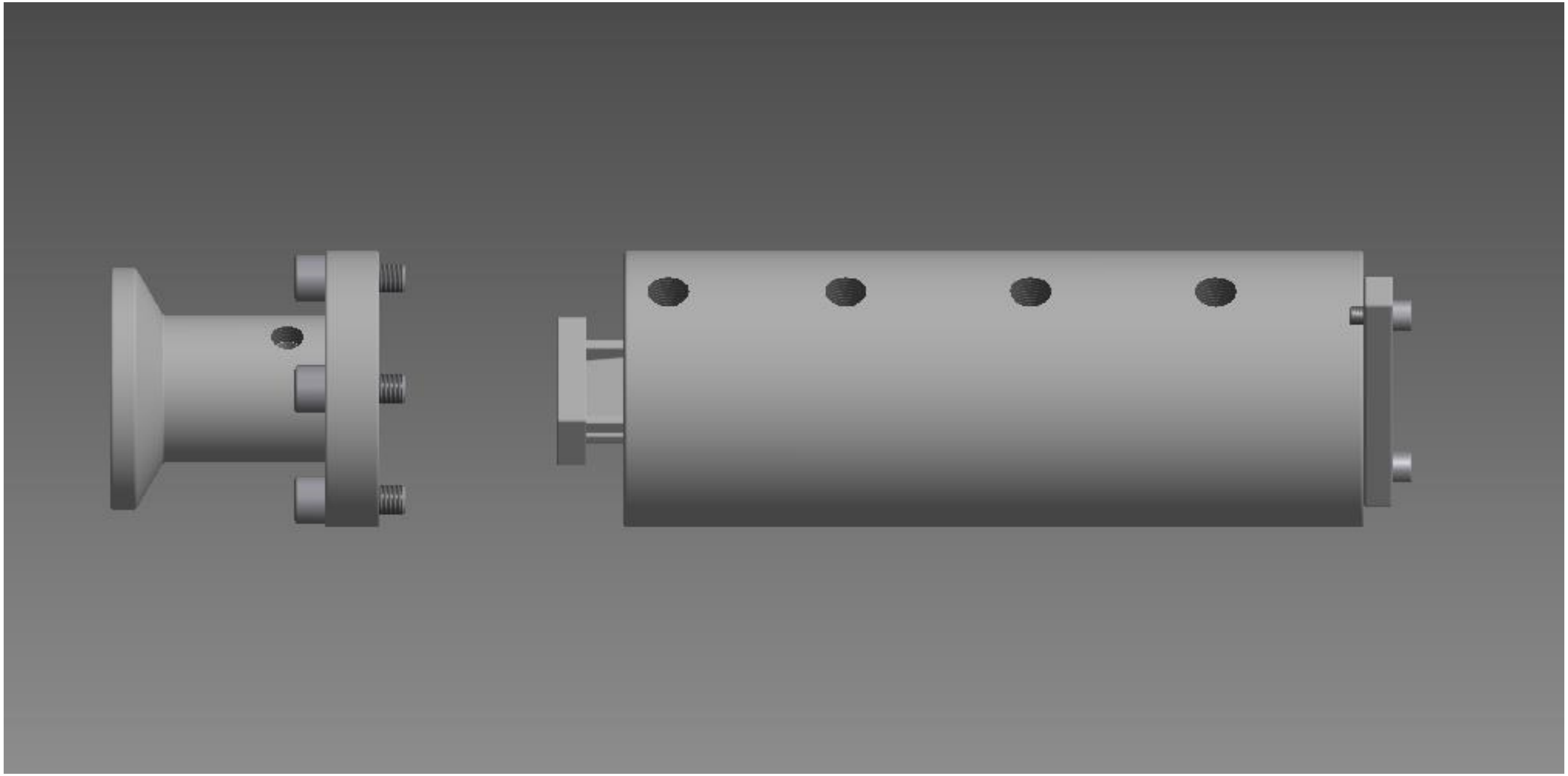
Background

- Importance of polymer viscosity
- Method
  - Commercial methods
  - Customized methods: Capillary and slit die rheometers
- Current measurement method
  - Bagley correction factor
  - Viscous heating
  - Distinguish the shear and thermal effects on viscosity
- Simulations we used COMSOL
  - Handrail Splicing Process
  - CSB and CFB Die design
  - Viscosity measurement

