

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**



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



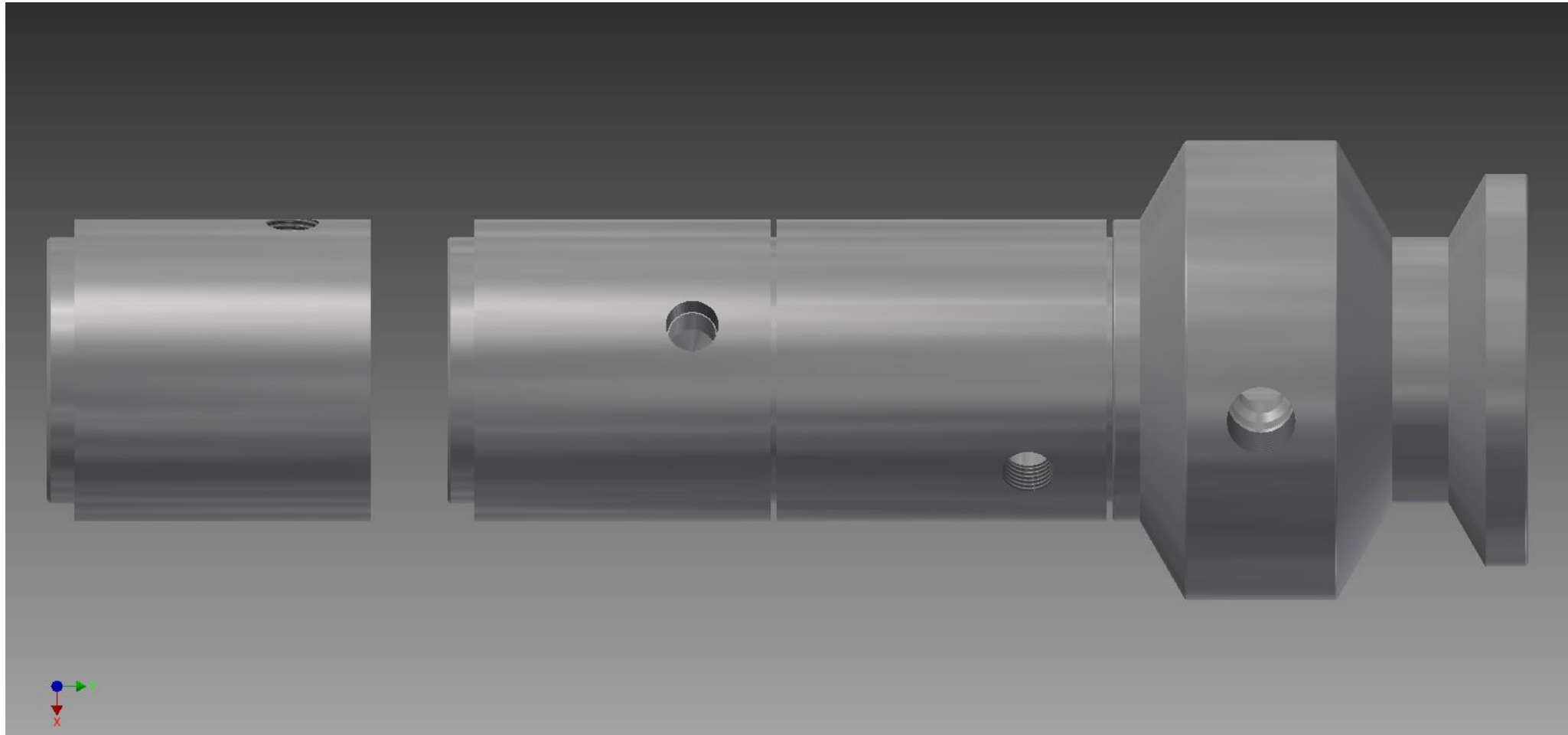
Outline

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

