

SPE EXTRUSION MINITEC

Profile-Tube Extrusion Die Design with Flow Simulation



Steve Schick
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Profile-Tube Extrusion Die Design with Flow Simulation

- Extrusion tooling for both profile and tube/pipe designs have evolved from split/insert dies to more complex designs incorporating EDM (both carbon and wire) and CNC.
- The design freedom gained from the use of this technology has allowed for the reduction of parts (SKUs) required to make a profile functional as well as the increase in co-extrusion dies to support a products form, fit and function.

Profile-Tube Extrusion Die Design with Flow Simulation

- The implementation of this mfg./design platform the tooling costs have increased, however the development costs for tuning in a die consume a greater percentage of the overall costs.
- The use of a flow analysis tool during the design phase can reduce the cost, timing and support the communications on the project development both internally and externally for an extrusion processor.

Profile-Tube Extrusion Die Design with Flow Simulation

- Why use Flow Simulation?
- Factors that Influence Flow Simulation in Extrusion
- ~~Review of Six (6) Step Process for Die Geometry Generation~~
- Utilizing Flow Simulation for Die Design and Process Development

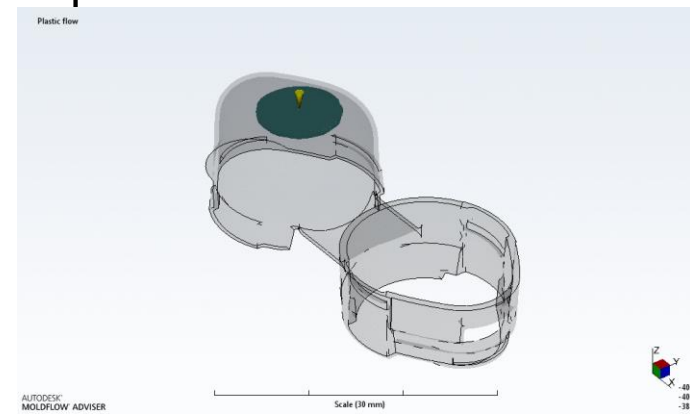
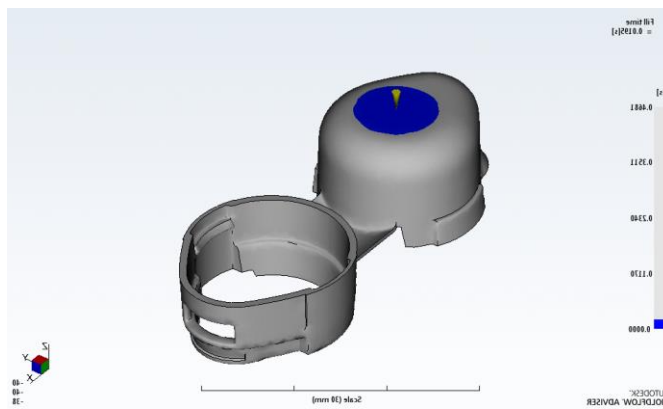
Profile-Tube Extrusion Die Design with Flow Simulation

- Why use Flow Simulation?



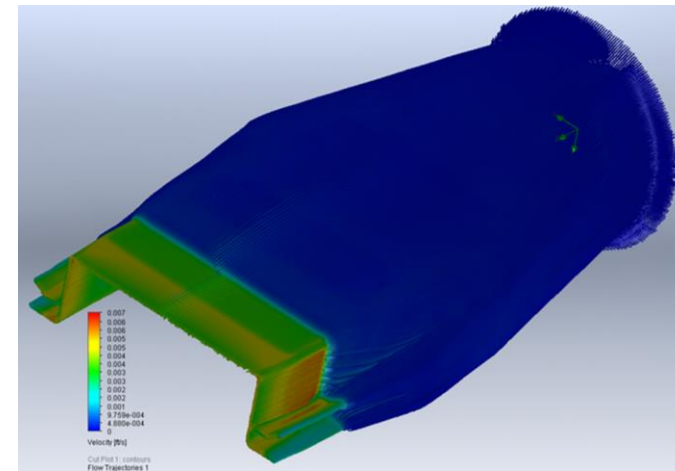
Why Use Flow Simulation?

- Understand current process conditions
- Determine alternative methods that can improve the process performance
- Determine the impact that rheological properties have on a current or future design
- Supports communication on polymer flow and the limitations of the design
- Provides input on the tool design and construction
- Reduces the costs of development and product lead-time



Factors that Influence Die Design

- Land Length and Land Length Ratio
 - Wall DDR (Draw Down Ratio)
- Die Design
 - Streamlined vs. Flat Back
- Process Temperature
- Surface Finish
- Output Rate (#'s or kg's per hour)
- Material Rheological Data



Die Designers Visual Guide of Polymers

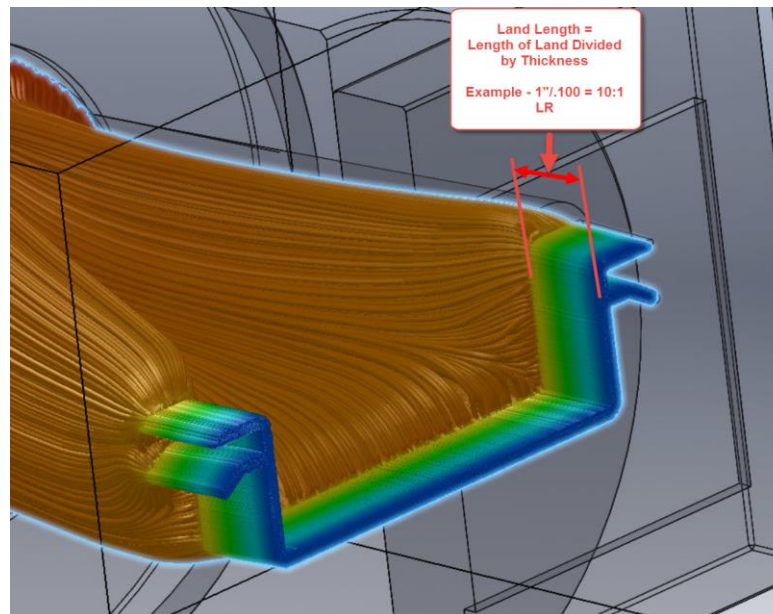
Polymer Abbreviations	Amorphous	Semi- Crystalline	Vicant Softening Point (°C)	Melting Point Tm (°C)	Glass Transistion Tg (°C)	Power Law Index, n	Density	Melt Strength (1-Poor 10 Great)	Glutinously (1-Poor 10 Great)	Draw Down (≥125#'s Hr)	Land Length (Walls .020"- .060")	Calibration		Sizing Plates		Die Design Minimums (Eight Hour Runs)		
												Wet	Dry	Wet (Sizing Tank)	Dry (Air Rack)	Flat Back	Semi- Streamlined	Stream-lined
PVC	Yes	-	92	-	80	0.3	1.4g/cm3	9	9	4-10%	10:1*	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PETG	Yes	-	85	-	80	0.66	1.27g/cm3	3	3	40-100%	25:1	Yes	Yes	Yes	No	No	No	Yes
Acrylic	Yes	-	99	-	105	0.25	1.11g/cm3	5	5	10-20%	15:1	Yes	Yes	Yes	Yes	No	Yes	Yes
ASA	Yes	-	98	-	100	0.713	1.05g/cm3	3	3	10-20%	10:1	Yes	No	Yes	No	No	Yes	Yes
ABS	Yes	-	103	-	115	0.25	1.04g/cm ³	8	7	15-25%	15:1	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PS	Yes	-	106	-	101	0.3	1.04g/cm3	8	8	15-25%	20:1	Yes	Yes	Yes	Yes	No	Yes	Yes
PC	Yes	-	146	-	146	0.7	1.20g/cm3	4	3	12-20%	15:1	Yes	No	Yes	No	No	No	Yes
SAN	Yes	-	106	-	115	0.3	1.06g/cm3	6	3	15-25%	15:1	Yes	No	Yes	No	No	Yes	Yes
CAB	Yes	-	115	-	140	.66*	1.2g/cm3	3	3	30-100%	25:1	Yes	Yes	Yes	No	No	Yes	Yes
TPU	Yes	-	87	-	80	0.28	1.19g/cm3	6	6	15-40%	15:1	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PEEK	Yes	Yes	-	343	143	0.553	1.28g/cm3	4	4	100-200%	15:1	Yes	Yes	Yes	Yes	No	No	Yes
PPS	-	Yes	-	280	90	0.52	1.4g/cm3	4	5	50-100%	20:1	Yes	No	Yes	No	No	Yes	Yes
PET	-	Yes	-	250	74	0.6	1.41g/cm3	2	2	100-200%	30:1	Yes	No	Yes	No	No	Yes	Yes
Nylon 6	-	Yes	-	225	50	0.7	1.07g/cm3	5	6	20-40%	20:1	Yes	Yes	Yes	Yes	No	Yes	Yes
Nylon 12	-	Yes	-	180	35	0.52	1.035g/cm3	6	4	20-40%	20:1	Yes	No	Yes	No	No	Yes	Yes
Acetal	-	Yes	-	175	-30	0.743	1.41g/cm3	6	4	60-80%	20:1	Yes	No	Yes	No	No	No	Yes
PVDF	-	Yes	-	160	-38	0.38	1.78g/cm3	3	3	20-50%	15:1	Yes	No	Yes	No	No	No	Yes
PP	-	Yes	-	175	-10	0.35	0.9g/cm3	6	4	40%	20:1	Yes/No	No	Yes	No	Yes	Yes	Yes
HDPE	-	Yes	-	130	-120	0.5	0.964g/cm3	6	3	40%	20:1	No	No	Yes	No	Yes	Yes	Yes
PBT	-	Yes	-	250	45	0.6	1.3g/cm3	2	4	20-45%	20:1	Yes	No	Yes	No	No	Yes	Yes
LDPE	-	Yes	-	120	-120	0.35	0.921g/cm3	4	2	40%	20:1	Yes	No	Yes	No	Yes	Yes	Yes

Die Designers Visual Guide of Polymers

Polymer Abbreviations	Draw Down (≥125#'s Hr)	Land Length (Walls .020" - .060")	Calibration		Sizing Plates		Die Design Minimums (Eight Hour Runs)		
			Wet	Dry	Wet (Sizing Tank)	Dry (Air Rack)	Flat Back	Semi- Streamlined	Stream-lined
PVC	4-10%	10:1*	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PETG	40-100%	25:1	Yes	Yes	Yes	No	No	No	Yes
Acrylic	10-20%	15:1	Yes	Yes	Yes	Yes	No	Yes	Yes
ASA	10-20%	10:1	Yes	No	Yes	No	No	Yes	Yes
ABS	15-25%	15:1	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PS	15-25%	20:1	Yes	Yes	Yes	Yes	No	Yes	Yes
PC	12-20%	15:1	Yes	No	Yes	No	No	No	Yes
SAN	15-25%	15:1	Yes	No	Yes	No	No	Yes	Yes
CAB	30-100%	25:1	Yes	Yes	Yes	No	No	Yes	Yes
TPU	15-40%	15:1	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PEEK	100-200%	15:1	Yes	Yes	Yes	Yes	No	No	Yes
PPS	50-100%	20:1	Yes	No	Yes	No	No	Yes	Yes
PET	100-200%	30:1	Yes	No	Yes	No	No	Yes	Yes
Nylon 6	20-40%	20:1	Yes	Yes	Yes	Yes	No	Yes	Yes
Nylon 12	20-40%	20:1	Yes	No	Yes	No	No	Yes	Yes
Acetal	60-80%	20:1	Yes	No	Yes	No	No	No	Yes
PVDF	20-50%	15:1	Yes	No	Yes	No	No	No	Yes
PP	40%	20:1	Yes/No	No	Yes	No	Yes	Yes	Yes
HDPE	40%	20:1	No	No	Yes	No	Yes	Yes	Yes
PBT	20-45%	20:1	Yes	No	Yes	No	No	Yes	Yes
LDPE	40%	20:1	Yes	No	Yes	No	Yes	Yes	Yes

Factors that Influence Die Design

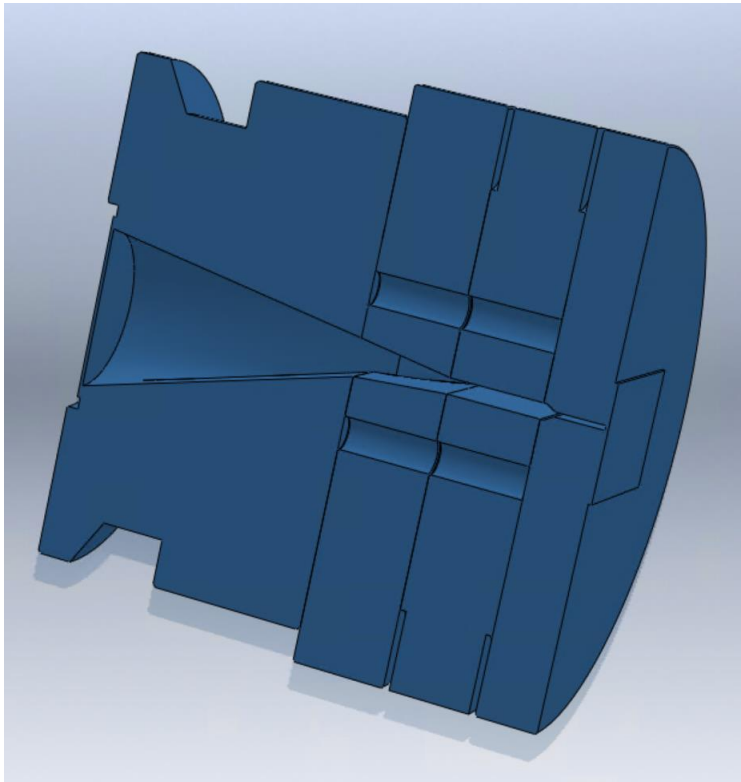
- Land Length and Land Length Ratio (LLR)
 - Land length –
 - Area of steel that run linear to the die exit
 - Provides “memory” to the part shape or size
 - A low LLR results in die swell – minimum value recommended is 10:1
 - Walls to print or swell factor depending upon polymer and die residence time



