Shear-Induced Flow Imbalance and MeltFlipper® in Autodesk® Moldflow® Injection Molding Simulation

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Class Summary

- *Overview of the development of shear induced melt imbalances*
- *Overview of the management of shear induced melt imbalances with MeltFlipper technologies.*
- *Impact of mesh design in predicting shear induced mold filling imbalances*
  - *Mesh density*
  - *Element aspect ratio*
- *Evaluation of intra-cavity flow prediction within a single cavity mold*
- *Evaluation of intra-cavity and weld line prediction in two cavity mold*

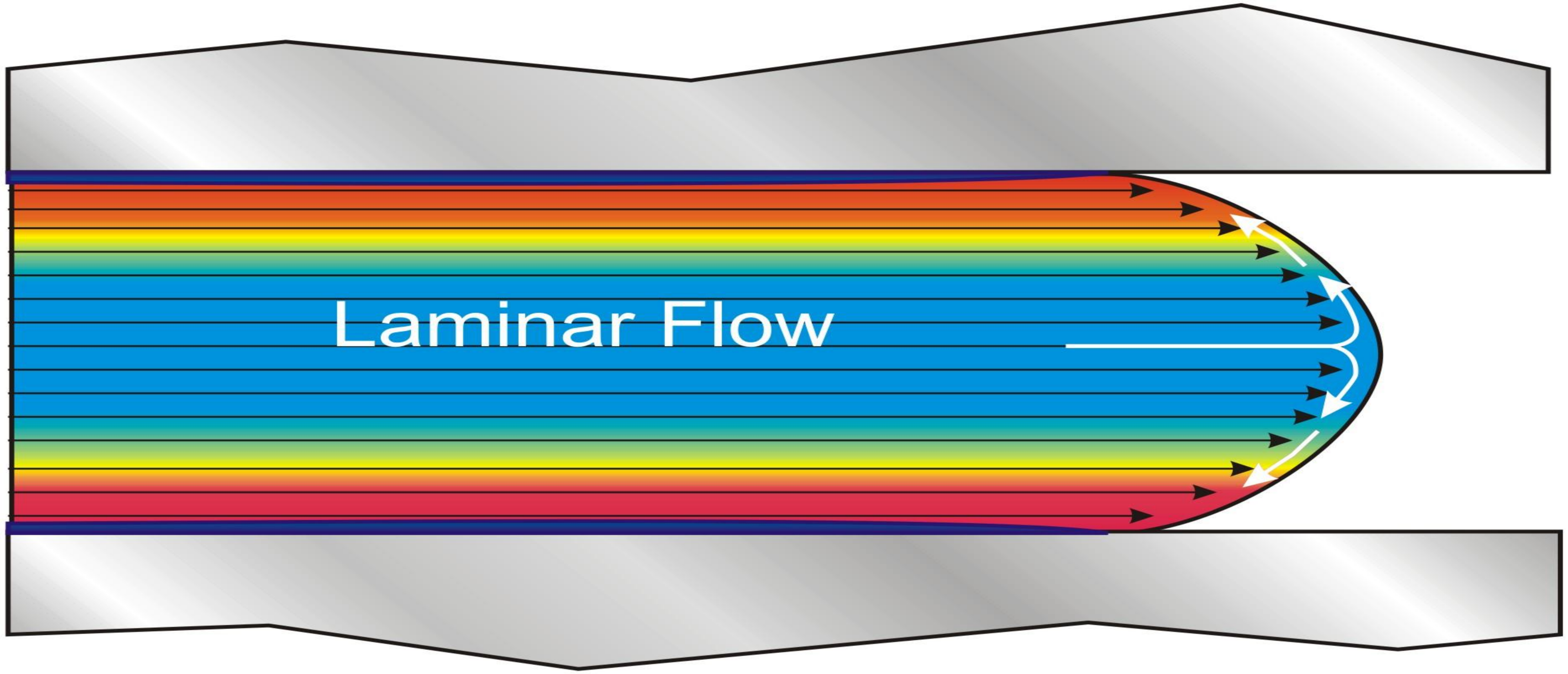
Learning Objectives

At the end of this class, you will be able to:

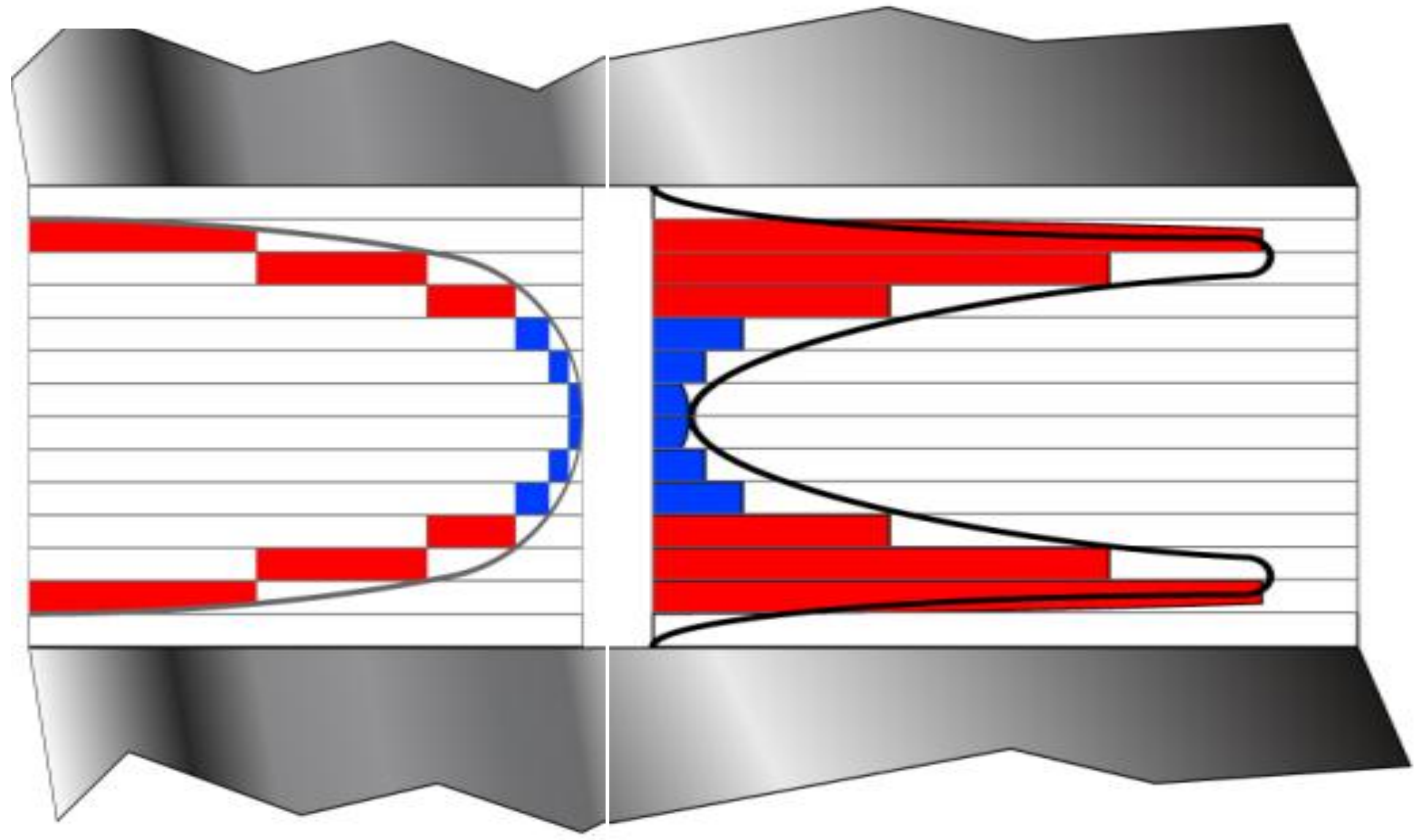
- Understand the how shear induced melt variations are developed
- Understand how to anticipate where shear induced melt variations might create a problem with molded parts
- Understand what type of problems result from the development of shear induced melt variations
- Understand the limitations of Moldflow for predicting shear induced melt variations
- How to get the most out of Moldflow when attempting to predict the effects of shear induced melt variations in single and multi-cavity molds

Understanding the Development & Impact of Shear Induced Melt Variations

Development of non-Homogeneous Melt Conditions

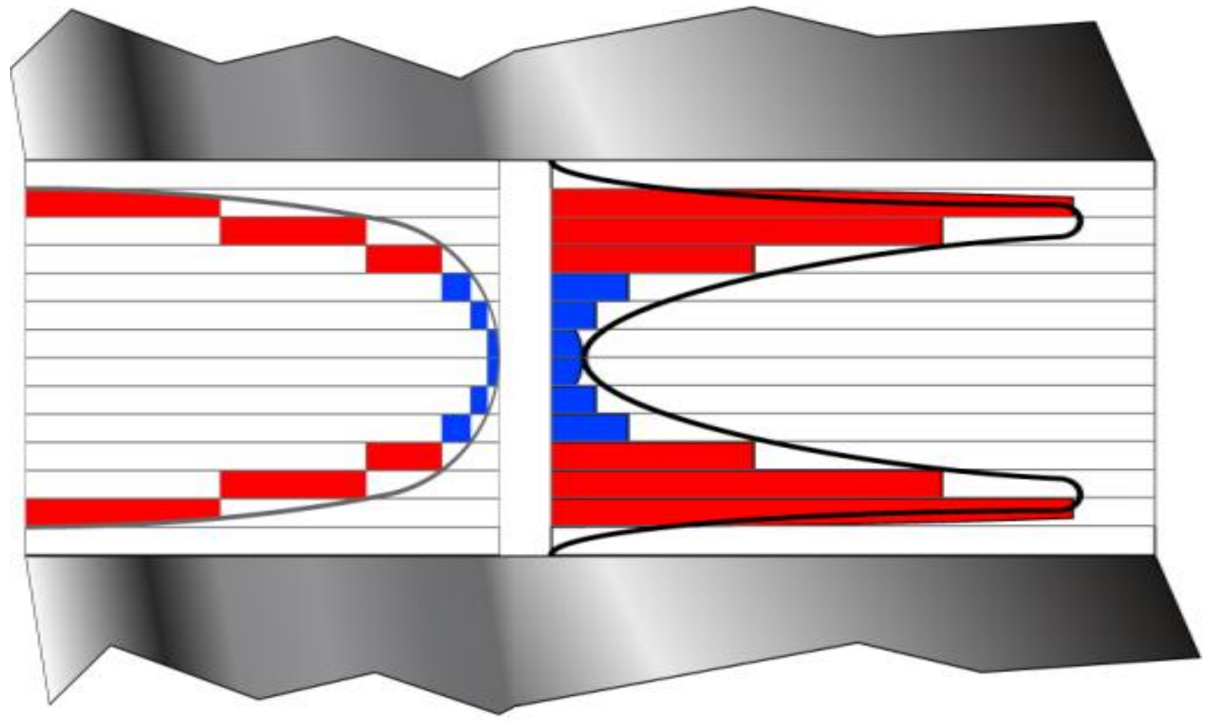


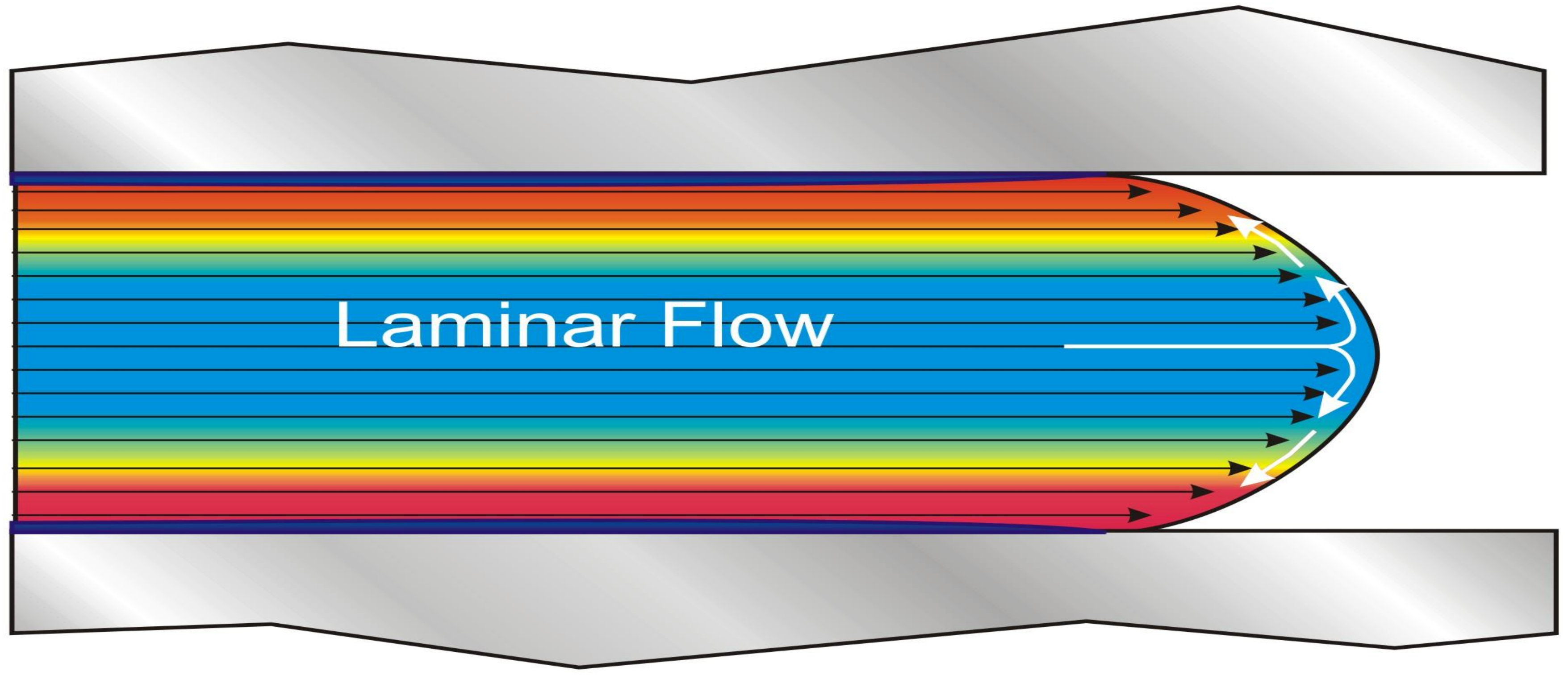
1. Flow is laminar during injection molding
2. Shear rate is developed from the velocity profile



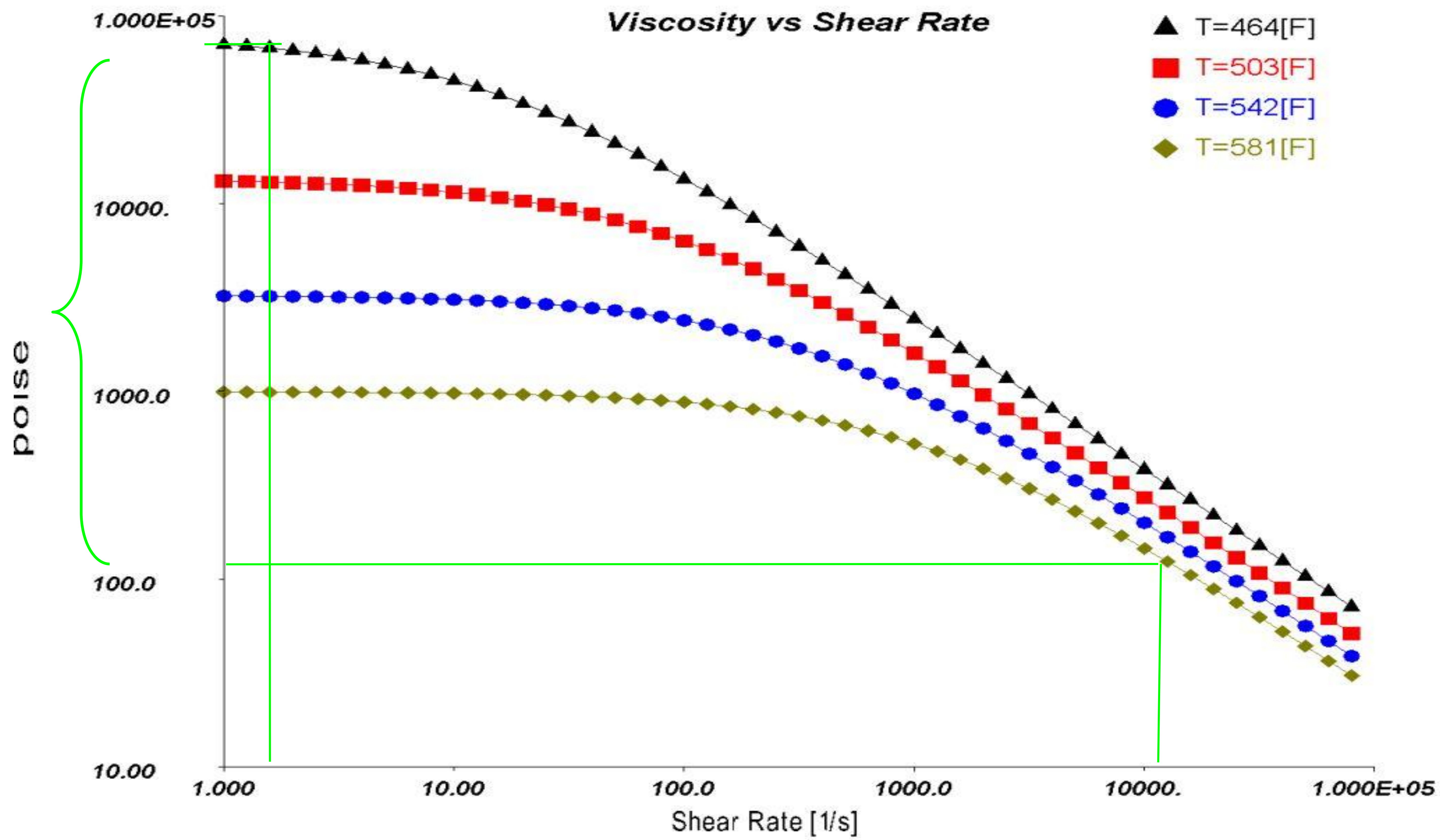
–Beaumont Runner Technologies, Inc.

Development of non-Homogeneous Melt Conditions



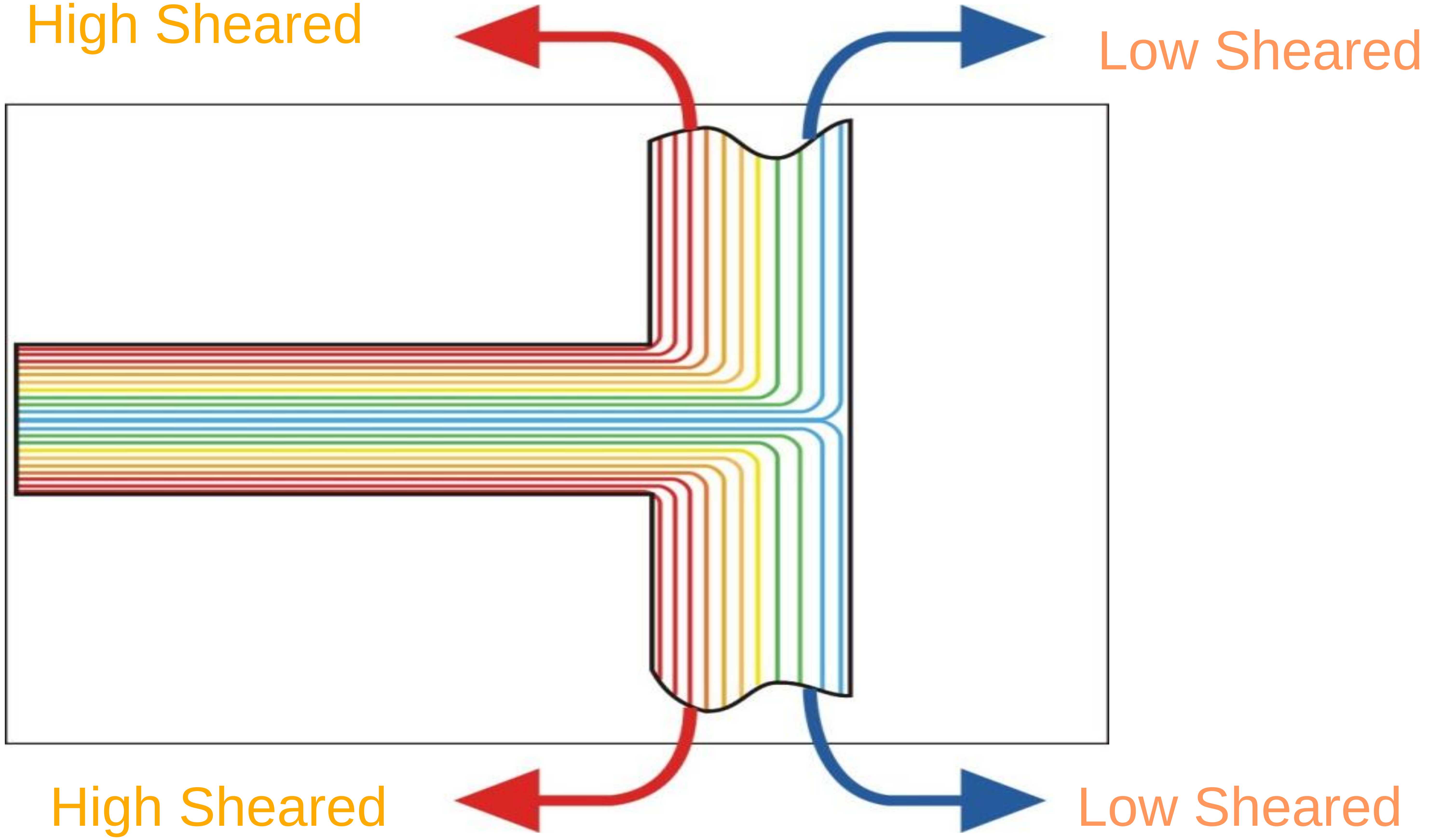


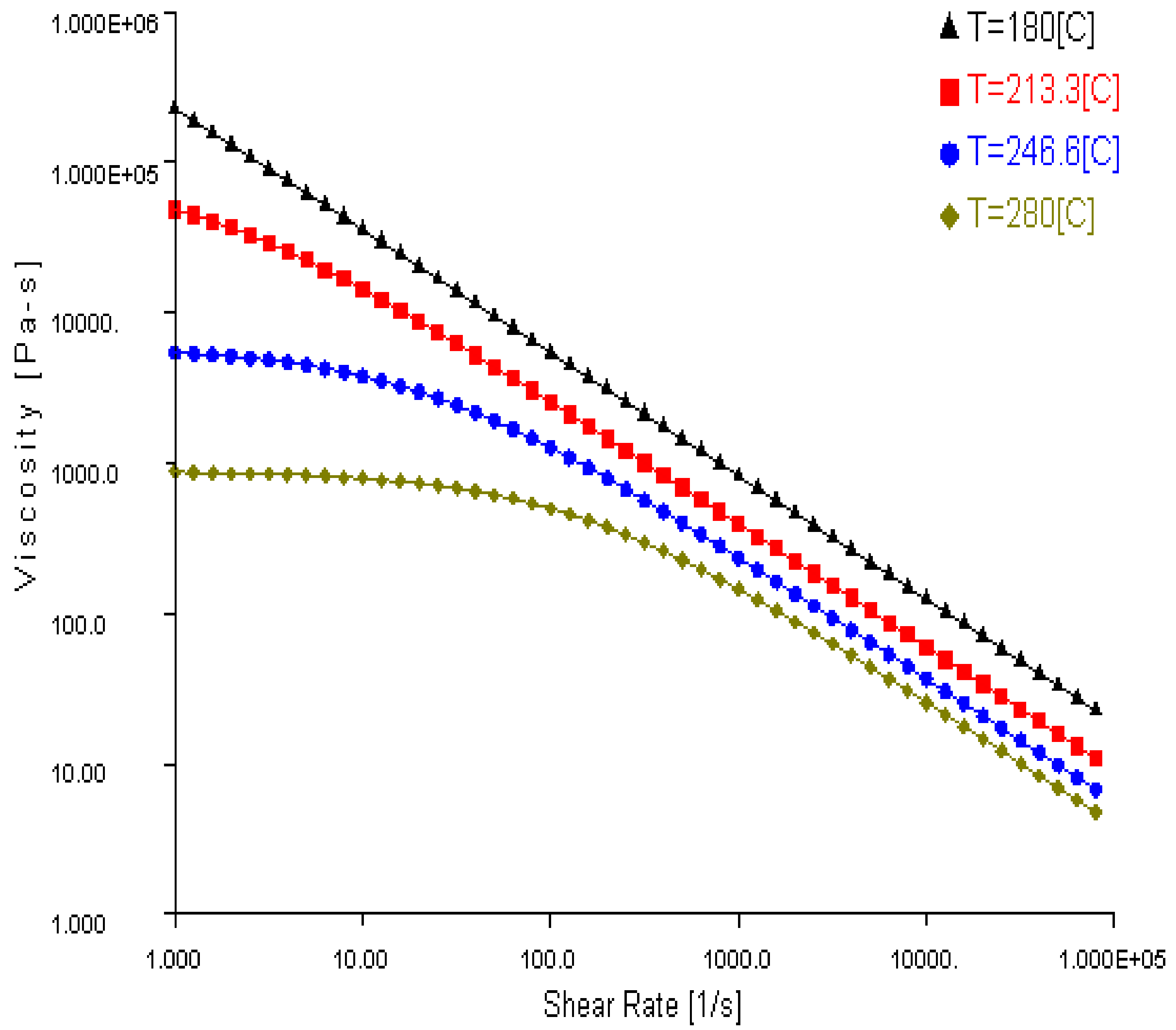
Viscosity of high sheared hotter outer laminates can be over 100x lower than inner laminates.



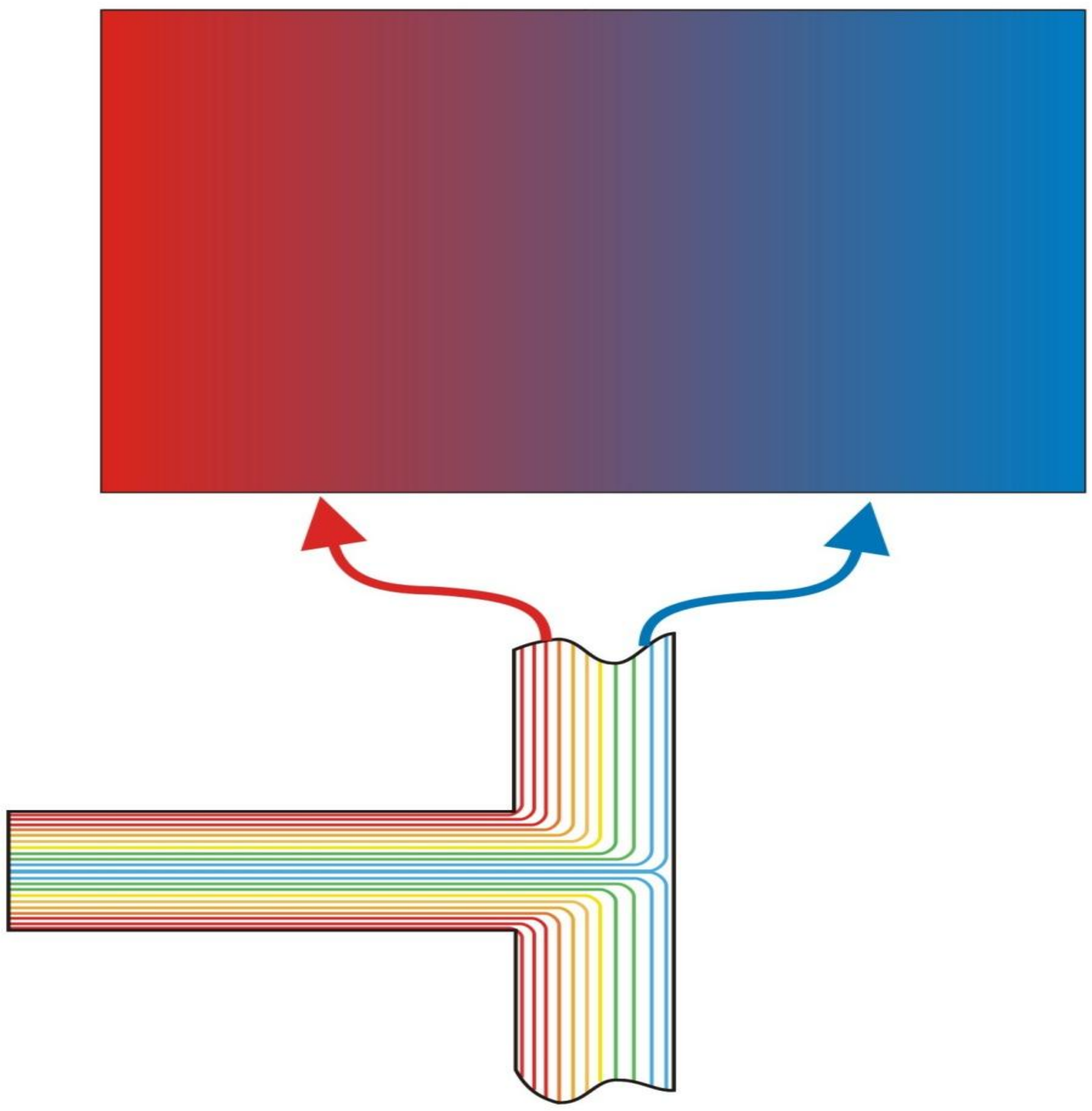
Development of non-Homogeneous Melt Conditions

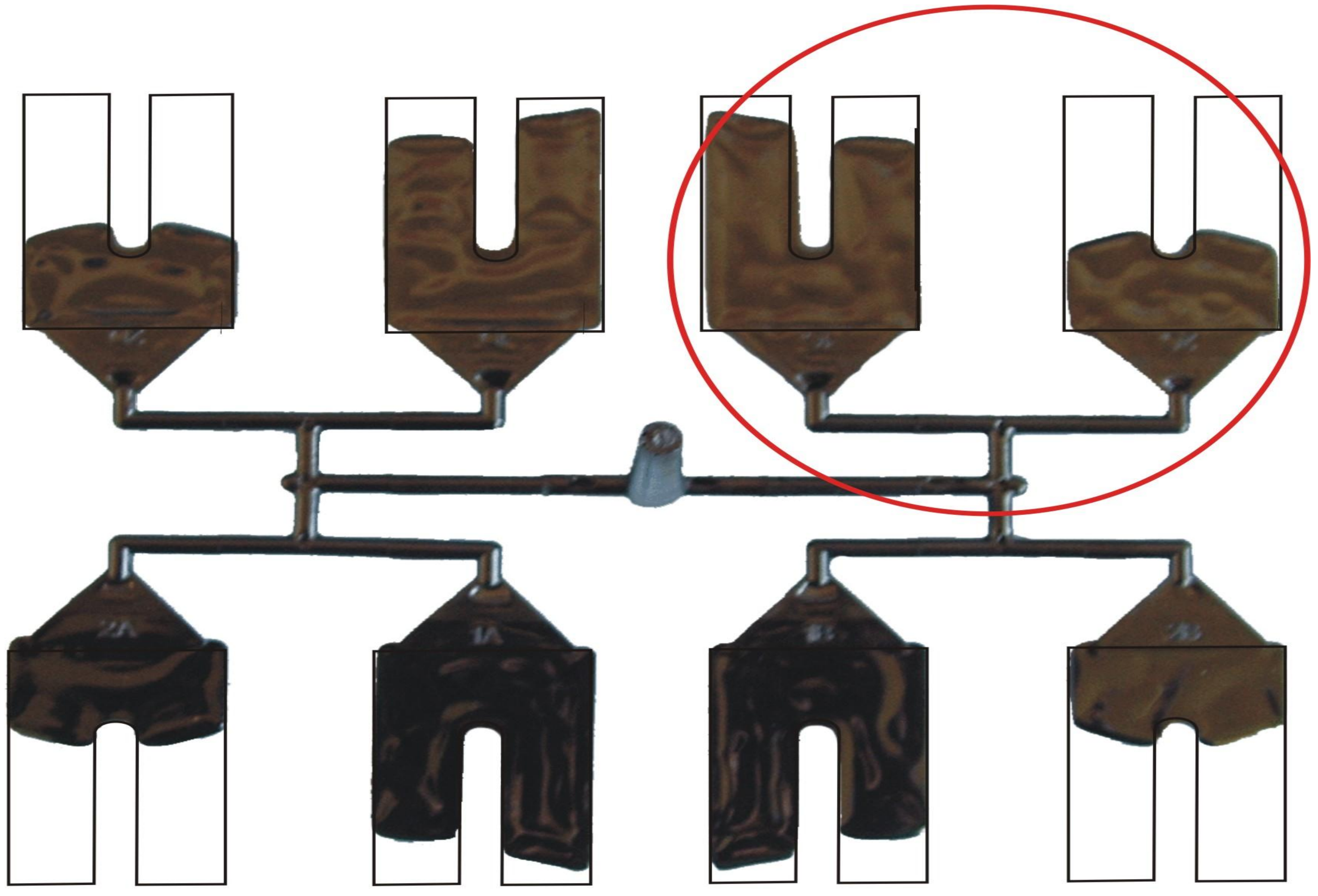
High and low sheared materials become non-homogeneously distributed as they are split into a branching runner.