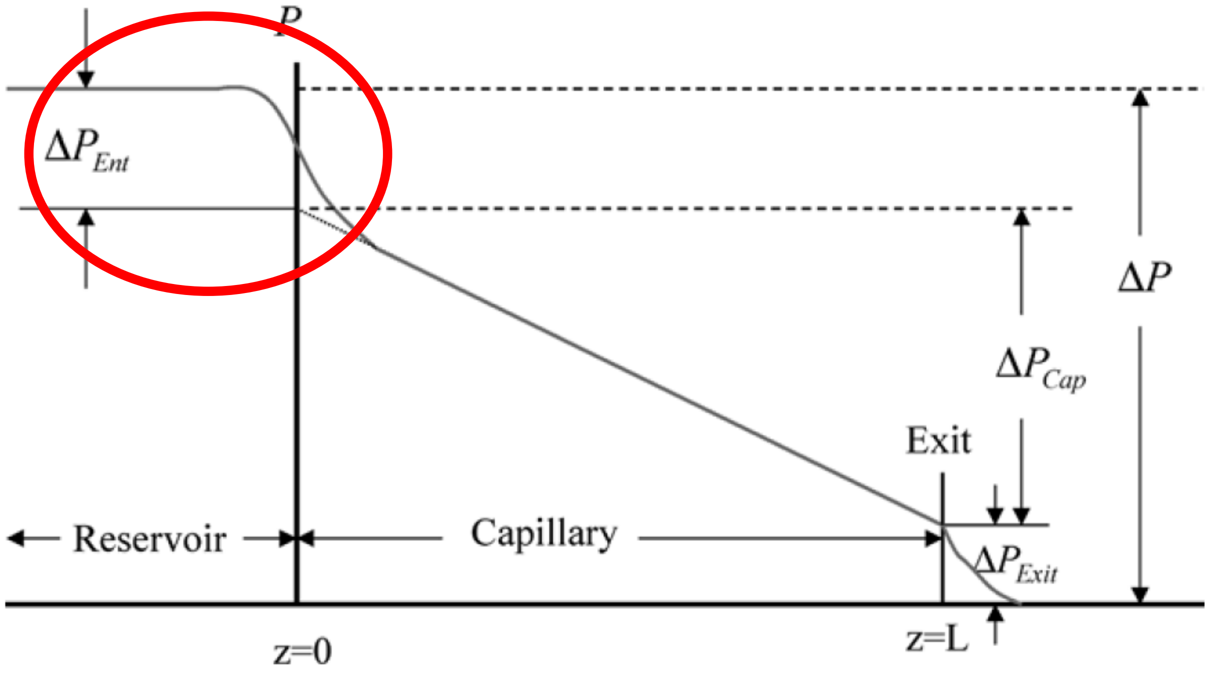
Capillary Rheometer

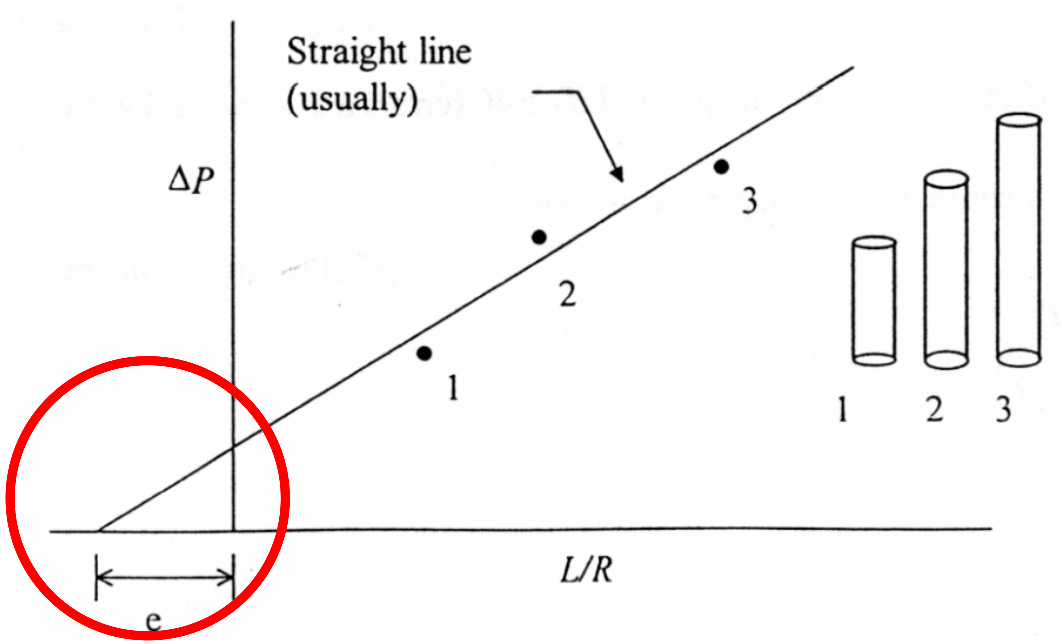


Slit Rheometer

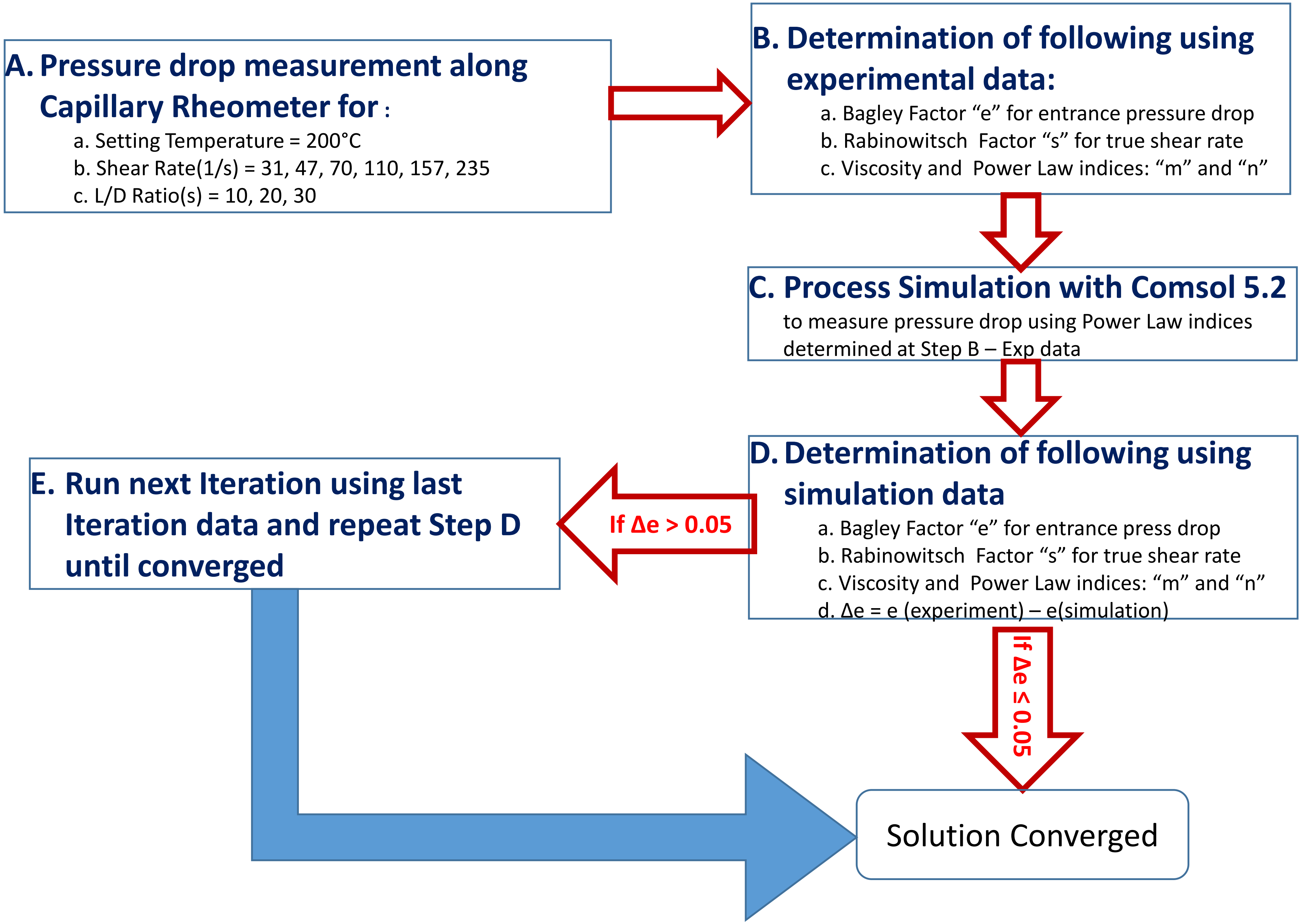


Current Method Based on Capillary Rheometer