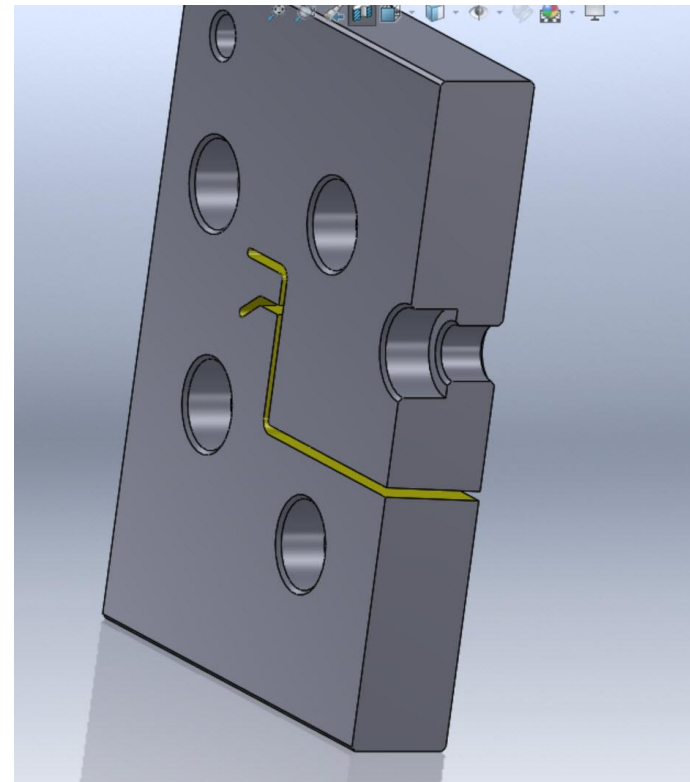
Factors that Influence Die Design

- Die Design

Streamlined

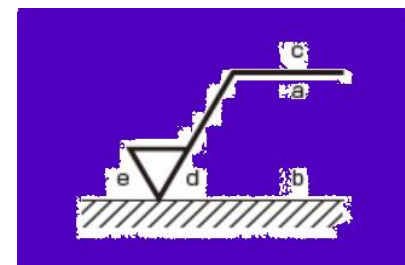
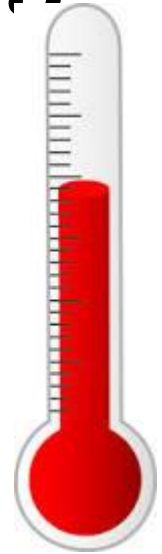


Flat Back



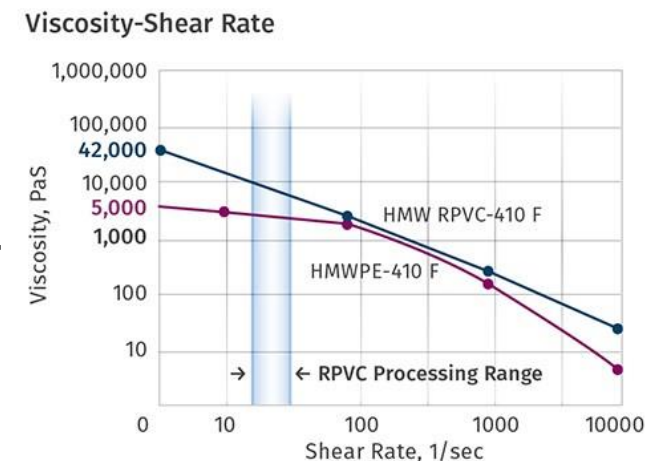
Factors that Influence Die Design

- Process Temperature
 - Consult your Material Supplier for Process Set-Points
 - Review your Current Product/Processes for the Average Melt Temperature you Process at your Plant Today
 - Set a Standard for the Process Temperature to Develop Modeling Standards
- Surface Finish – What is your Value?
 - Plated – Hard w/Flash, Nickel, Teflon (i.e.)
 - Polished – To What Level
 - How do you maintain the level – (manual polish or Extrudehone)
 - WEDM finish
 - Rough vs. Finish Cuts (Develop a Standard)
 - Many Processors complete two finish cuts (higher costs)
 - Steel Selection does Impact Longevity of Steel Finish

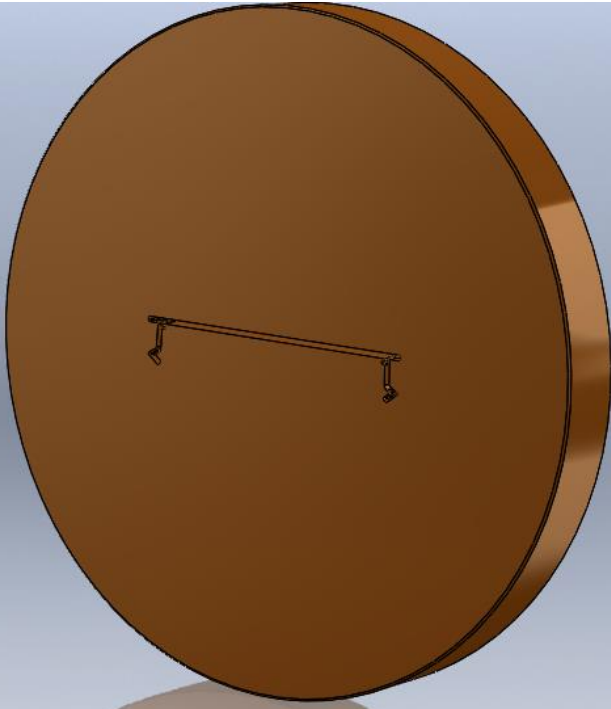


Factors that Influence Die Design

- Output Rate (#'s or kg's per hour)
 - Process or Residence Time Considerations
 - Related to Process/Product Costs (i.e. feet per hour)
 - Material Properties (i.e. process stability, drying, melting, conveying)
- Material Rheological Data
 - Model the appropriate Shear Rate for the Polymer
 - Develop a Material Database for your House Resins



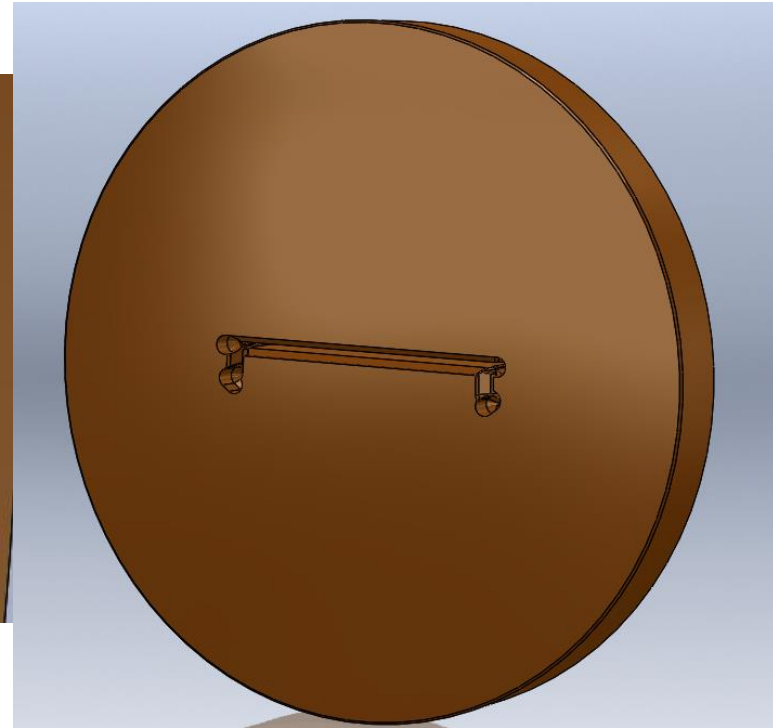
Utilizing Flow Simulation for Die Design and Process Development