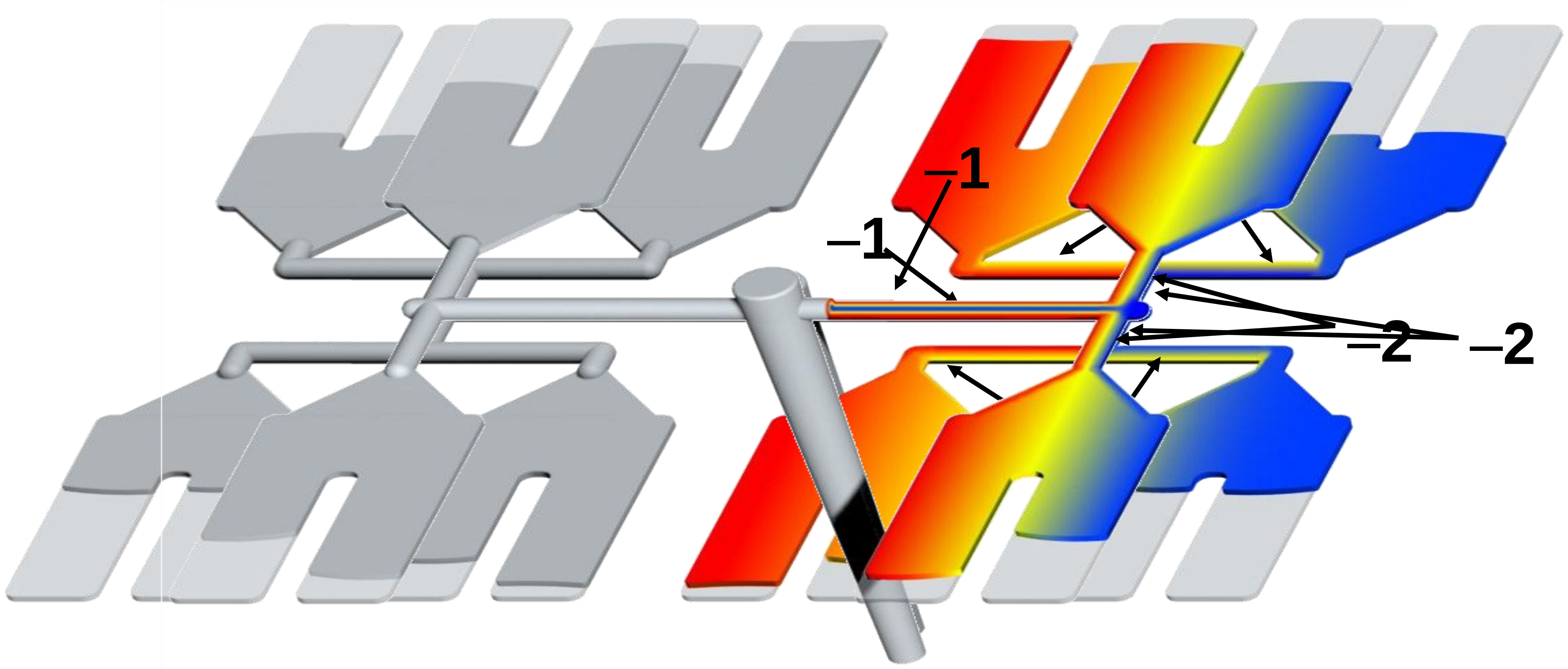


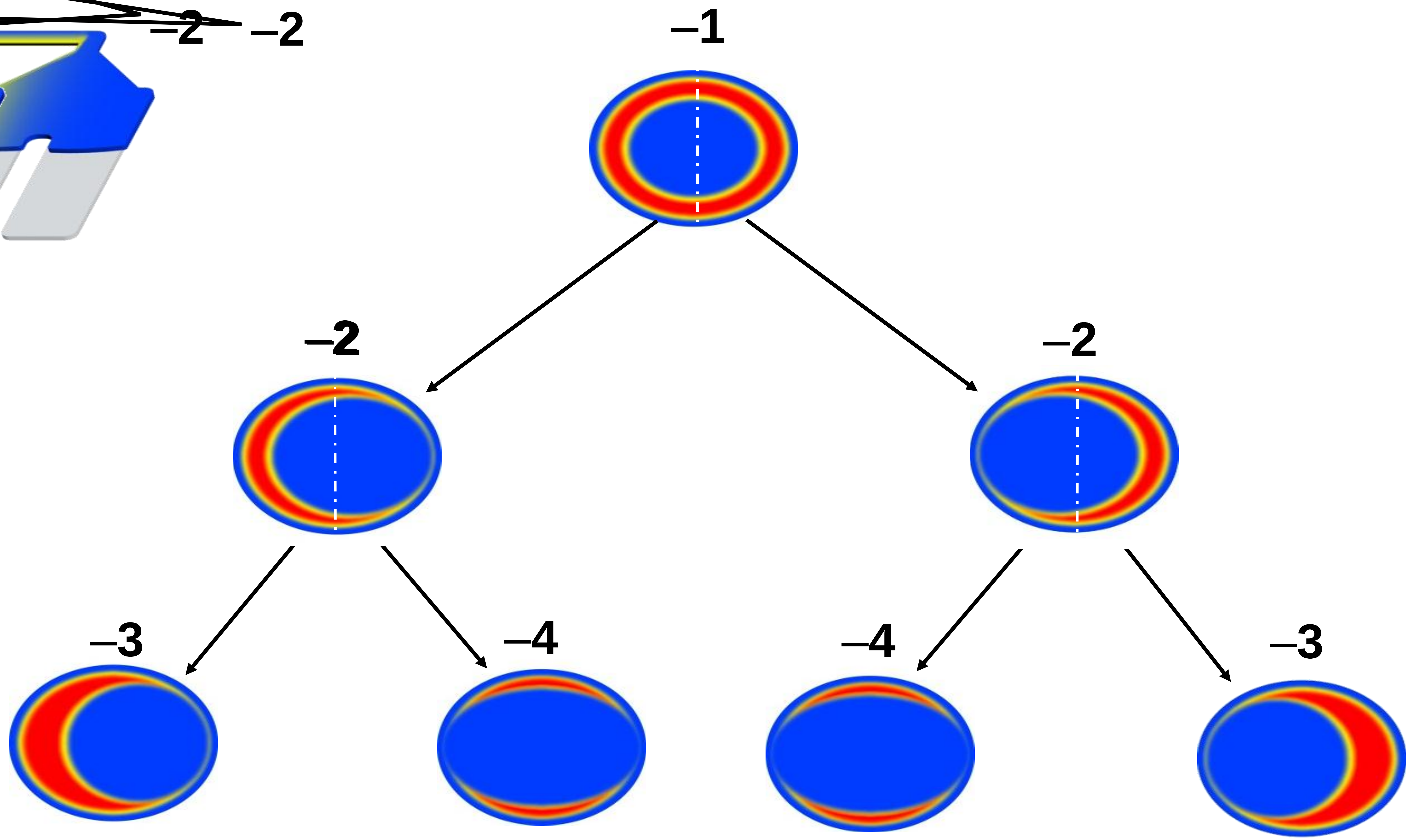
Development of non-Homogeneous Melt Conditions



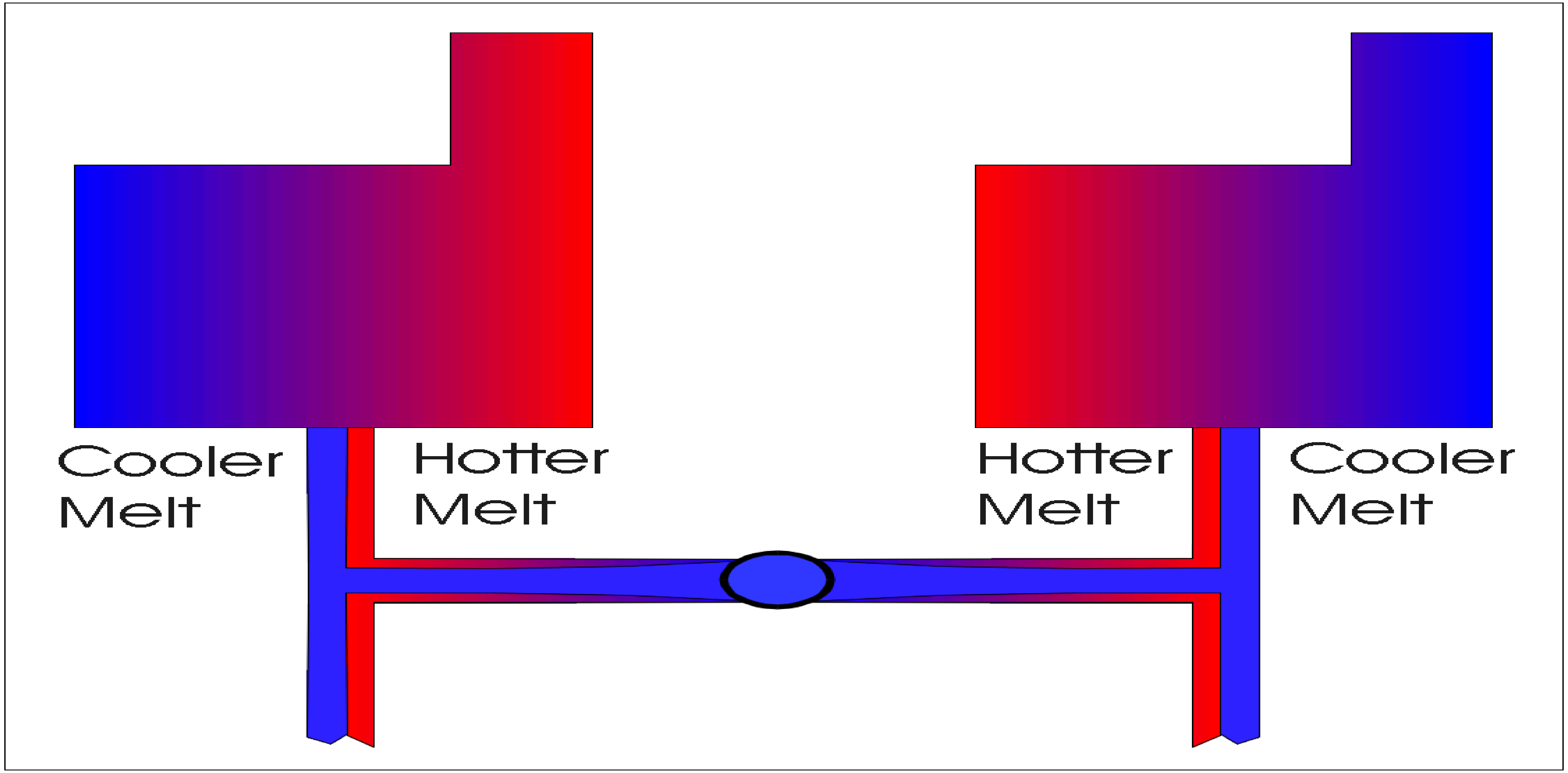


Development of non-Homogeneous Melt Conditions



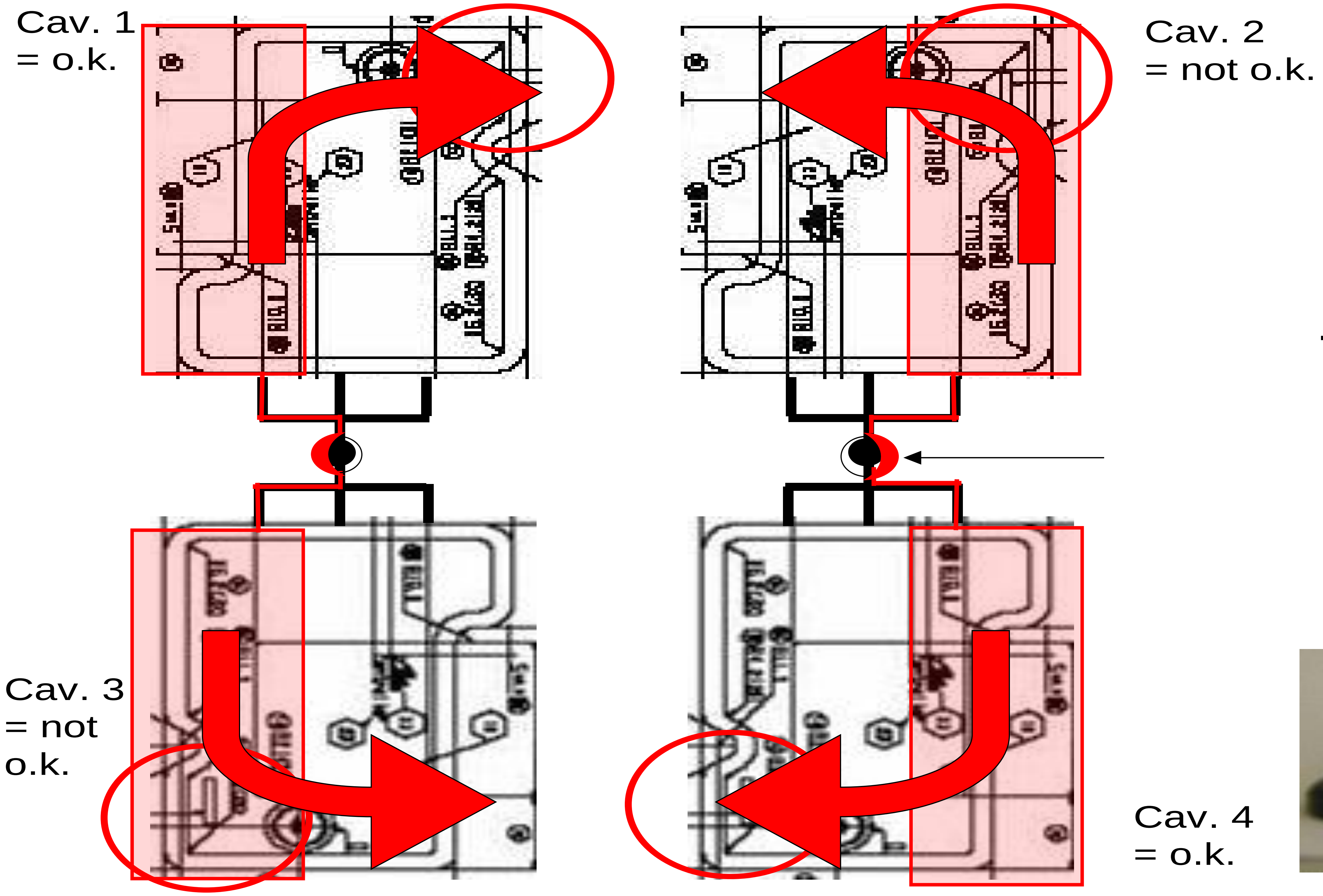


Development of non-Homogeneous Melt Conditions



Product Variations Resulting from Material Variations

Shear induced melt variations developed in hot runner resulting in Warpage variations in 4 Cavity Mold

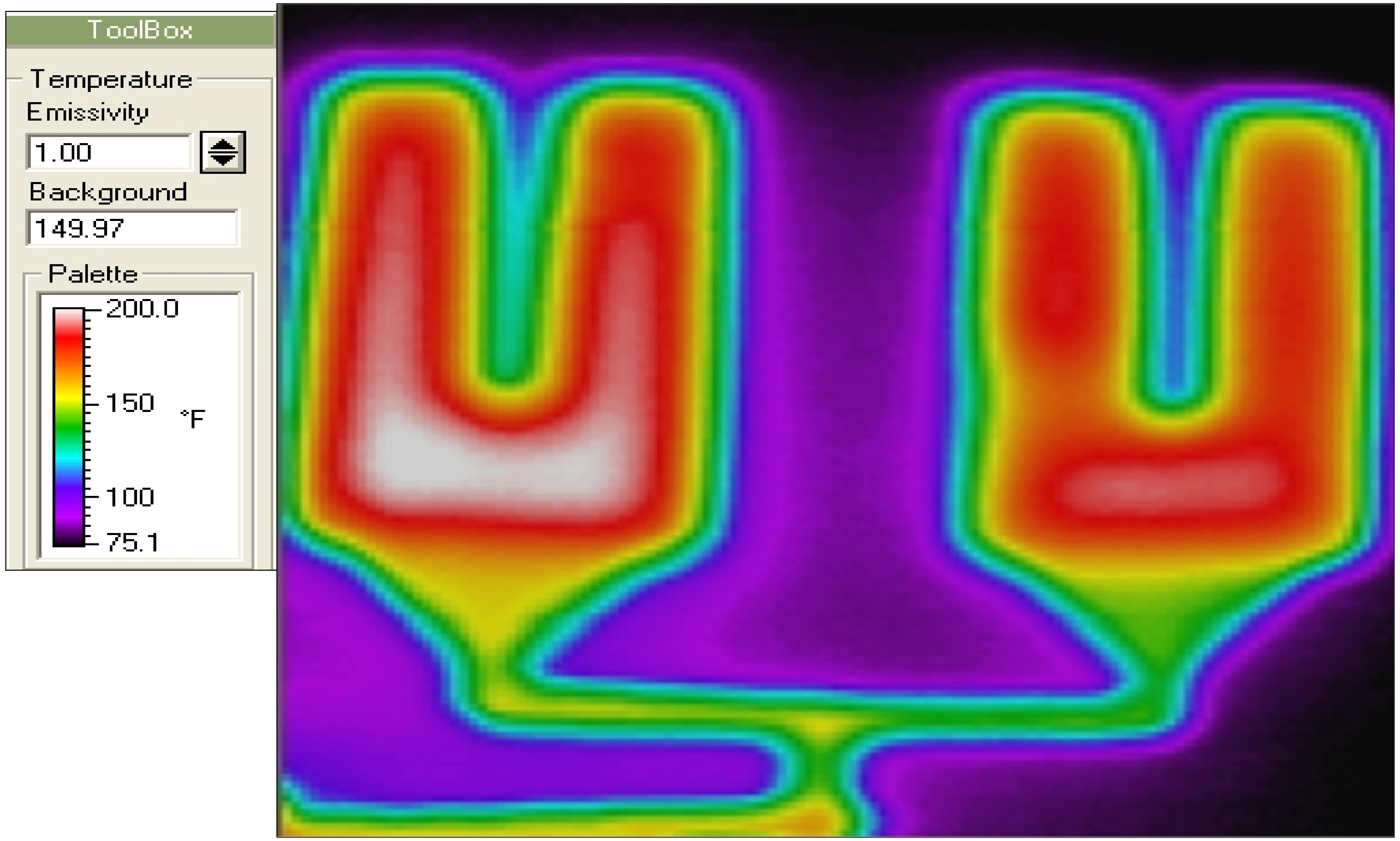


–Warp in Cavities 2 & 3

–Warp in Cavities 1 & 4

Shear Effects: Material Properties and Cycle Time

Conventional Geometrically Balanced Runner



Thermal Variations

= Variations in Crystallinity

= Shrink and warp

- Thermal Variations
- Pressure Variations

= Non-homogeneous distribution of Fillers

- Distribution
- Size

= Residual stresses

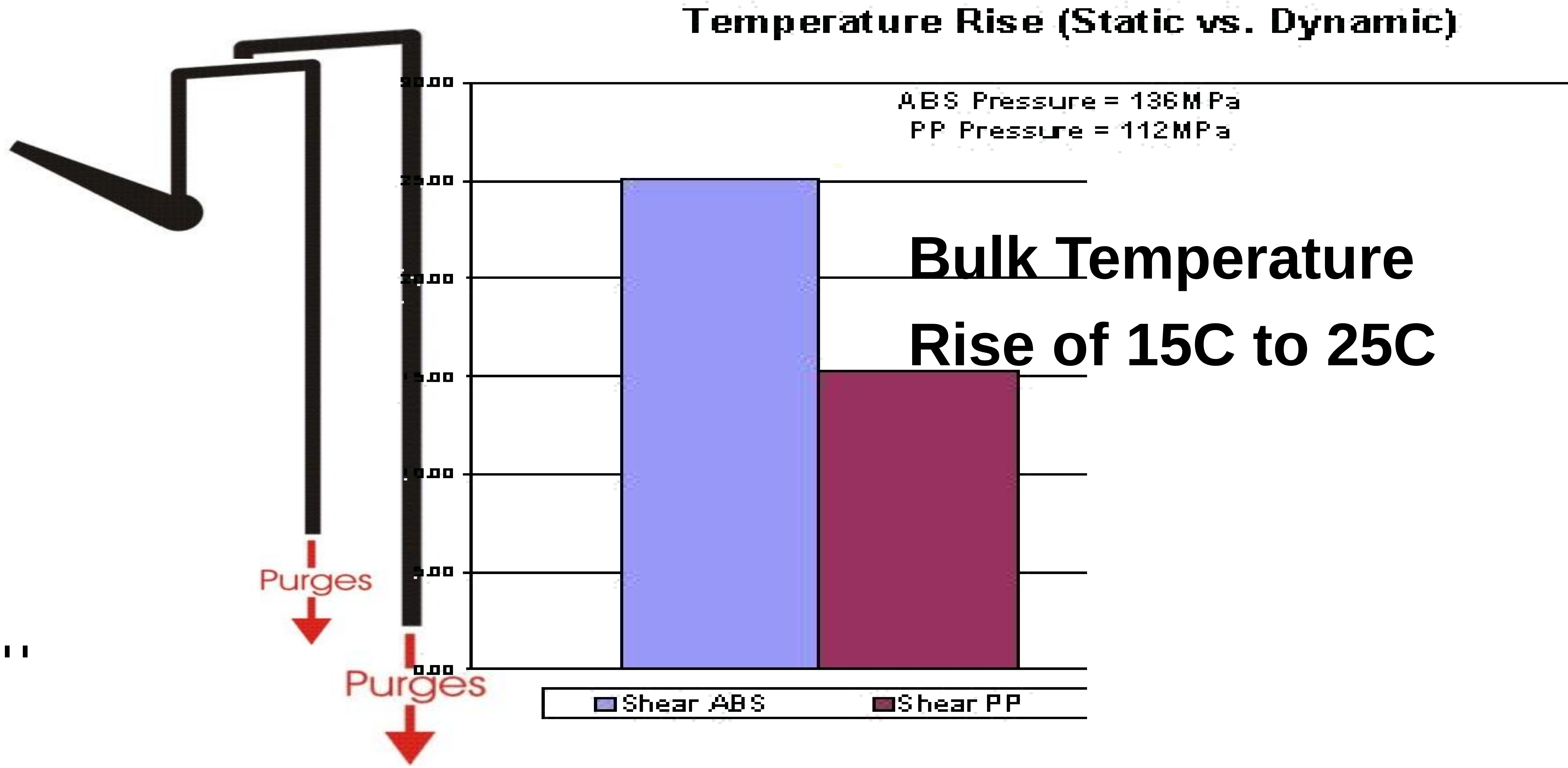
Frictional Heating Developed in the Runner

Purge Mold used to determine frictional heating of the melt in a runner.

Runner Length = 25 cm

3.2mm Parabolic Cross-sectio

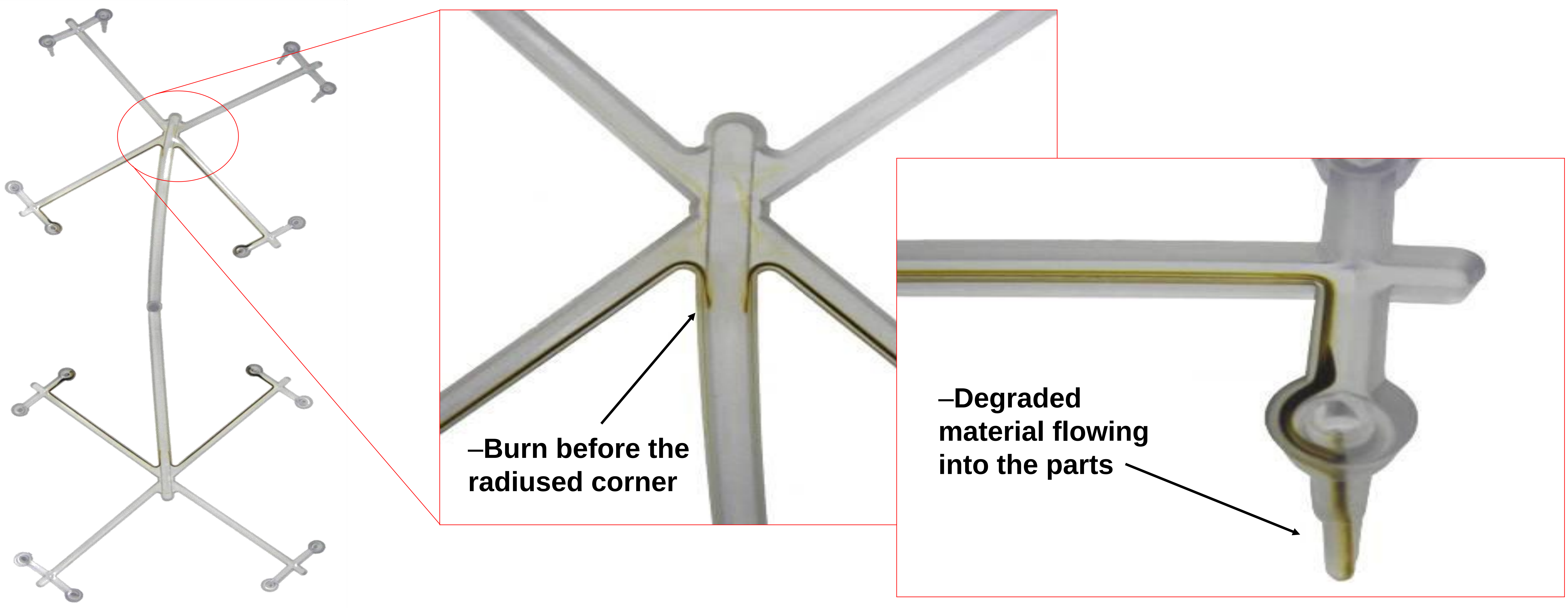
Mold Temp = 38 ° C



Bulk Temperature Rise of 15C to 25C

Frictional Heating in Runner Causing Material to Burn

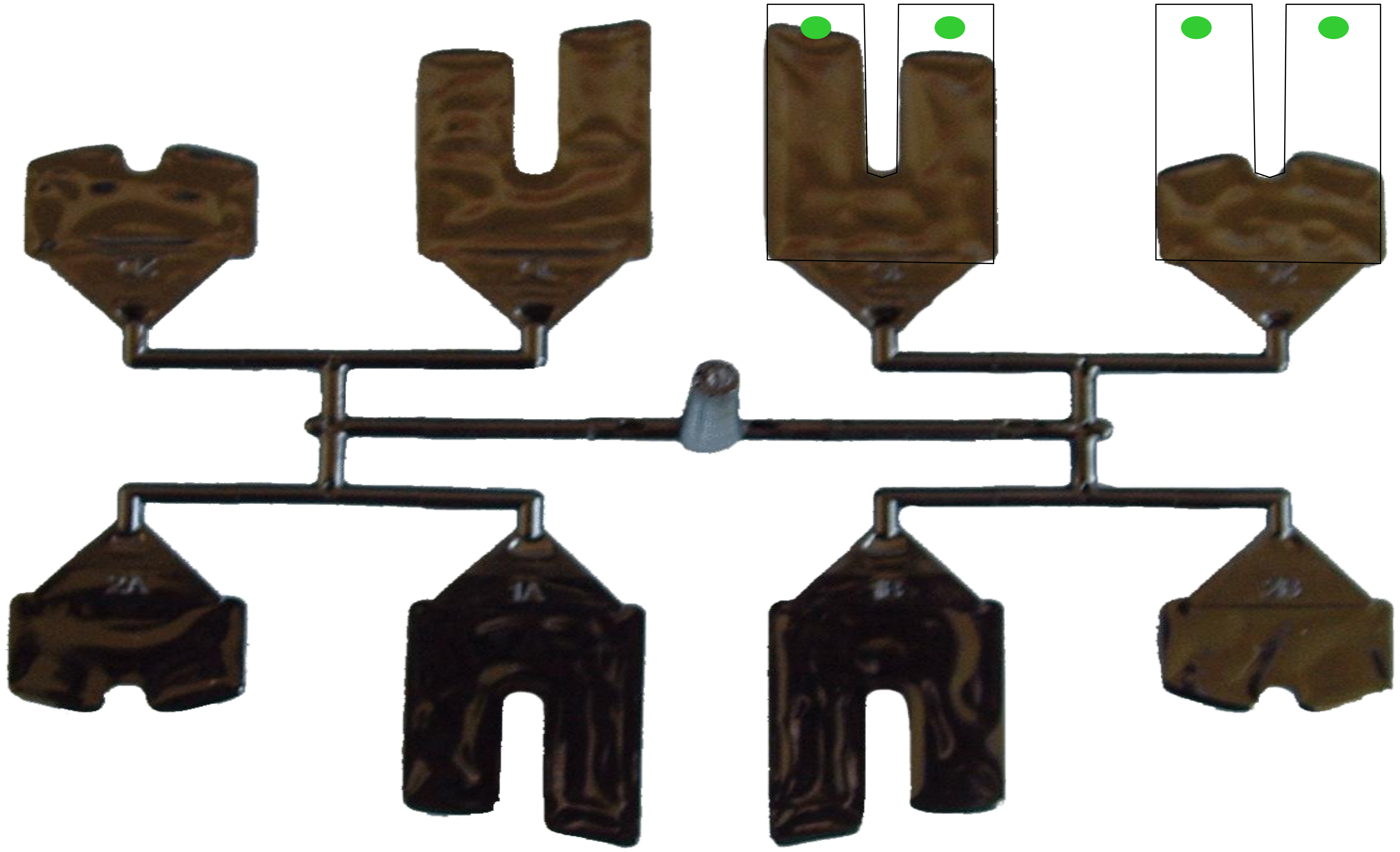
Frictional heating developed prior to the first branch is fed to inner cavities. This creates product variations and rejects.