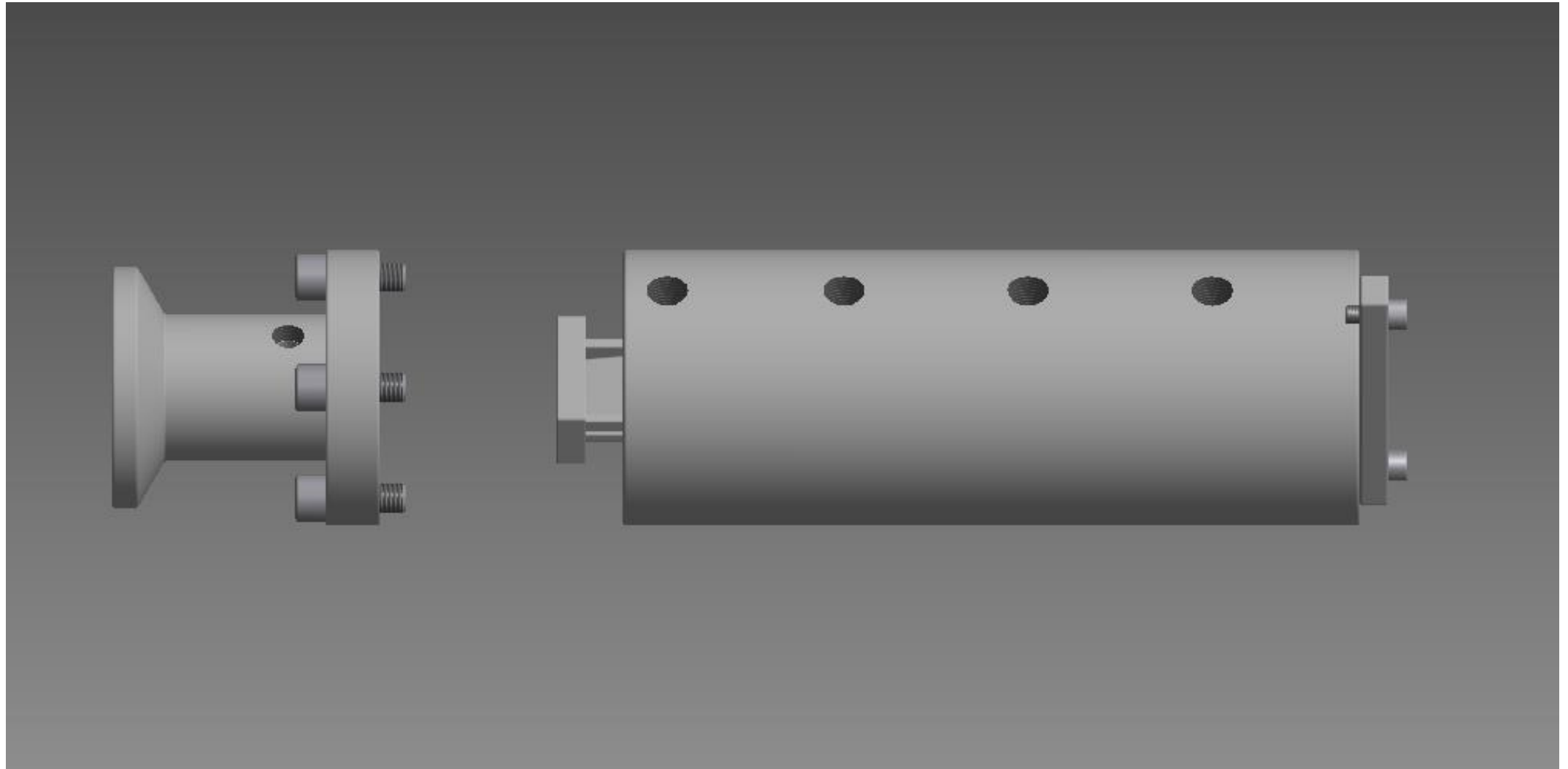
Background

- **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**

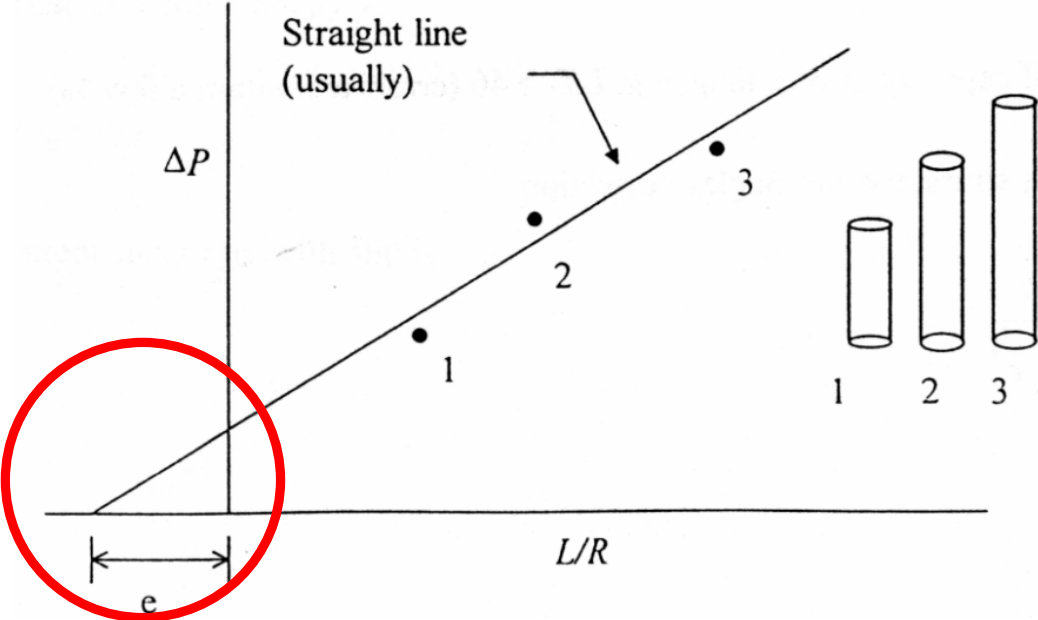
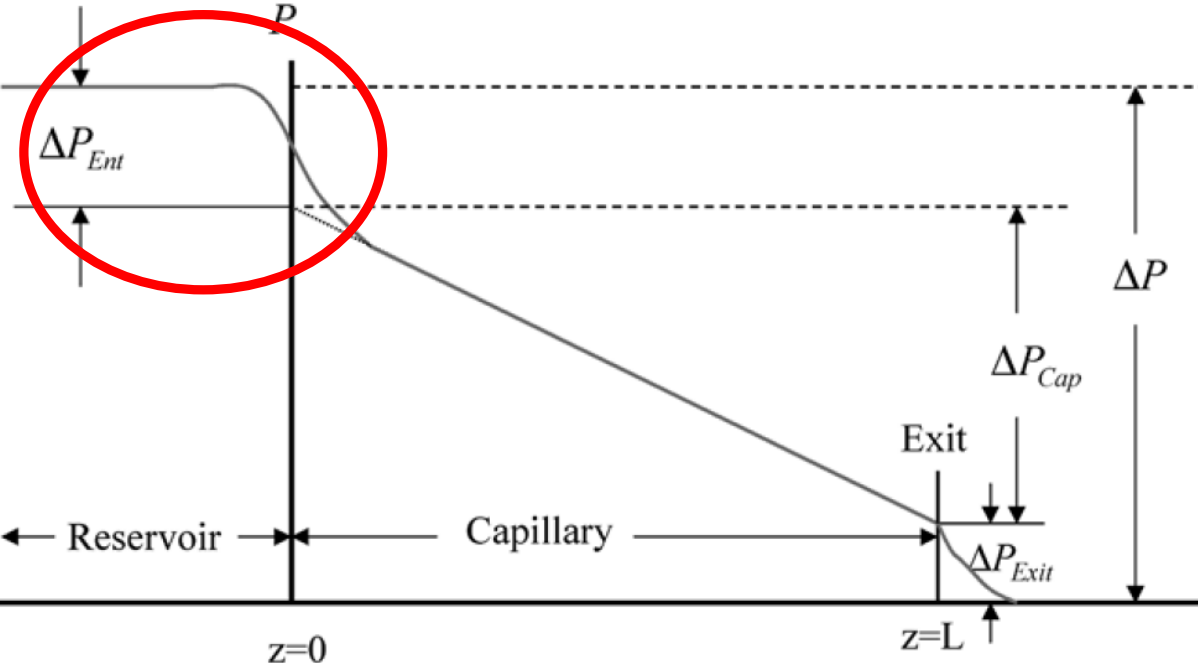
Capillary Rheometer