Die Exit

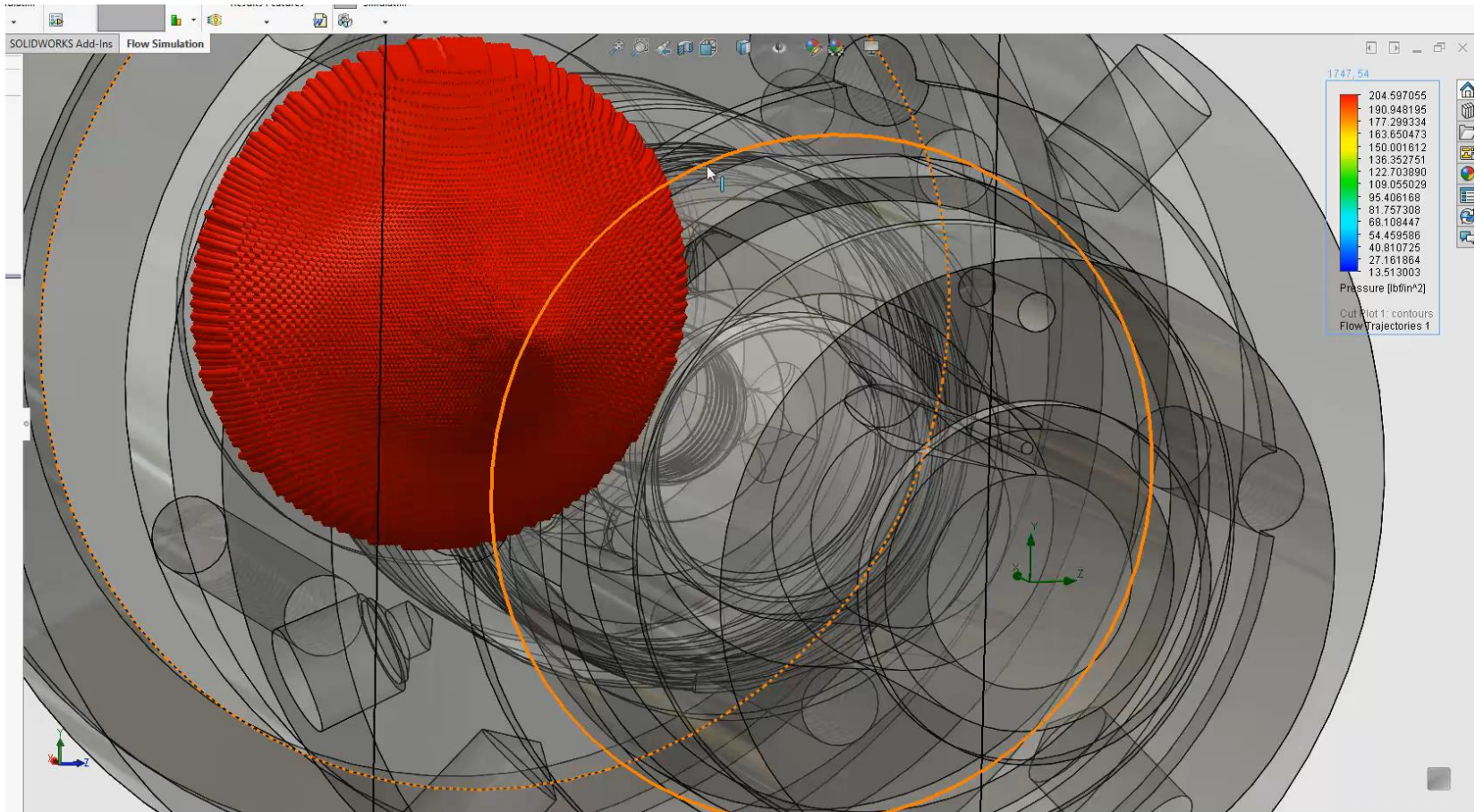


Side View –
Land Drop



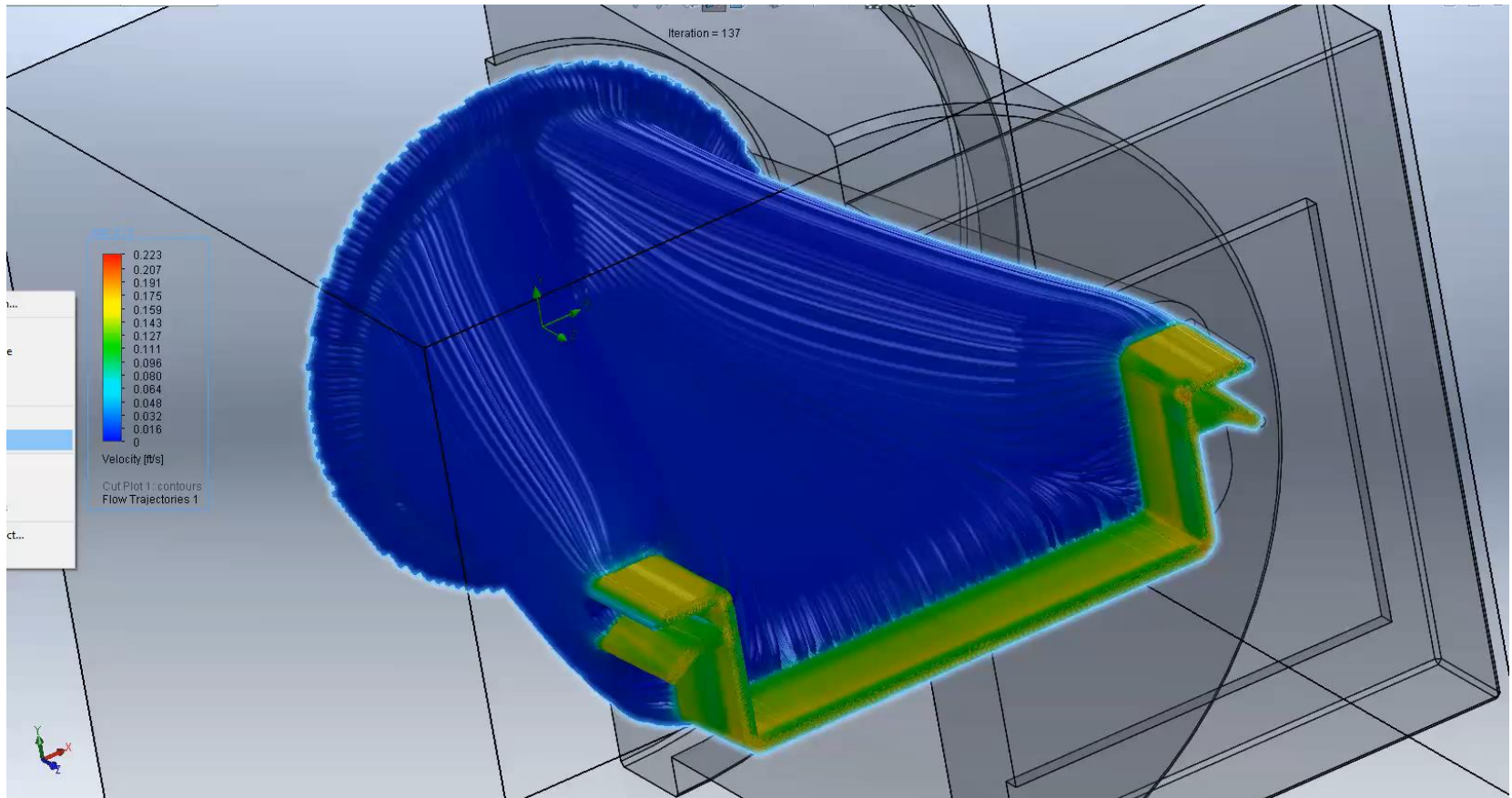
Die
Entry

Profile-Tube Extrusion Die Design with Flow Simulation



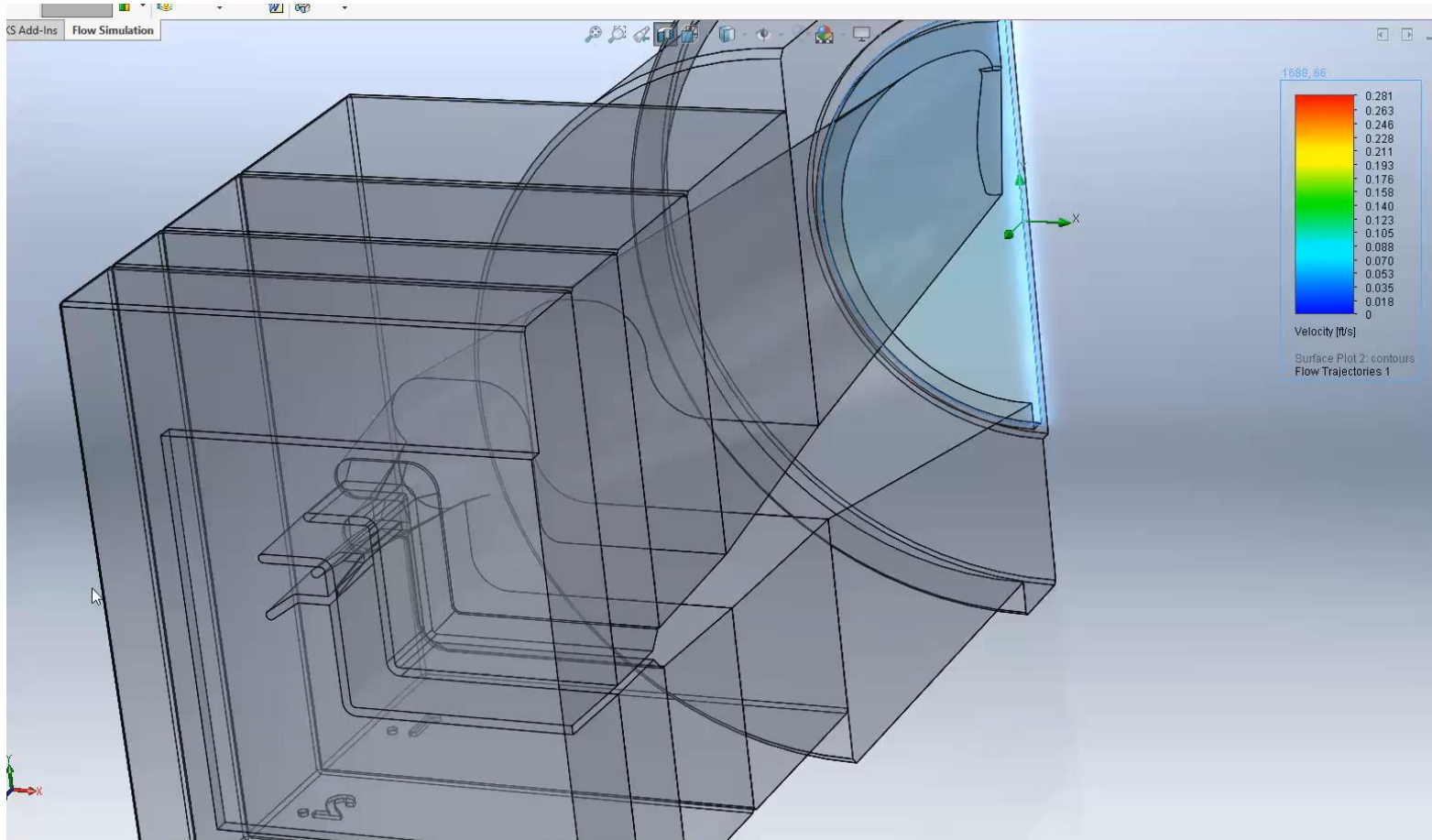
Modeling a Multi-Lumen

Profile-Tube Extrusion Die Design with Flow Simulation



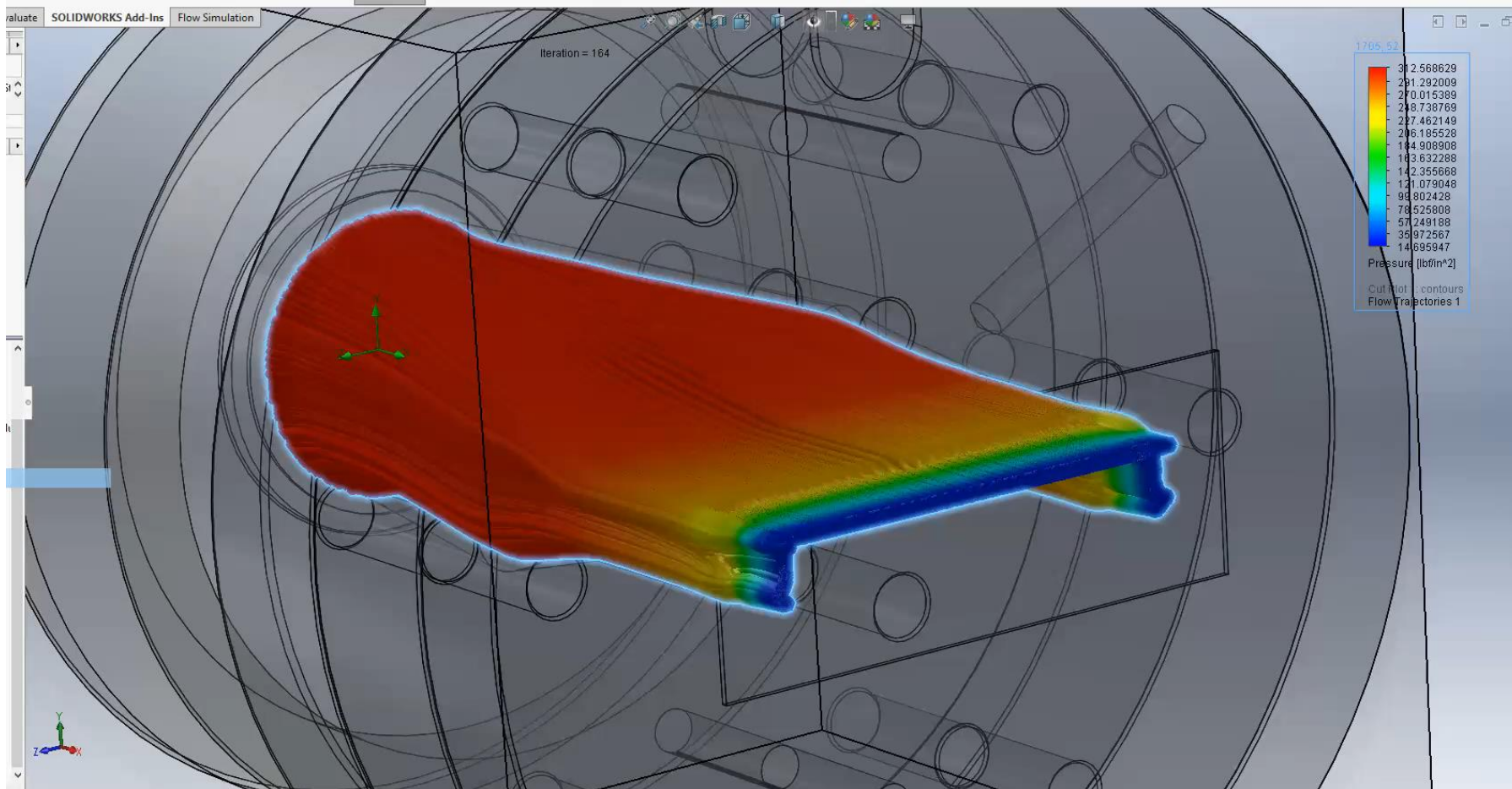
Modeling of Semi-Streamlined Die

Profile-Tube Extrusion Die Design with Flow Simulation



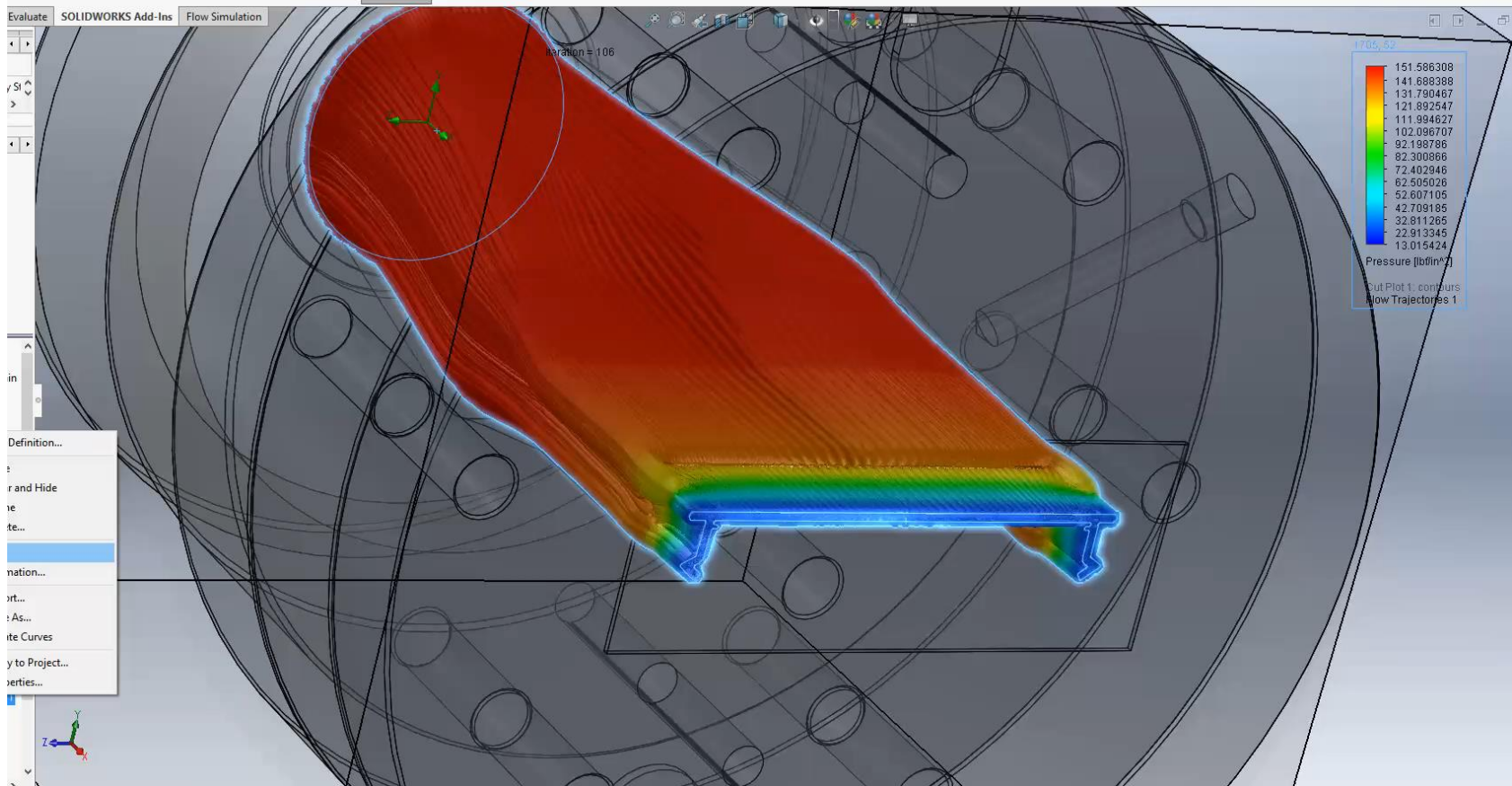
Modeling of Streamlined Die

Profile-Tube Extrusion Die Design with Flow Simulation



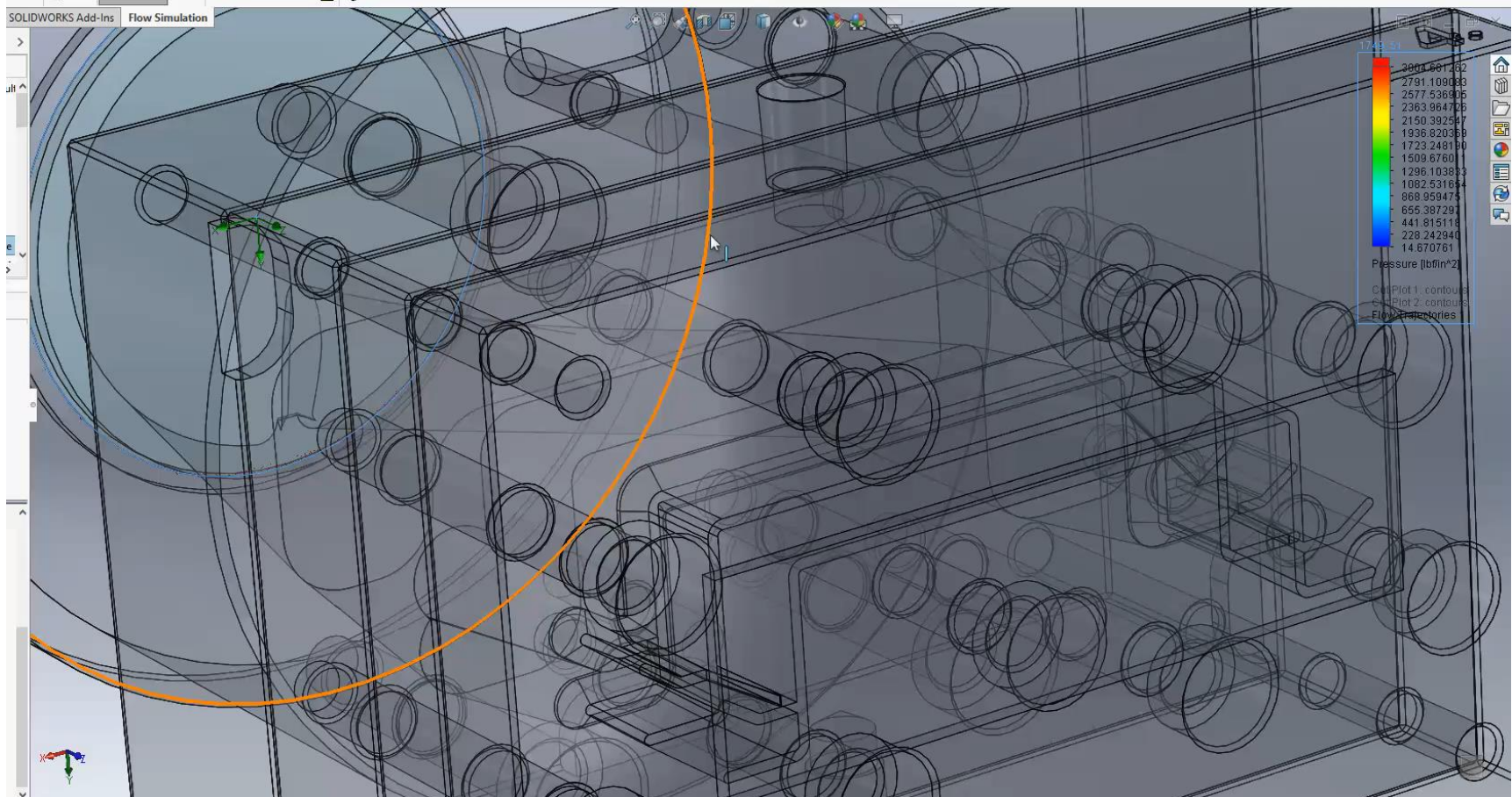
Acrylic Model – Land Length

Profile-Tube Extrusion Die Design with Flow Simulation



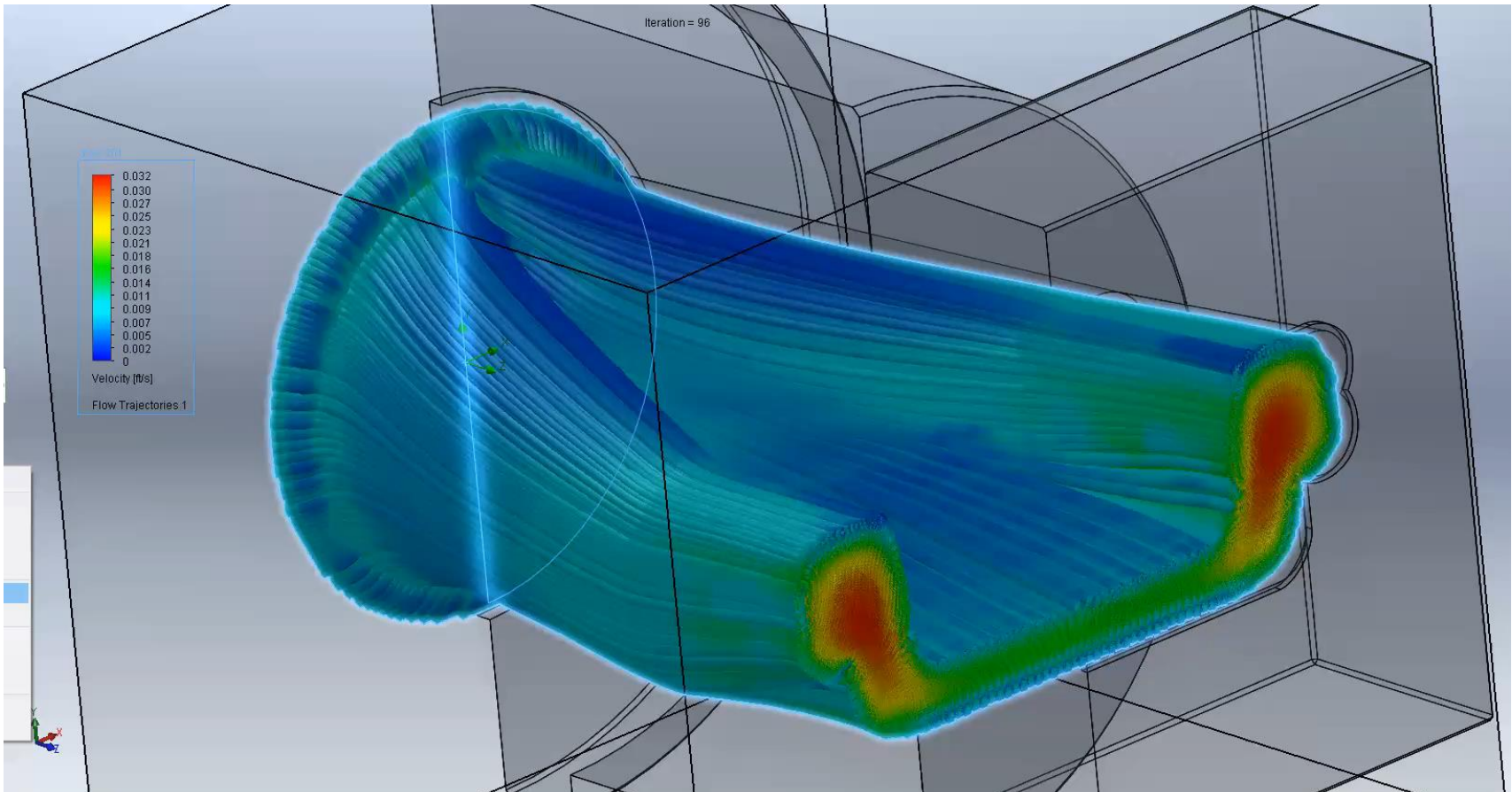
HDPE Model – No Land Length Change

Profile-Tube Extrusion Die Design with Flow Simulation