Impact on Molding Process Set-up Procedures

Scientific / Decoupled^{SM} Injection Molding

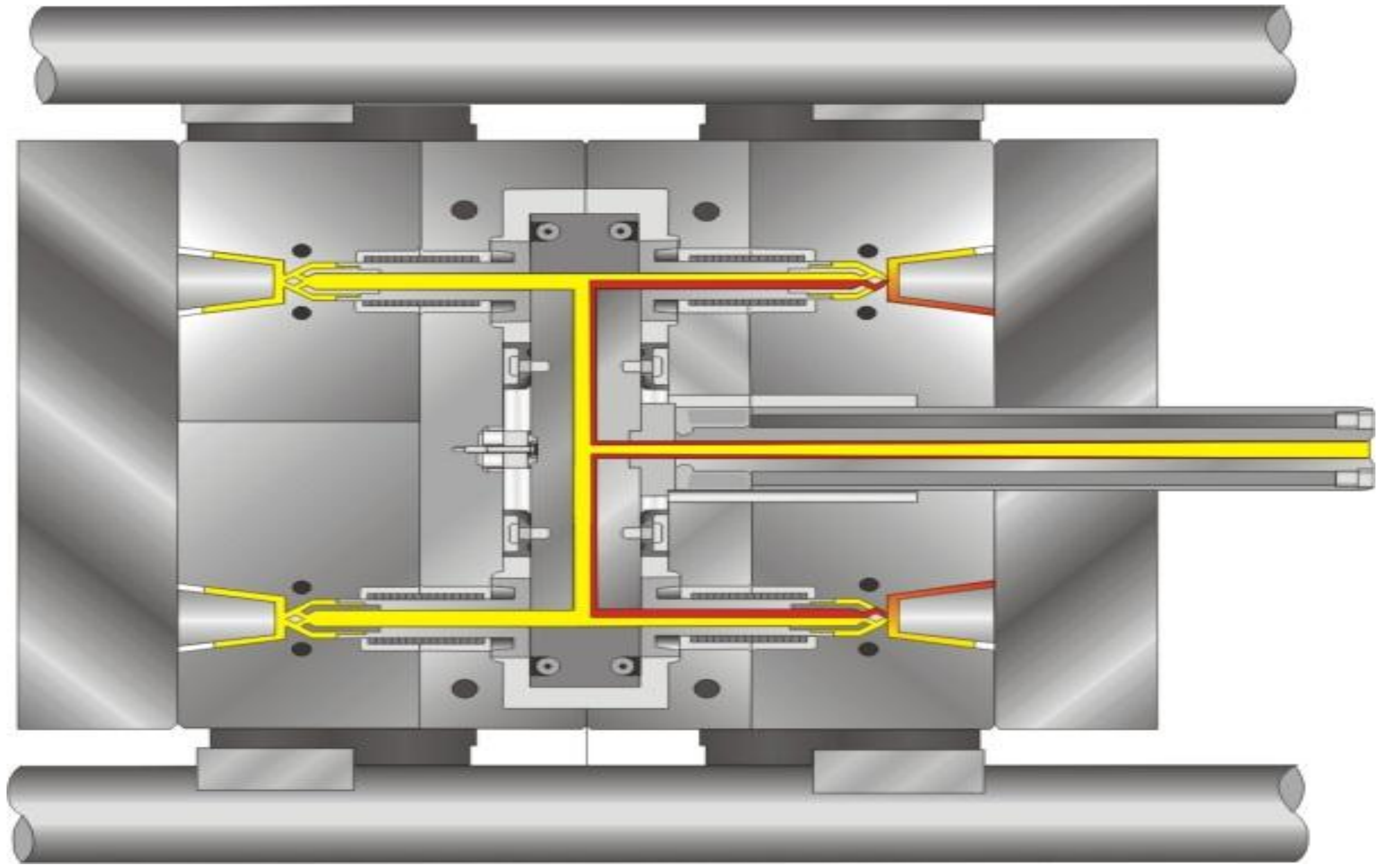
1. *Determine optimum fill based on mold trials (Relative Viscosity vs. Relative Shear Rate)*
2. *Transfer to packing phase should happen when the cavities are 95-99% full*

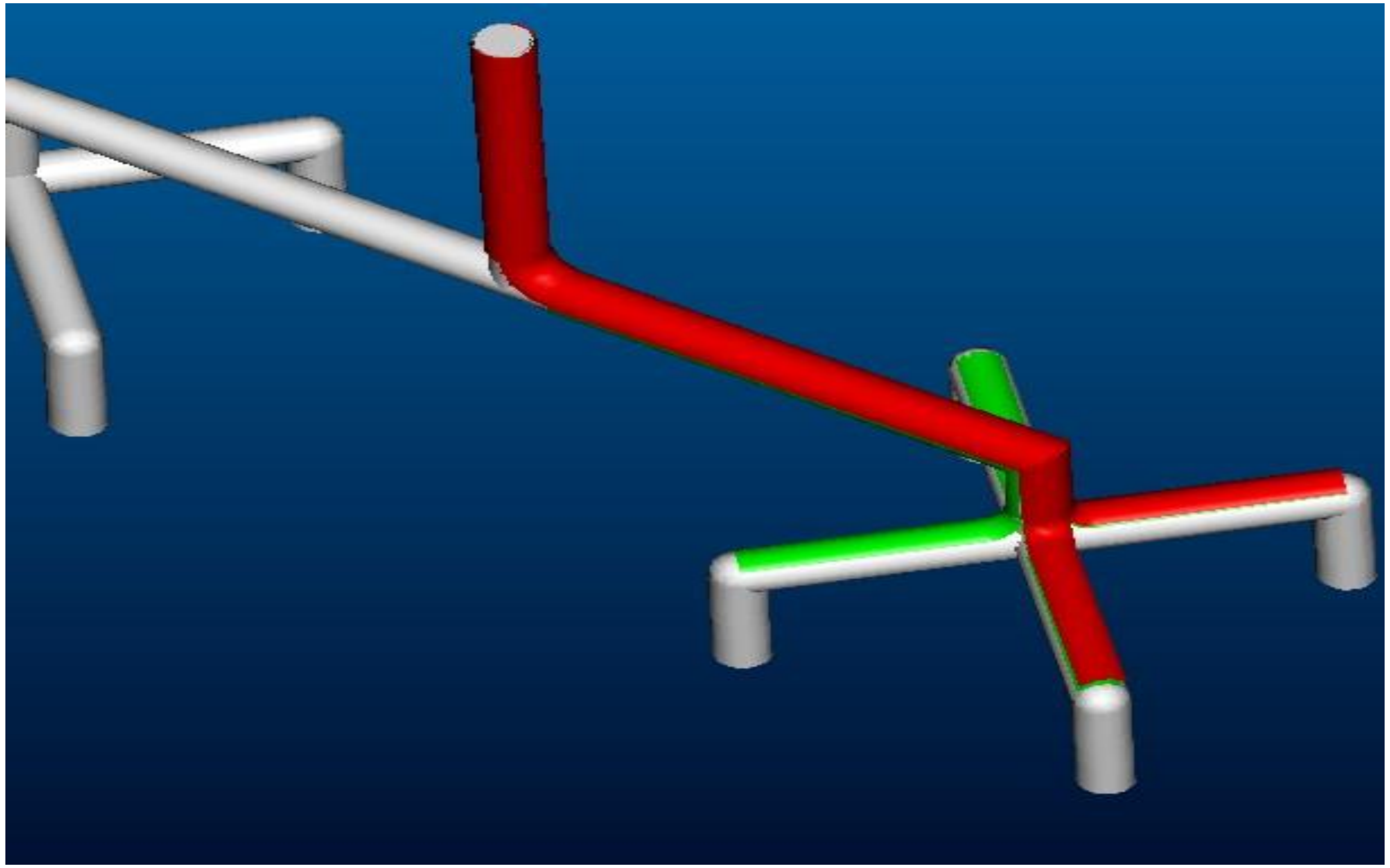


Which cavity?

Where within the cavity?

Shear Induced Melt Variations in Hot Runners



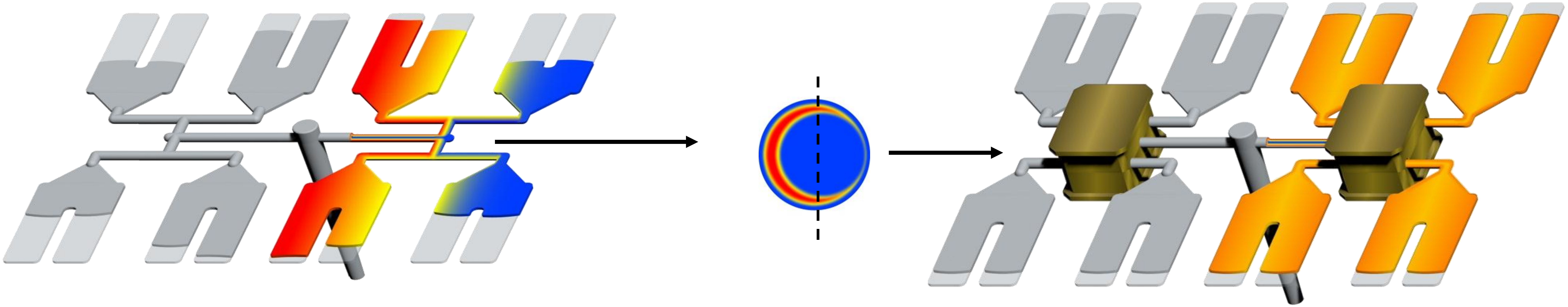


Managing Shear Induced Melt Variations

- Melt Rotation Technology
  - MeltFlipper™ (In Mold Rheological Control)
  - MAX™ (Multi Axis Rheological Control)
  - iMARC™ (in Mold Adjustable Rheological Control)
- Applications
  - Balance filling and melt conditions in multi-cavity molds
    - Conventional materials
    - Gas assist
    - Mucell
    - Co-Injection
  - Intra-cavity Melt Control
    - Fill Patterns
    - Warpage
    - Weld Lines
    - Cosmetics

Managing Shear Induced Melt Variations

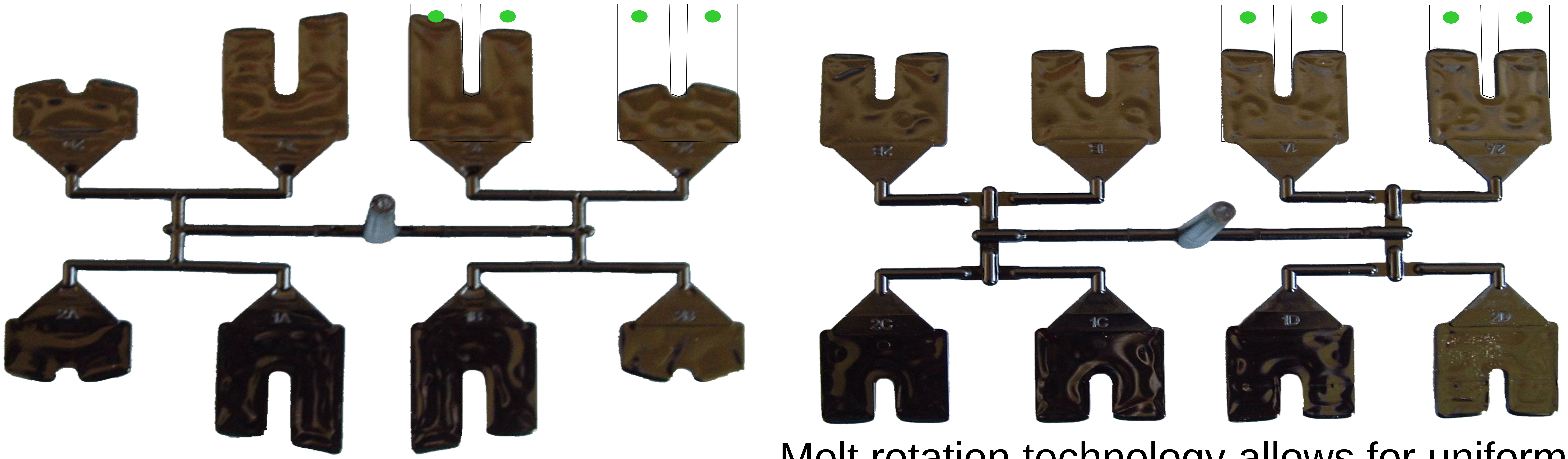
- MeltFlipper Single axis melt rotation technology rotates asymmetric melt conditions to provide a homogeneous distribution to downstream cavities.



Improved Process Control

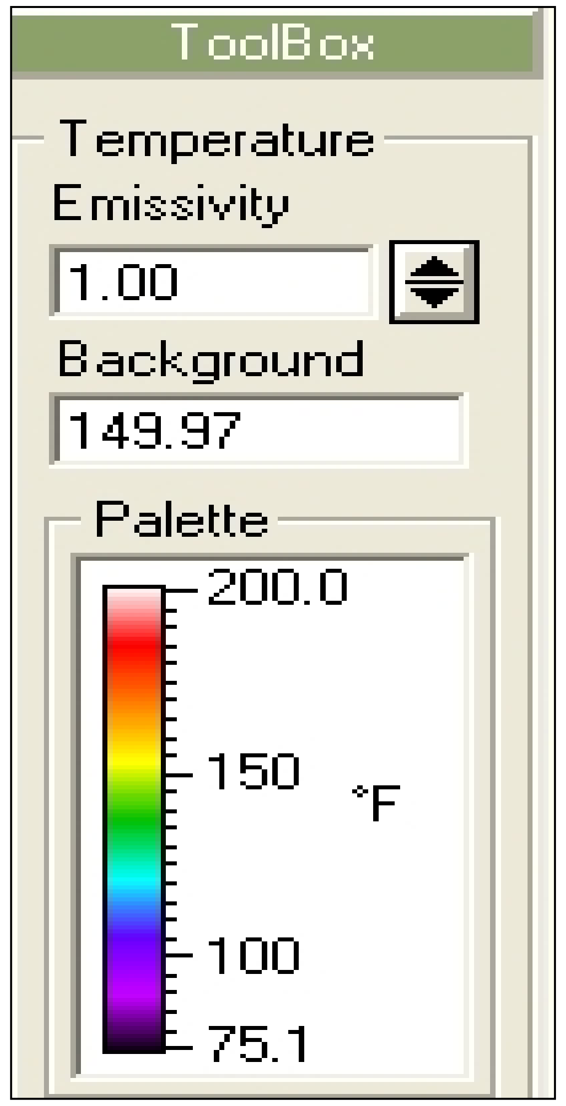
Scientific / Decoupled^{SM} Injection Molding

Conventional runner designs prevent processors from apply 2 Stage Molding processes as they are intended due to unbalanced filling (Transfer to packing phase should happen when the cavities are 95-99% full)



Melt rotation technology allows for uniform decoupling of filling versus packing

Thermal Imaging on 8 Cavity Mold

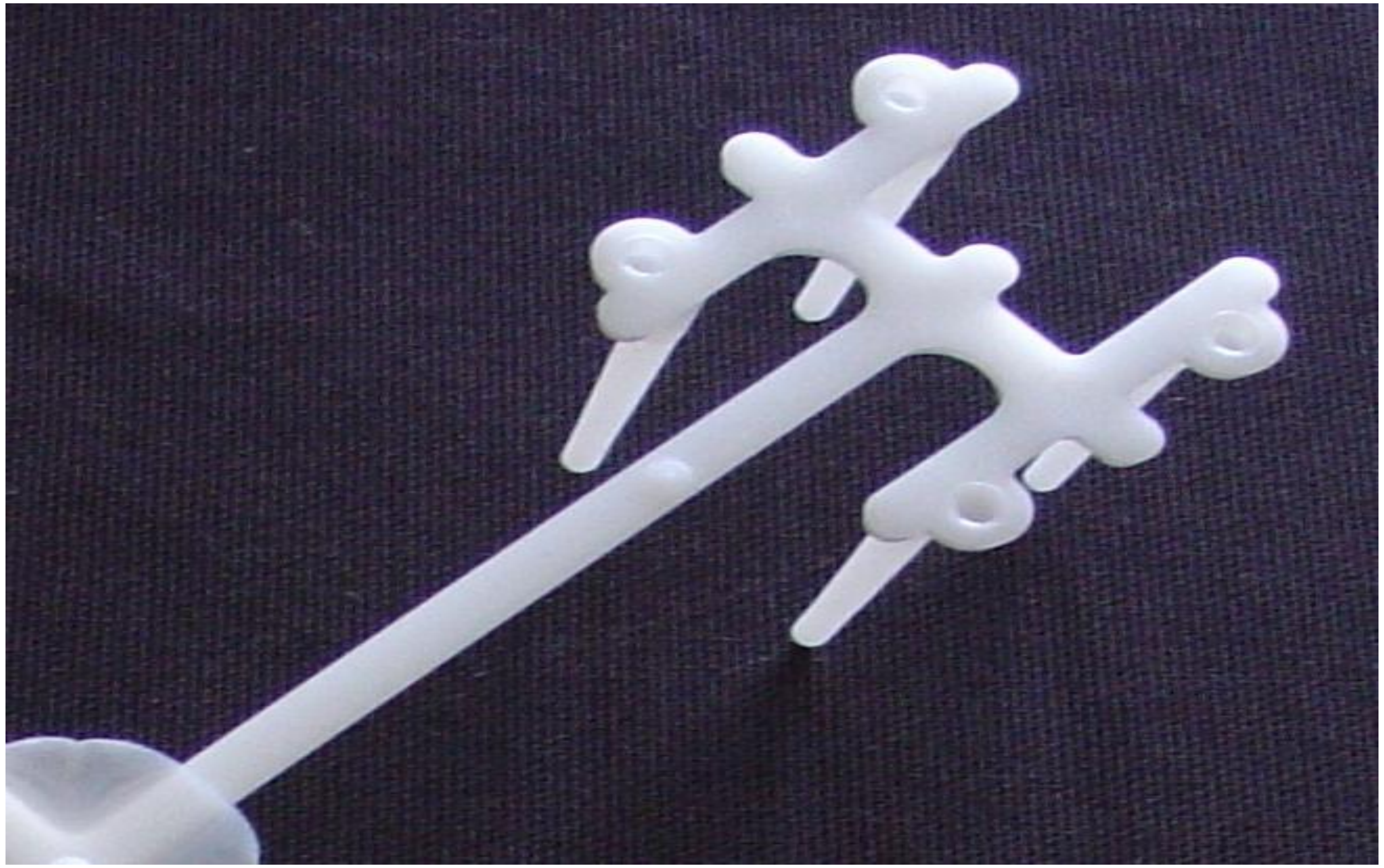


Conventional Runner

MeltFlipper Runner

Thermal and Filling Imbalance in 2 Cavity Gear Mold

Winzler Gear's – Standard vs. new
High Precision Gears



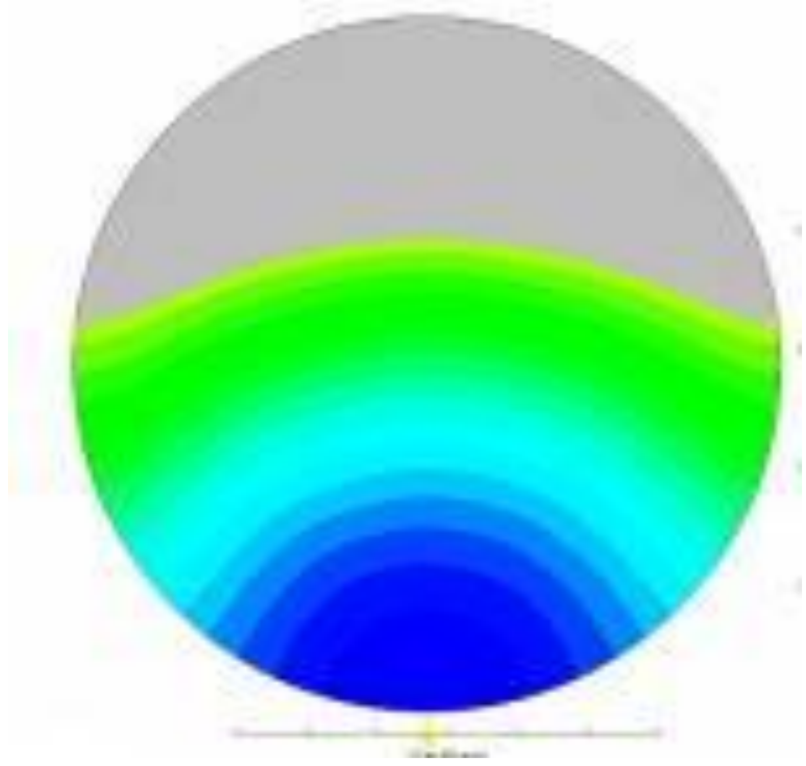
Before Melt Rotation. Temp Diff of 25F

After Melt Rotation. Temp Diff of only 5F

2 ½ D Injection Molding Simulation

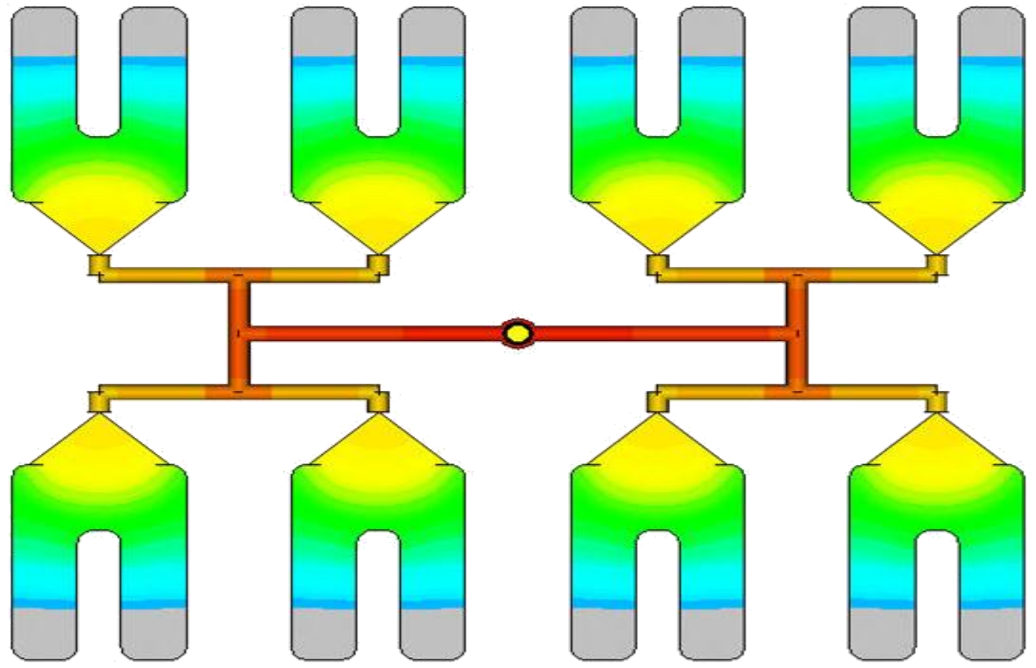
–2 ½ D Injection Molding Simulation can NOT pick up the effects of shear induced melt imbalances

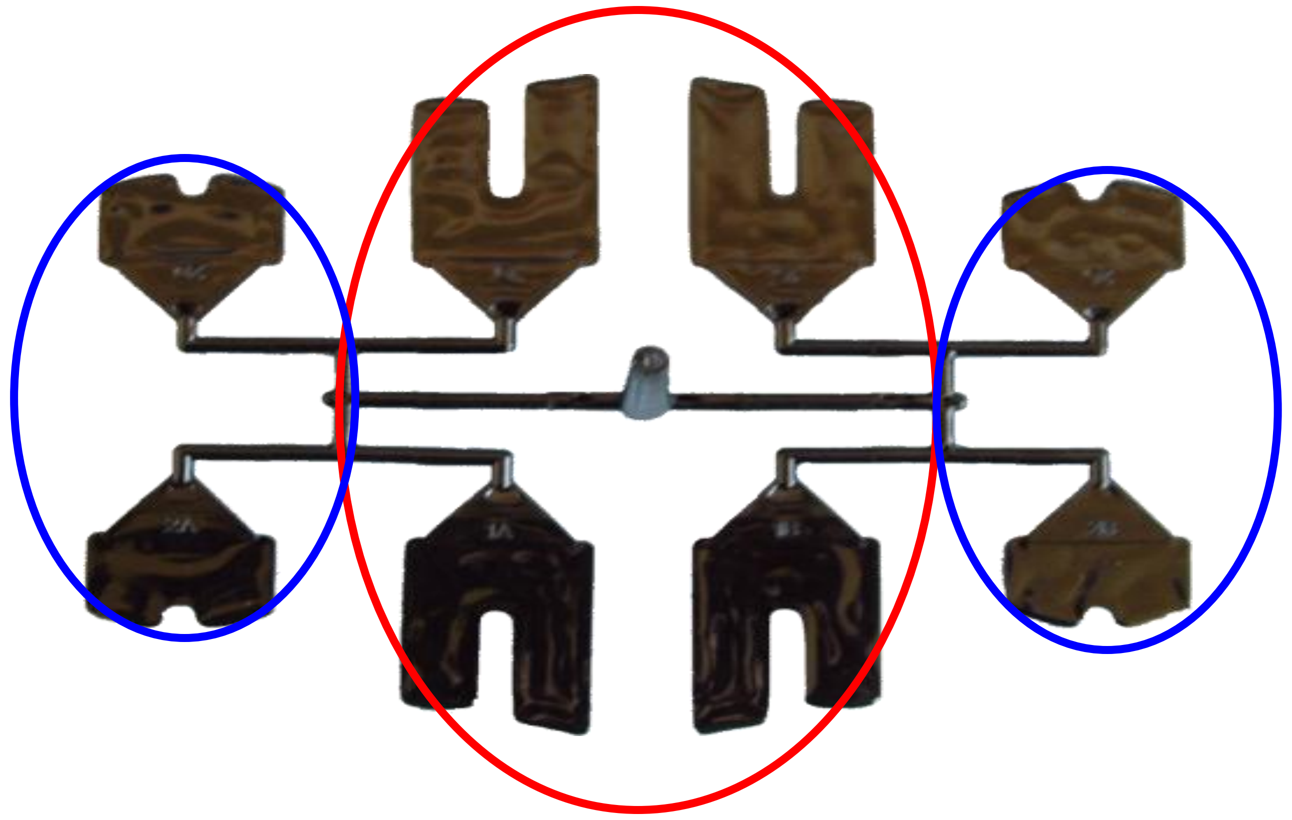
–Single Cavity



–Intra-Cavity Imbalance

–Multi-Cavity



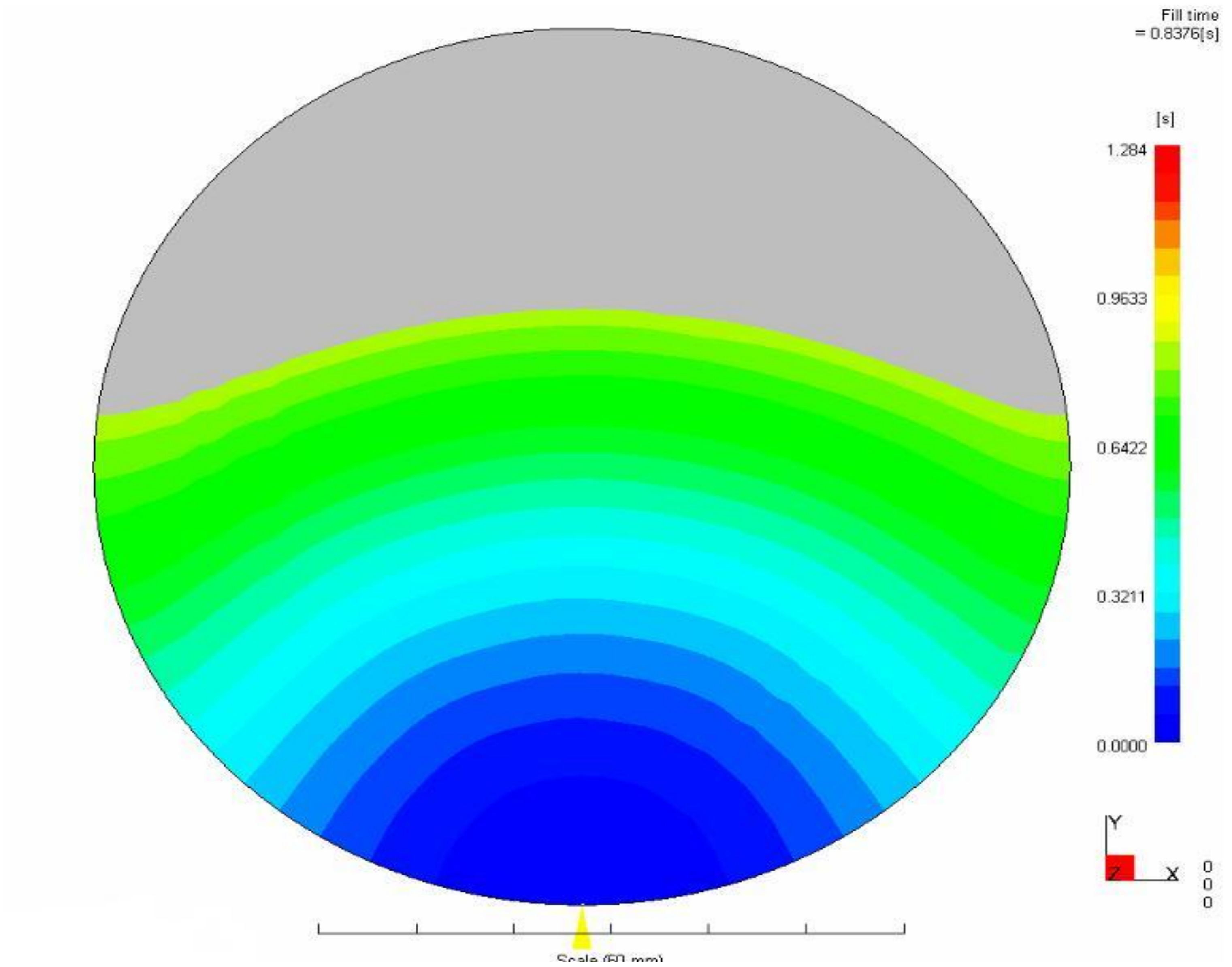


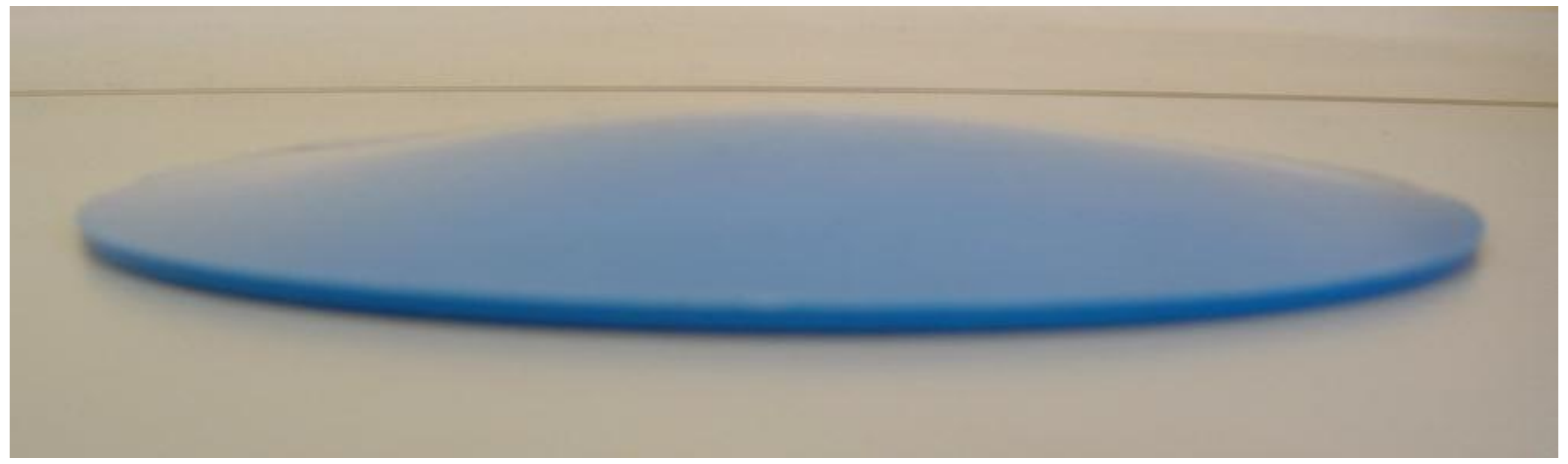
–Flow Group Imbalance

Intra-Cavity Shear Induced Melt Variations

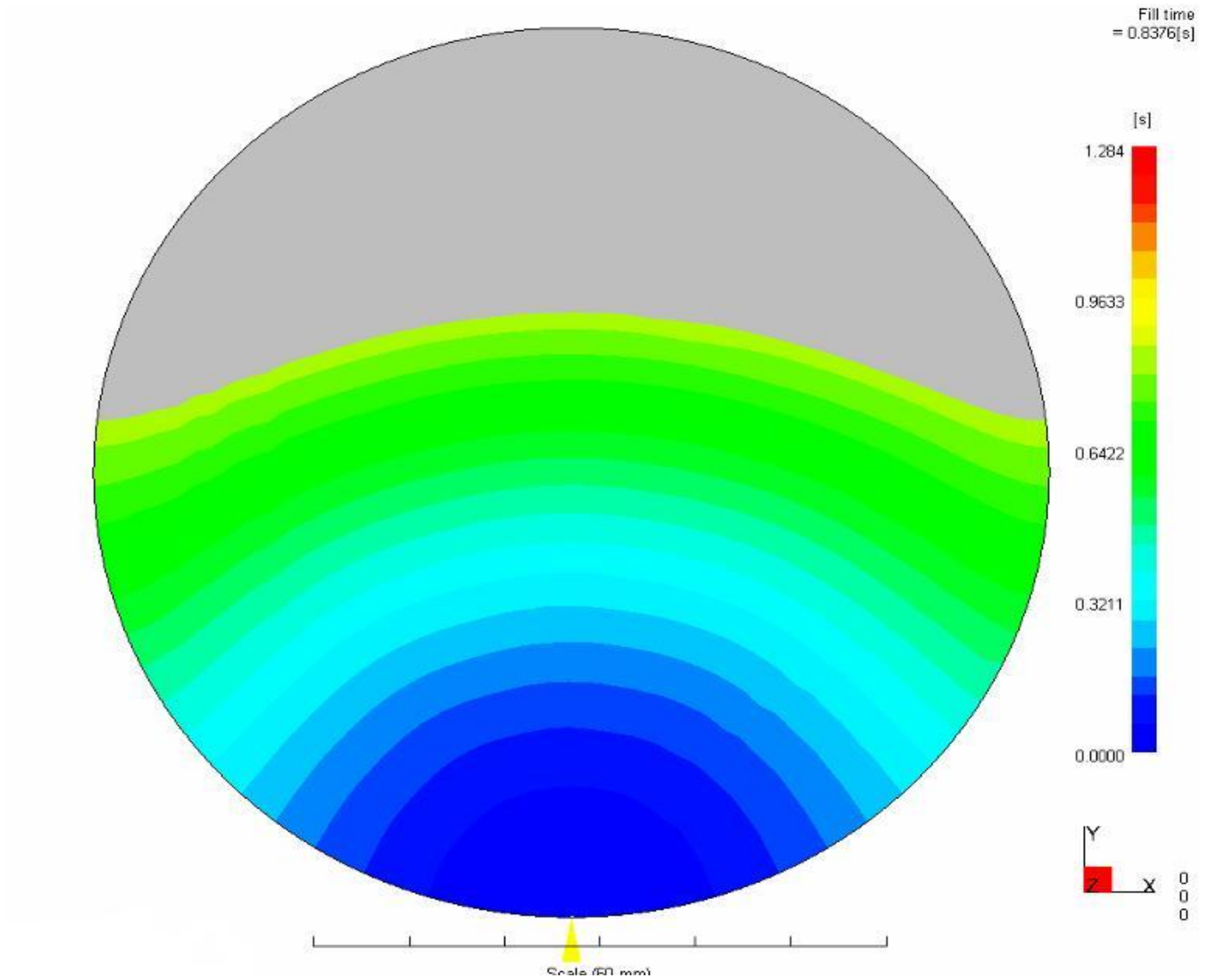
Shear induced melt variations impacting filling pattern and part warpage.