Flow Chart - Convergence Procedure



Simulation Physics and Study

3D Model

- Inventor 2014

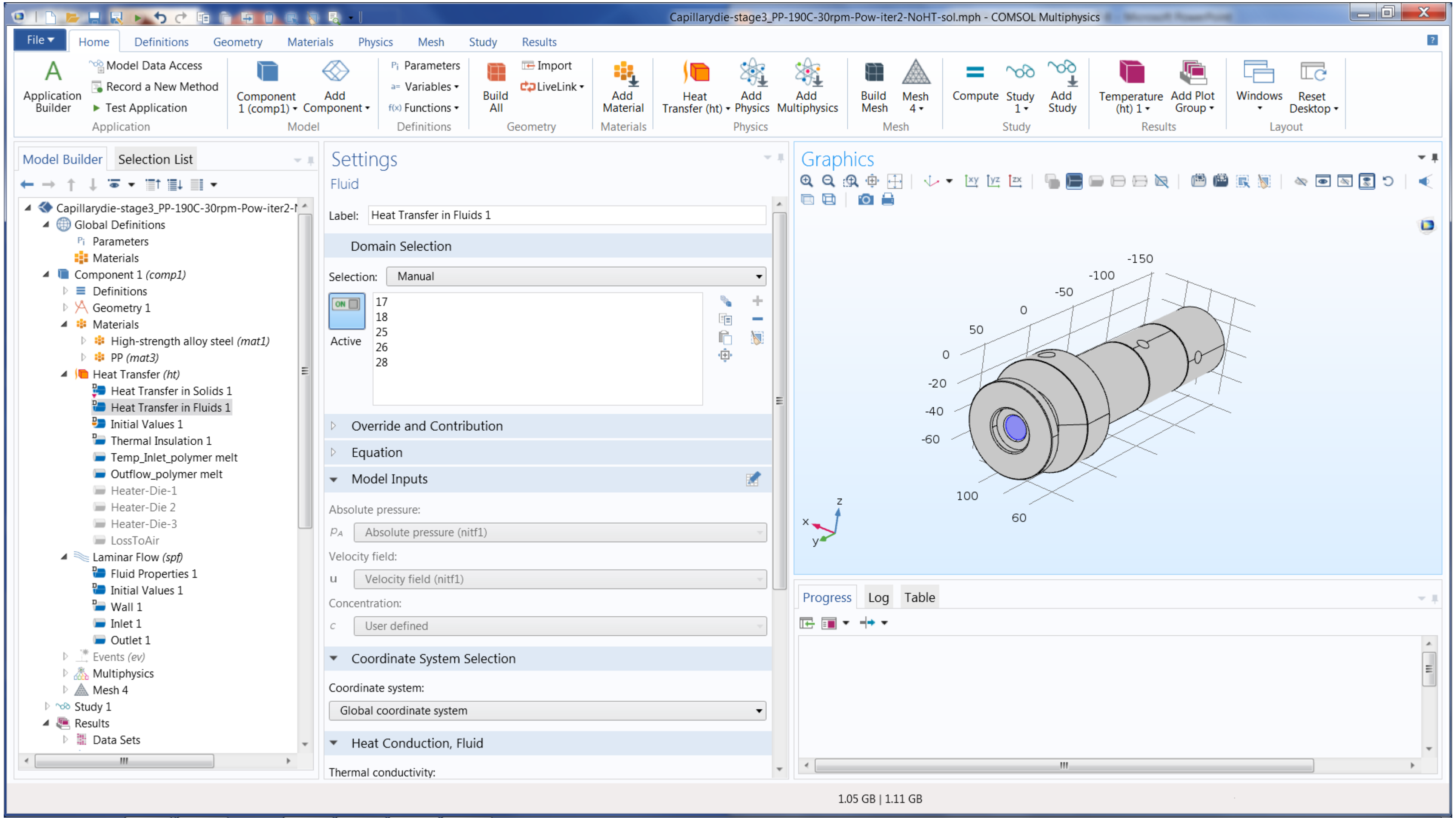
Physics

- Heat Transfer in Solids
- Heat Transfer in Fluids
- Non-isothermal Laminar Flow