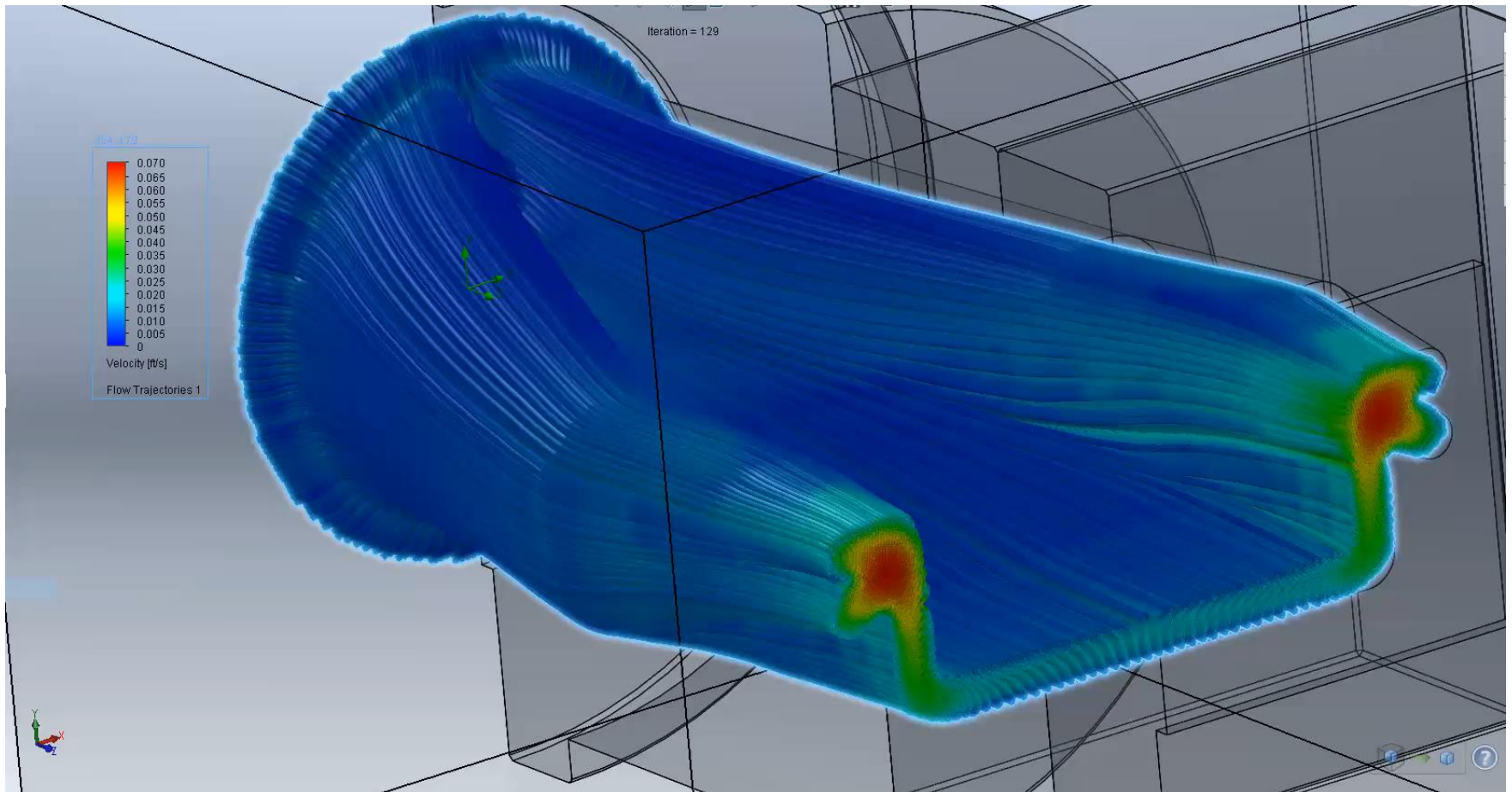
PVC Model

Profile-Tube Extrusion Die Design with Flow Simulation



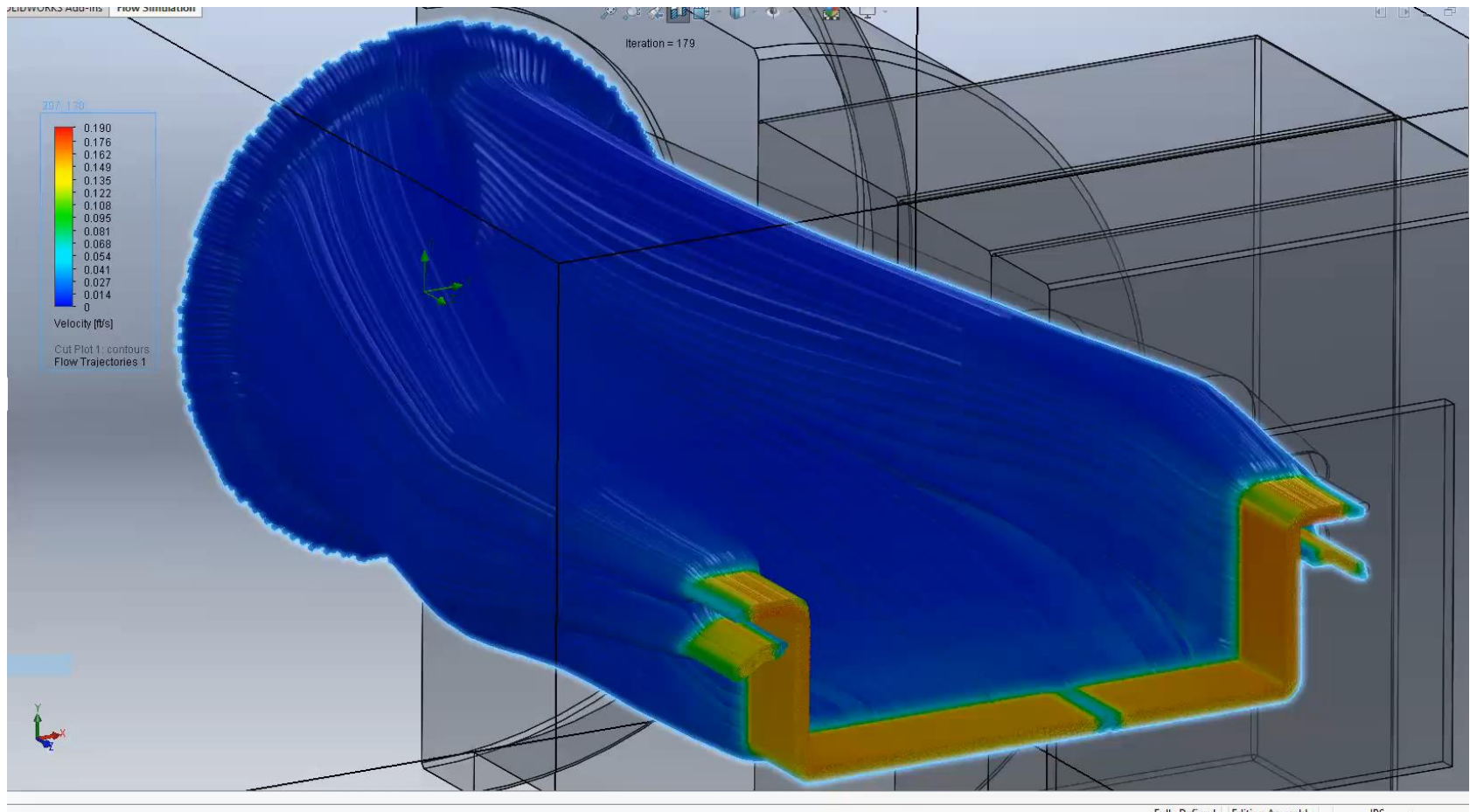
Model of Gate/Sleeve Alone

Profile-Tube Extrusion Die Design with Flow Simulation



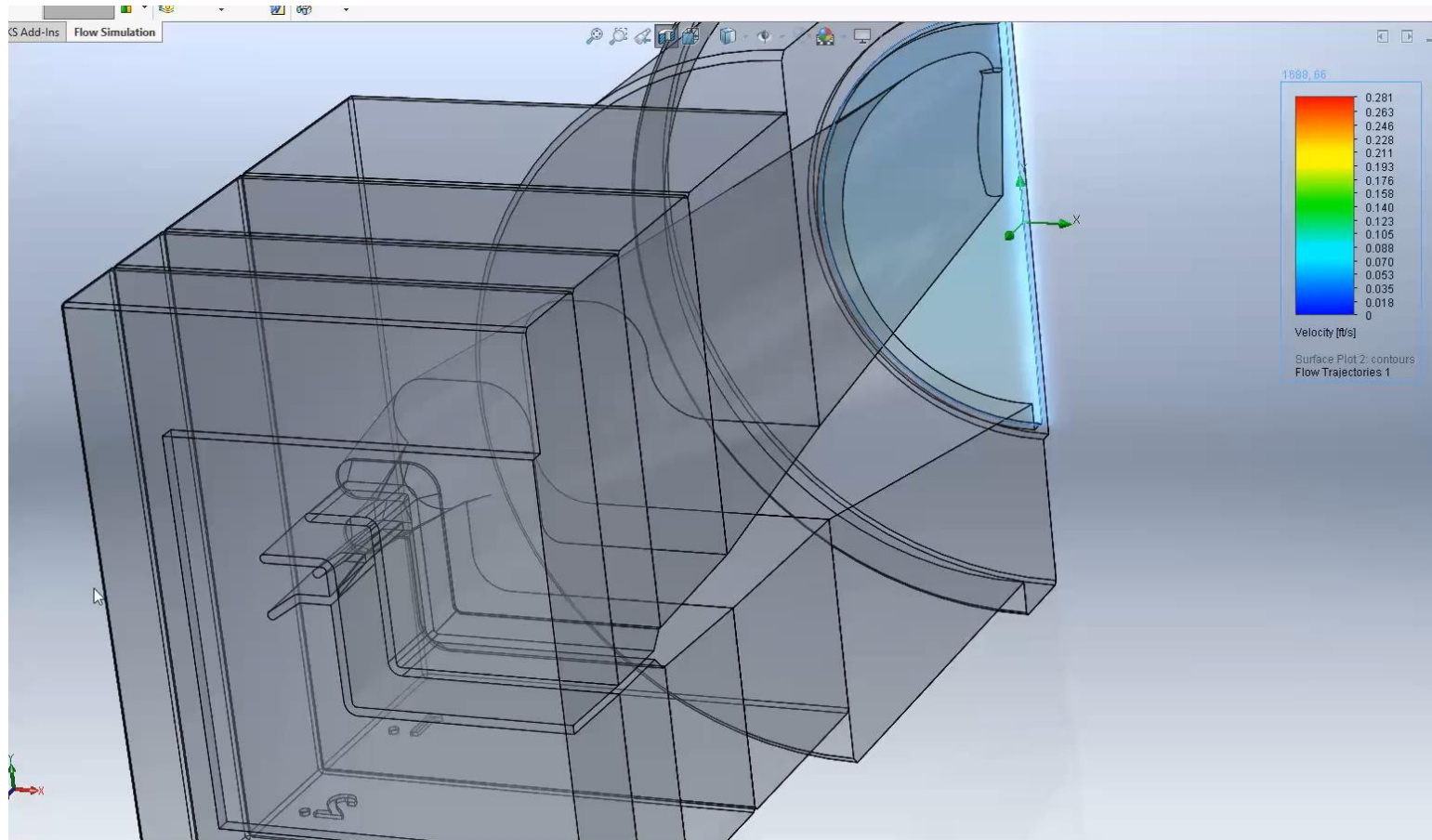
Model of Gate & Lead-In Alone

Profile-Tube Extrusion Die Design with Flow Simulation



Model of Gate, Lead-In & Transition

Profile-Tube Extrusion Die Design with Flow Simulation



Model of Gate, Lead-In, Transition & Die Plate

Antec Paper (2013) – Optimizing Pipe Extrusion Dies Using Numerical Simulation

John Puentes

- Under the direction of:
- Professor Tim A. Osswald

 Polymer Engineering Center
University of Wisconsin - Madison