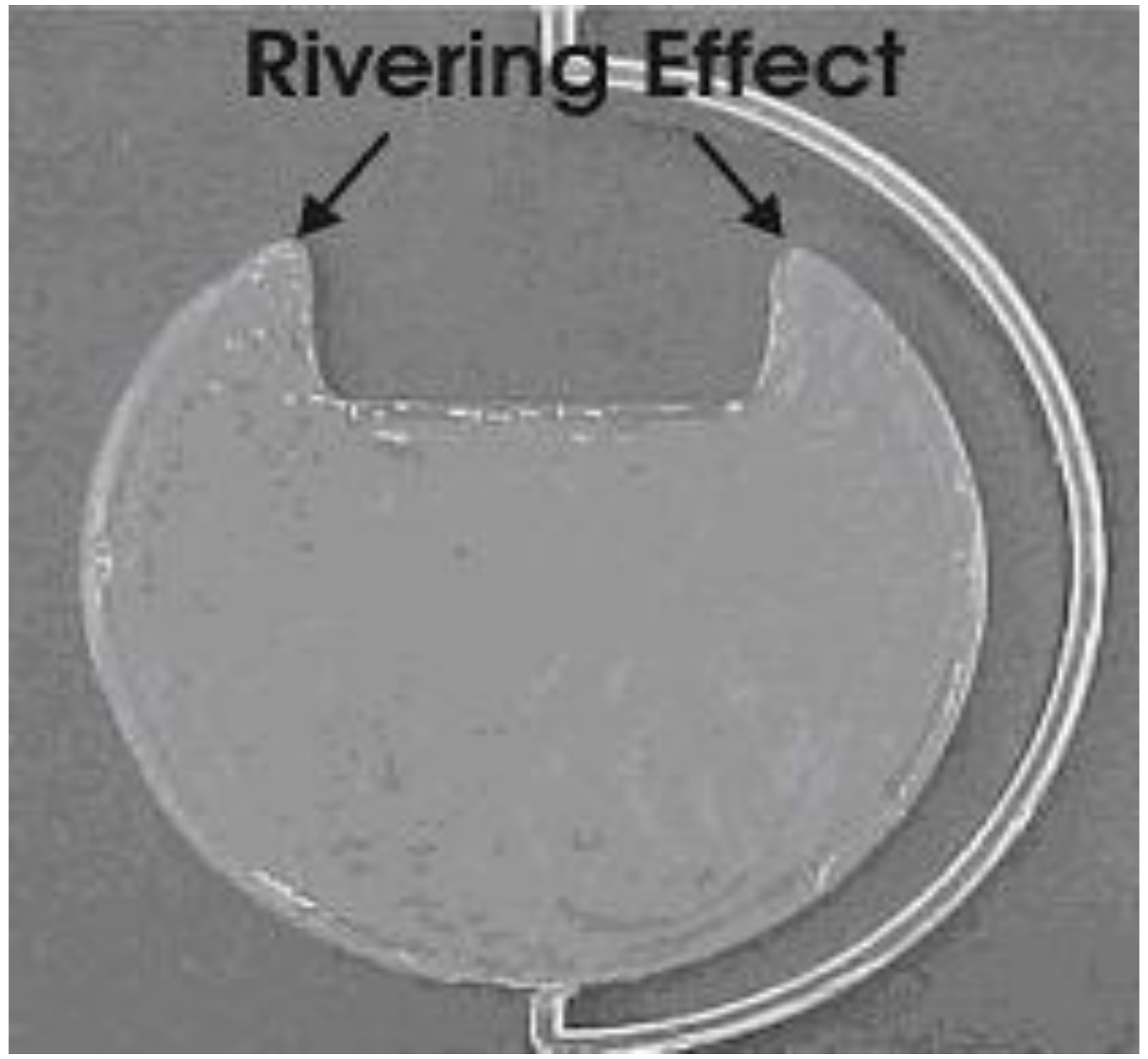
Single Cavity

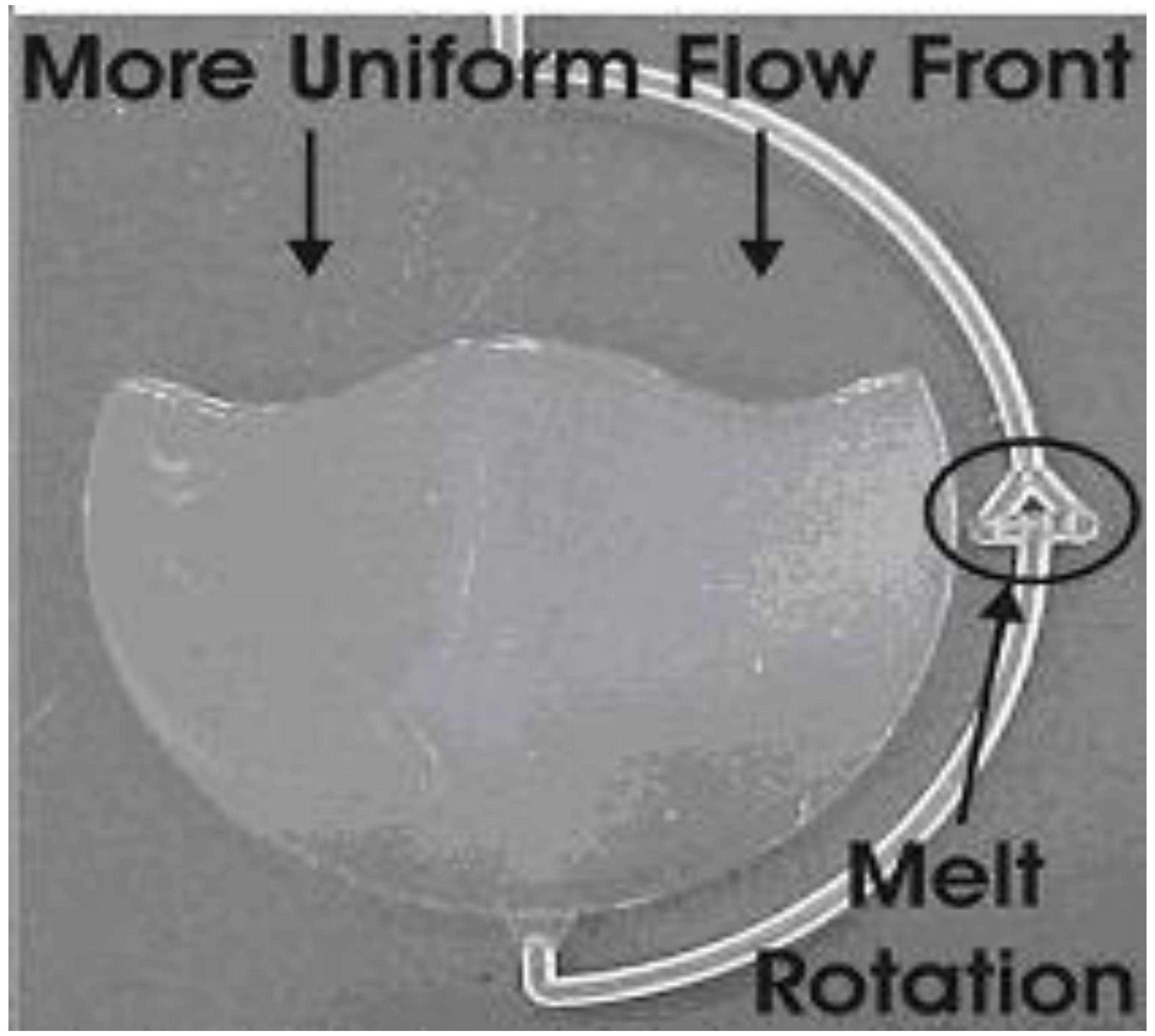


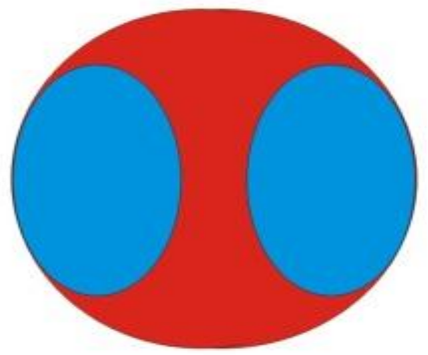


Controlling the Melt Flow Front









Traditional Runner

MAX™ Technology

Multi-Axis Control (MAX™): Glass Fiber / Cosmetics

Traditional Runner

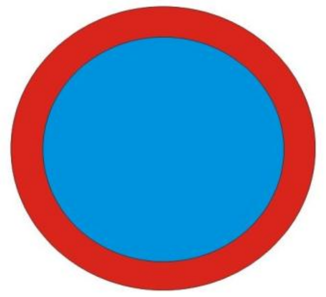
MAX Technology

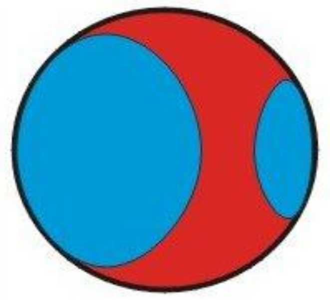
Glass Fiber:

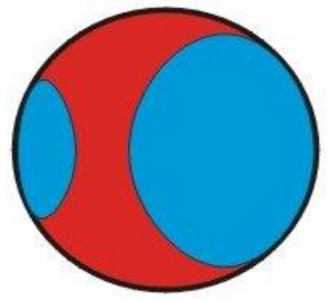
- ✓ Improved distribution
- ✓ Improved cosmetics

Multi-Axis Control (MAX™): Glass Fiber / Cosmetics

In mold adjustability to control melt conditions and filling pattern.







Changing Fill Patterns with MAX™

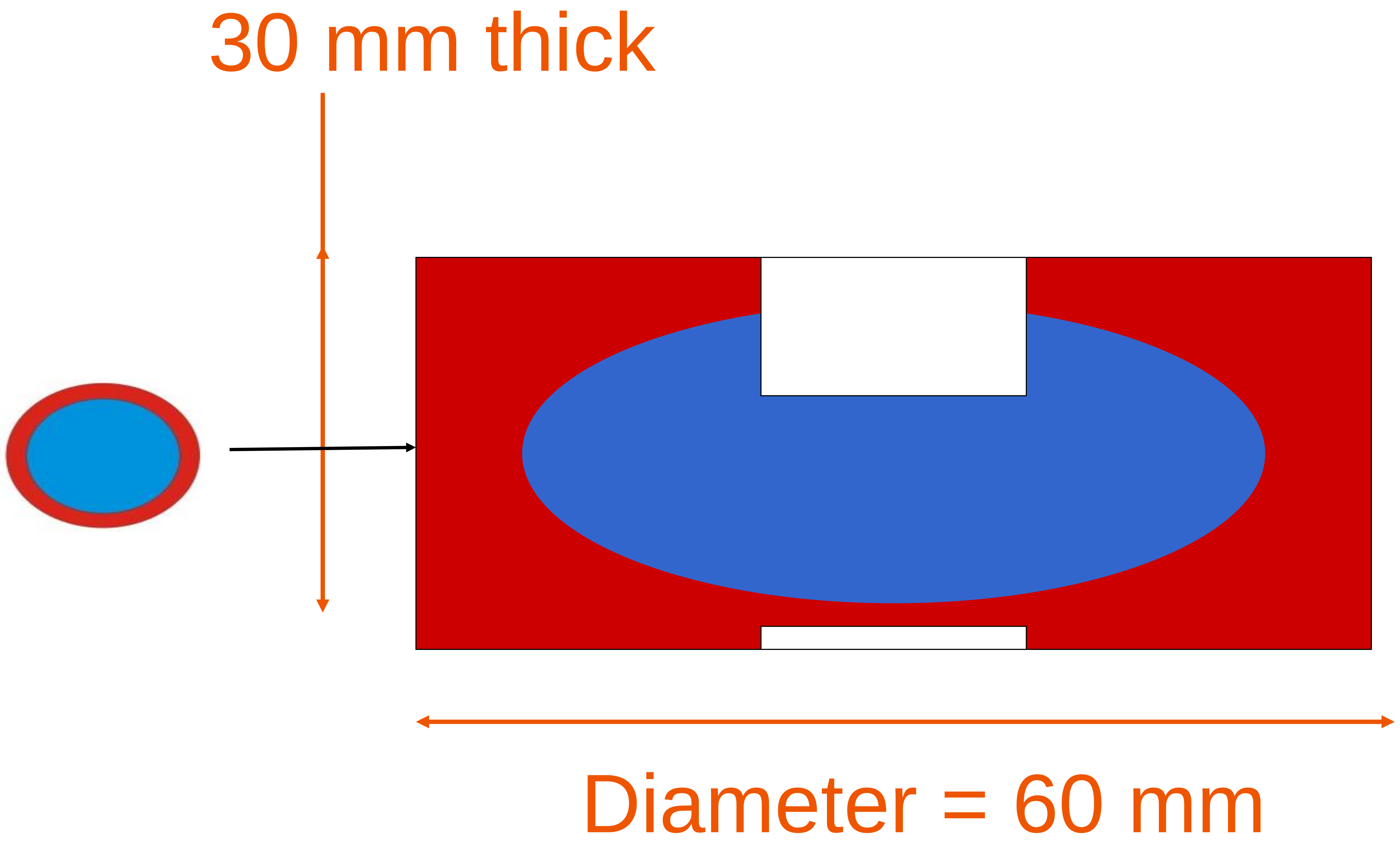
Original fill pattern created weld line issues visible with plating/painting process

Original

Melt Rotation

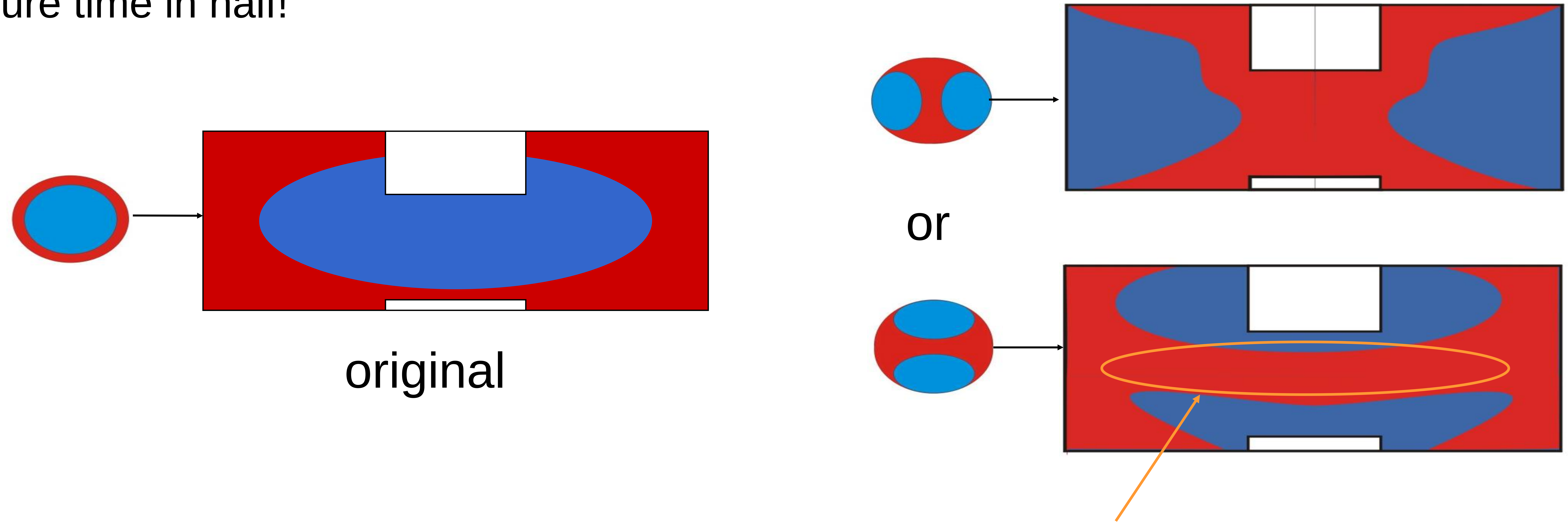
Melt Rotation designed to enhance flow through the center regions and move the weld line to the corners...less visible area

Multi-Axis: 2-Cavity, AVS Rubber Mount



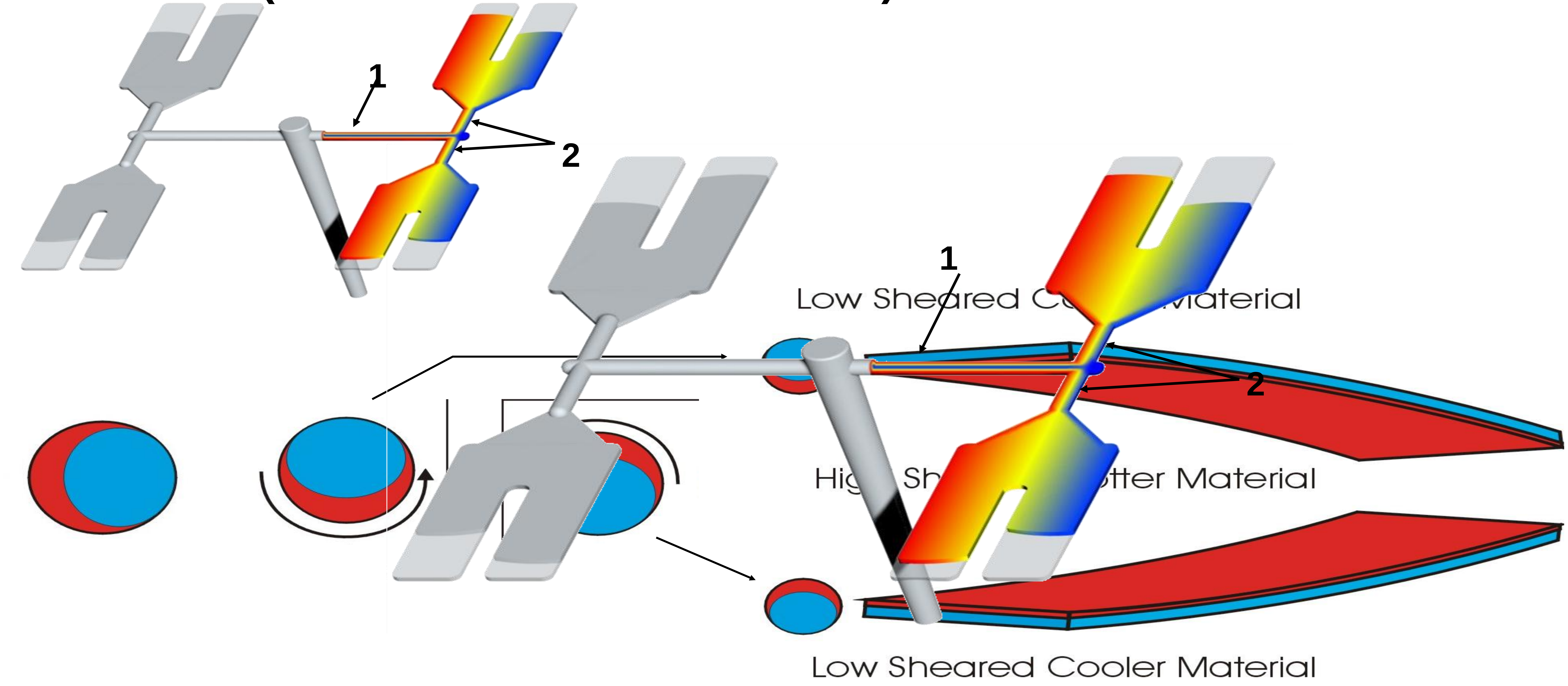
Multi-Axis: Thermoset Rubber Cure Time cut in Half!

High sheared laminates from runner turned inside-out as they enter the cavity. This strategic placement of high sheared laminates cuts cure time in half!



Part is now heated from *inside out* as well as *outside in*.

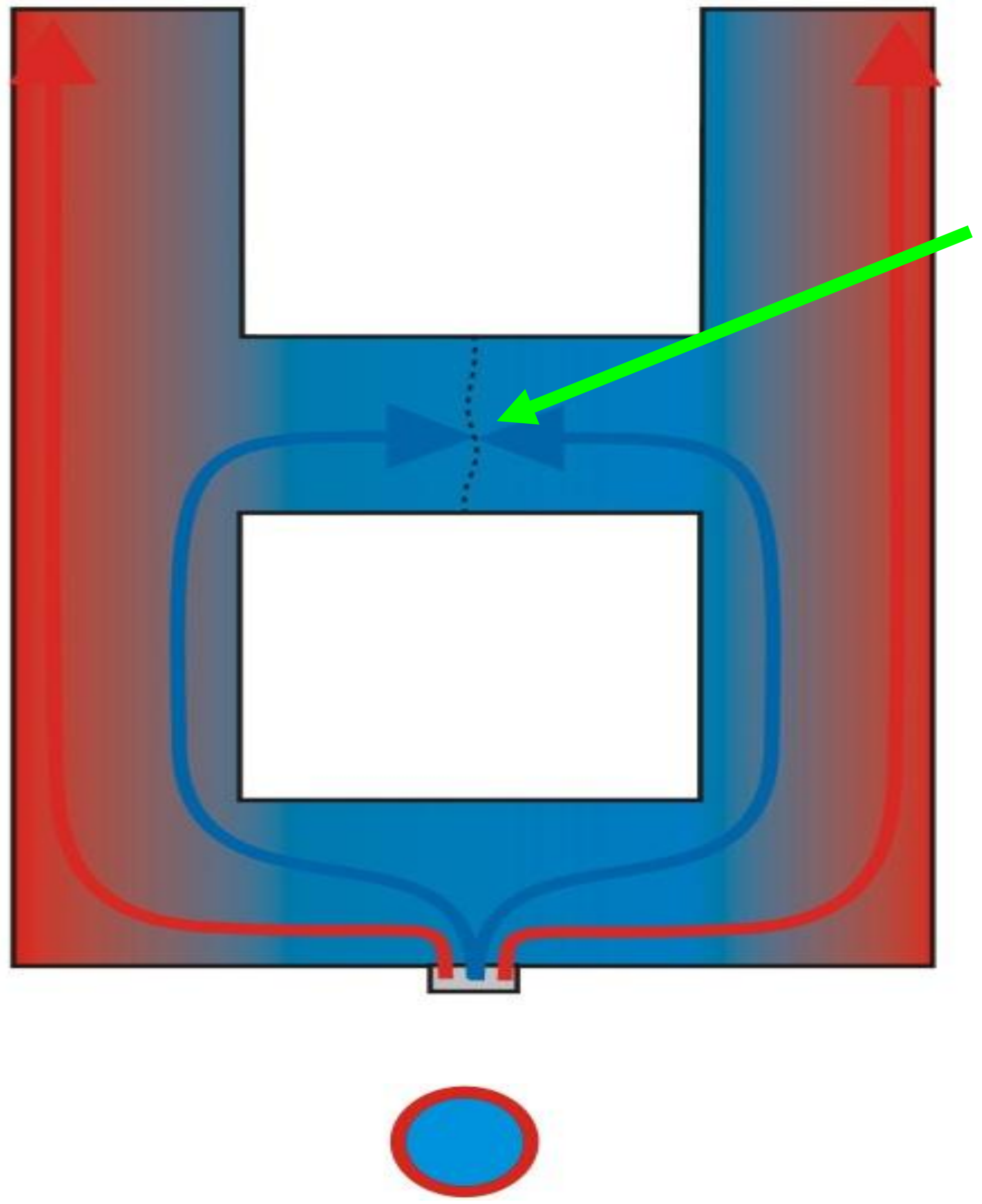
Affecting Warpage by Controlling Regional & Side-to-Side Shrinkage Variation (Shear Induced Melt Variations)



1. ANTEC 2006 – Beaumont, Myers & Hugel
2. ANTEC 2008 – Toomey & Skiba

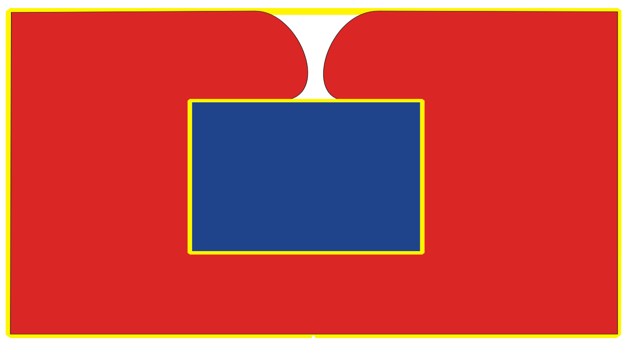
Controlling Weld Position and Strength

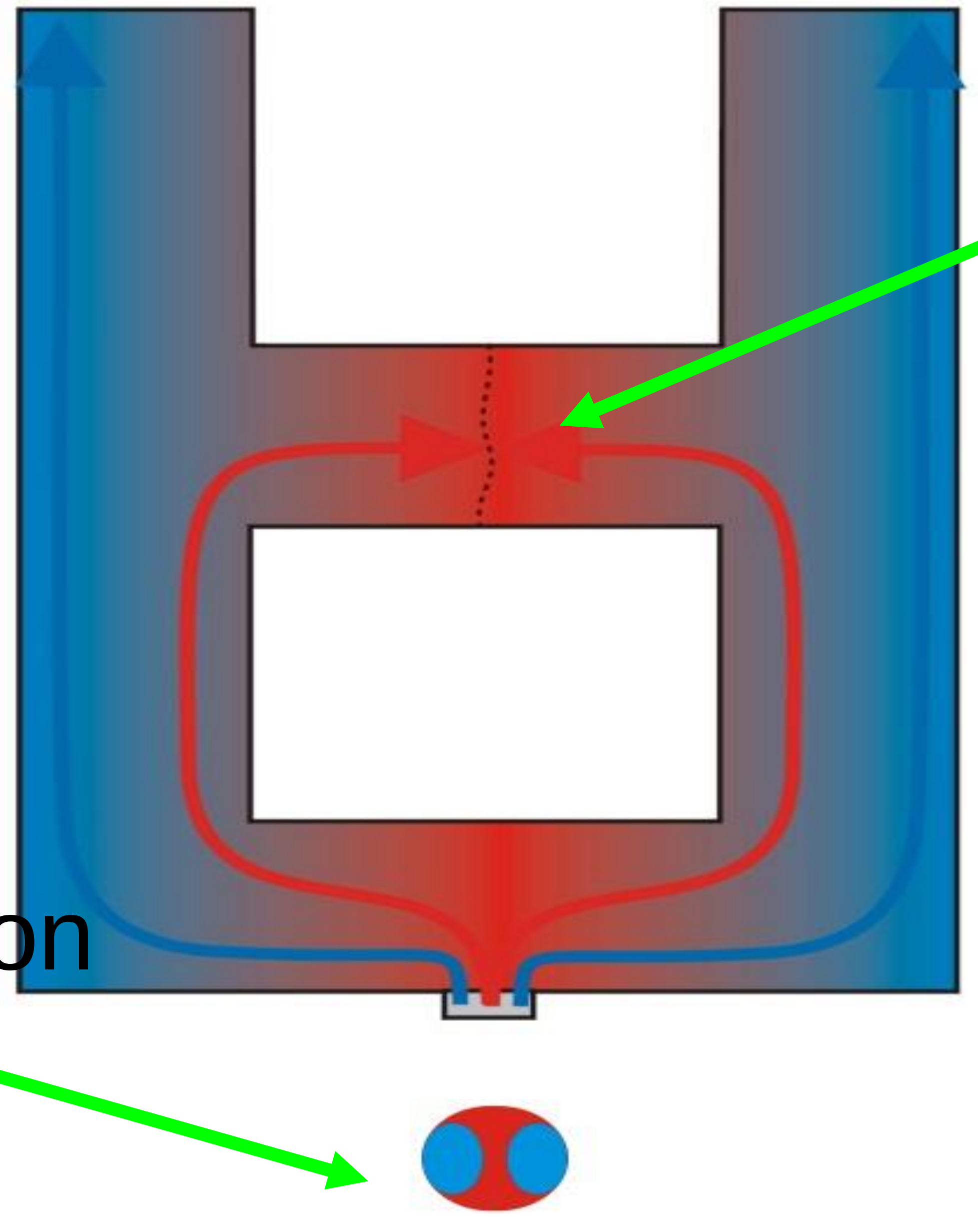
- Strategic positioning of hotter material
- Redefining the melt Front



Weld Line

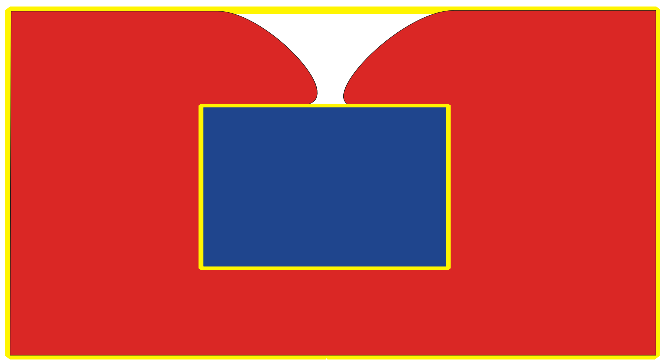
(cold material, butt weld)