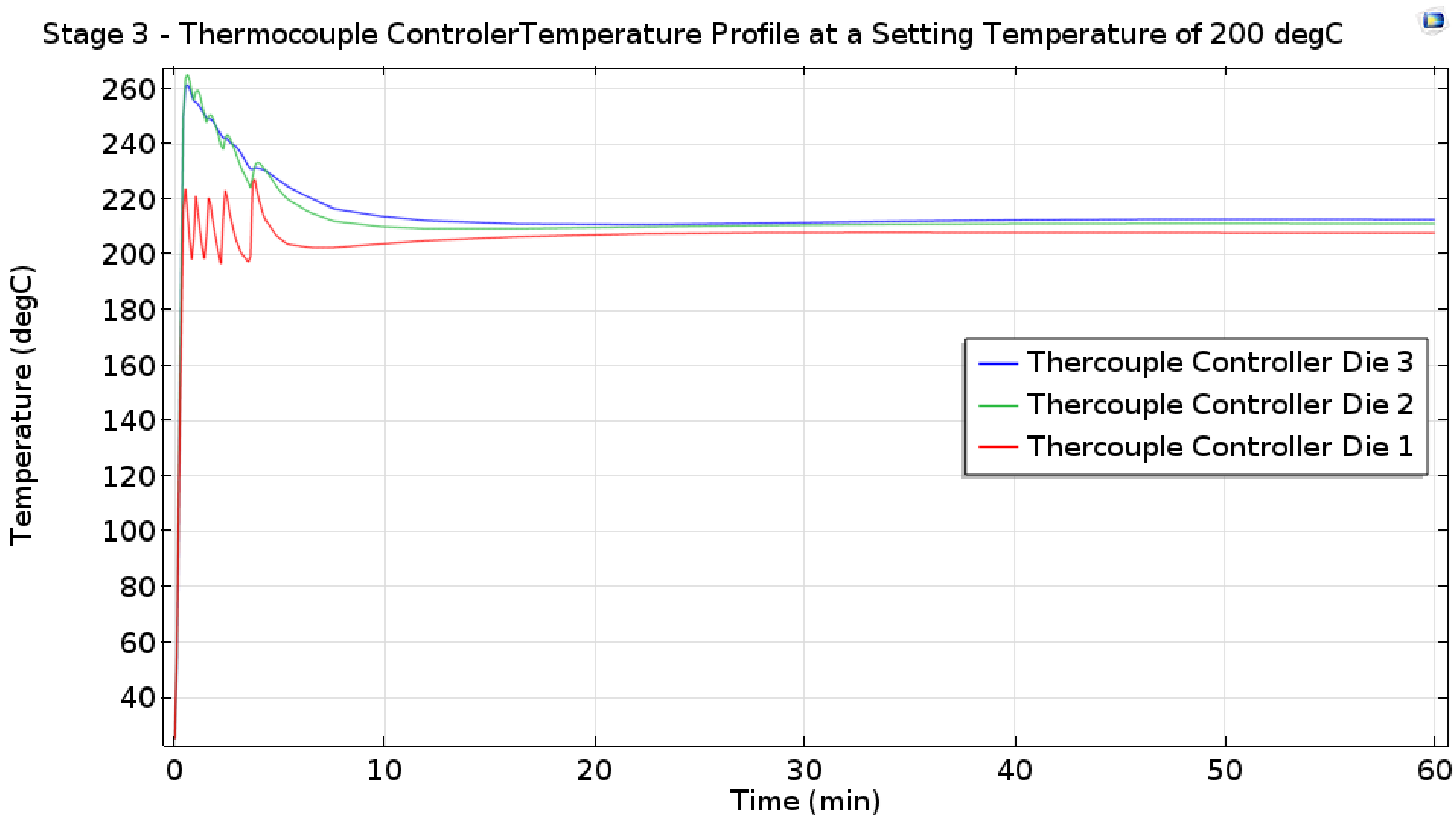
Study

- Stationary
- Time Dependent

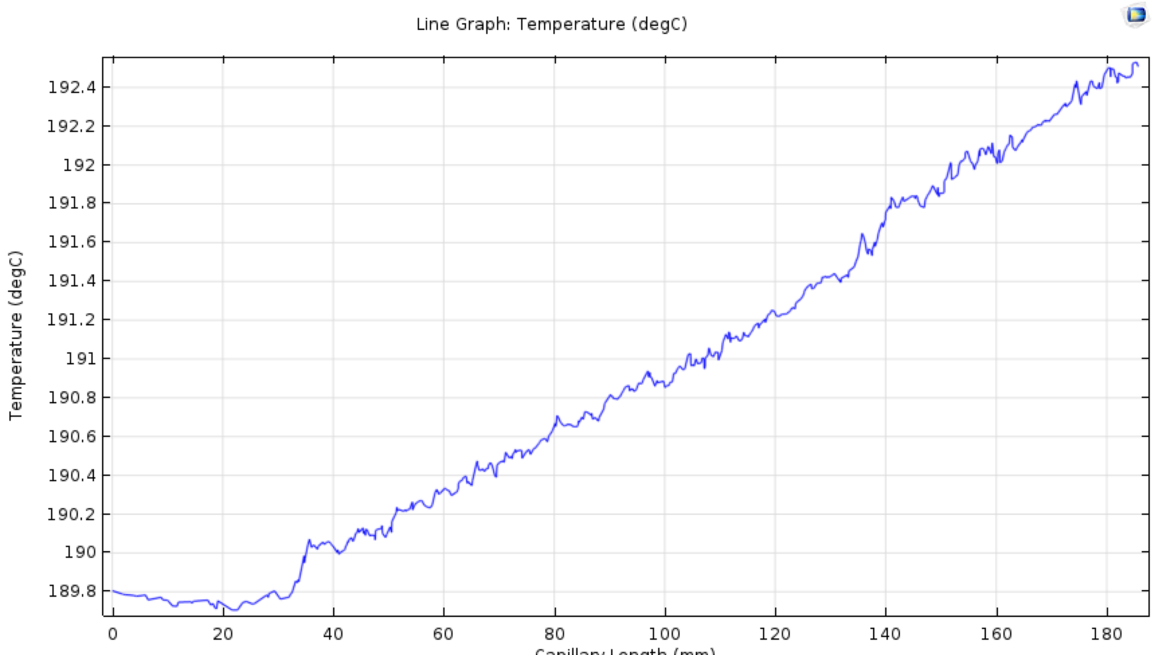
Heat Transfer In Fluids

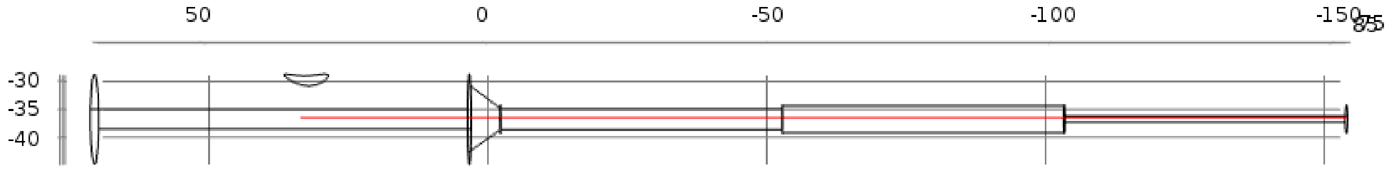


Temperature profile at thermocouple controller points for 3 pieces of capillary rheometer



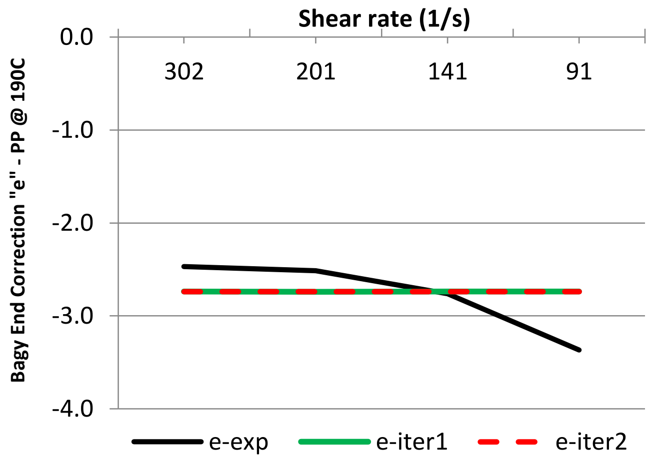
Temperature Profile along Capillary Length (for PP @190°C, shear rate around 287 1/s)





End Corrections & Power Law Coefficients
PP @ 190°C

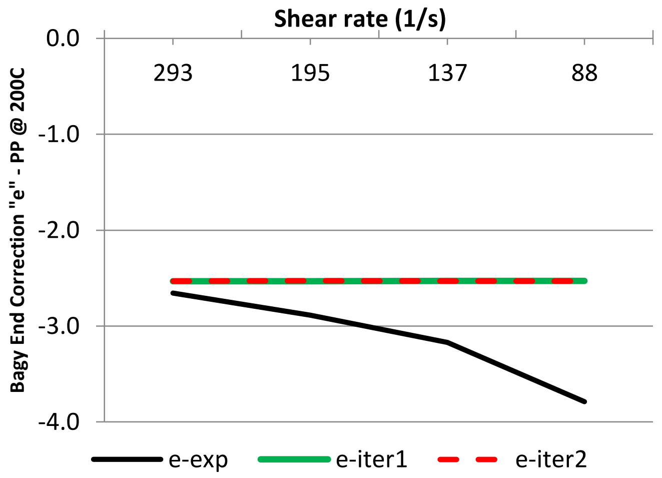
PP @ 190°C		Experimental Data			Simulation Data-Iteration 1			Simulation Data-Iteration 2		
		Bagley Correction	Power Law Coeff.		Bagley Correction	Power Law Coeff.		Bagley Correction	Power Law Coeff.	
rpm	Q cm3/s	e	m	n	e	m	n	e	m	n
30	2.5568	-2.468	2668.0	0.4961	-2.739	2617.8	0.4958	-2.739	2563.3	0.4959
20	1.7045	-2.514			-2.739			-2.740		
14	1.1932	-2.760			-2.737			-2.740		
9	0.7670	-3.367			-2.738			-2.739		