The logo for the Polymer Engineering Center at the University of Wisconsin - Madison. It features a large, stylized blue number "7" to the left of the text "Polymer Engineering Center" in a blue, sans-serif font. Below this, the text "University of Wisconsin - Madison" is written in a smaller, black, sans-serif font.

In Collaboration with:
Steve Schick and Jed Berg

Degradation during Processing/Reprocessing of HDPE

Causes of degradation

- Temperature history
- Shear history
- Longer Residence time
- Oxygen
- Catalyst residuals

Detection of degradation in HDPE

Phillips-type HDPE (Cross-linking)

MW ↑

η ↑

MFI ↓

Ziegler-type HDPE (Chain scission)

MW ↓

η ↓

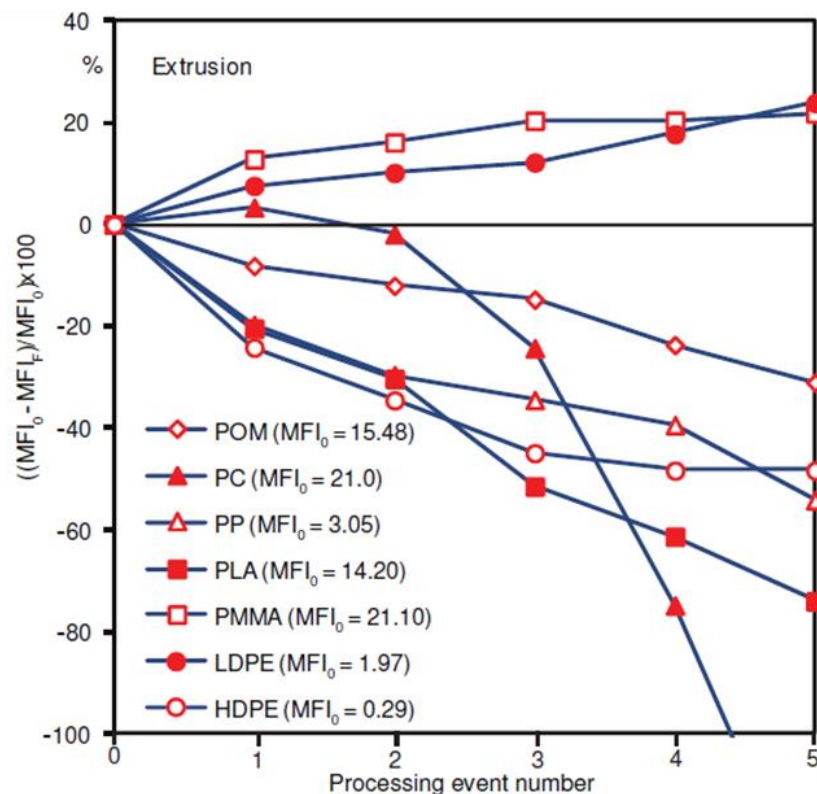
MFI ↑

Gels on the surface of a Polyolefin Pipe



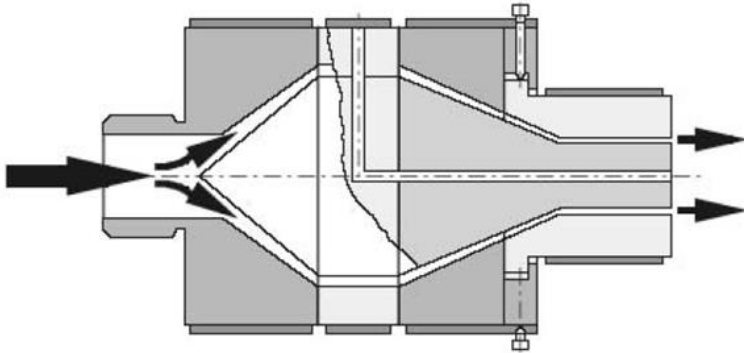
Changes in MFI over Several Extrusion Events

Change in MFI as a function of number of extrusion processing events [1].