Weld Line

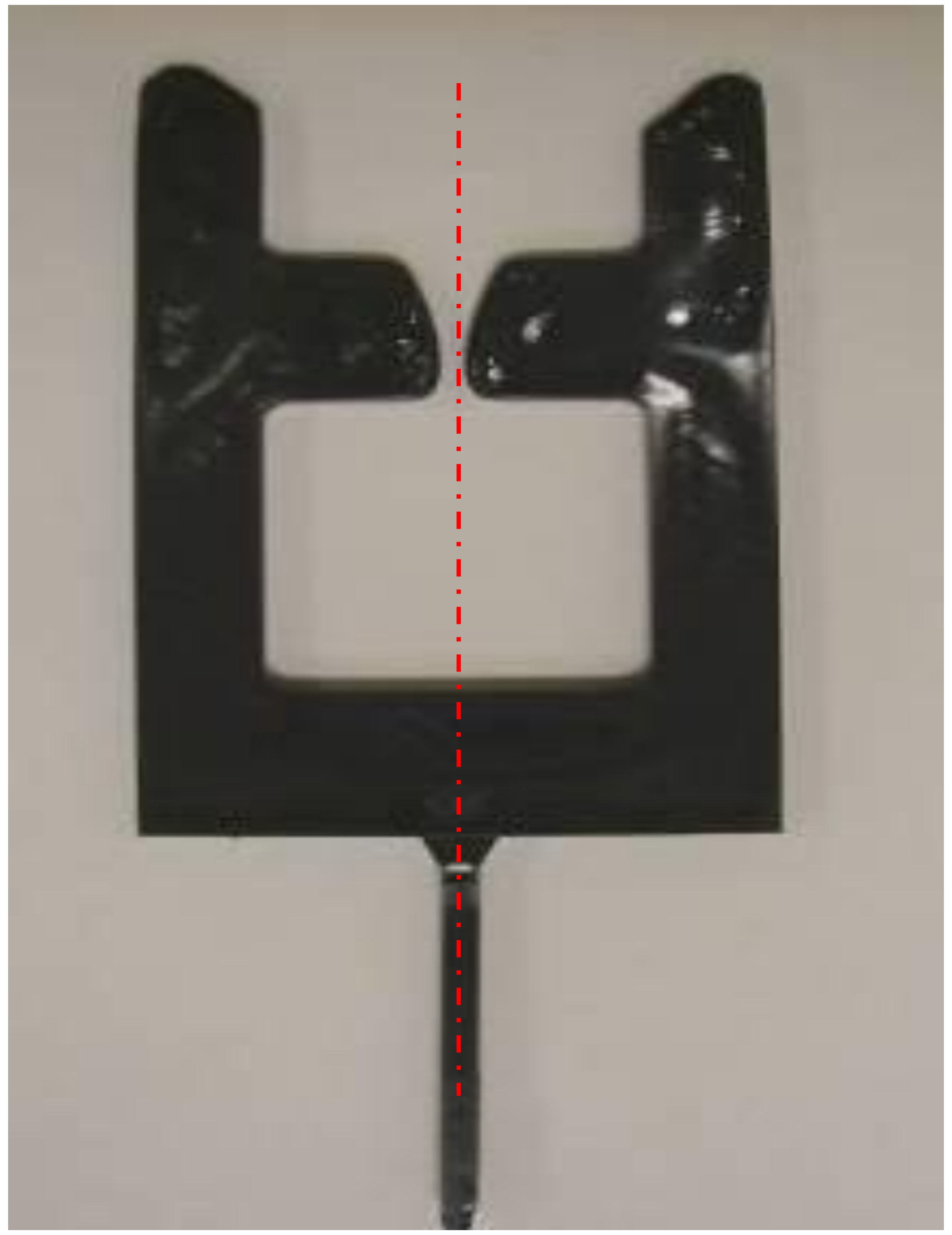
(hot material, meld)



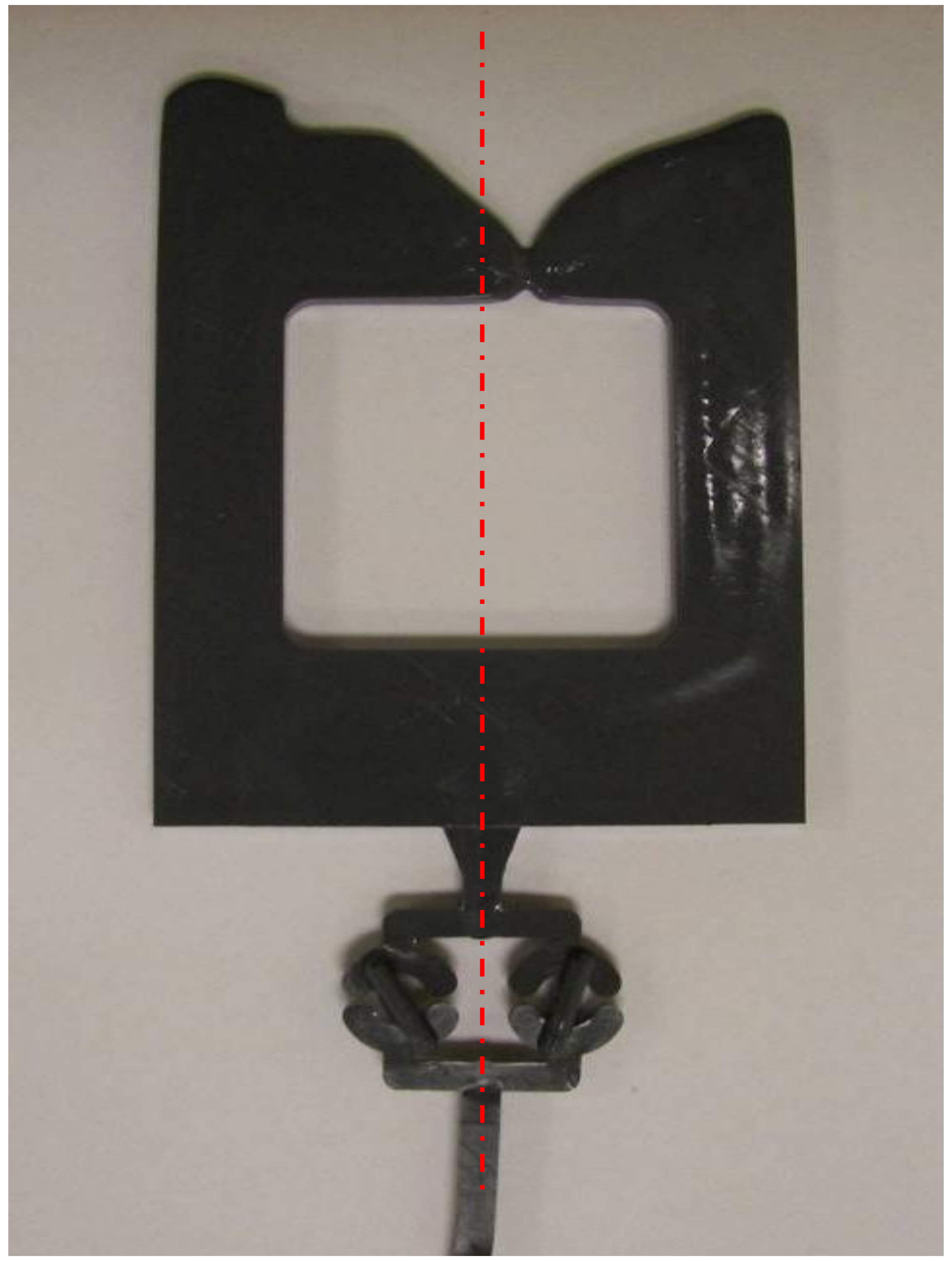
Multi-Axis Melt Rotation Technology

Controlling Weld Position and Strength

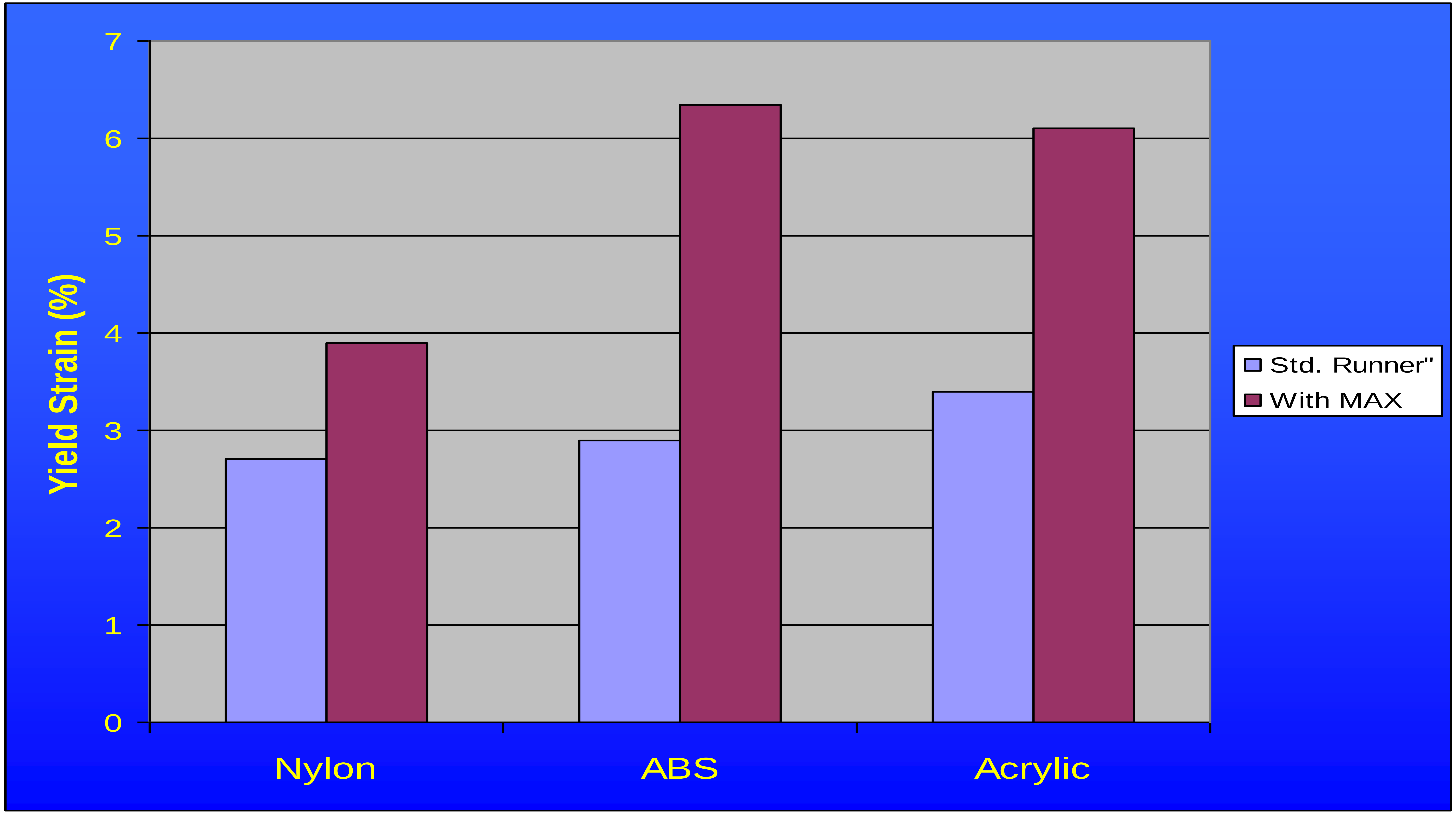
Conventional Weld Line Location



Influence of iMARC on Weld Line Locations

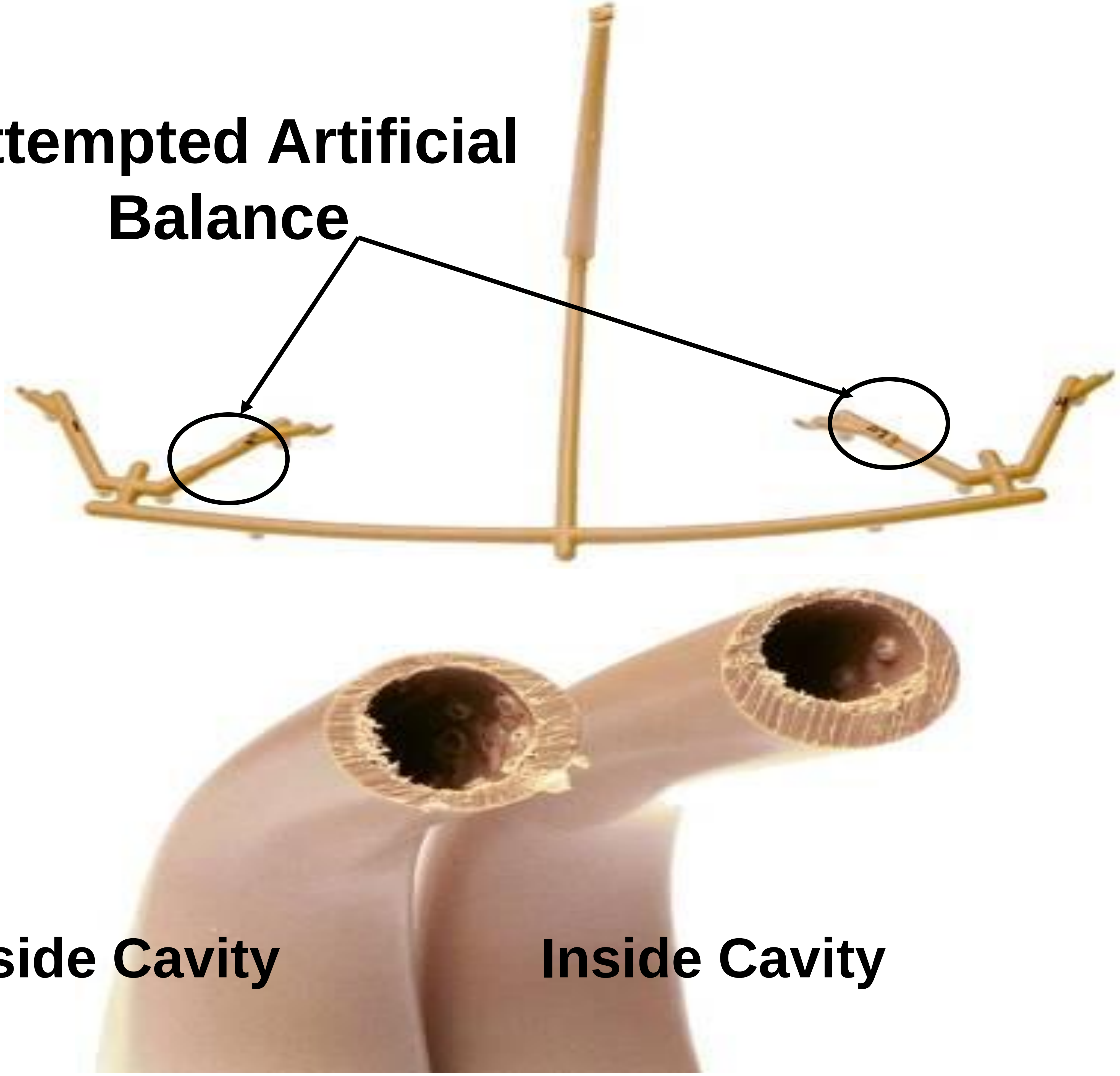


Controlling Weld Line Position and Strength



Gas-Assist Injection Molding

Case Study: 4-Cavity Automotive Handle Mold

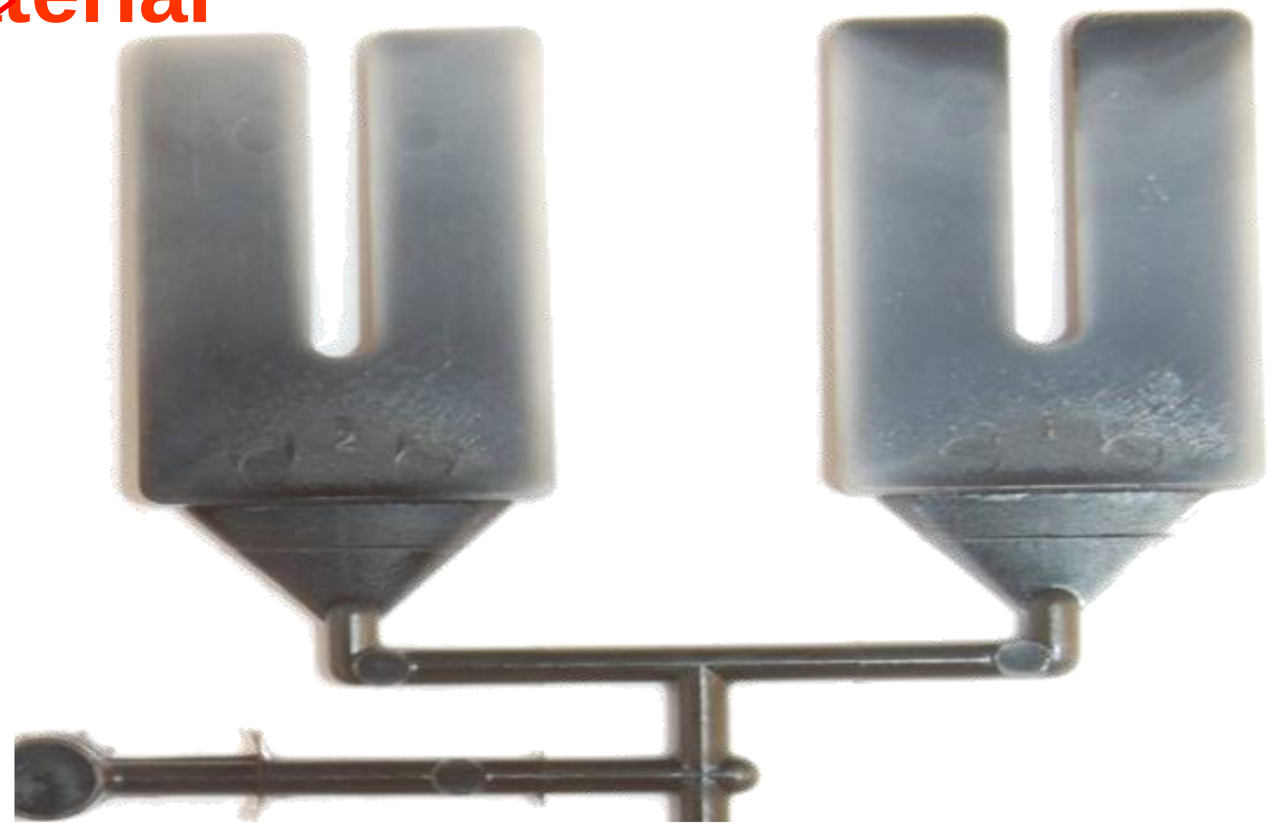


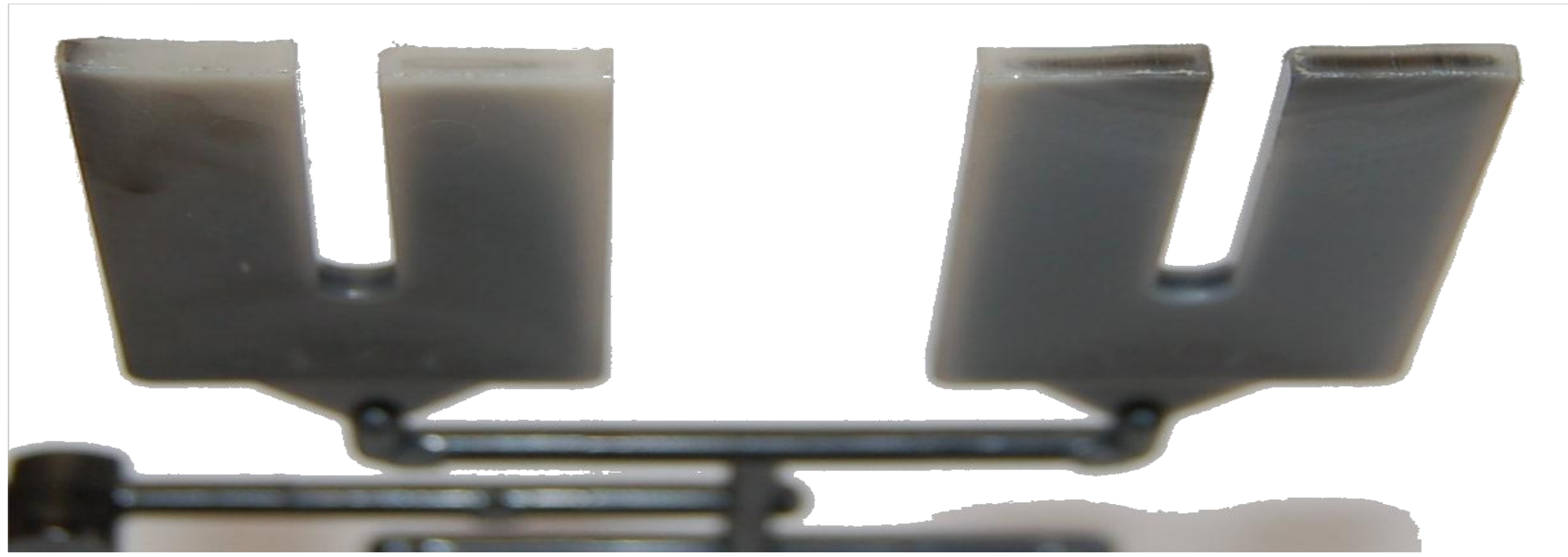
Co-Injection / Twinshot / Gas Assist / MuCell

Co-Injection / Twinshot / Gas Assist / MuCell

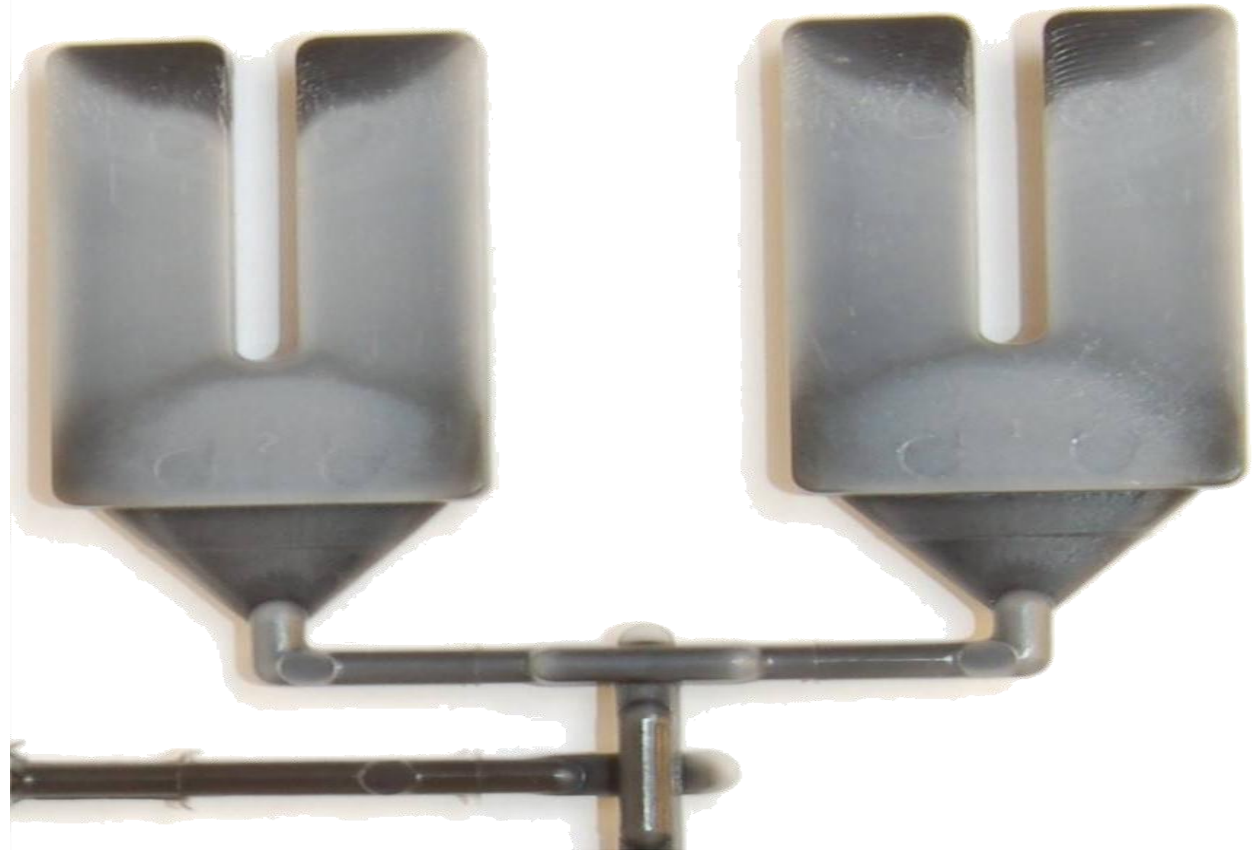
More Skin Material / Less Core Material

More Core Material / Less Skin Material





Uniform Core/Gas Material



Modeling Methods and techniques to predict shear induced imbalances.

1. Injection Nodes
2. Beam runners
3. 3D runners, Effect of number of Element layers, Element Layer Bias, Inertia

Common Materials Ranked in relative order of Sensitivity to Shear:

50%

Poly Vinyl chloride (PVC)
Poly Carbonate (PC)
Acrylic (PMMA)
Poly Styrene (PS)
Acetal (POM)
ABS
Polyamide - Nylons (PMA)
PBT
Liquid Crystal Polymers (LCP)
Thermoplastic Elastomers/Urethanes (TPE/TPR)
PP
HDPE

10%

Myths:

Shear imbalance is created by sharp corners.

Pic 1

Pic 2

Eight cavity Plaque test mold.

Introductory slide: Picture of mold   Full Parts.

Mold Eight cavity Plaque test mold.

Injection nodes – show single cavity plaque with injection nodes

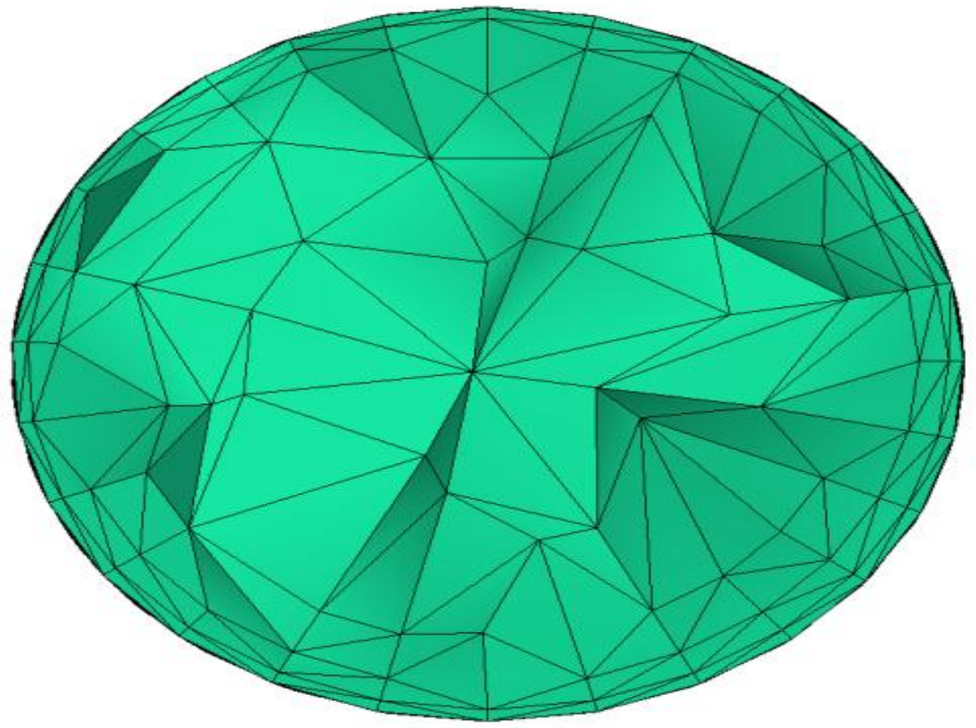
Eight cavity Plaque test mold.

show single cavity plaque with beam runner and occurrences

Eight cavity Plaque test mold.

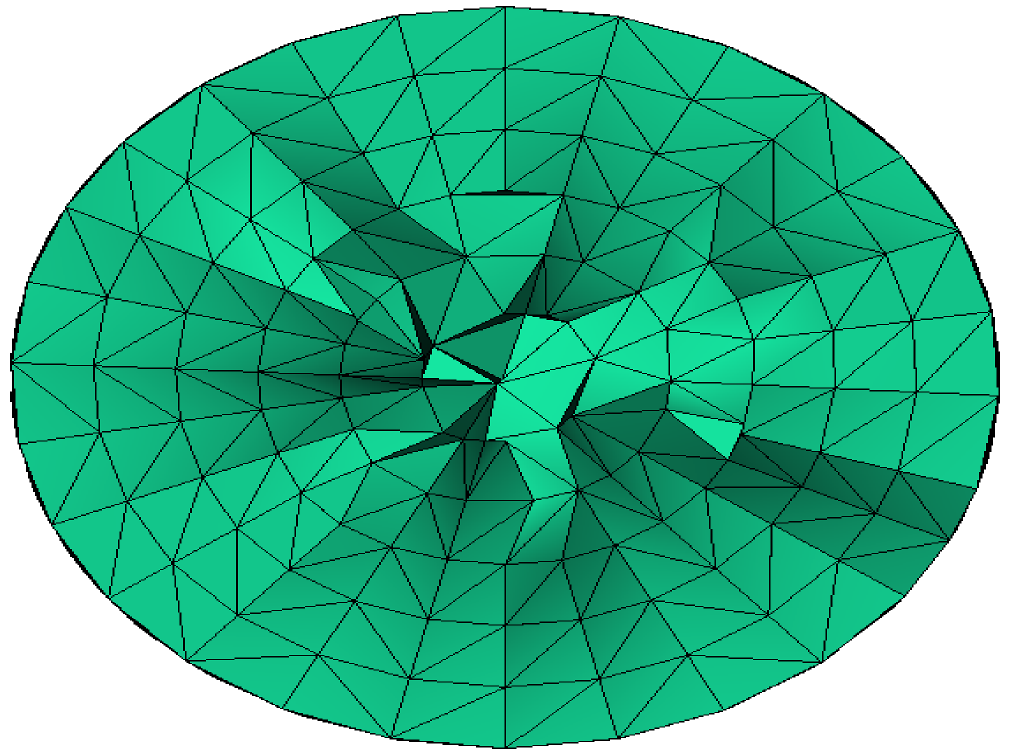
Mesh Comparisons – Primary Runner X Section

10 Layers – 2.0 Bias



Moldflow File name: t-seg_3D-20-p1
Mesh Diagnostics
Mesh Type: 3D runner and part
# of Elements = 4,352,867
Minimum # of Elements through the thickness = 10 (2.0 Bias)

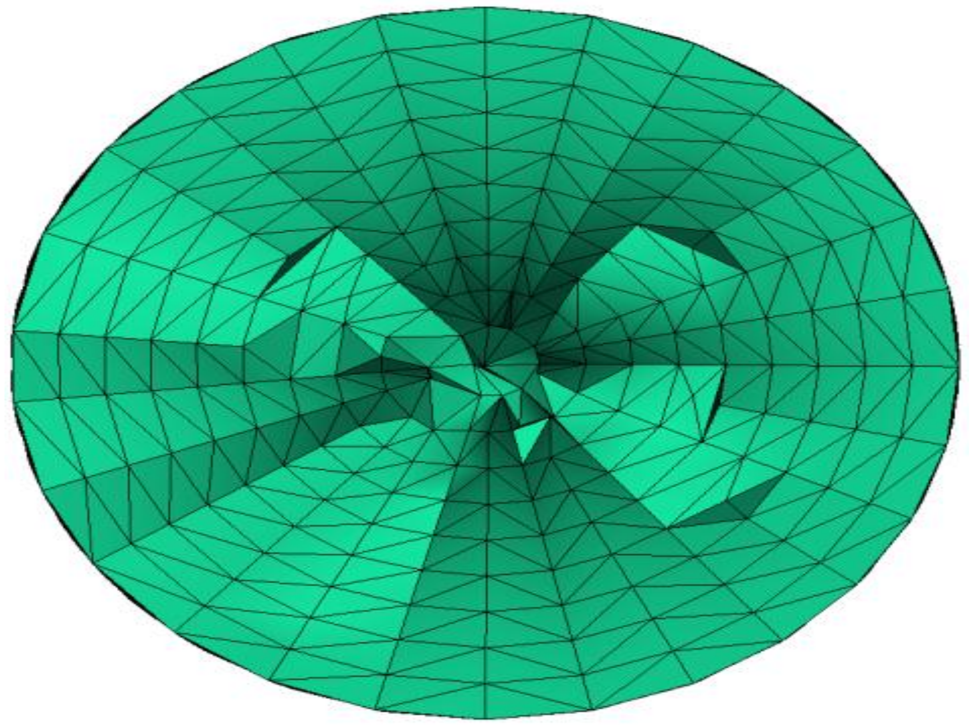
12 Layers – No Bias



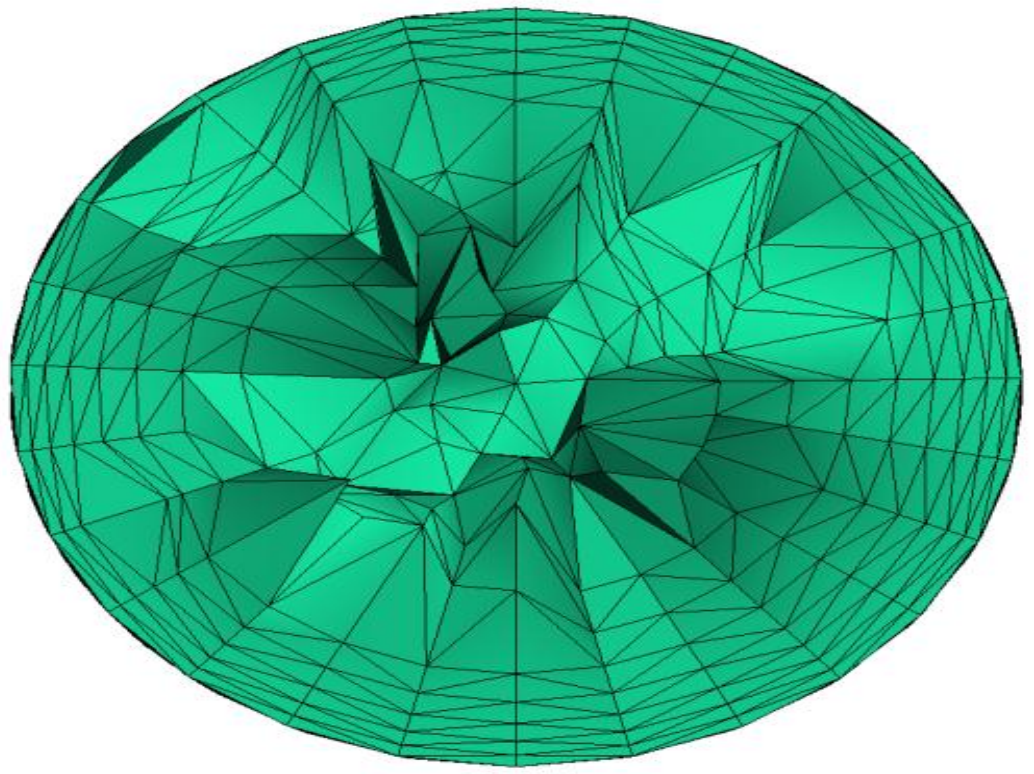
Moldflow File name: t-seg_3D-12-p1
Mesh Diagnostics
Mesh Type: 3D runner and part
# of Elements = 5,224,694
Minimum # of Elements through the thickness = 12