Solution for “e” completely converged at iteration 2

End Corrections & Power Law Coefficients PP @ 200°C

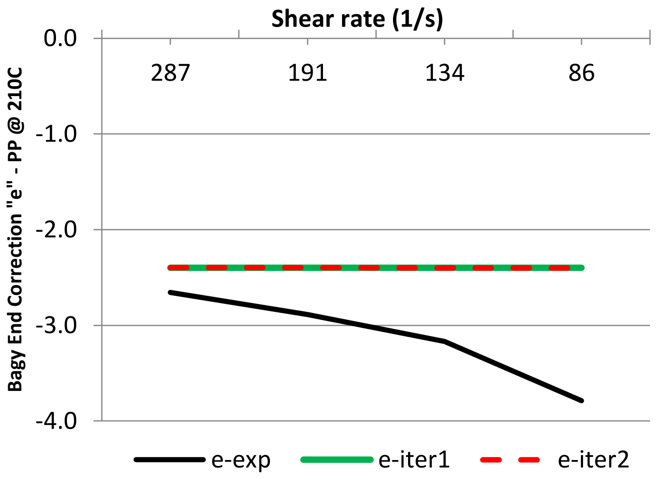
PP @ 200°C		Experimental Data			Simulation Data-Iteration 1			Simulation Data-Iteration 2		
		Bagley Correction	Power Law Coeff.		Bagley Correction	Power Law Coeff.		Bagley Correction	Power Law Coeff.	
rpm	Q cm3/s	e	m	n	e	m	n	e	m	n
30	2.9545	-2.657	1935.2	0.5368	-2.531	1898.8	0.5369	-2.530	1863.8	0.5370
20	1.9697	-2.886			-2.531			-2.528		
14	1.3788	-3.169			-2.530			-2.531		
9	0.8864	-3.787			-2.528			-2.530		



Solution for “e” completely converged at iteration 2

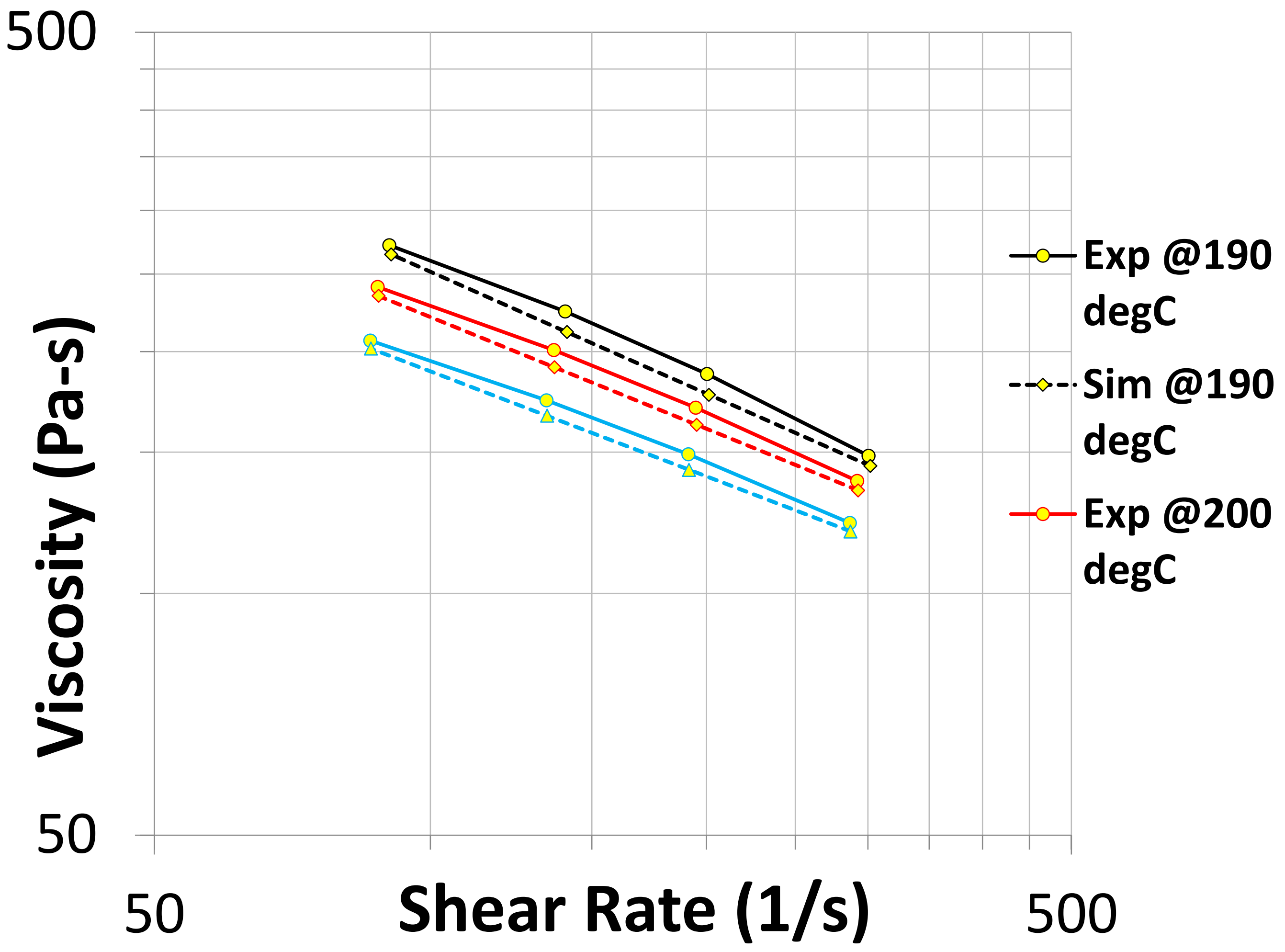
End Corrections & Power Law Coefficients PP @ 210°C

PP @ 210°C		Experimental Data			Simulation Data-Iteration 1			Simulation Data-Iteration 2		
		Bagley Correction	Power Law Coeff.		Bagley Correction	Power Law Coeff.		Bagley Correction	Power Law Coeff.	
rpm	Q cm3/s	e	m	n	e	m	n	e	m	n
30	2.9545	-2.657	1452.0	0.5646	-2.397	1428.8	0.5645	-2.398	1404.6	0.5646
20	1.9697	-2.886			-2.397			-2.397		
14	1.3788	-3.169			-2.397			-2.398		
9	0.8864	-3.787			-2.397			-2.399		