Slit Rheometer



Current Method Based on Capillary Rheometer



Flow Chart - Convergence Procedure

A. Pressure drop measurement along Capillary Rheometer for :

- a. Setting Temperature = 200°C
- b. Shear Rate(1/s) = 31, 47, 70, 110, 157, 235
- c. L/D Ratio(s) = 10, 20, 30

B. Determination of following using experimental data:

- a. Bagley Factor "e" for entrance pressure drop
- b. Rabinowitsch Factor "s" for true shear rate
- c. Viscosity and Power Law indices: "m" and "n"

C. Process Simulation with Comsol 5.2

to measure pressure drop using Power Law indices determined at Step B – Exp data

D. Determination of following using simulation data

- a. Bagley Factor "e" for entrance press drop
- b. Rabinowitsch Factor "s" for true shear rate
- c. Viscosity and Power Law indices: "m" and "n"
- d. $\Delta e = e(\text{experiment}) - e(\text{simulation})$

E. Run next Iteration using last Iteration data and repeat Step D until converged

If $\Delta e > 0.05$

If $\Delta e \leq 0.05$

Solution Converged

Simulation Physics and Study

3D Model

- Inventor 2014

Physics

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

Study

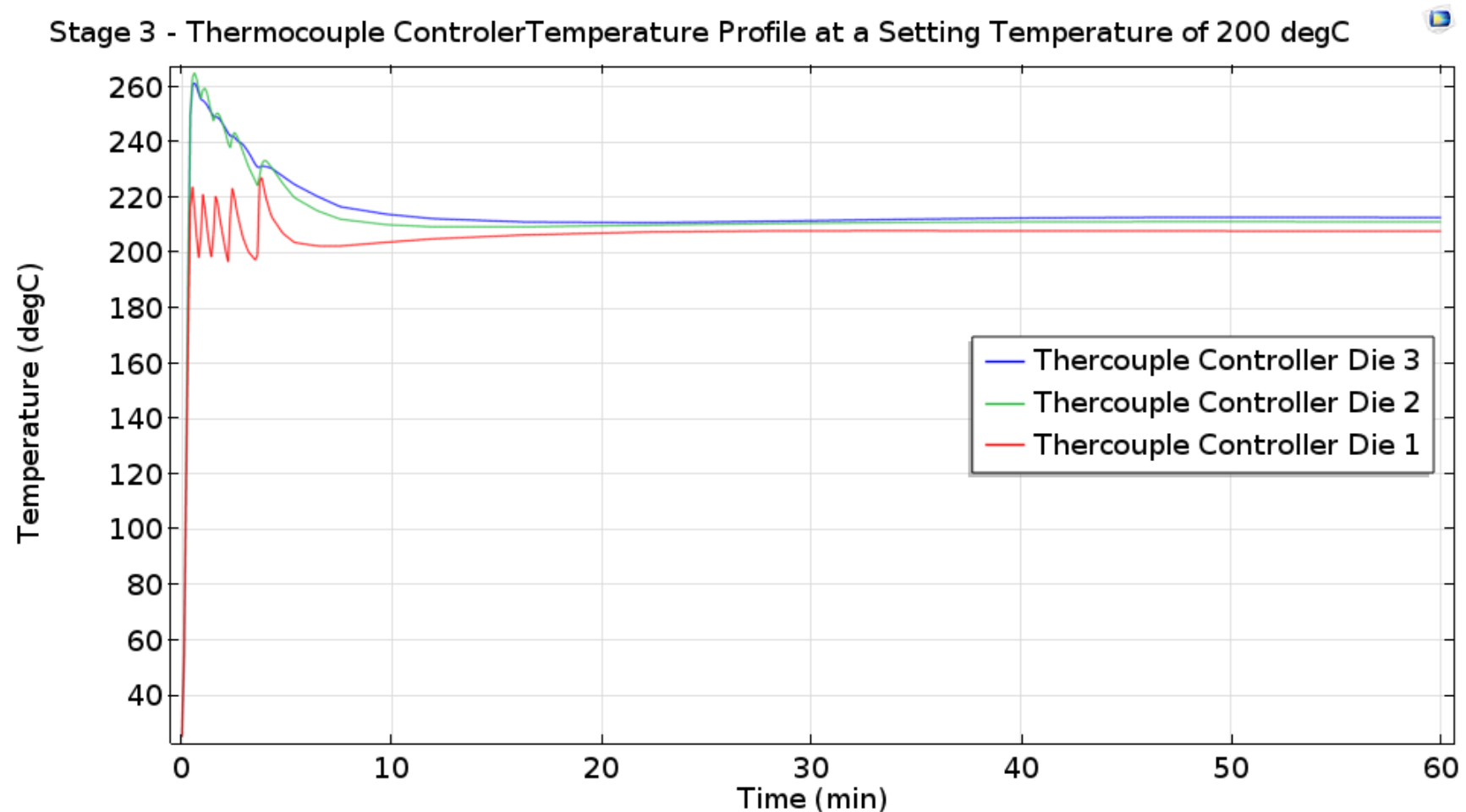
- Stationary
- Time Dependent

Heat Transfer In Fluids

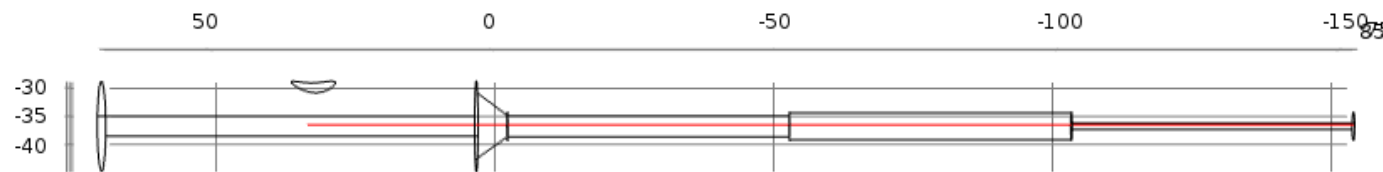
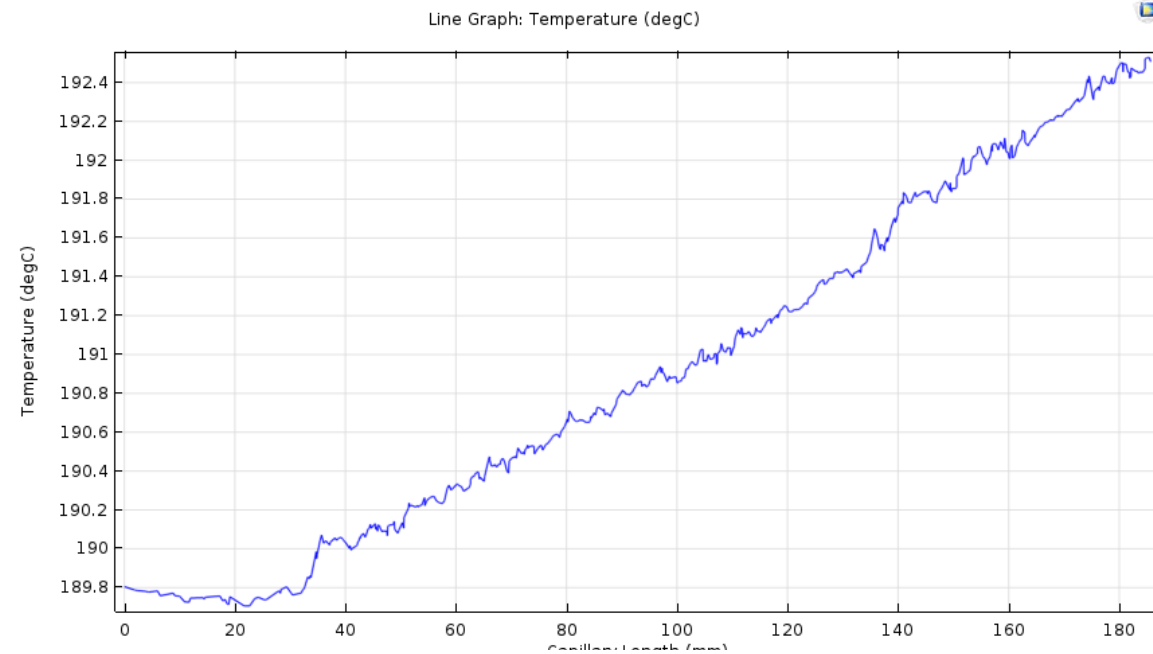
The screenshot displays the COMSOL Multiphysics software interface. The title bar indicates the file name: "Capillarydie-stage3_PP-190C-30rpm-Pow-iter2-NoHT-sol.mph - COMSOL Multiphysics". The interface is divided into several panels:

- Home Tab:** Contains various toolbars for model building, including "Application Builder", "Model Data Access", "Component 1 (comp1)", "Add Component", "Parameters", "Import", "Add Material", "Heat Transfer (ht)", "Add Physics", "Add Multiphysics", "Build Mesh", "Mesh 4", "Compute", "Study 1", "Add Study", "Temperature (ht) 1", "Add Plot Group", "Windows", and "Reset Desktop".
- Model Builder:** Shows a tree view of the model structure. The "Heat Transfer (ht)" node is expanded, showing "Heat Transfer in Fluids 1" selected. Other nodes include "Global Definitions", "Materials", "Component 1 (comp1)", "Definitions", "Geometry 1", "Materials", "High-strength alloy steel (mat1)", "PP (mat3)", "Laminar Flow (spf)", "Fluid Properties 1", "Initial Values 1", "Wall 1", "Inlet 1", "Outlet 1", "Events (ev)", "Multiphysics", "Mesh 4", "Study 1", and "Results".
- Settings Panel:** Displays the configuration for "Heat Transfer in Fluids 1".
 - Label:** Heat Transfer in Fluids 1
 - Domain Selection:** Selection: Manual. A list of domains is shown with "Active" status: 17, 18, 25, 26, 28.
 - Override and Contribution:** (Collapsed)
 - Equation:** (Collapsed)
 - Model Inputs:**
 - Absolute pressure: p_A Absolute pressure (nitf1)
 - Velocity field: u Velocity field (nitf1)
 - Concentration: c User defined
 - Coordinate System Selection:**
 - Coordinate system: Global coordinate system
 - Heat Conduction, Fluid:**
 - Thermal conductivity: (Field)
- Graphics Panel:** Shows a 3D visualization of the capillary die geometry. The die is a cylindrical component with a central bore and a flange. The coordinate system (x, y, z) is shown. The die is positioned in a 3D grid with axes ranging from -100 to 100.
- Progress Panel:** Shows "Progress", "Log", and "Table" tabs. The "Progress" tab is active, showing a progress bar and a "1.05 GB | 1.11 GB" indicator.