Mesh Comparisons – Primary Runner X Section

20 Layers – No Bias



20 Layers – 1.25 Bias



Process Set-up for Analysis

The following parameters were used to run the analysis:

Material: PC - Lexan 121

Melt Temperature: 560° F

Mold Temperature: 180° F

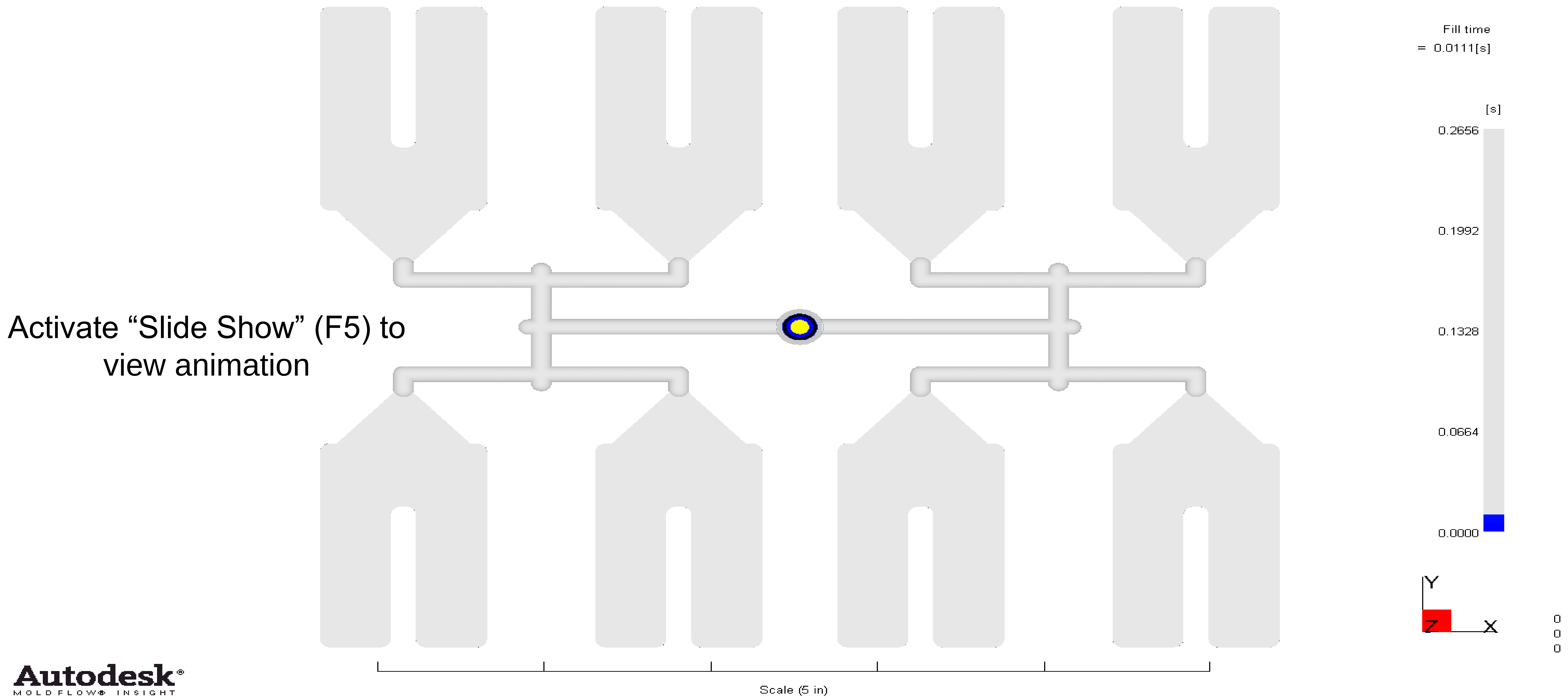
Injection time: 0.25 seconds

Runner Configuration

Fill Time

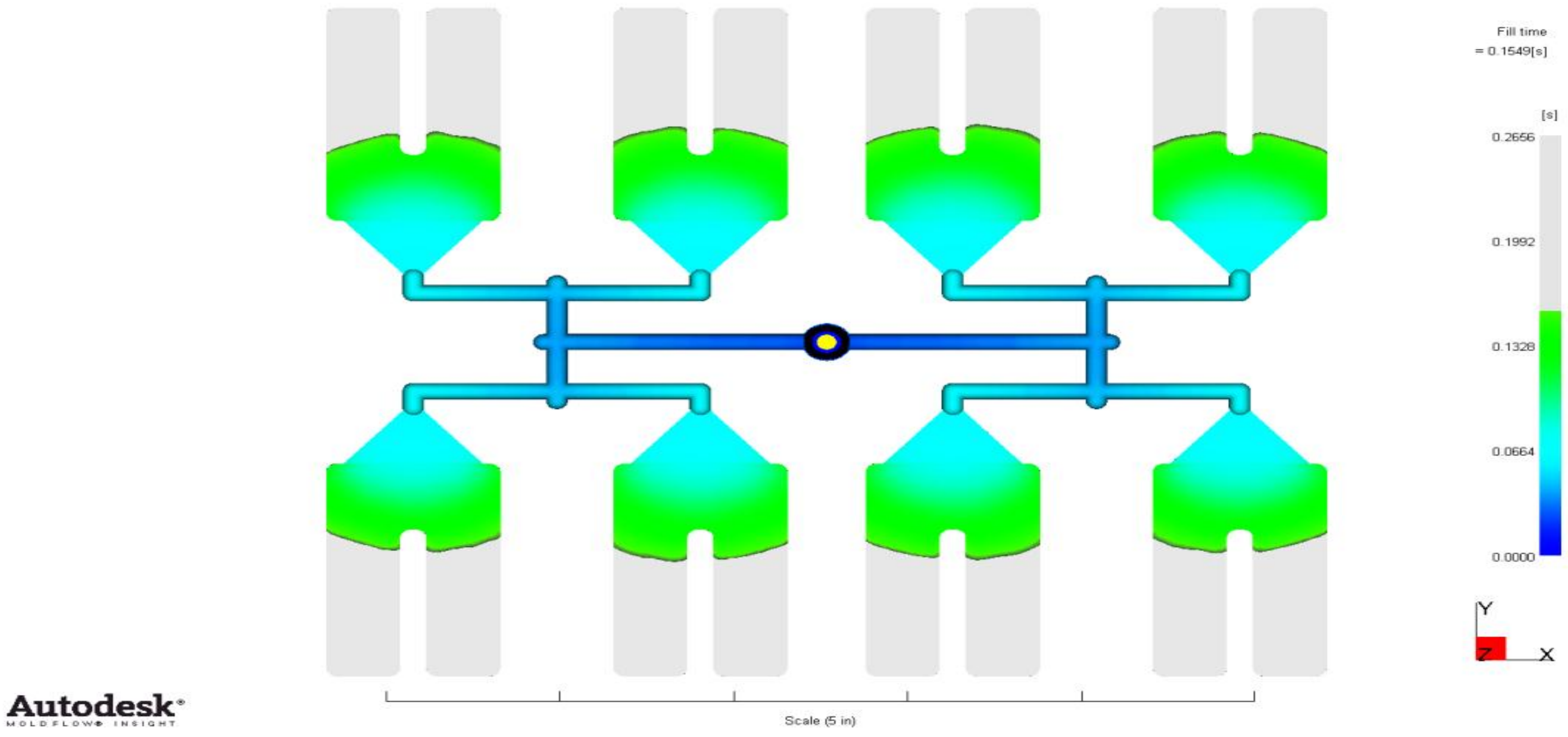
The mold was filled using a constant flow rate that resulted with an injection time of 0.27 seconds.

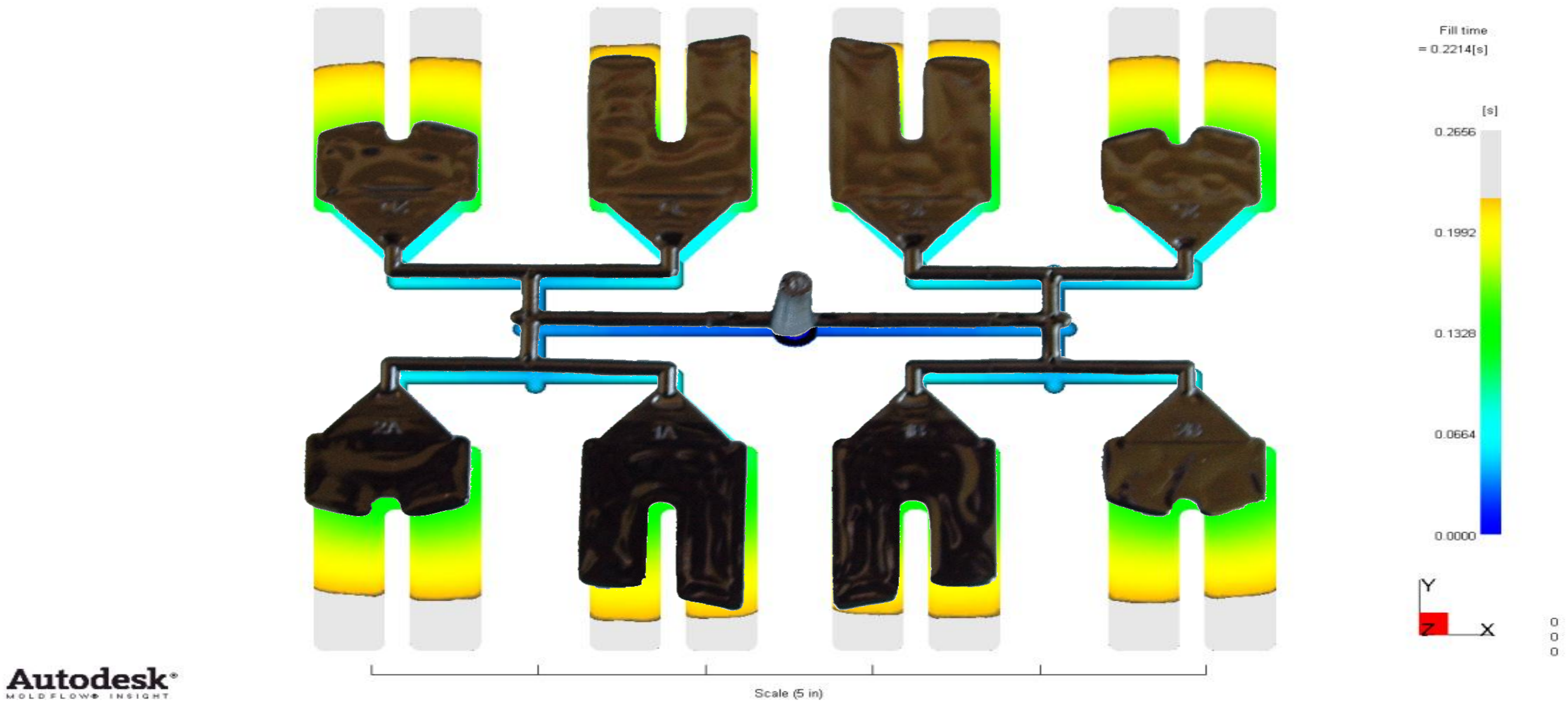
Activate "Slide Show" (F5) to view animation



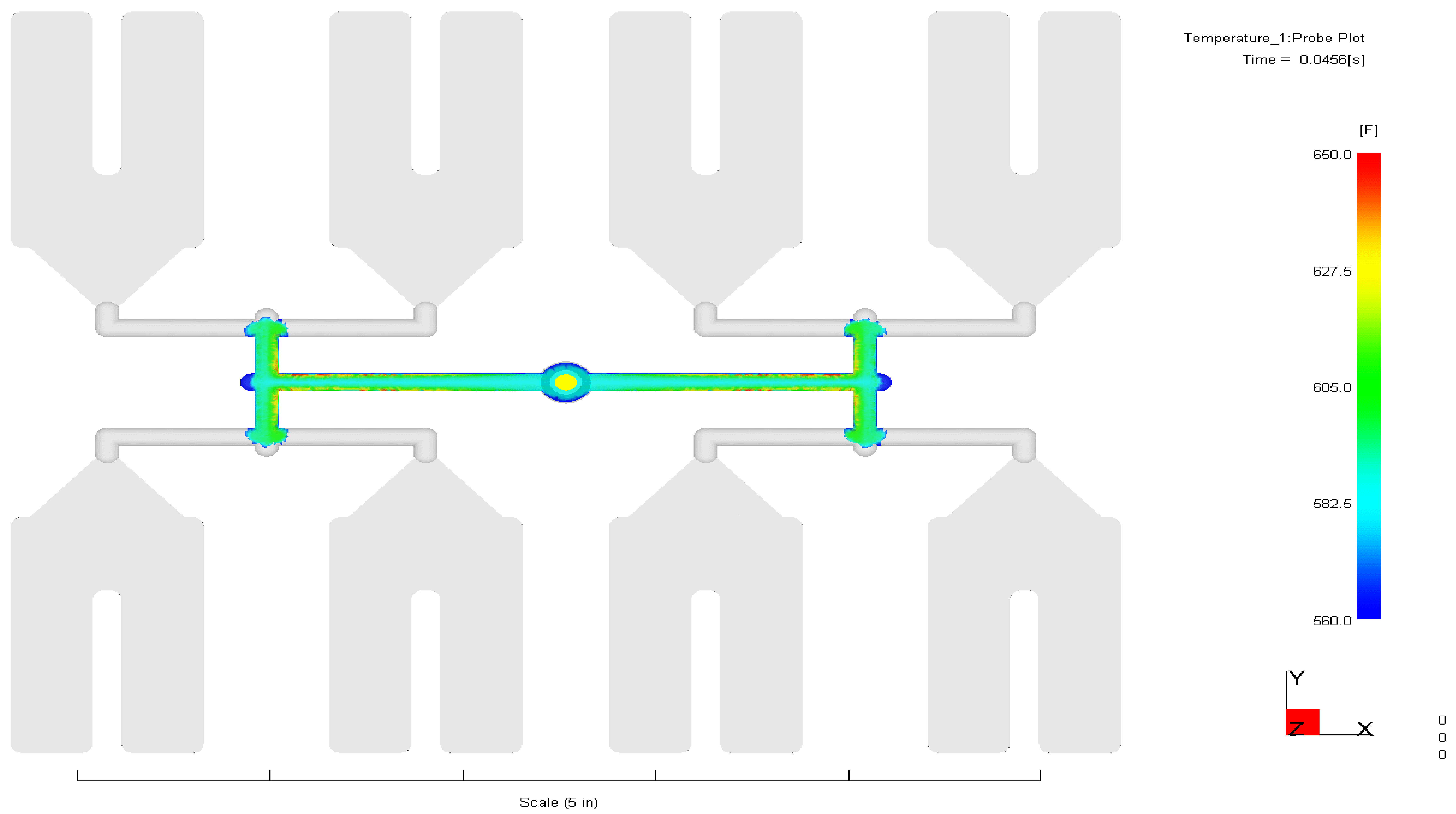
Filling Pattern Comparison: Actual vs Moldflow

The images below compare the actual molded filling progression with the Moldflow predictions





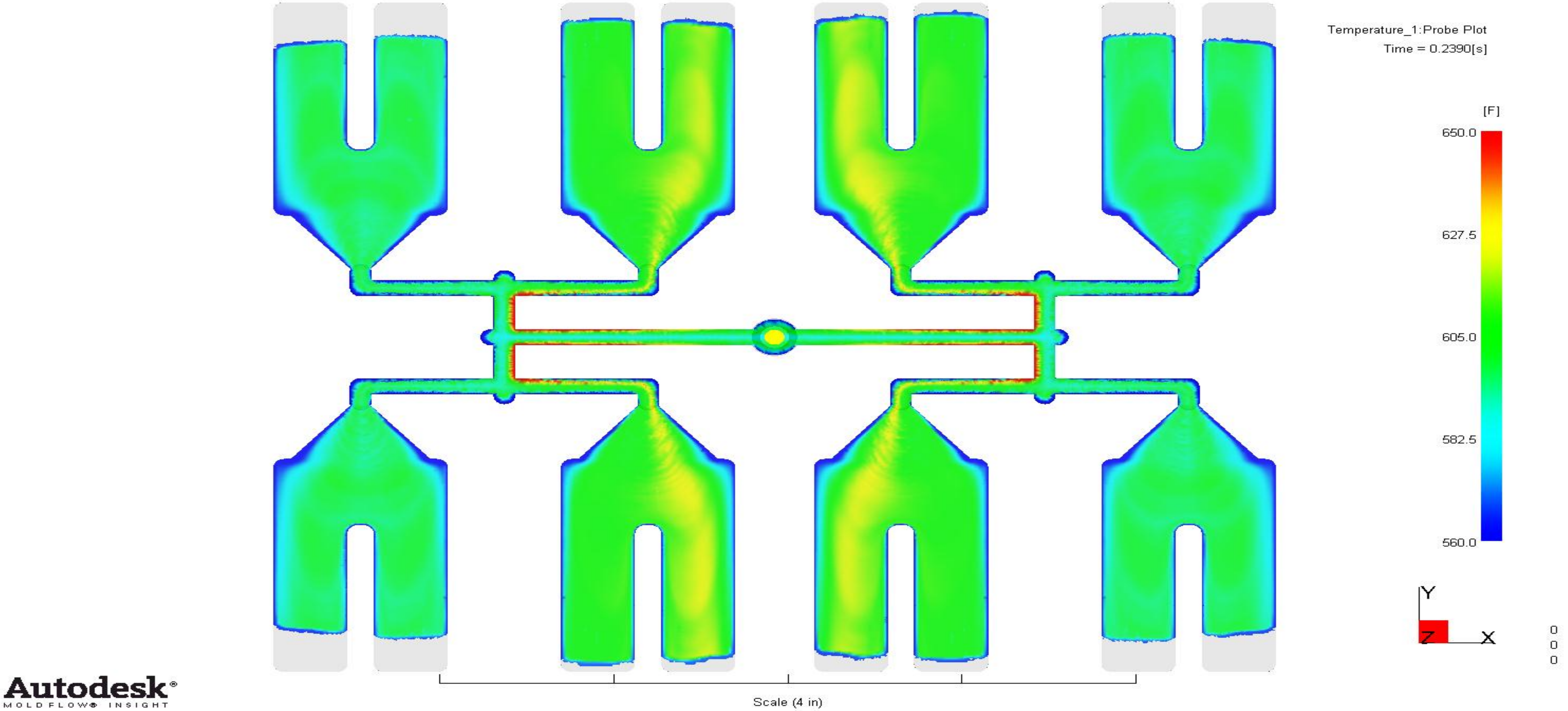
Temperature Animation



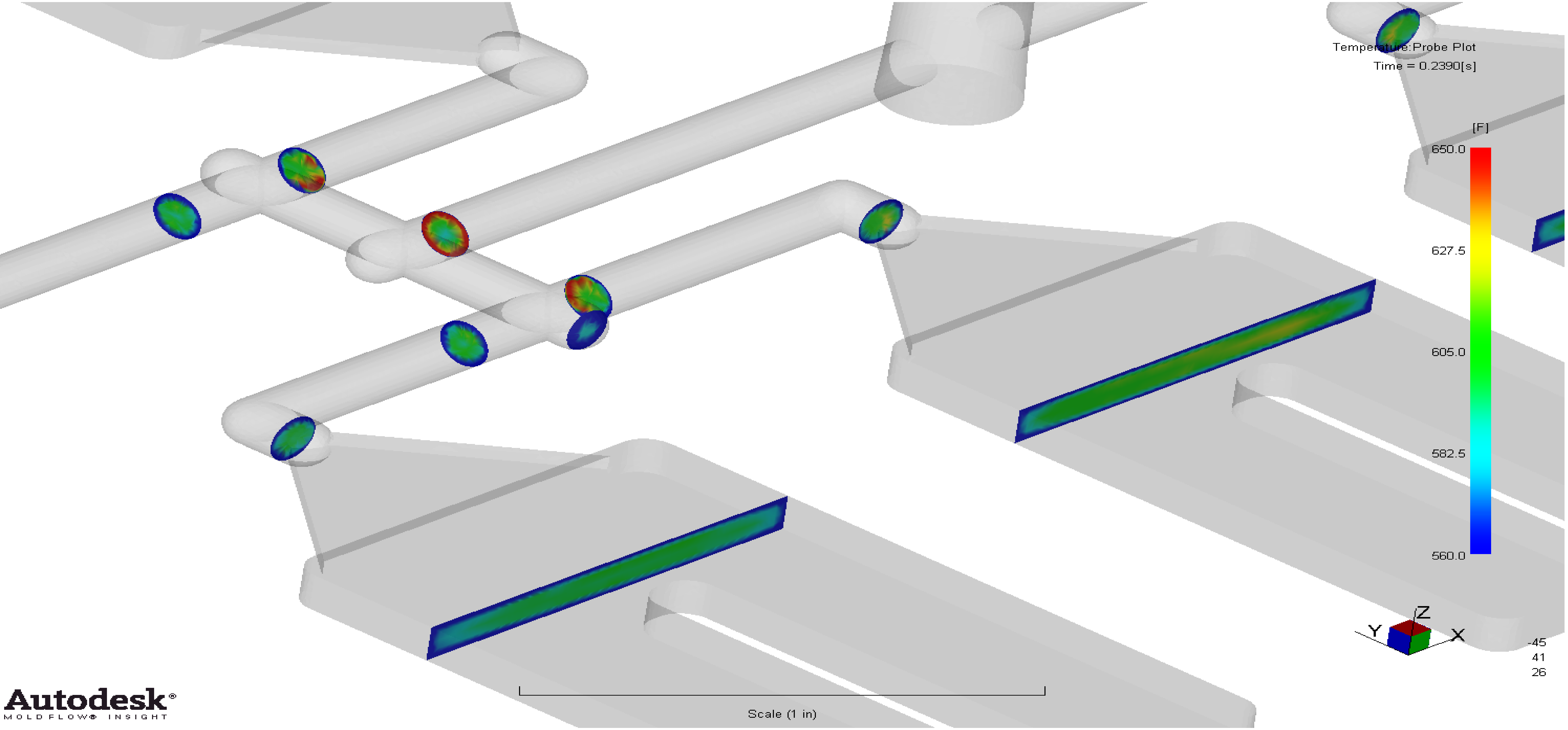
Autodesk MOLDFLOW® INSIGHT

Temperature at 90% Volume

The images below shows the predicted temperature profile in the part. This result shows a cross section through the part thickness at 90% volume.



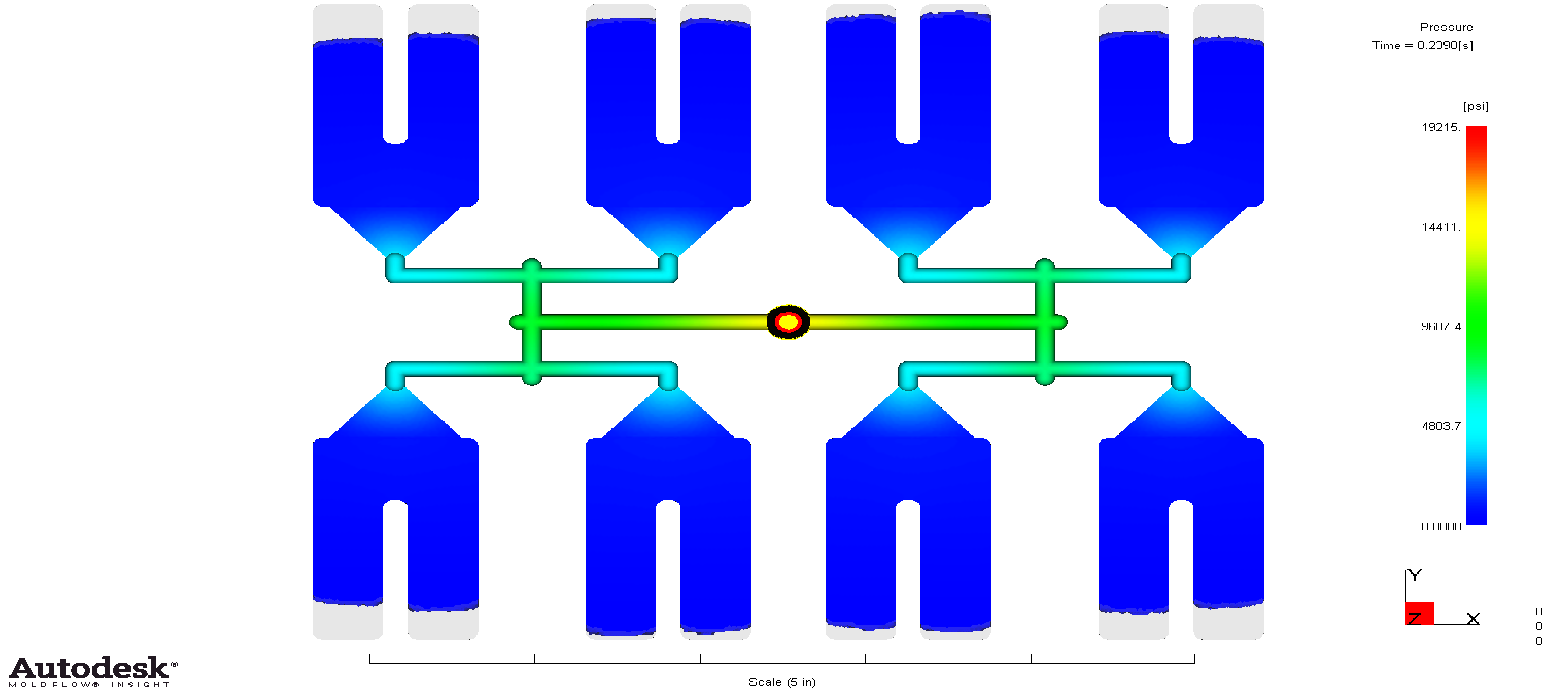
Temperature: Probe Plot



Pressure Comparison @ 90% Volume

The predicted pressure at 80% volume was 19,215 psi. This pressure prediction does not include pressure losses through the machine nozzle and barrel (Depending on the machine set up, pressures around 3,000 to 4,000 psi would be typical).

The actual molded samples at the same process conditions required 25,245 psi to fill to 90%.