Solution for "e" completely converged at iteration 2

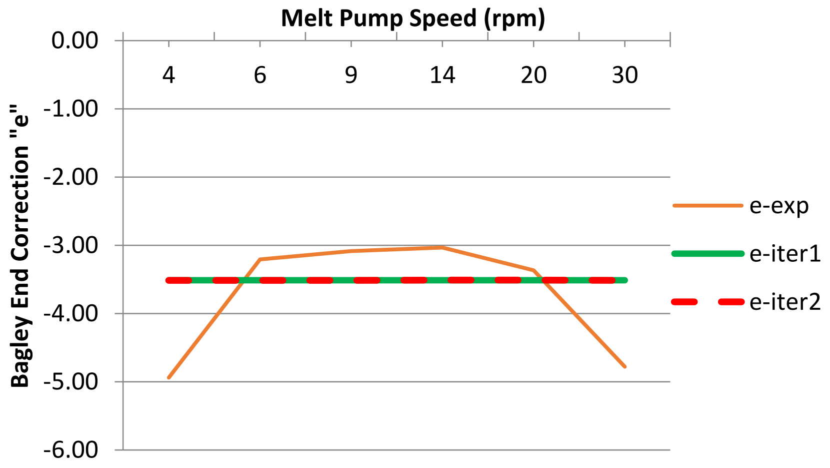
PP Viscosity Curves - Experimental vs Simulation



Simulation viscosity curves show 3 ~ 6% lower viscosity than experimental

End Corrections & Power Law Coefficients LDPE @ 190°C

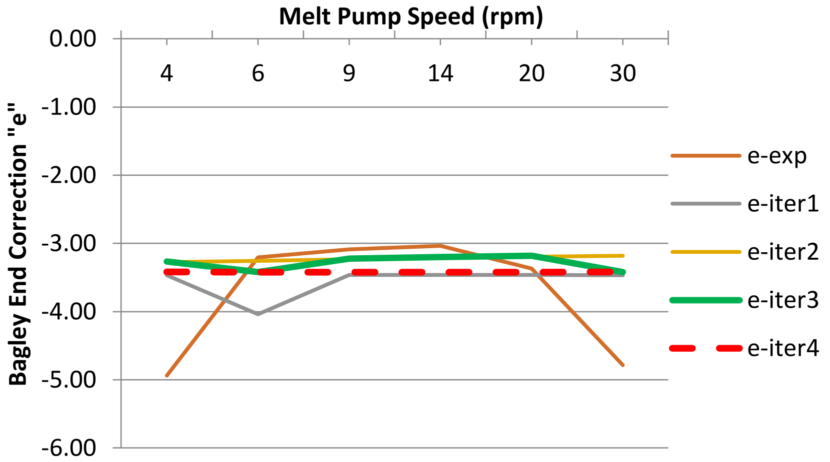
LDPE @ 190°C		Experimental Data			Simulation Data-Iteration 1			Simulation Data-Iteration 2		
		Bagley Correction	Power Law Coeff.		Bagley Correction	Power Law Coeff.		Bagley Correction	Power Law Coeff.	
Pump RPM	Q cm3/s	e	m	n	e	m	n	e	m	n
4	0.385	-4.94	12840	0.3697	-3.51	12480	0.3699	-3.51	12180	0.3723
6	0.577	-3.21			-3.51			-3.51		
9	0.866	-3.09			-3.51			-3.51		
14	1.347	-3.03			-3.51			-3.51		
20	1.925	-3.37			-3.51			-3.51		
30	2.887	-4.78			-3.51			-3.51		



Solution for “e” completely converged at iteration 2

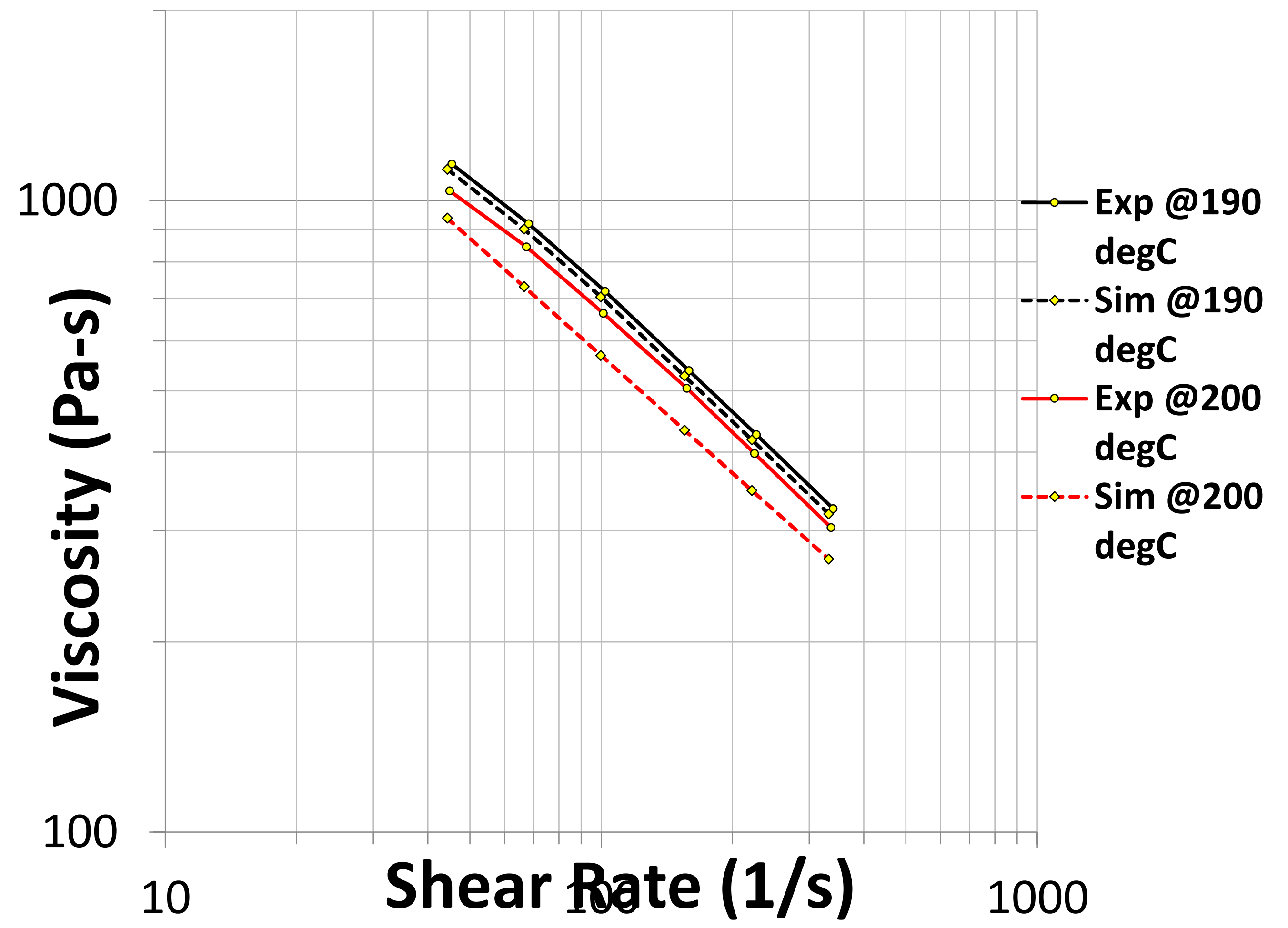
End Corrections & Power Law Coefficients LDPE @ 200°C