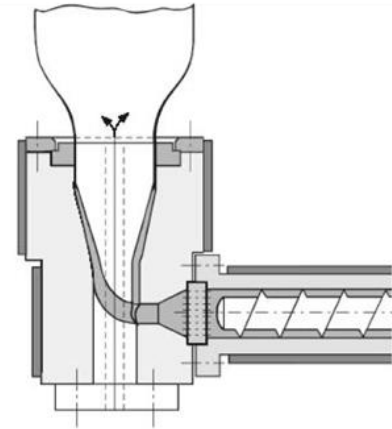


Pipe and Tubular Dies

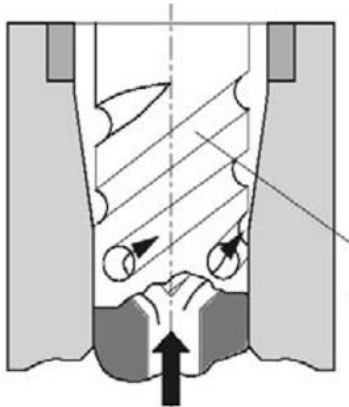
Spider leg tubing die



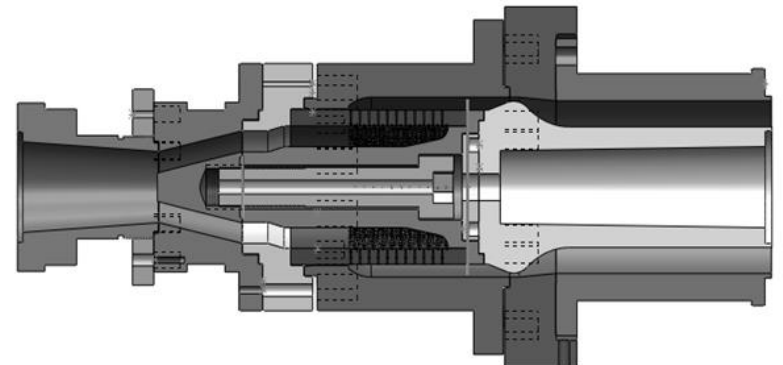
Cross-head tubing die



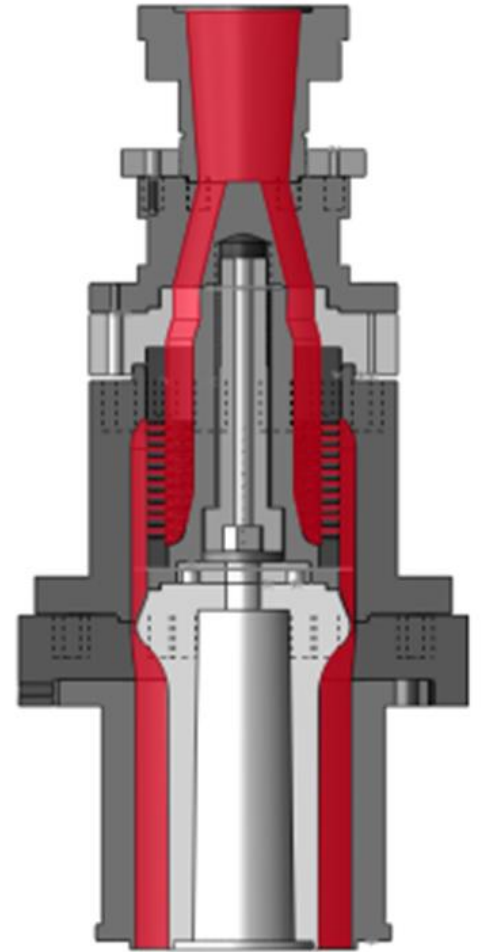
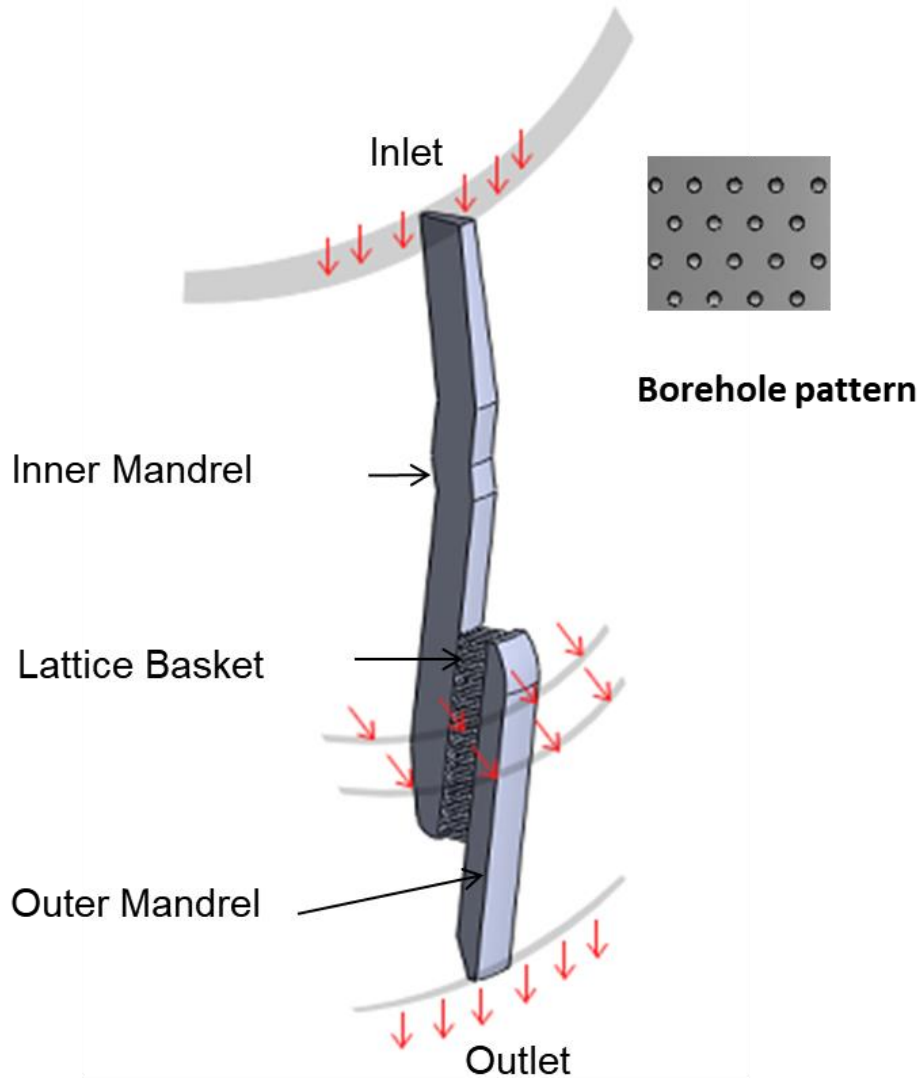
Spiral mandrel



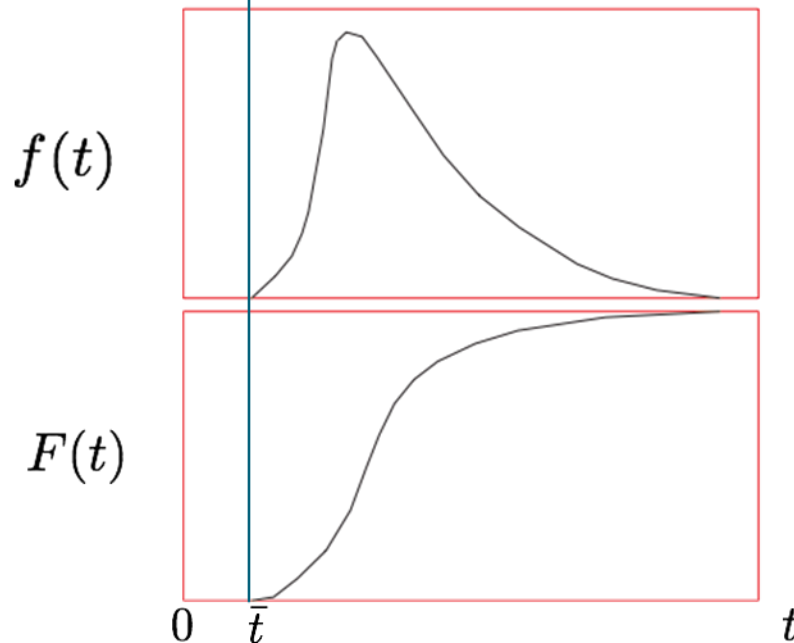
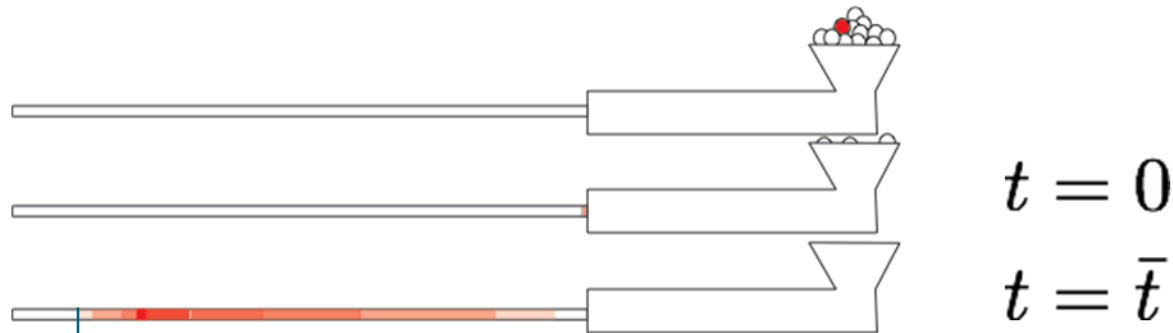
Lattice Basket



Lattice Basket Die



RTD and CRTD



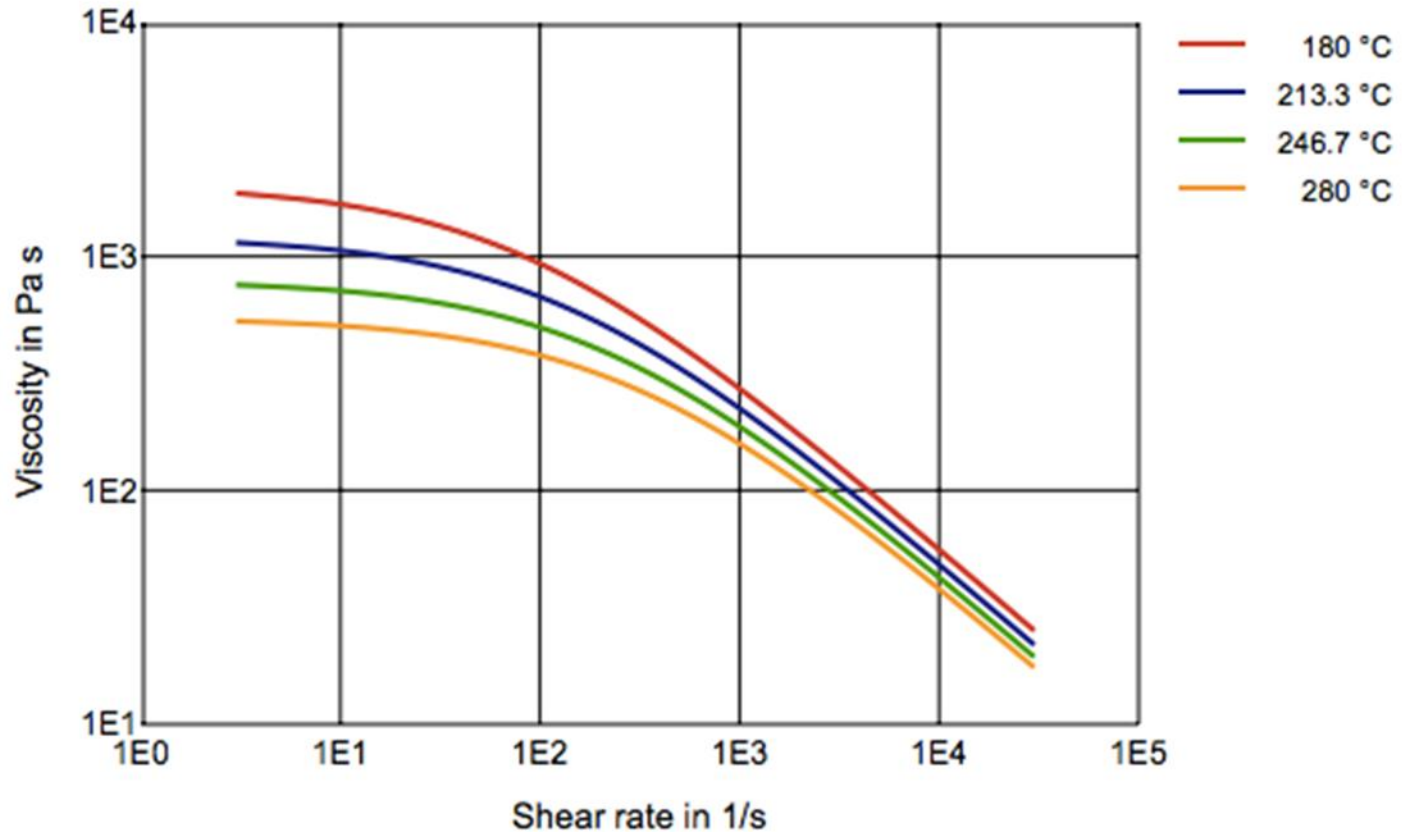
**Residence Time
Distribution (RTD)**

**Cumulative Residence
Time Distribution (CRTD)**

$$F(t) = \int_0^t f(t) dt$$

Case Study

- Viscosity data of Chevron Phillips Marlex HDPE [2]