Process Set-up for Analysis

The following parameters were used to run the analysis:

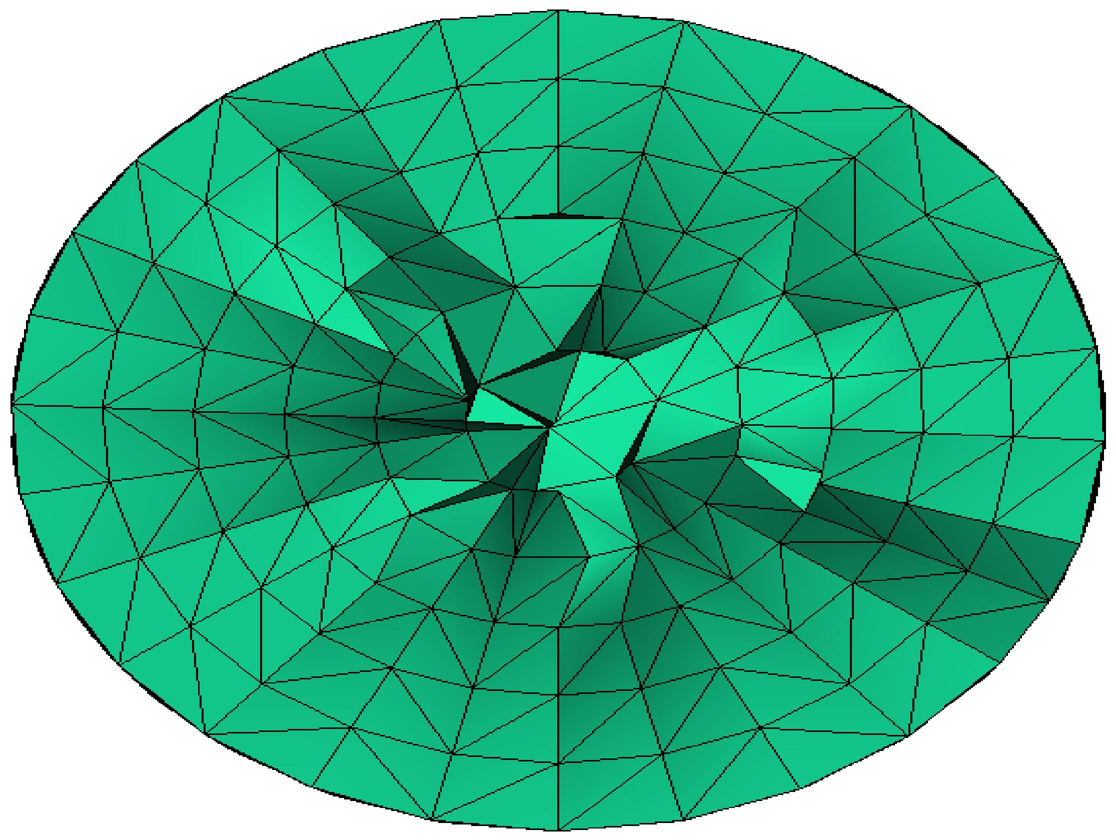
Material: PC - Lexan 121

Melt Temperature: 560° F

Mold Temperature: 180° F

Injection time: 0.25 seconds

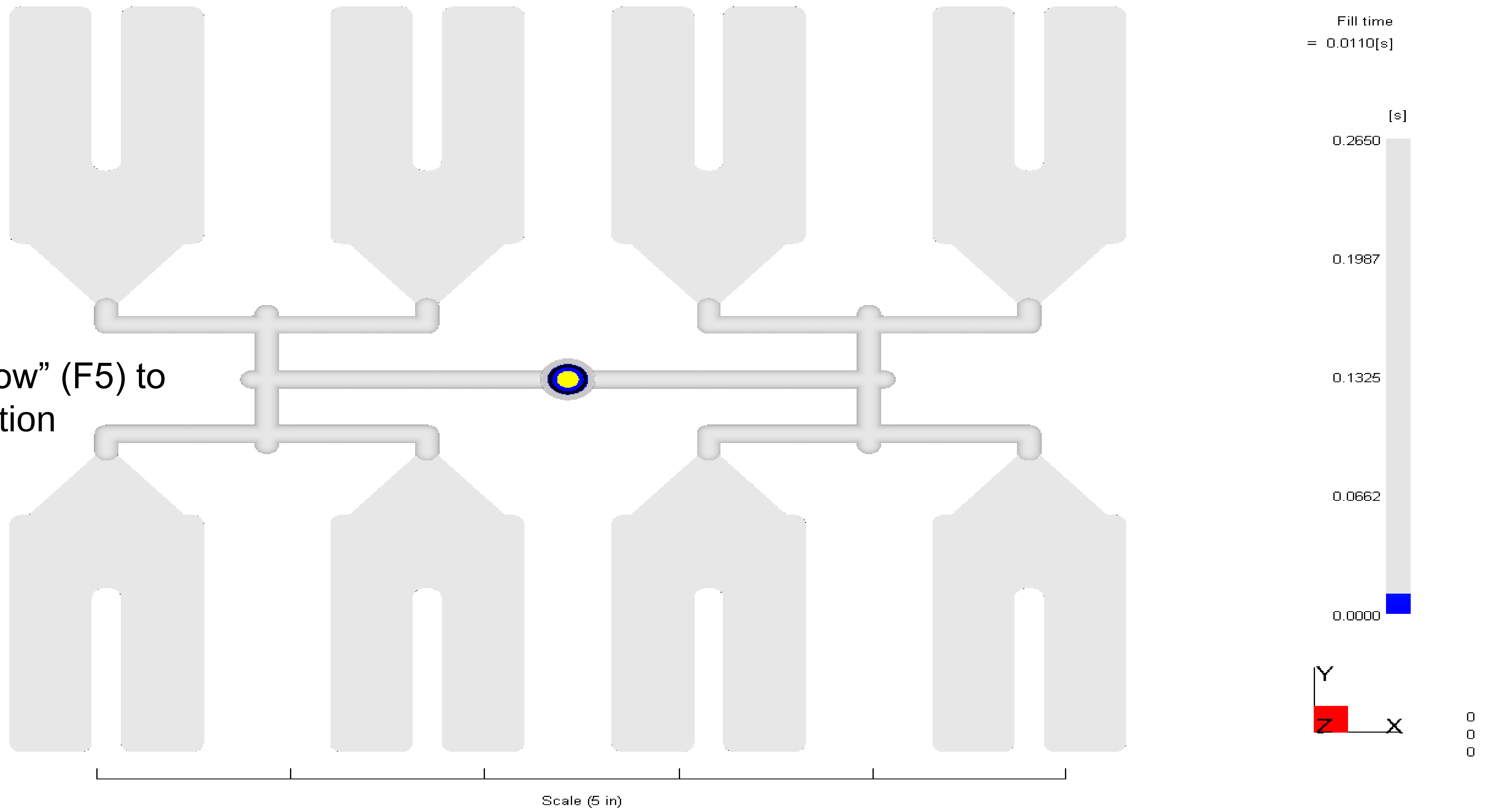
Runner Configuration



Fill Time

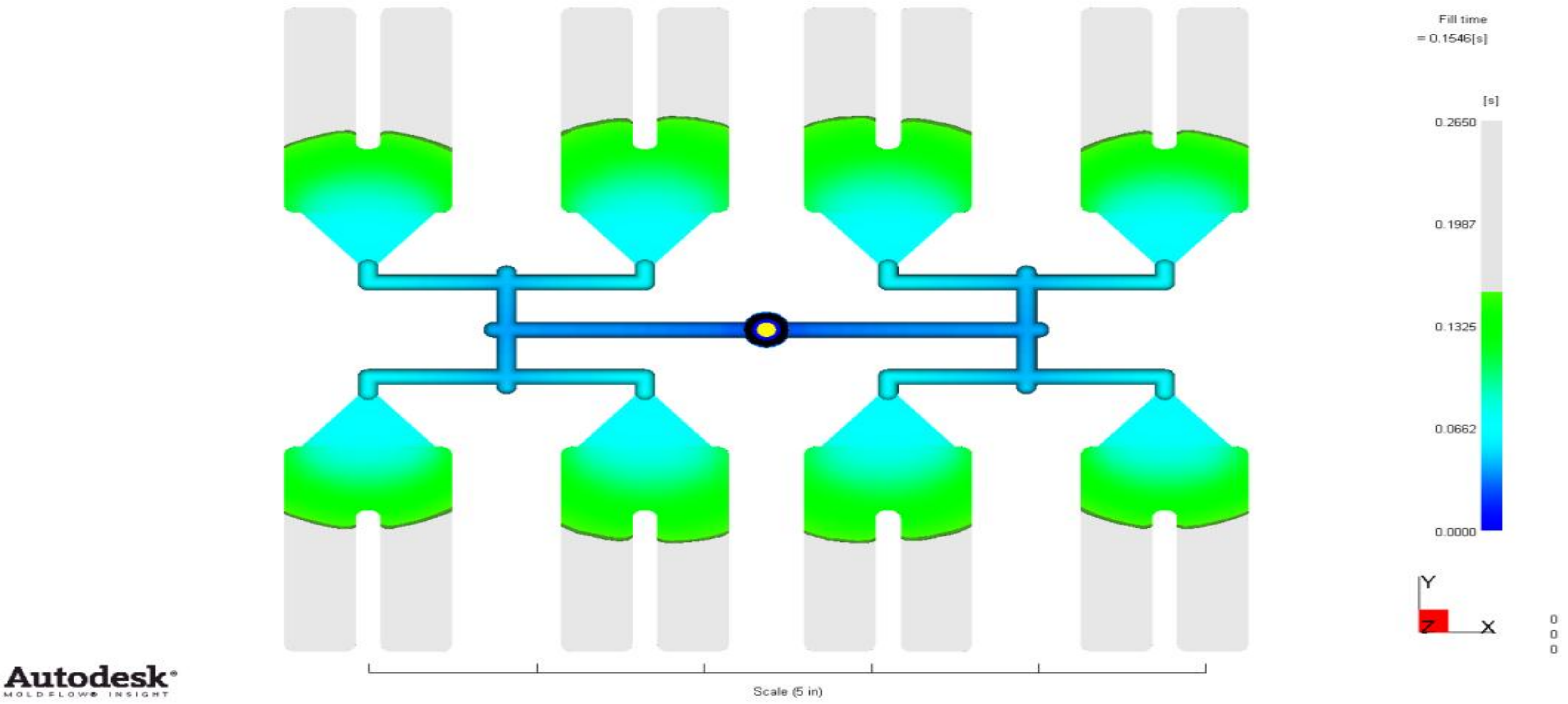
The mold was filled using a constant flow rate that resulted with an injection time of 0.27 seconds.

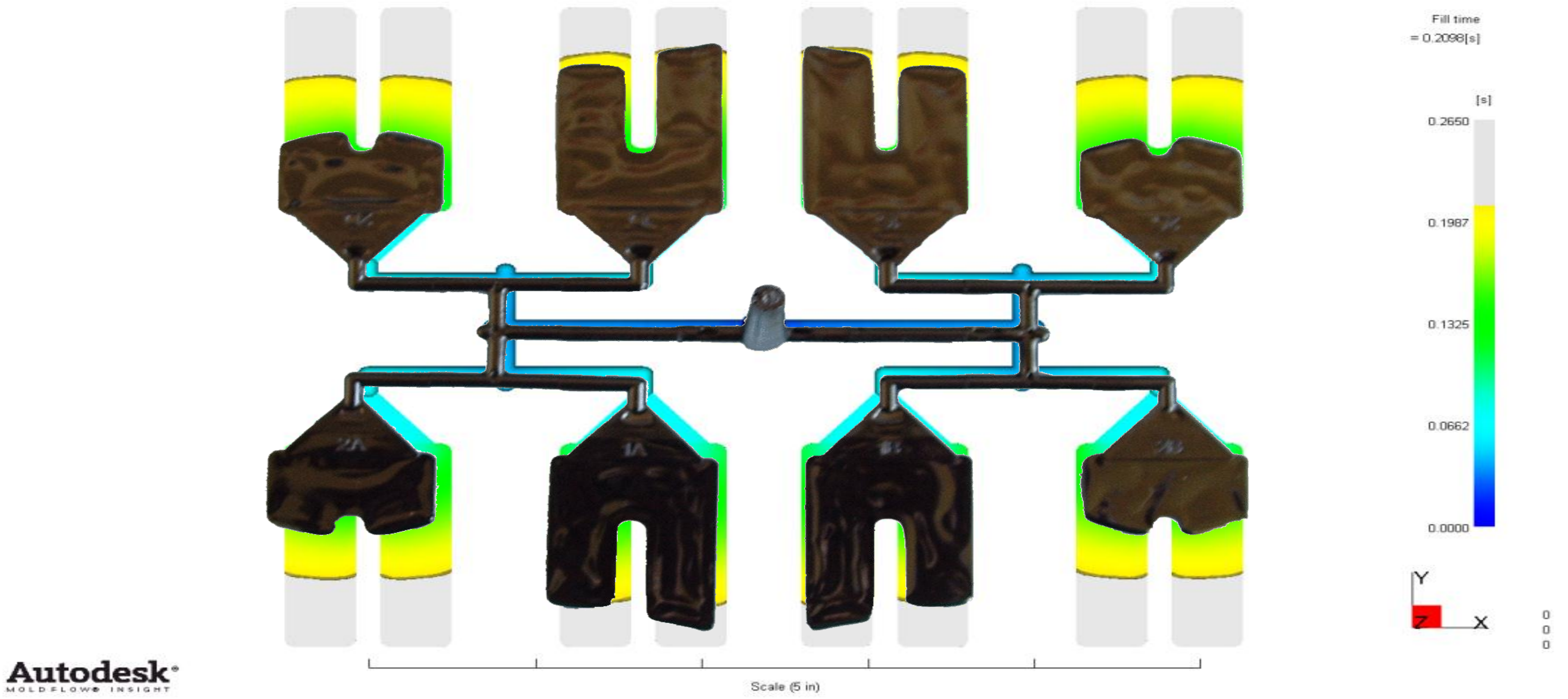
Activate "Slide Show" (F5) to view animation



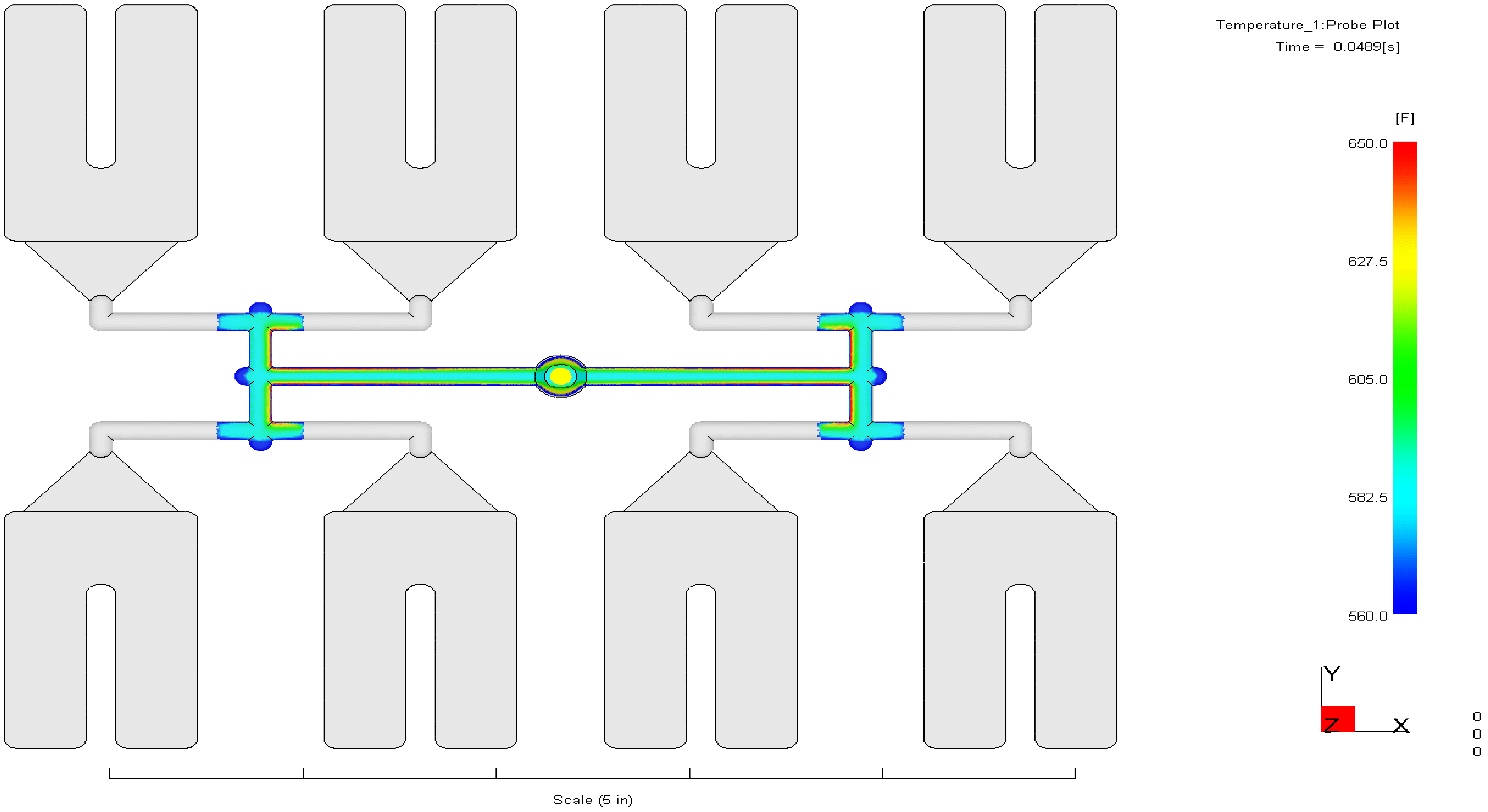
Filling Pattern Comparison: Actual vs Moldflow

The images below compare the actual molded filling progression and the Moldflow predicted filling pattern.





Temperature Animation



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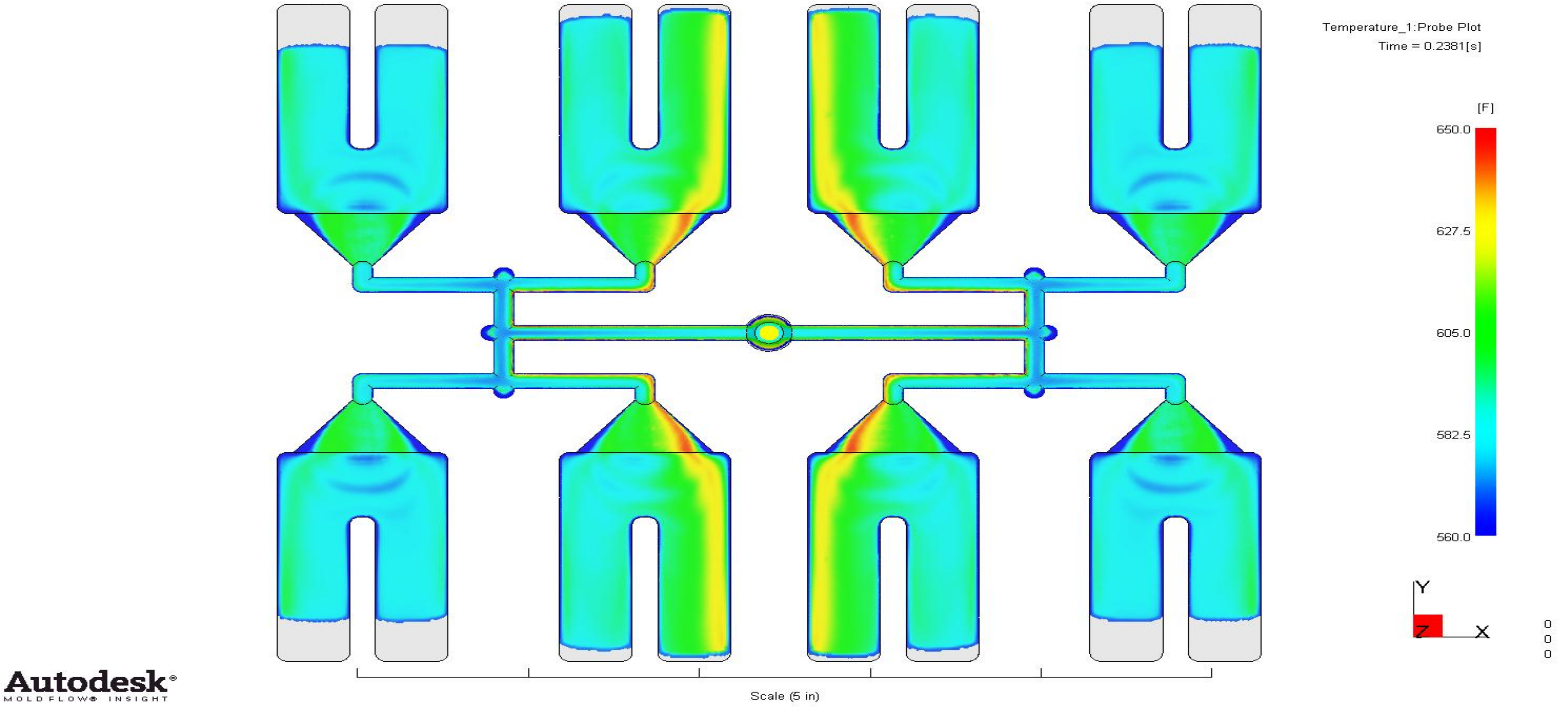
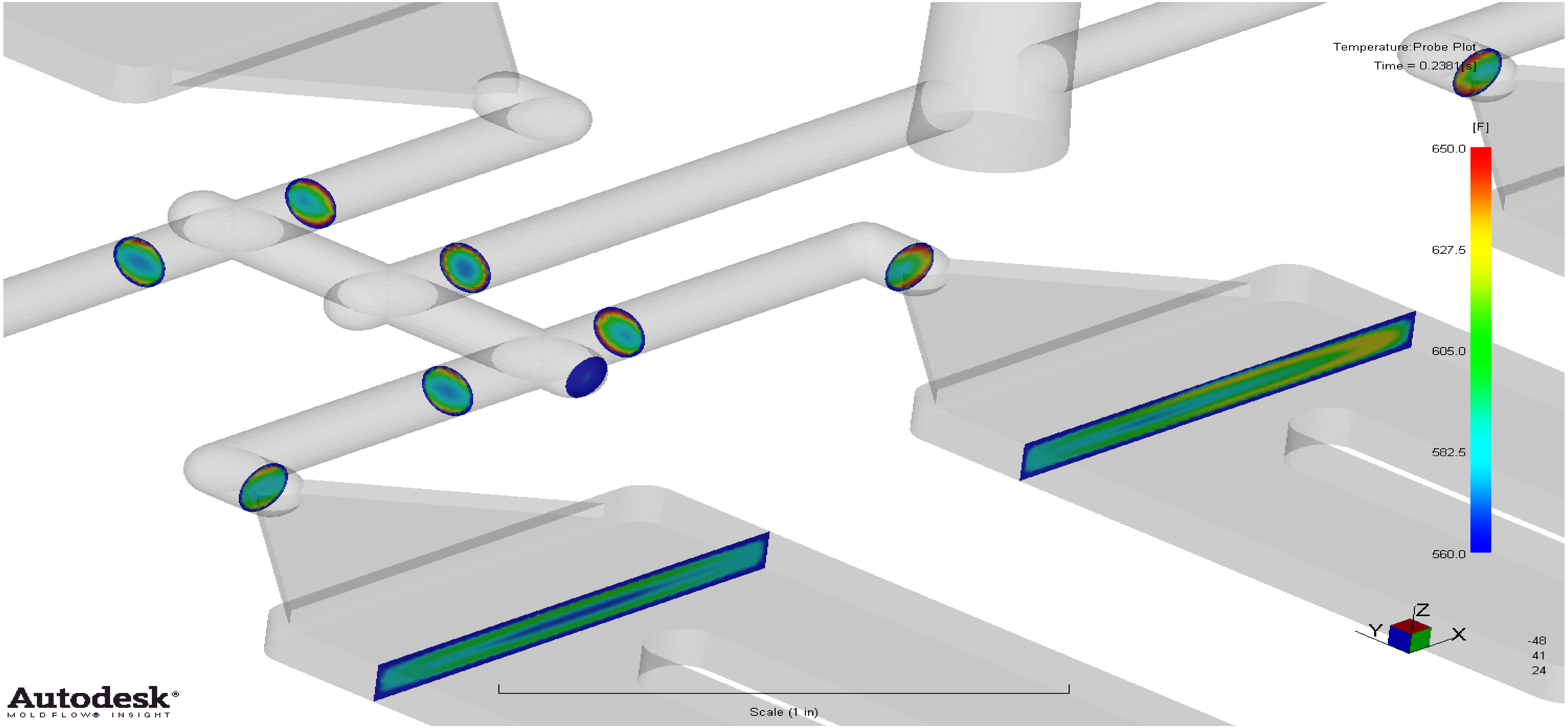
Temperature at 90% Volume

The images below shows the predicted temperature profile in the part. This result shows a cross section through the part thickness at 90% volume.



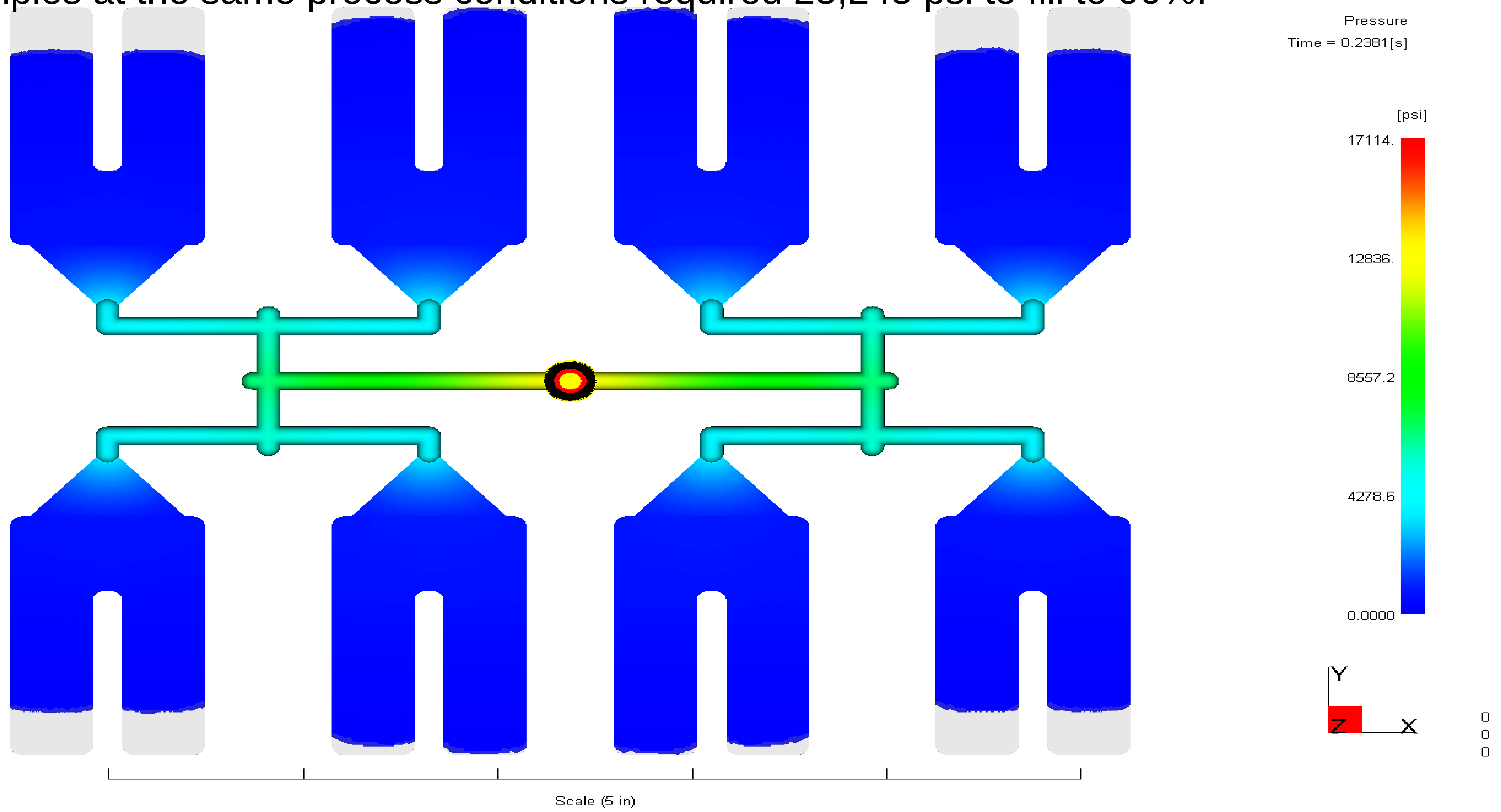
Temperature: Probe Plot



Pressure Comparison @ 90% Volume

The predicted pressure at 80% volume was 17,114 psi. This pressure prediction does not include pressure losses through the machine nozzle and barrel (Depending on the machine set up, pressures around 3,000 to 4,000 psi would be typical).

The actual molded samples at the same process conditions required 25,245 psi to fill to 90%.

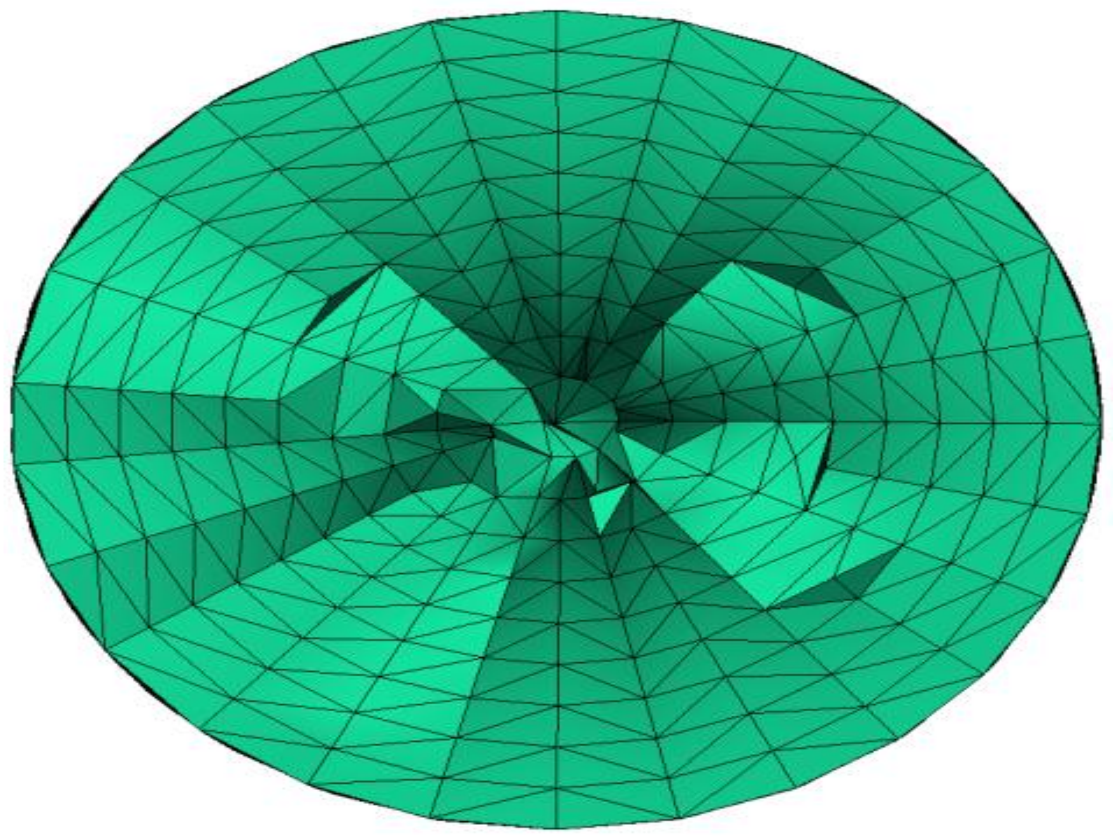


Process Set-up for Analysis (20 layers)

The following parameters were used to run the analysis:

Material: PC - Lexan 121
Melt Temperature: 560° F
Mold Temperature: 180° F
Injection time: 0.25 seconds

Runner Configuration

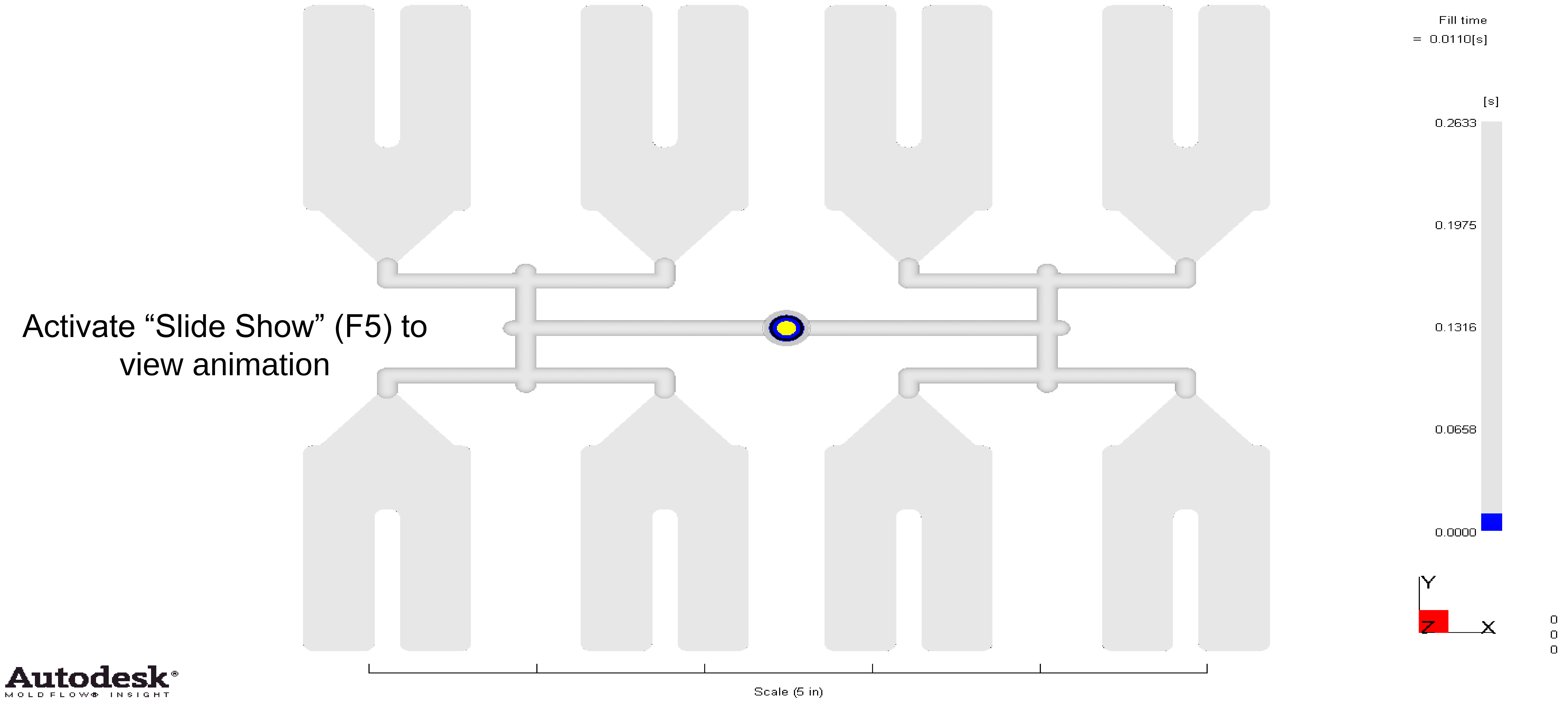


Moldflow File name: t-seg_3D-20-p1
Mesh Diagnostics
Mesh Type: 3D runner and part
# of Elements = 8,934,561
Minimum # of Elements through the thickness = 20

Fill Time

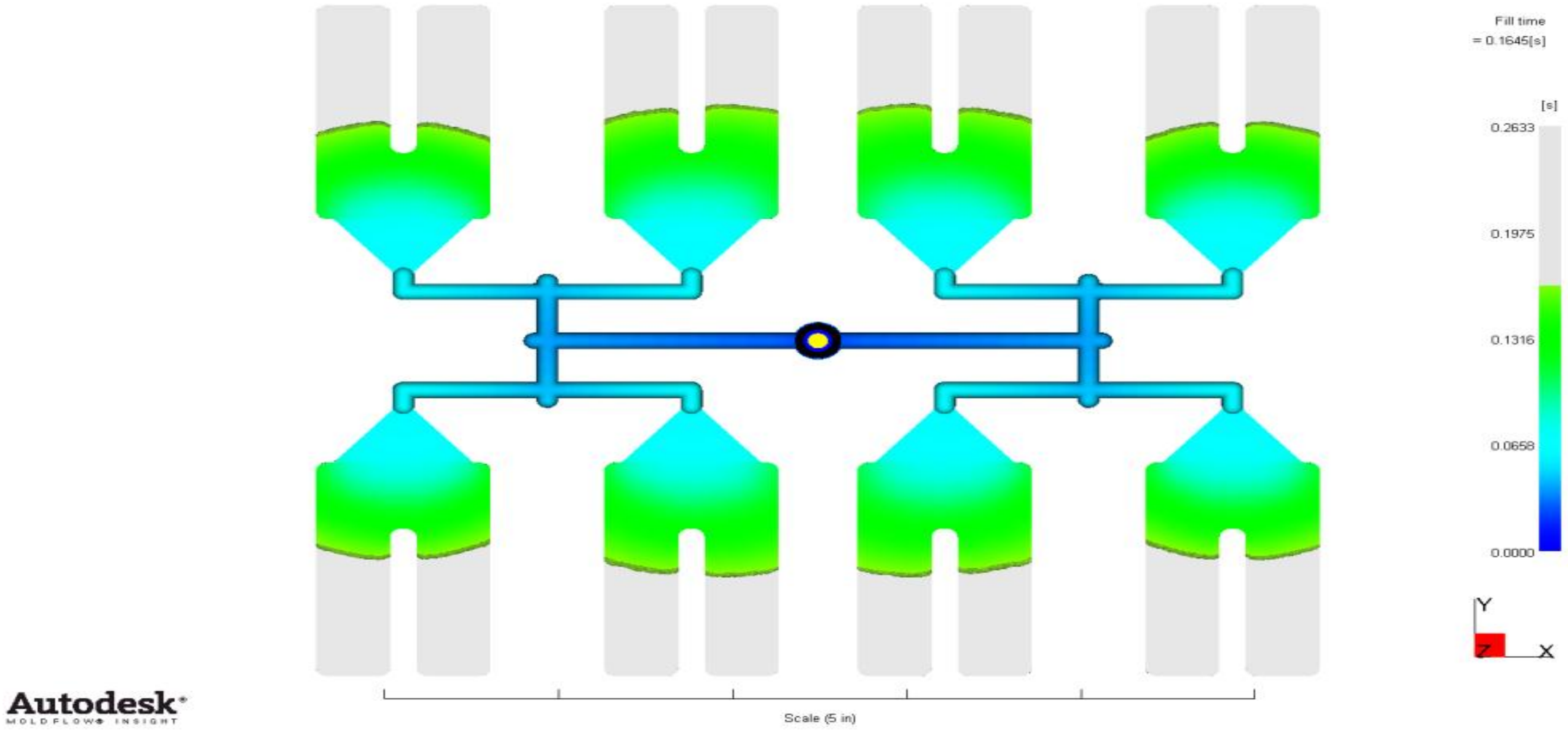
The mold was filled using a constant flow rate that resulted with an injection time of 0.27 seconds.