LDPE @ 200°C		Experimental Data			Simulation Data-Iteration 1			Simulation Data-Iteration 2			Simulation Data-Iteration 3			Simulation Data-Iteration 4		
		Bagley Correction	Power Law Coeff.		Bagley Correction	Power Law Coeff.		Bagley Correction	Power Law Coeff.		Bagley Correction	Power Law Coeff.		Bagley Correction	Power Law Coeff.	
Pump RPM	Q cm3/s	e	m	n	e	m	n	e	m	n	e	m	n	e	m	n
4	0.385	-4.94	11162	0.377	-3.47	10530	0.383	-3.27	10200	0.383	-3.26	9954	0.383	-3.42	9700	0.3827
6	0.577	-3.21			-4.04			-3.25			-3.42			-3.42		
9	0.866	-3.09			-3.46			-3.23			-3.22			-3.42		
14	1.347	-3.03			-3.46			-3.21			-3.20			-3.42		
20	1.925	-3.37			-3.46			-3.20			-3.18			-3.42		
30	2.887	-4.78			-3.46			-3.18			-3.42			-3.42		

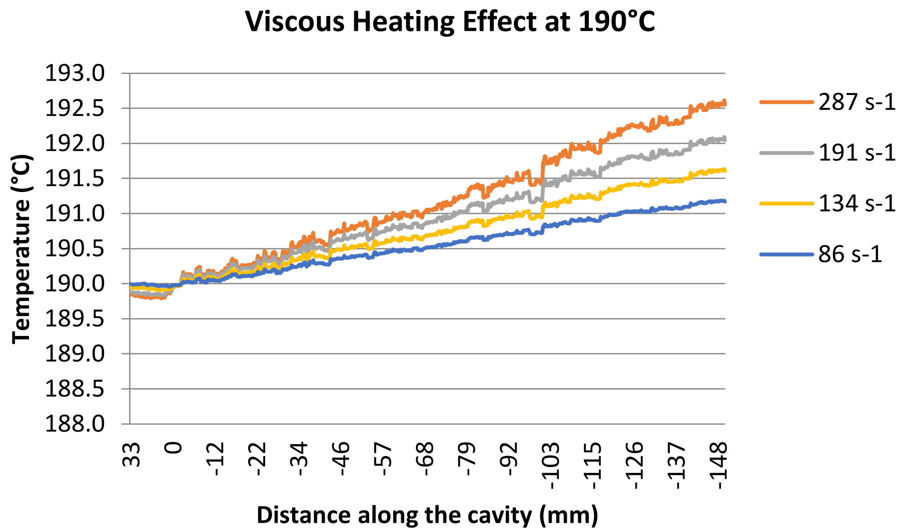


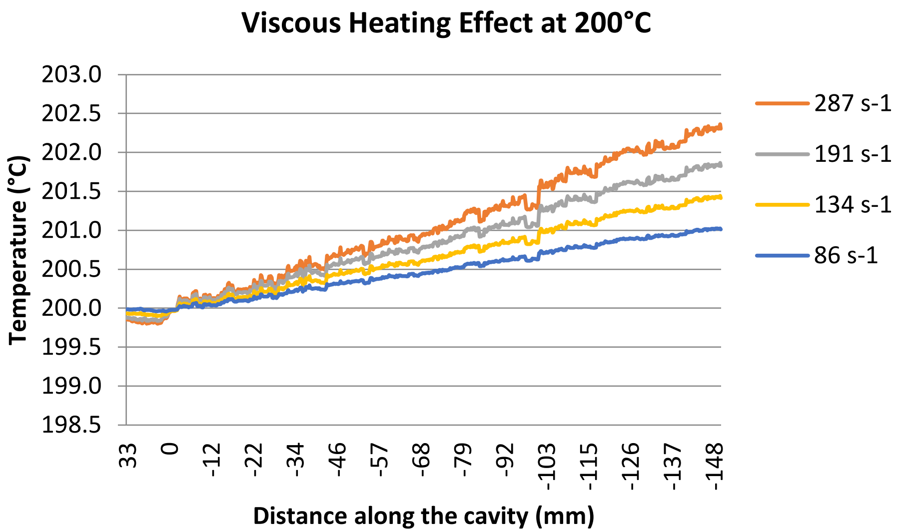
Solution for “e” completely converged at iteration 4

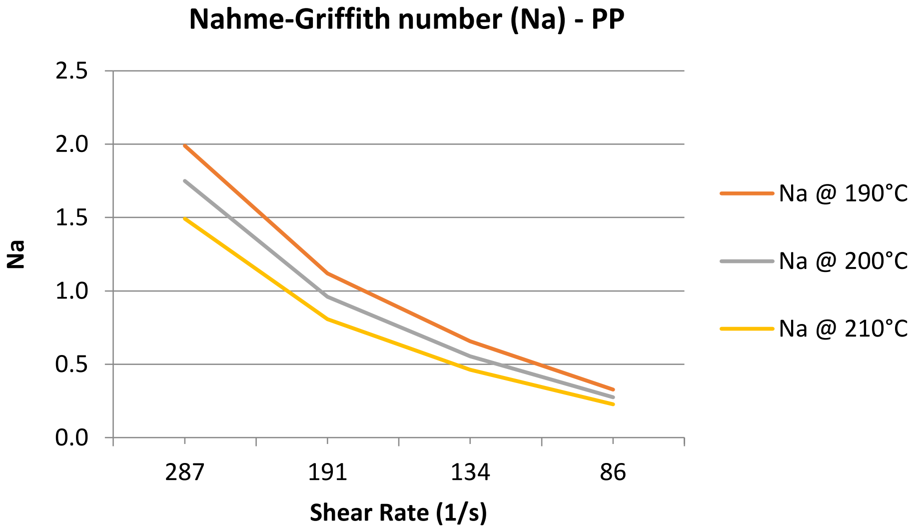
LDPE Viscosity Curves - Experimental vs Simulation