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



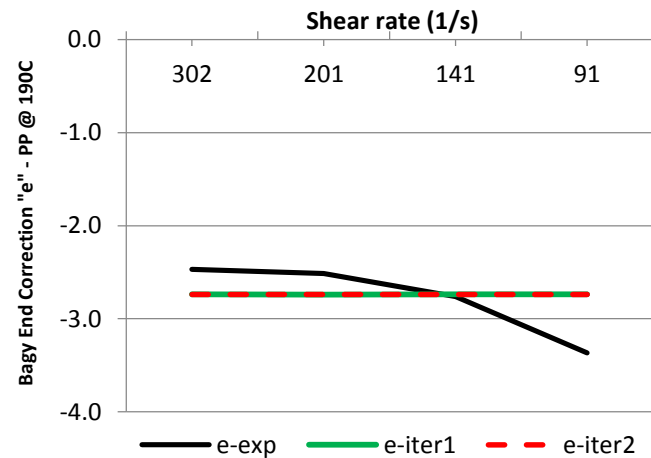
Temperature Profile along Capillary Length (for PP @190°C, shear rate around 287 1/s)



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 cm ³ /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		

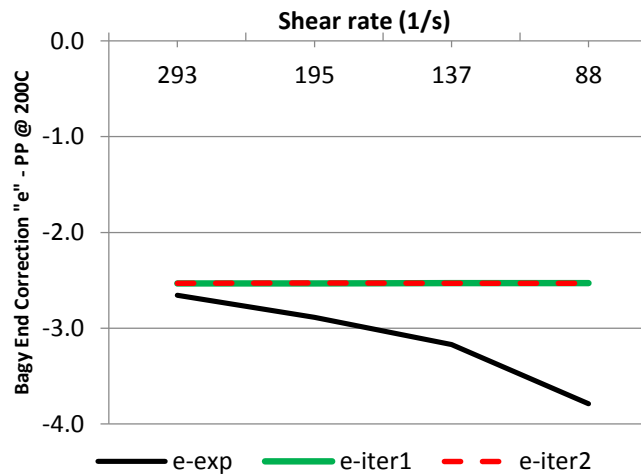


Solution for "e" completely converged at iteration 2

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 cm ³ /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		

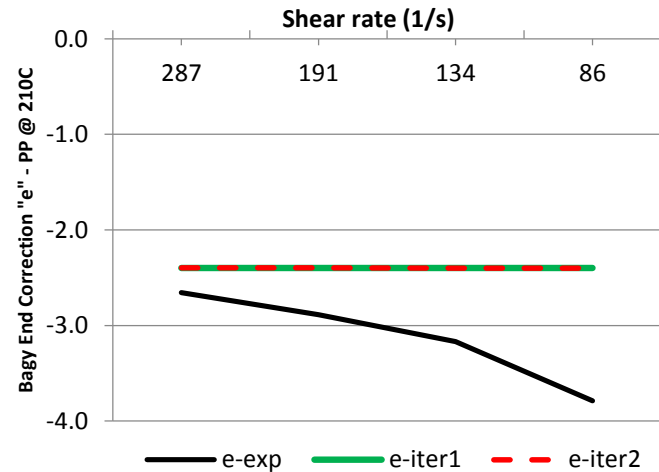


Solution for "e" completely converged at iteration 2

End Corrections & Power Law Coefficients

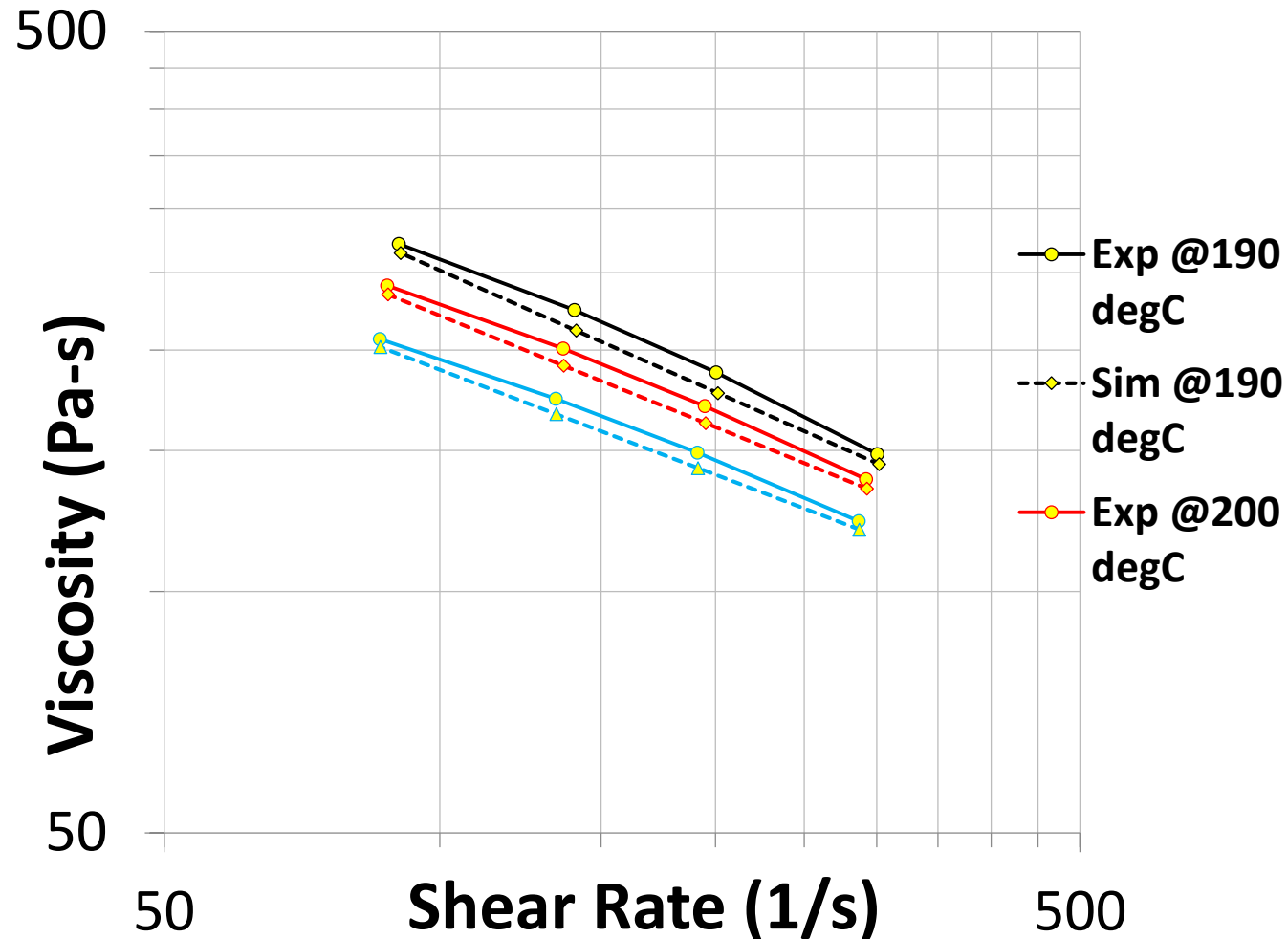
PP @ 210°C

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 cm ³ /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