Lattice Basket Die

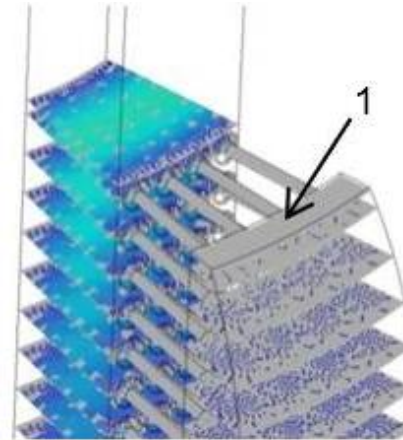
2000 Particles



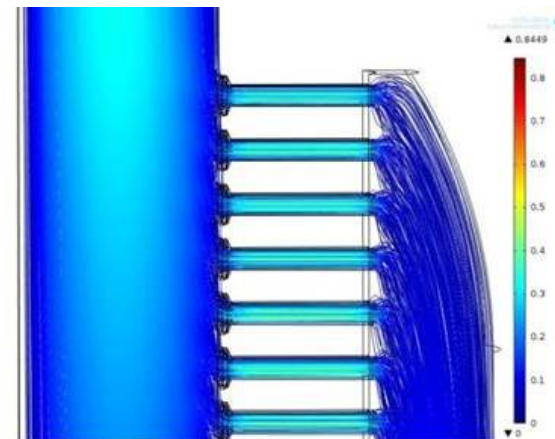
No-slip walls

Outlet

Poincaré sections

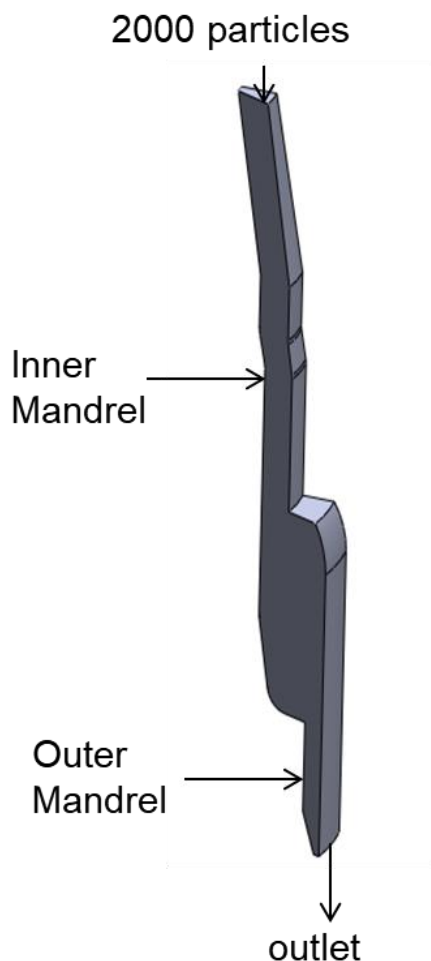


Tracer curves

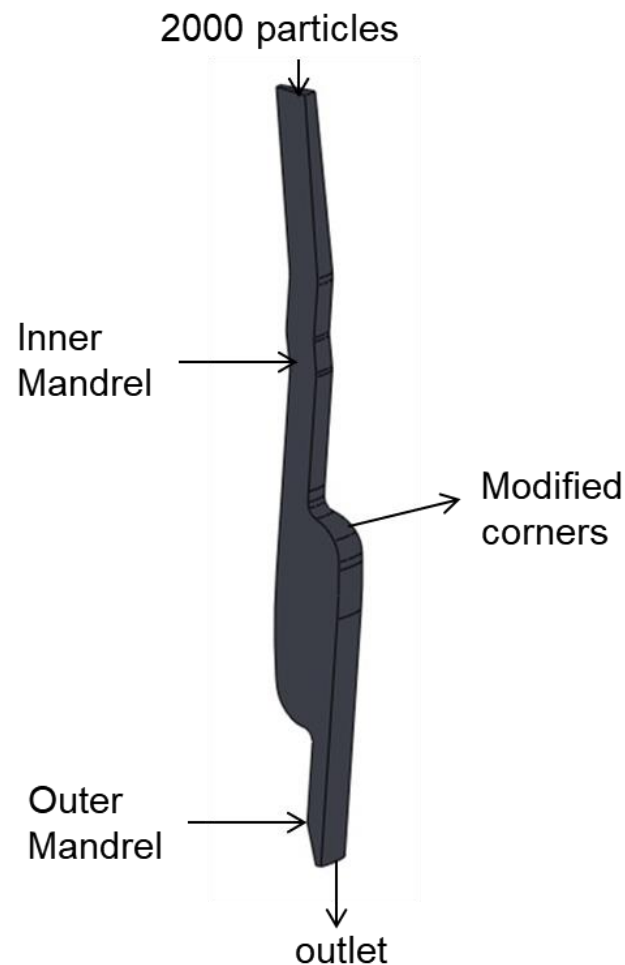


Optimization of the Mandrels

Die without lattice

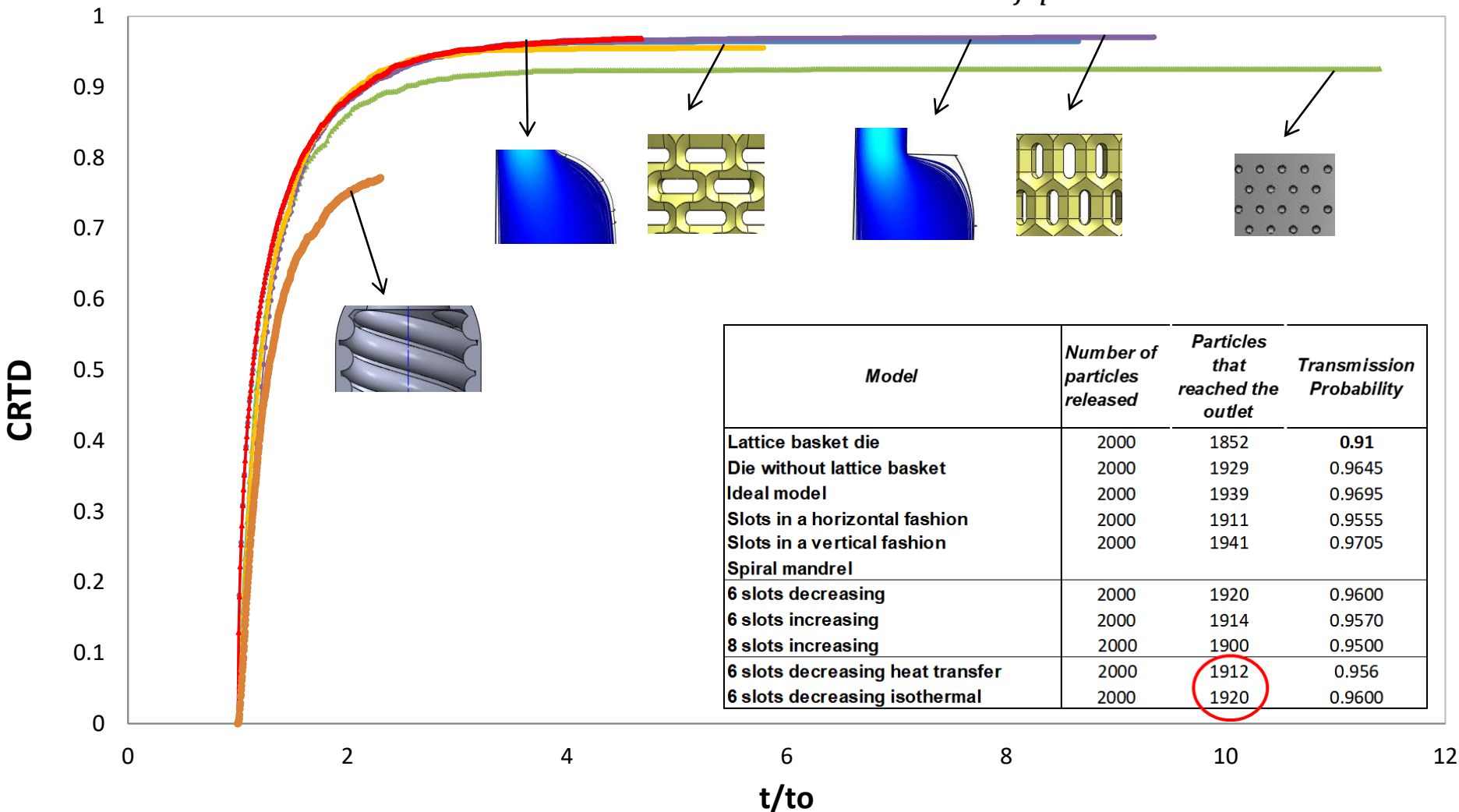


Hypothetical model



CRTD

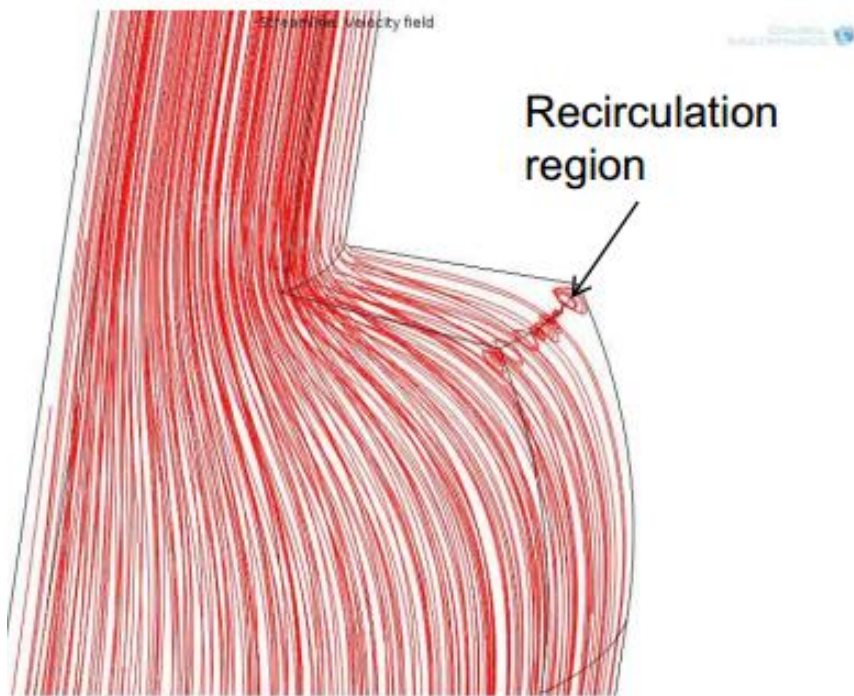
$$\text{Transmission Probability} = \frac{\text{number of particles which reach the outlet}}{\text{number of particles released}}$$