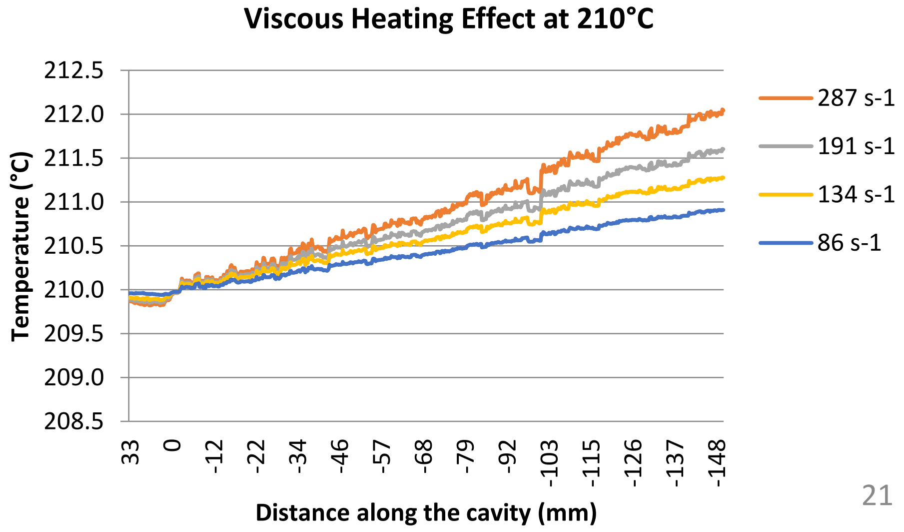


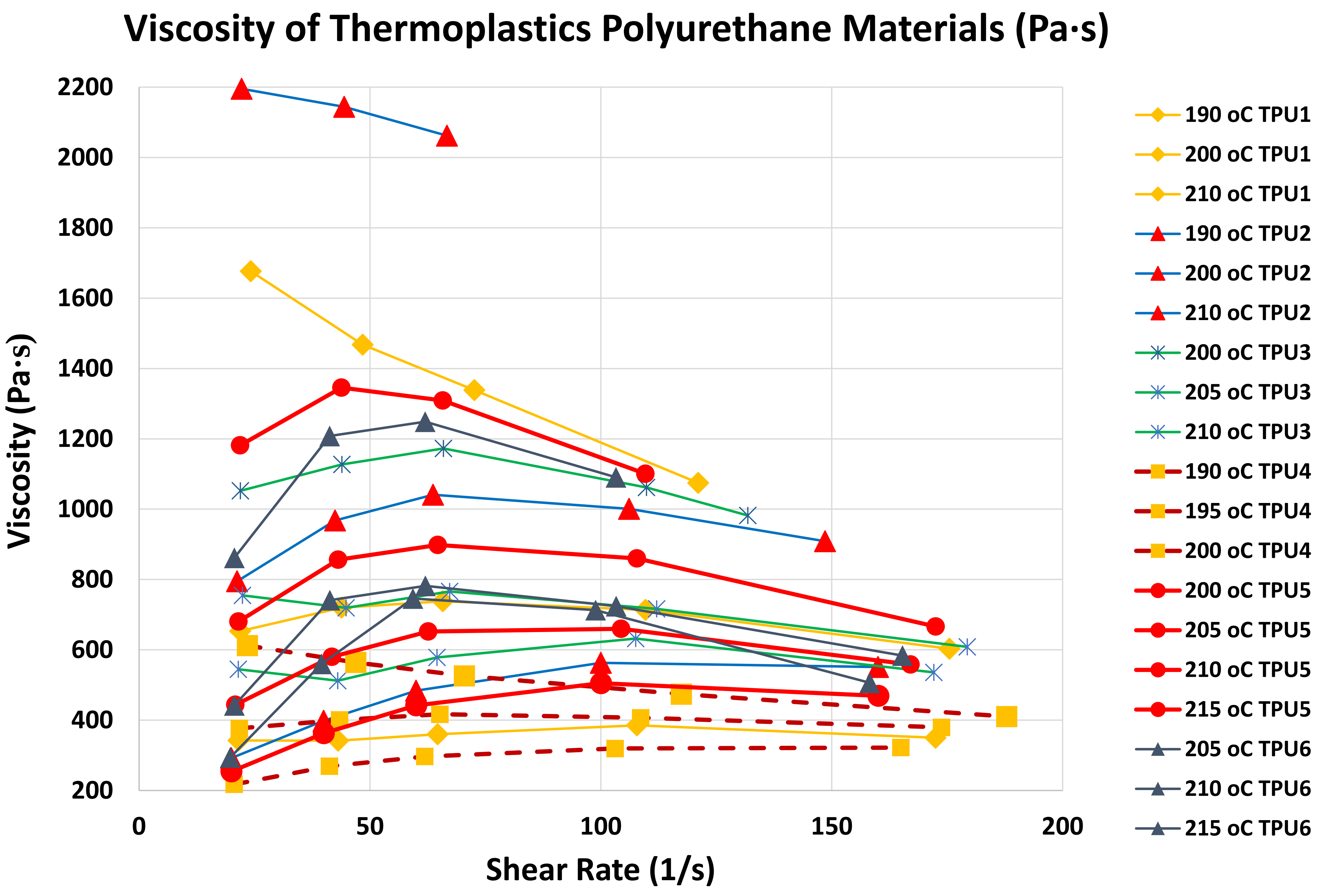
Viscous Heating Effect along Cavity – PP










Viscosity of Thermoplastics Polyurethane Materials (Pa·s)
Viscosity (Pa·s)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
50
100
150
200
Shear Rate (1/s)
190 oC TPU1
200 oC TPU1
210 oC TPU1
190 oC TPU2
200 oC TPU2
210 oC TPU2
200 oC TPU3
205 oC TPU3
210 oC TPU3
190 oC TPU4
195 oC TPU4
200 oC TPU4
200 oC TPU5
205 oC TPU5
210 oC TPU5
215 oC TPU5
205 oC TPU6
210 oC TPU6
215 oC TPU6

Conclusions

- **Bagley correction factor could be obtained by using COMSOL simulation**
- **Combining the simulation and experimental results, a precise viscosity of polymers could be obtained**
- **In general, the simulation results are lower than the experimental results**

Future Work

Viscosity simulation

- **Separate the shear rate and temperature effects to viscosity**
- **Separate the viscous heating contribution to viscosity**
- **Precisely measure thermoplastics polyurethane viscosity**

- **Structural mechanical simulation**
- **Fatigue simulation**
- **Wear simulation**