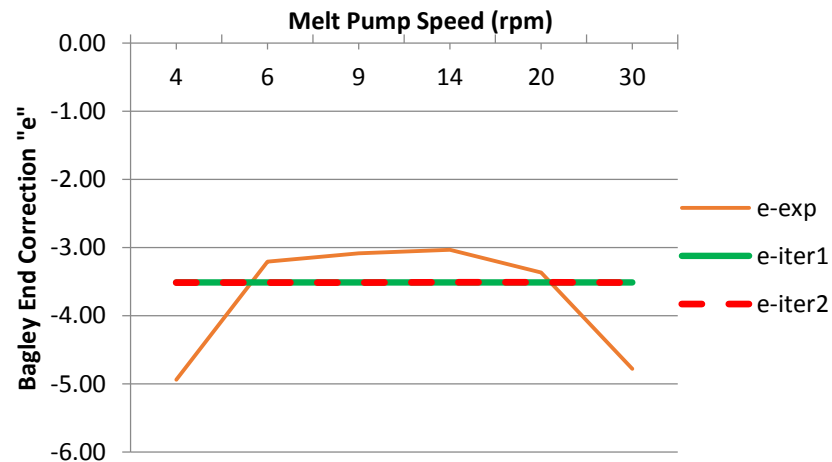


Simulation viscosity curves show 3 ~ 6% lower viscosity than experimental

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 cm ³ /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		