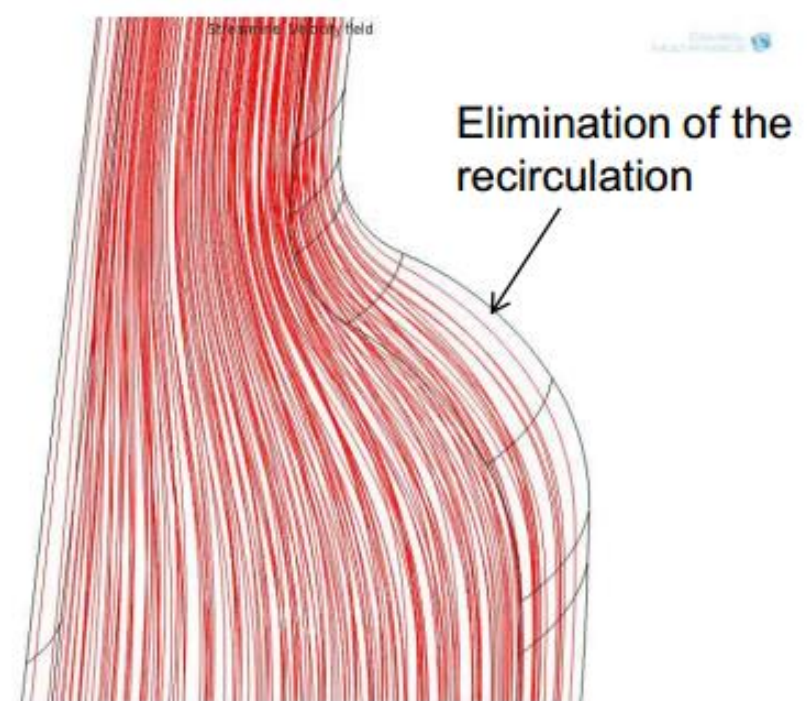
Recirculation in Sharp Corners

- Streamline Results

Die without lattice

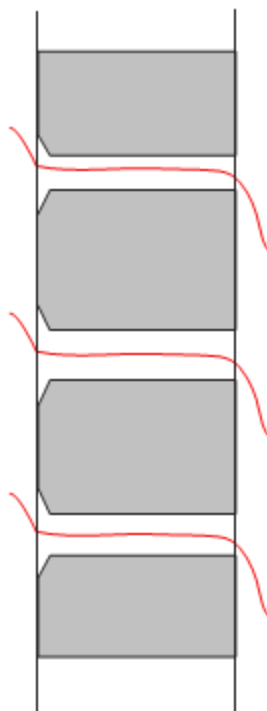


Hypothetical model

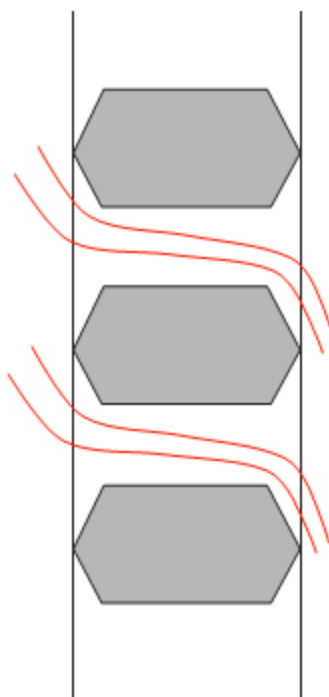


Optimization of the Die Cavities

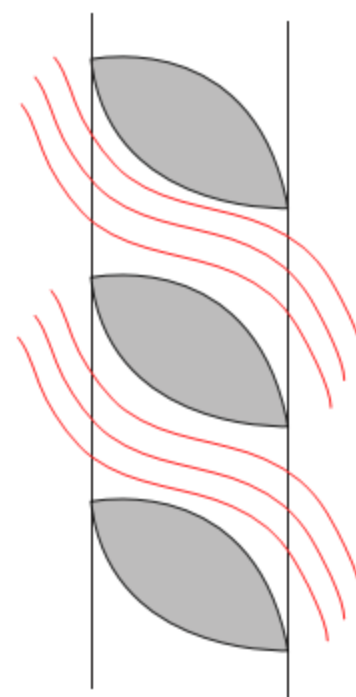
Borehole pattern



Machineable profile

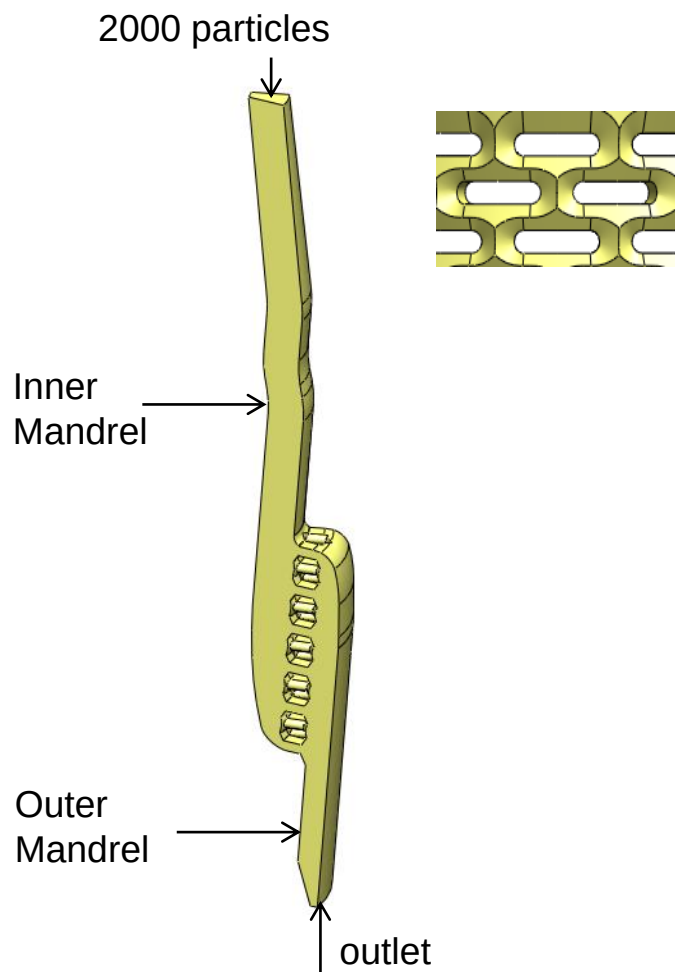


Ideal model

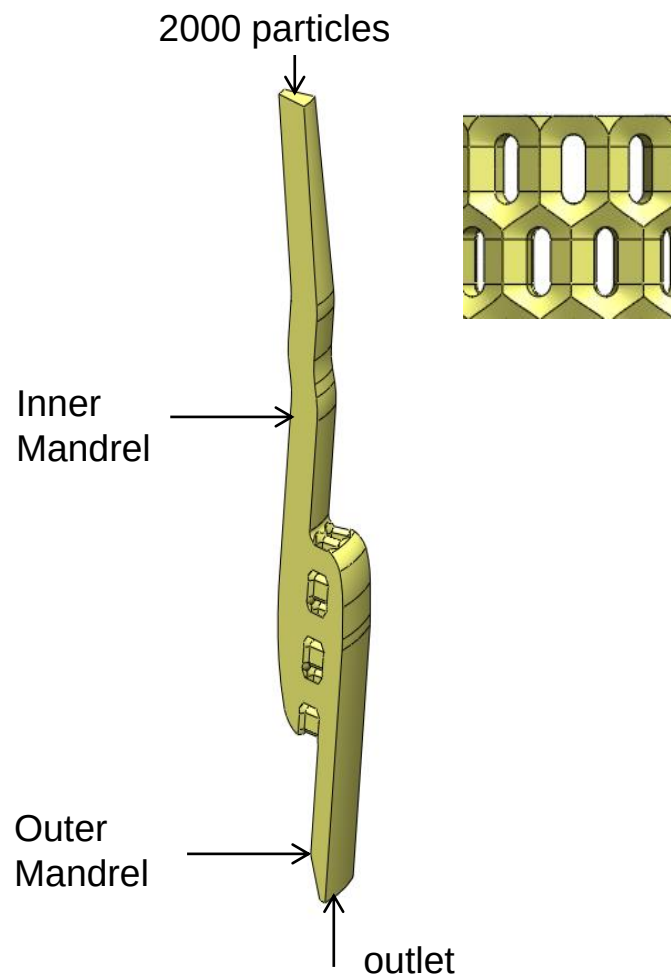


Novel Flow Channel Profiles

Horizontal slots



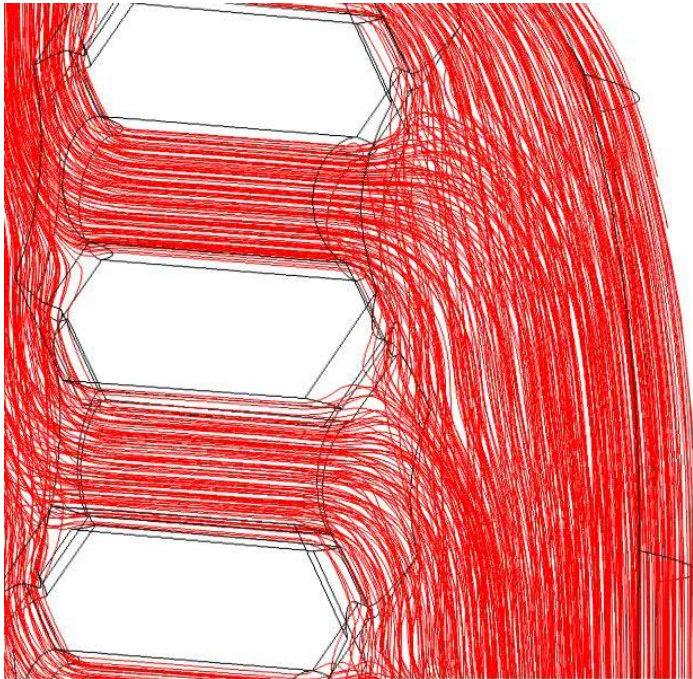
Vertical slots



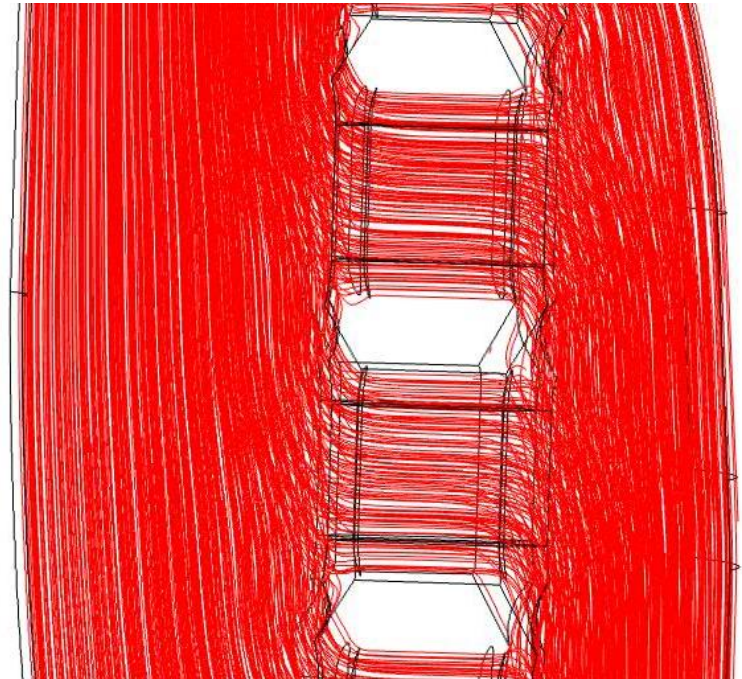
Novel Flow Channel Profiles

- Streamline Results

Lattice with horizontal slots

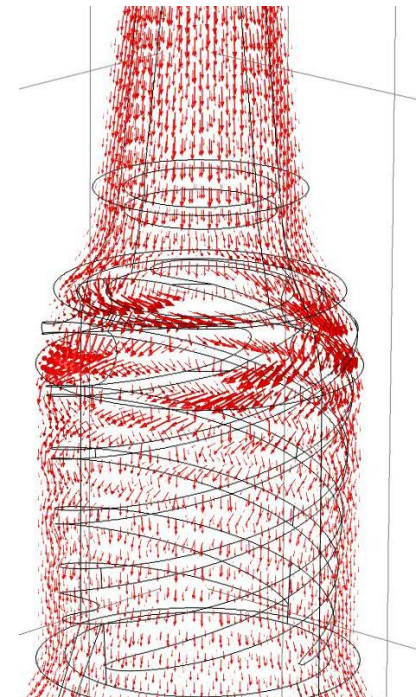
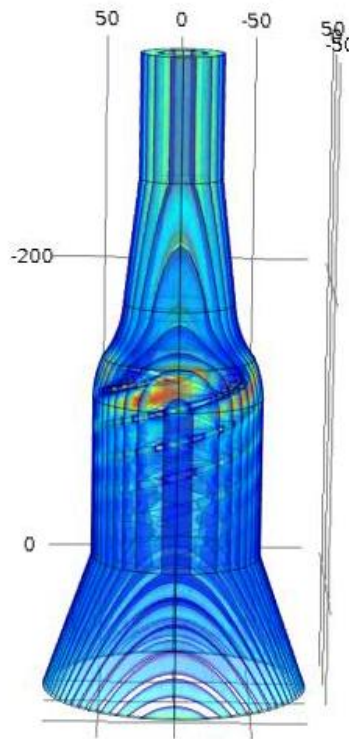
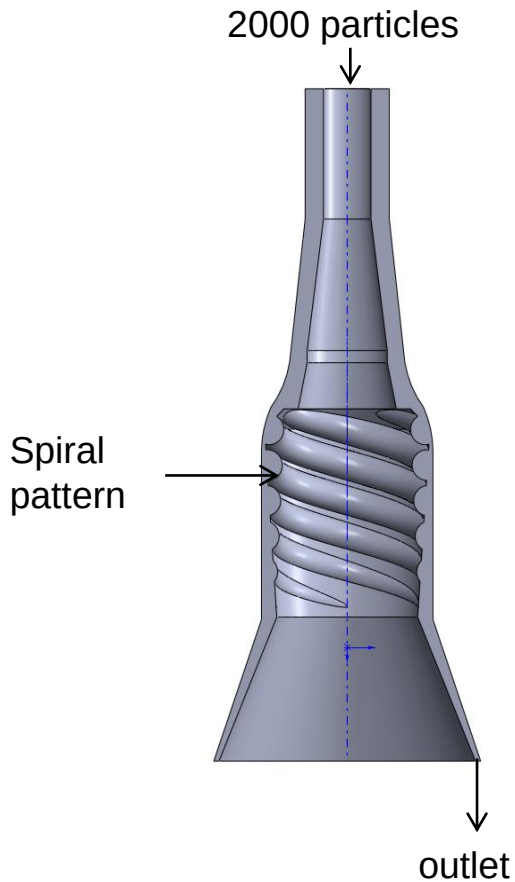


Lattice with vertical slots



Spiral Mandrel

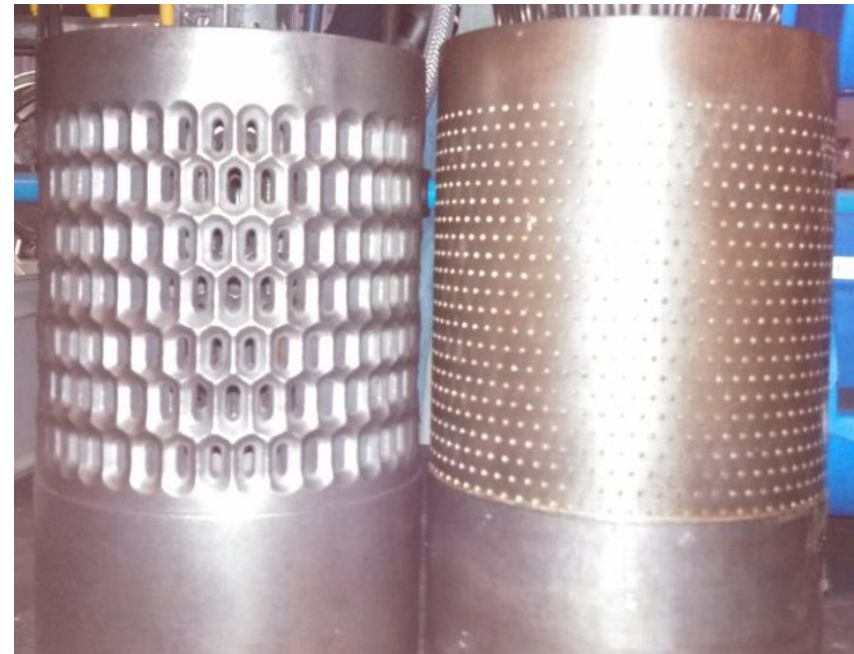
- Particle Tracing and Streamline Results



Successful Case

- **Benefits of the New Design**

- The RTD was reduced by 75%.
- RPM requirement for the pressure build-up decreased from 70 RPM to 58 RPM.
- Power consumption decreased 1.6 times.
- The production lasted 360 h (15 days) compared to 64 h with the old design.
- The new extrusion die halved the pressure build-up in the extruder.
- The heater temperatures were lowered 8 K.



Profile-Tube Extrusion Die Design with Flow Simulation – Suggested Protocol

- Determine your Standard Materials (Acquire Rheological Data)
- Determine your Design Standards and Model Existing Tooling
- Determine and Standardize on your Design Process (6-Steps)
- Model all Plates Individually
 - Front Die Plate in Principle is Perfect
 - Flow Imperfections to the Back of the Die Plate make the Die Plate Imperfect
 - Design so that by Exit of Transition Plate – Die Flow and Pressure are Balanced Across the Exit
- Model the Entire Die – Final Design Approval
- Utilize Modeling for Comparing of Materials (ABS vs. GFPA)
 - Supports Reasoning for Capital or Development Costs
- Develop your Companies “Die Designers Visual Guide of Polymers”
- Share your Results – Let EVERYONE have X-RAY Vision of the DIE!

References

Osswald T. A., J. P. Hernández-Ortiz, "Polymer Processing Modeling and Simulation." Hanser, Munich (2006).

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CRTD

$$\text{Transmission Probability} = \frac{\text{number of particles which reach the outlet}}{\text{number of particles released}}$$

<i>Model</i>	<i>Particles that reached the outlet</i>	<i>Transmission Probability</i>	<i>Retained particles</i>
<i>Lattice basket die</i>	1852	0.91	148
<i>Die without lattice basket</i>	1929	0.9645	71
<i>Hypothetical model</i>	1939	0.9695	61
<i>Slots in a horizontal fashion</i>	1911	0.9555	89
<i>Slots in a vertical fashion</i>	1941	0.9705	59
<i>Spiral Mandrel</i>	1543	0.7715	457