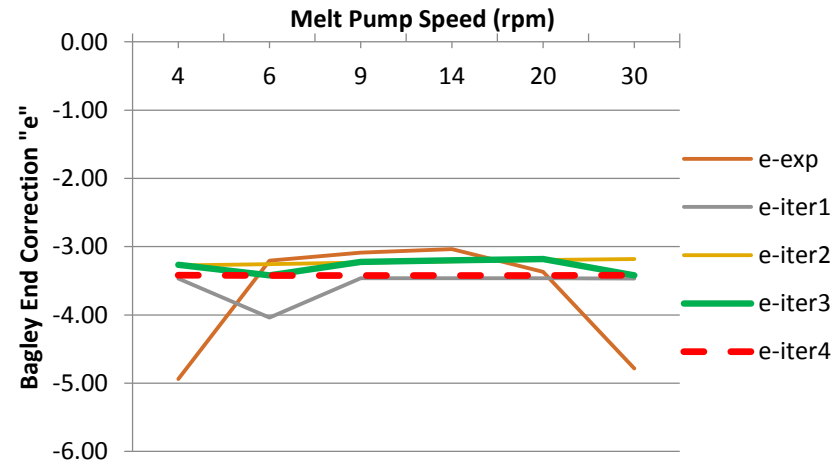


Solution for "e" completely converged at iteration 2

End Corrections & Power Law Coefficients

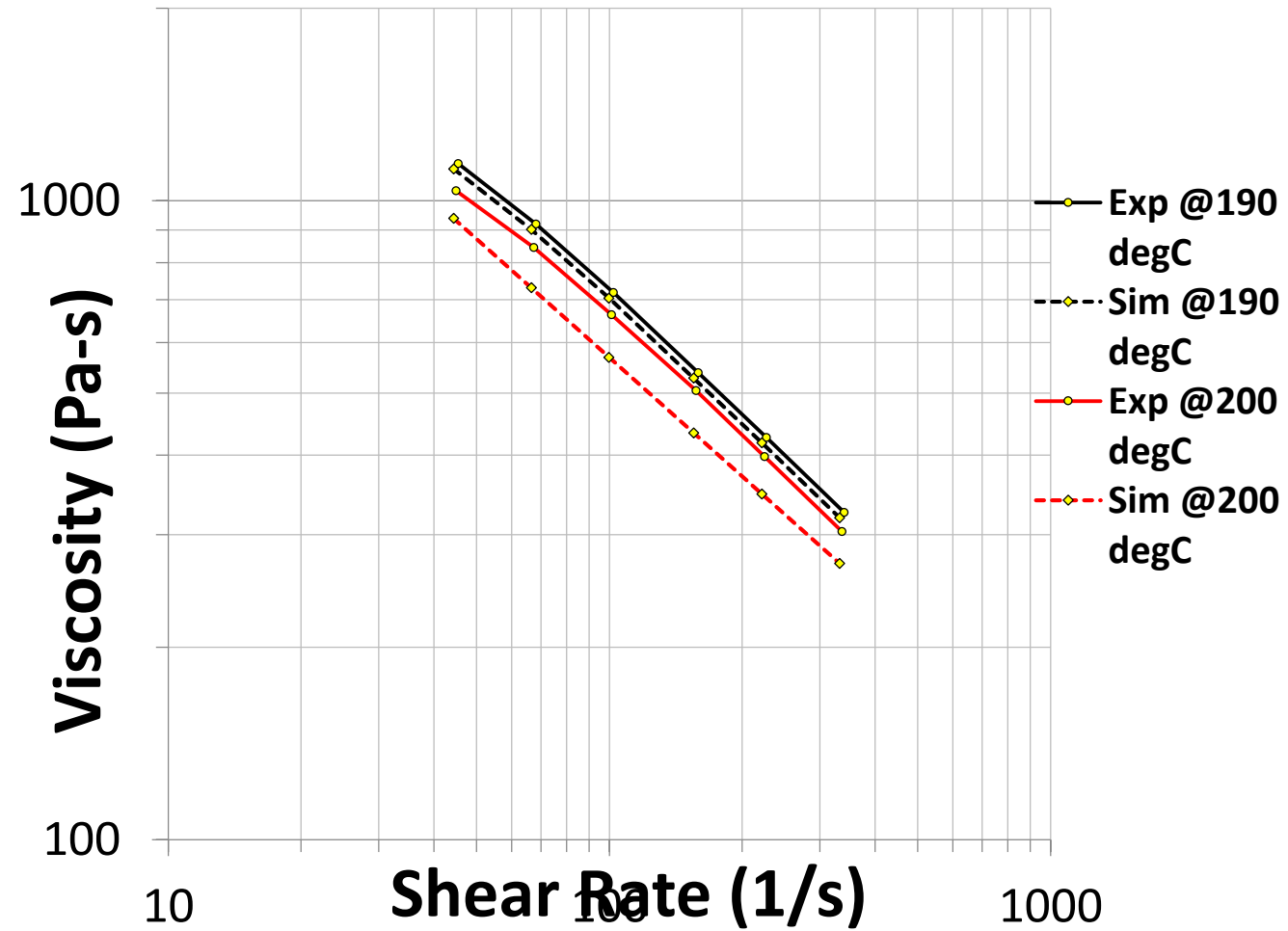
LDPE @ 200°C

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 cm ³ /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					
9	0.866	-3.09			-3.46			-3.23			-3.22					
14	1.347	-3.03			-3.46			-3.21			-3.20					
20	1.925	-3.37			-3.46			-3.20			-3.18					
30	2.887	-4.78			-3.46			-3.18			-3.42					



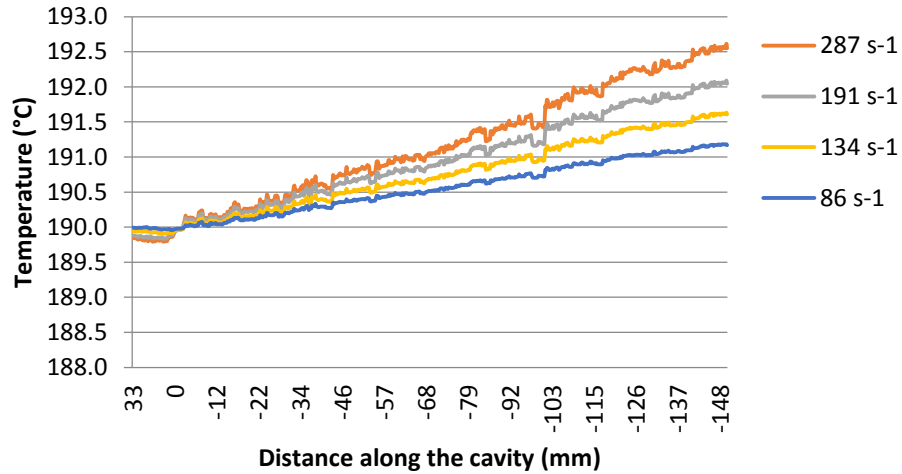
Solution for "e" completely converged at iteration 4

LDPE Viscosity Curves - Experimental vs Simulation

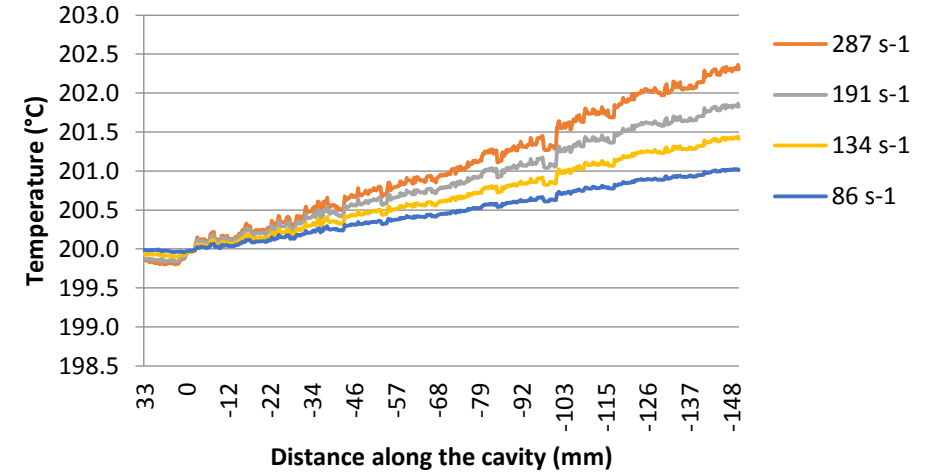


Viscous Heating Effect along Cavity – PP

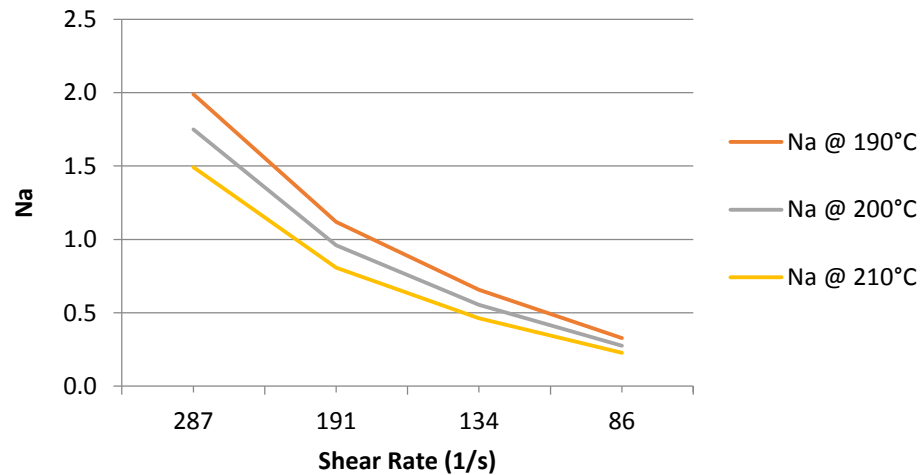
Viscous Heating Effect at 190°C



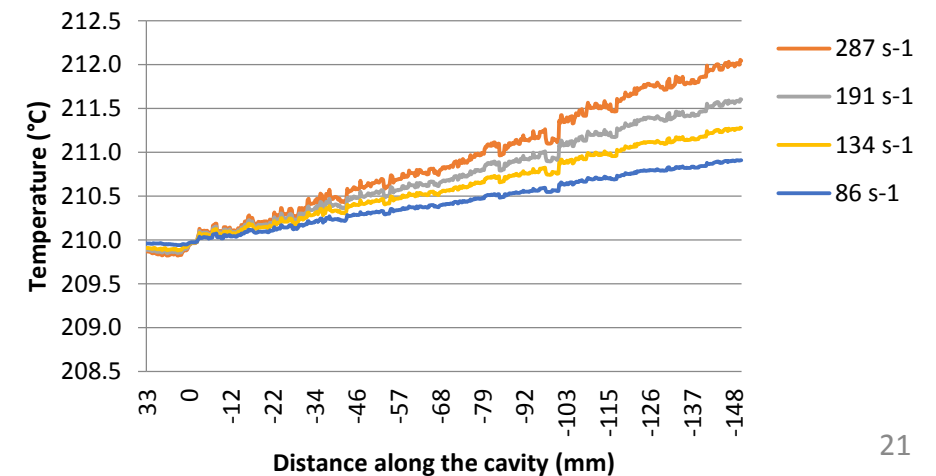
Viscous Heating Effect at 200°C



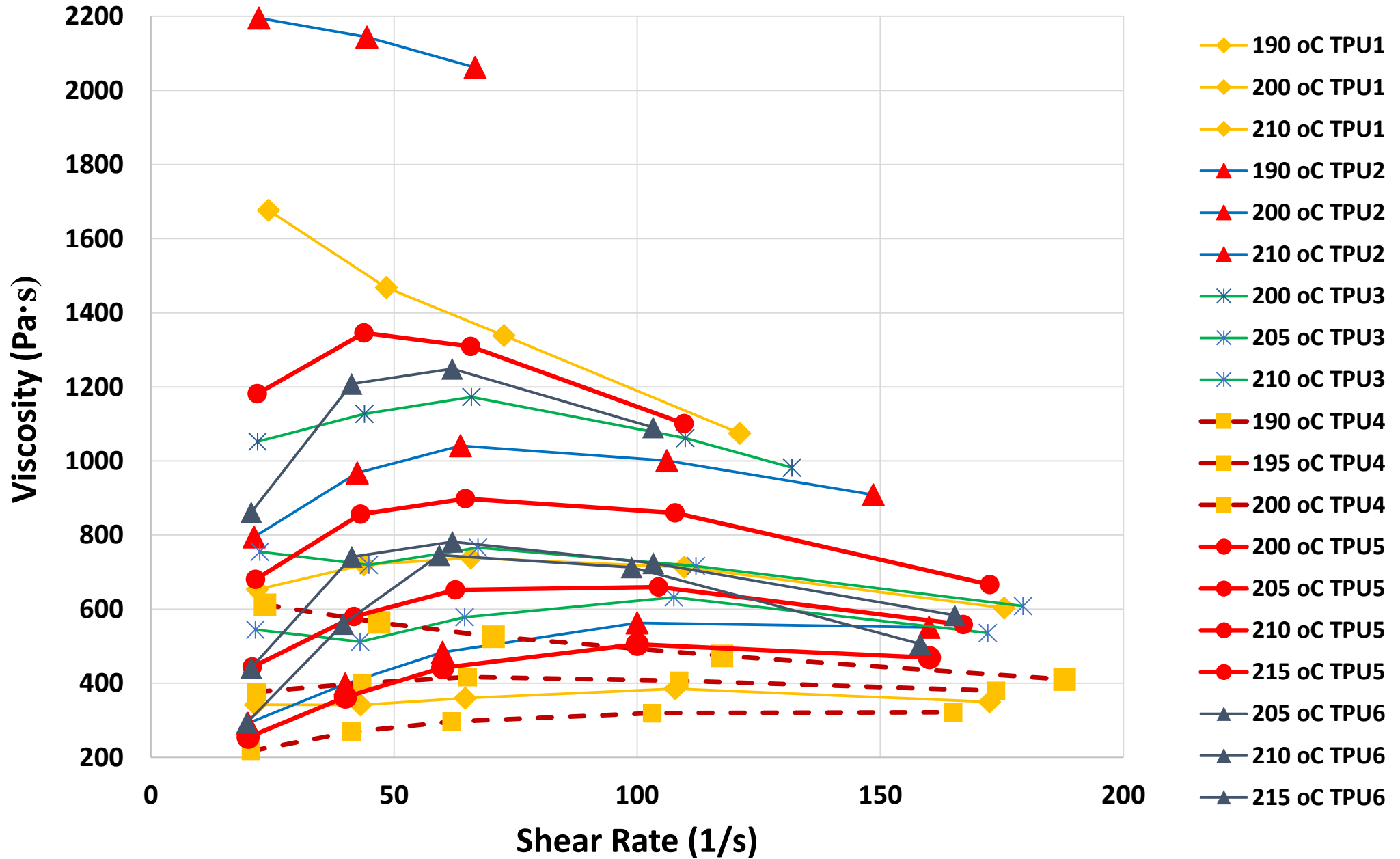
Nahme-Griffith number (Na) - PP



Viscous Heating Effect at 210°C



Viscosity of Thermoplastics Polyurethane Materials (Pa·s)



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**