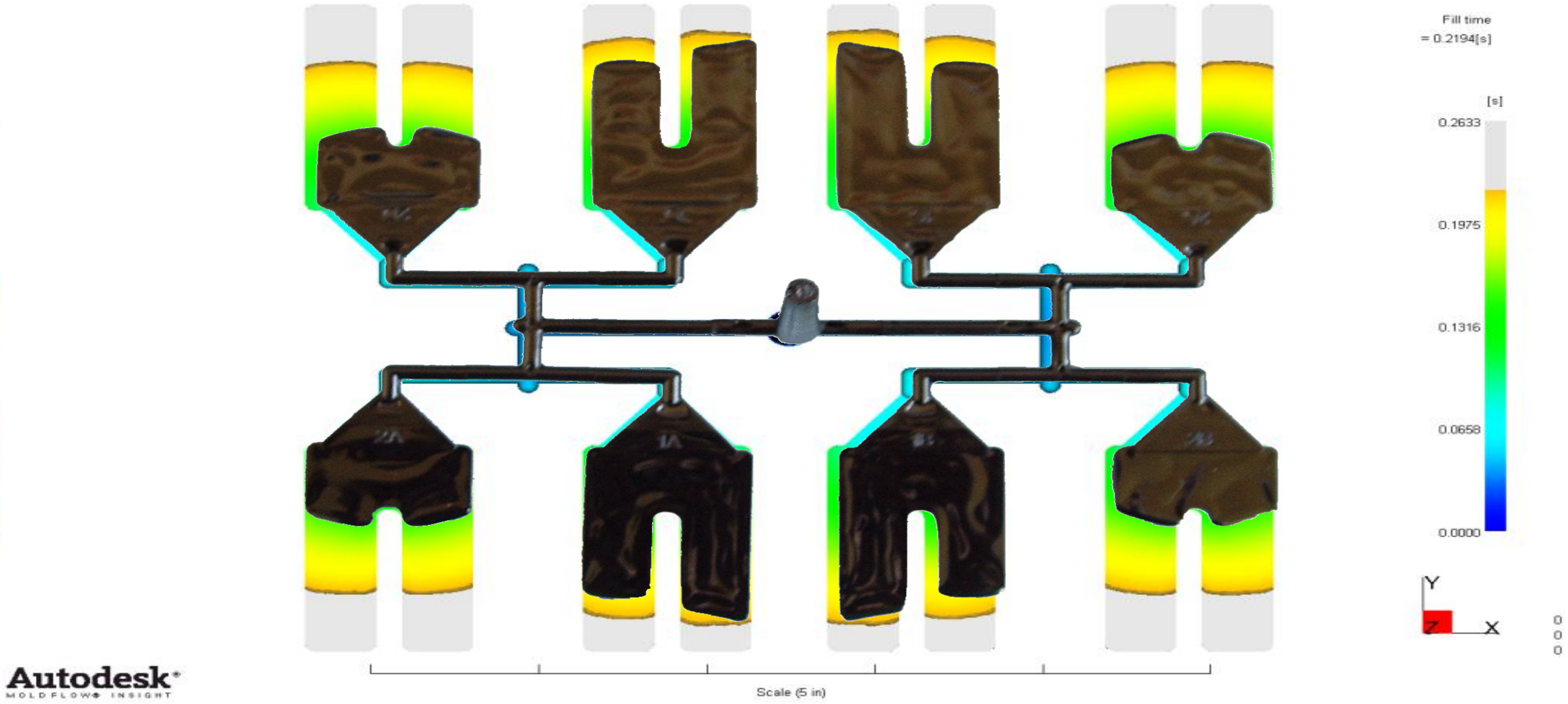
Activate "Slide Show" (F5) to view animation



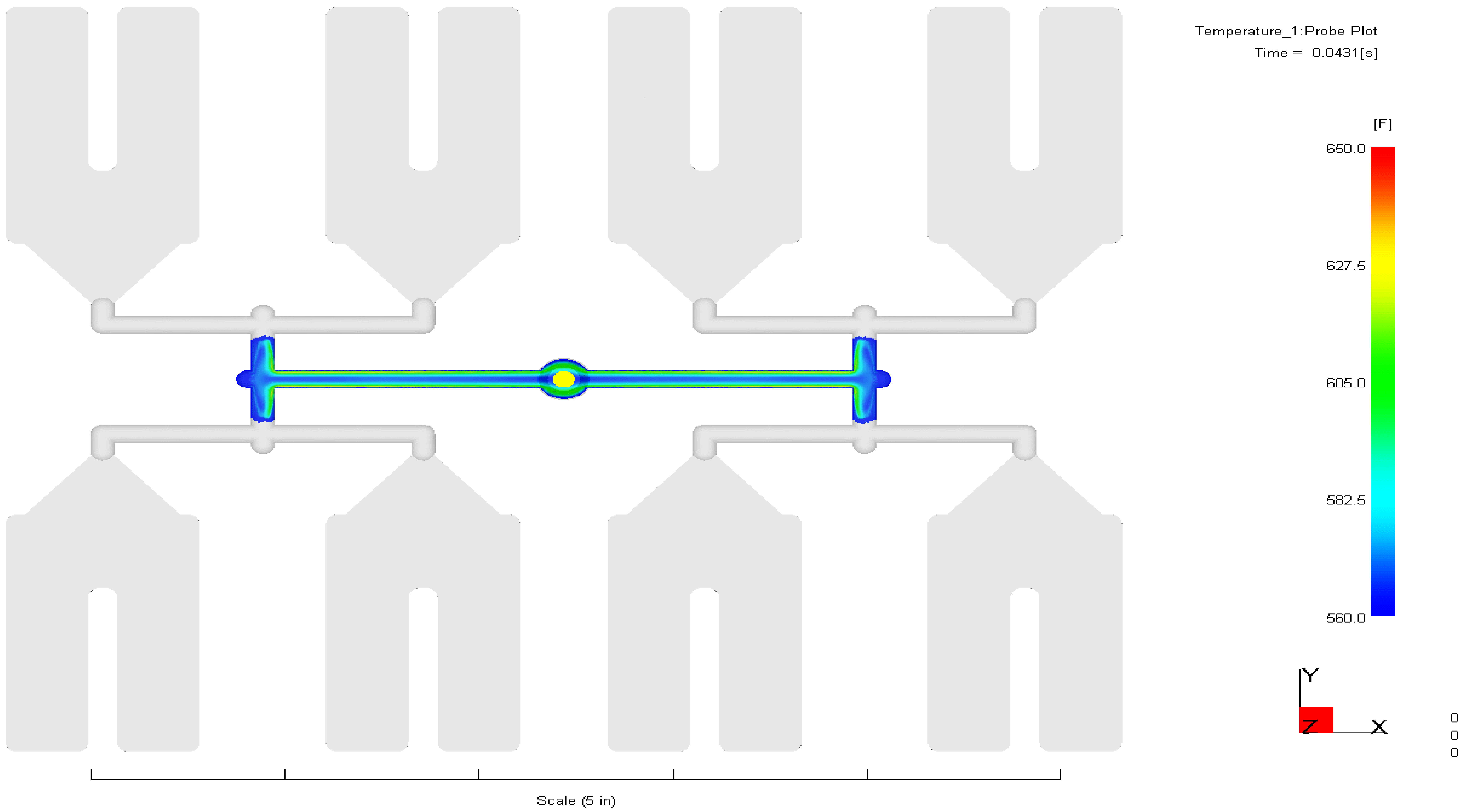
Filling Pattern Comparison: Actual vs Moldflow

The images below compare the actual molded filling progression and the Moldflow predicted filling pattern.





Temperature Animation



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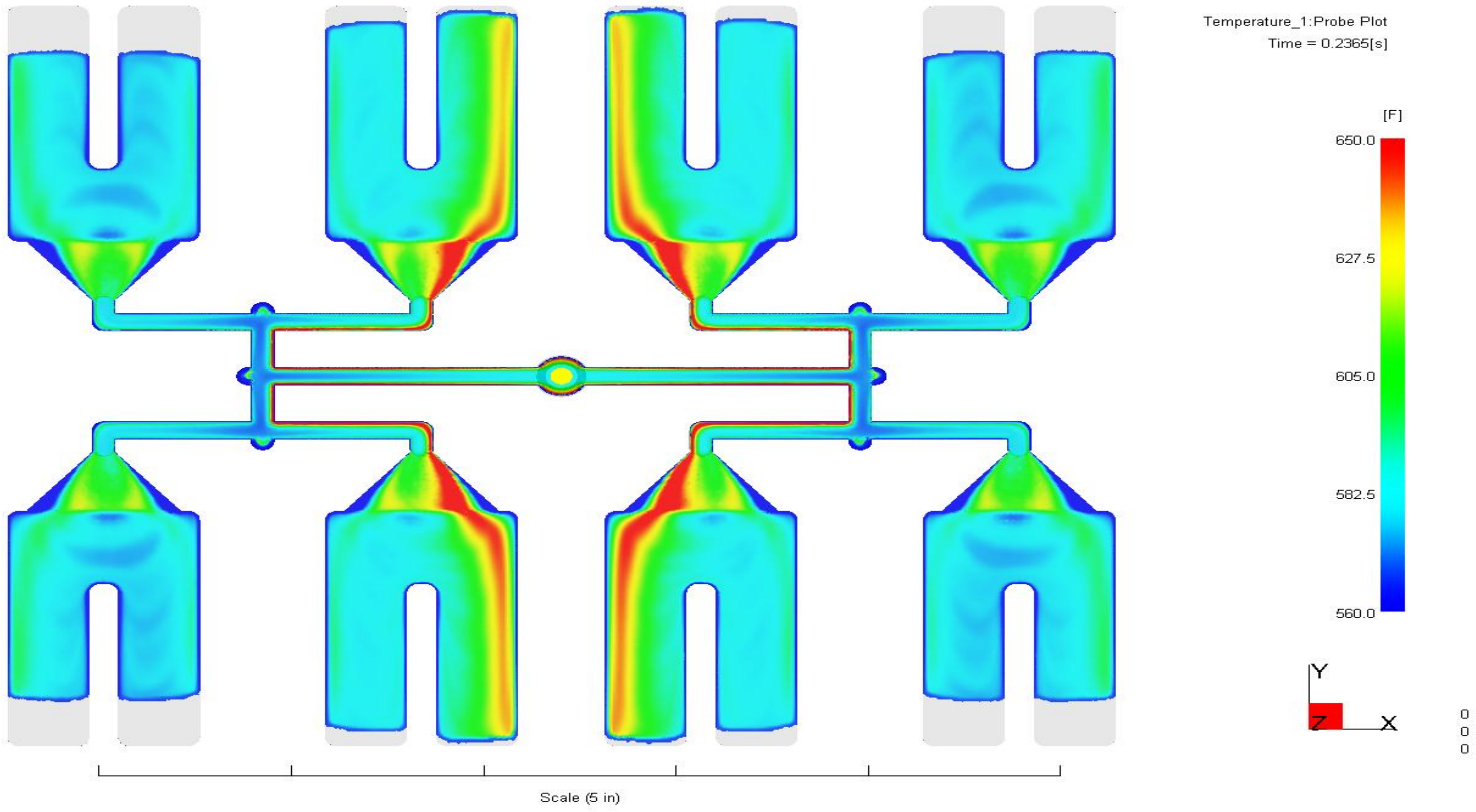
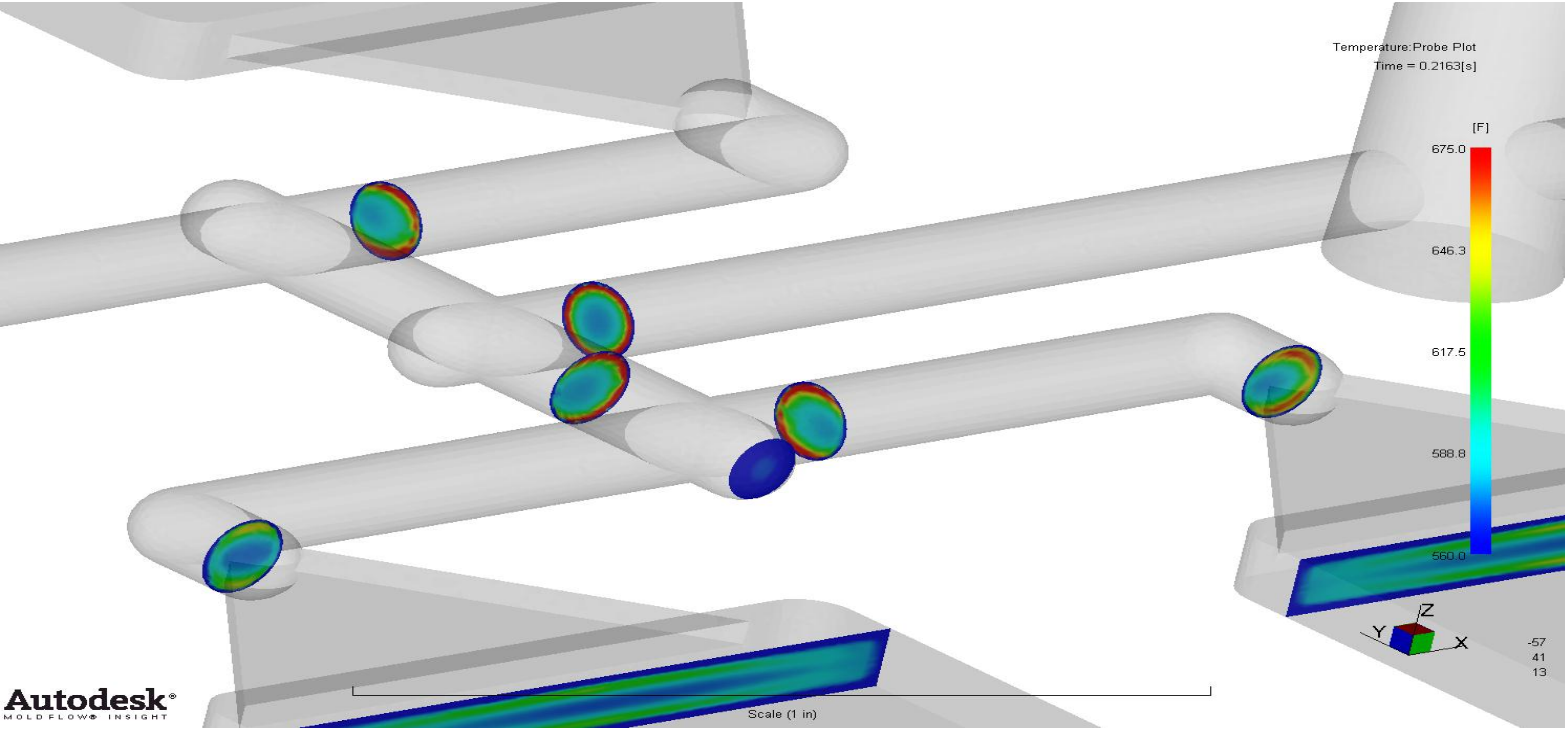
Temperature at 90% Volume

The images below shows the predicted temperature profile in the part. This result shows a cross section through the part thickness at 90% volume.



Autodesk MOLDFLOW INSIGHT

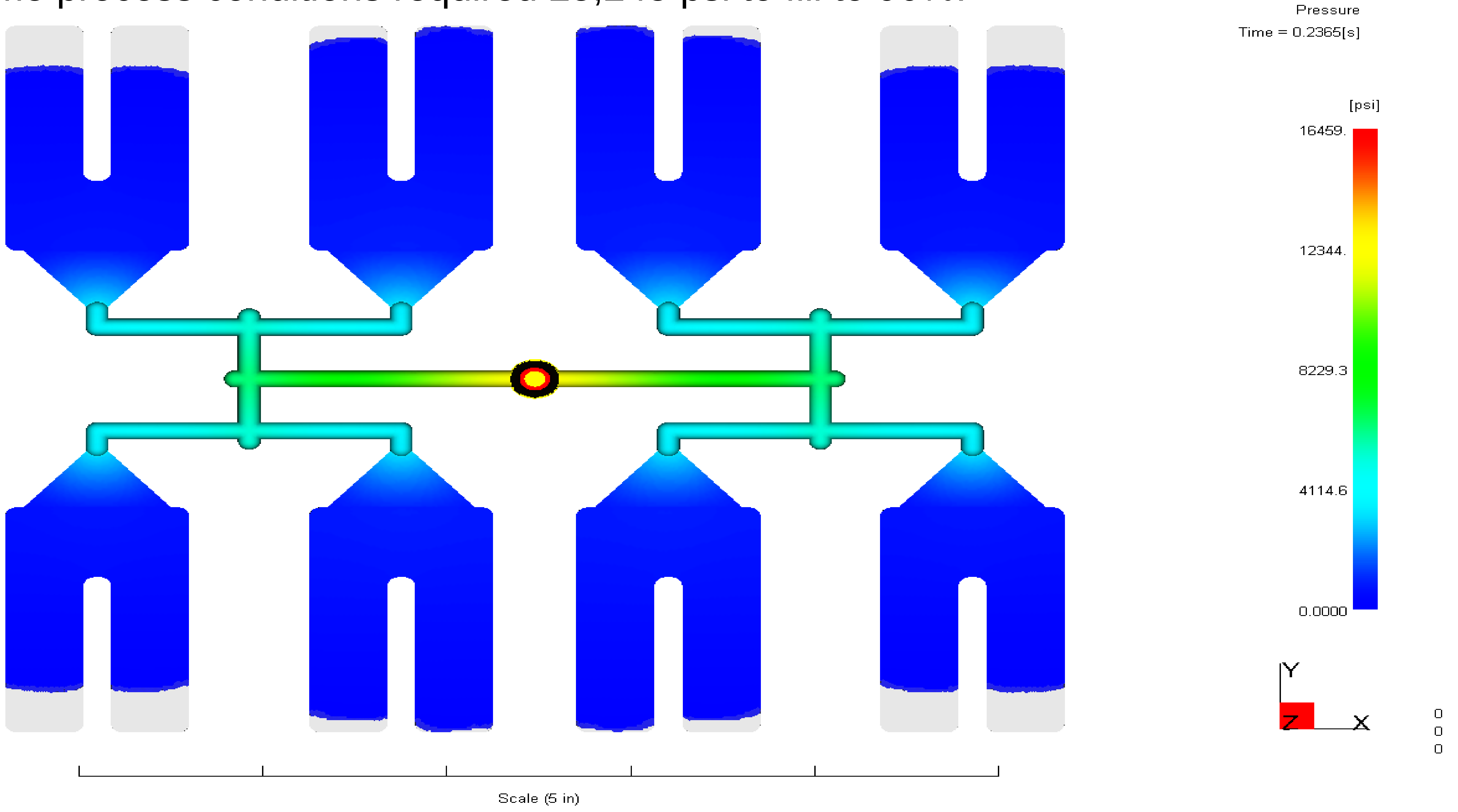
Temperature: Probe Plot



Pressure Comparison @ 90% Volume

The predicted pressure at 80% volume was 16,459 psi. This pressure prediction does not include pressure losses through the machine nozzle and barrel (Depending on the machine set up, pressures around 3,000 to 4,000 psi would be typical).

The actual molded samples at the same process conditions required 25,245 psi to fill to 90%.



Autodesk MOLDFLOW® INSIGHT

Process Set-up for Analysis

The following parameters were used to run the analysis:

Material: PC - Lexan 121

Melt Temperature: 560° F

Mold Temperature: 180° F

Injection time: 0.25 seconds

Runner Configuration

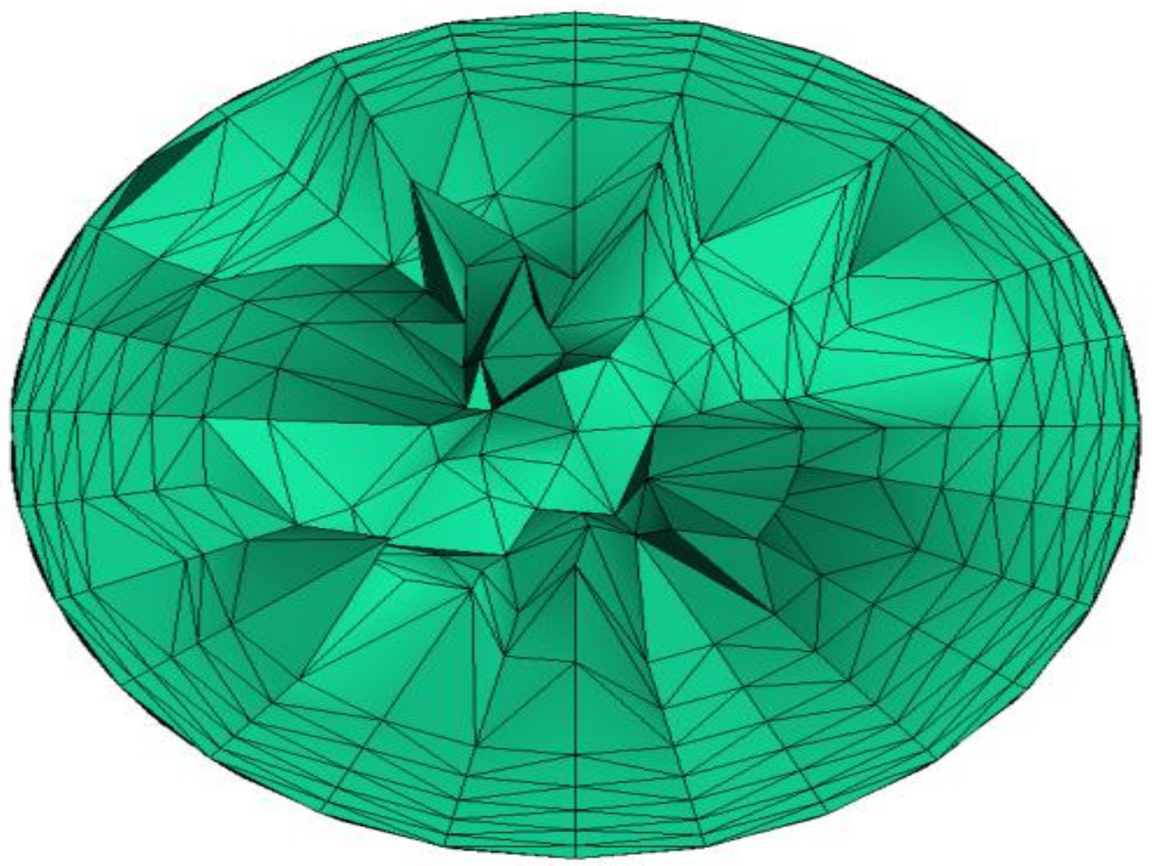
Moldflow File name: t-seg_3D-20-p1

Mesh Diagnostics

Mesh Type: 3D runner and part

# of Elements = 8,934,561

Minimum # of Elements through the thickness = 20 (1.25 Bias)



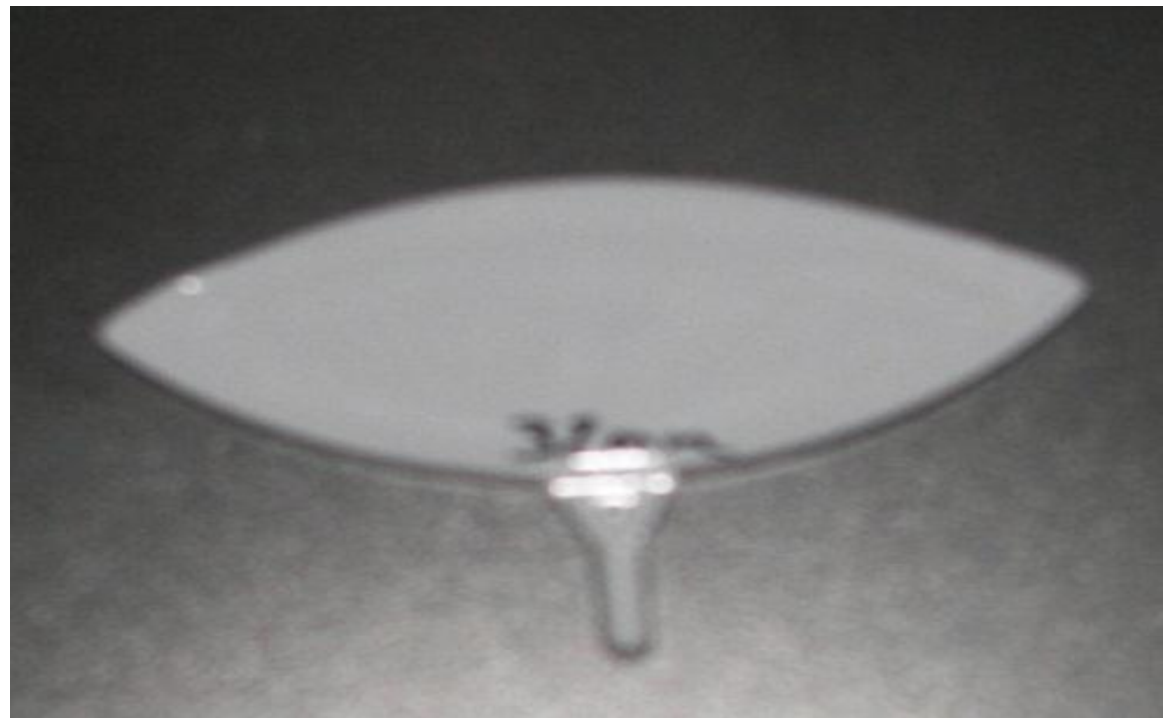
Summary of results

Single cavity disk mold – Need picture of full part here


47mm


42mm

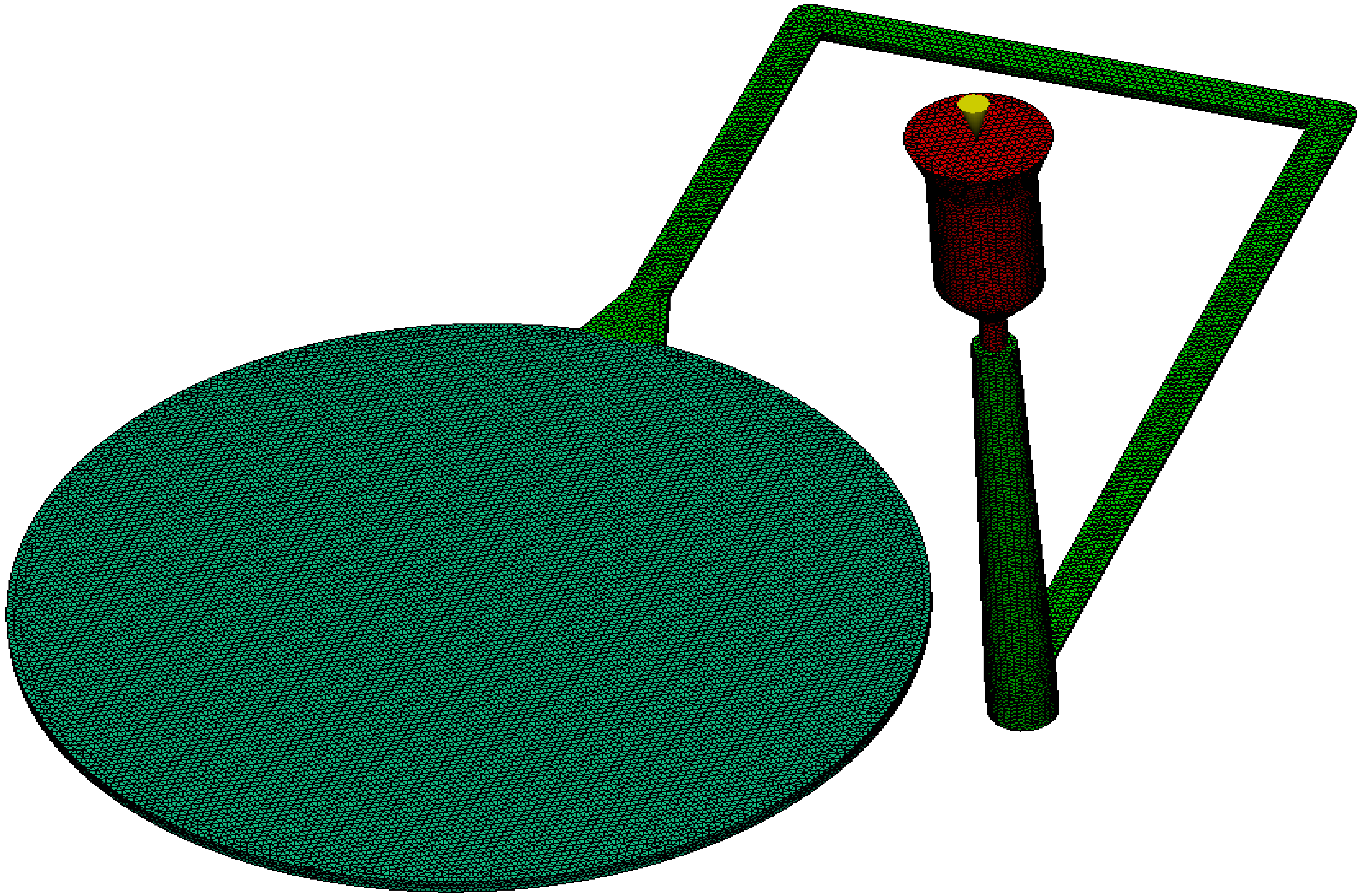

37mm



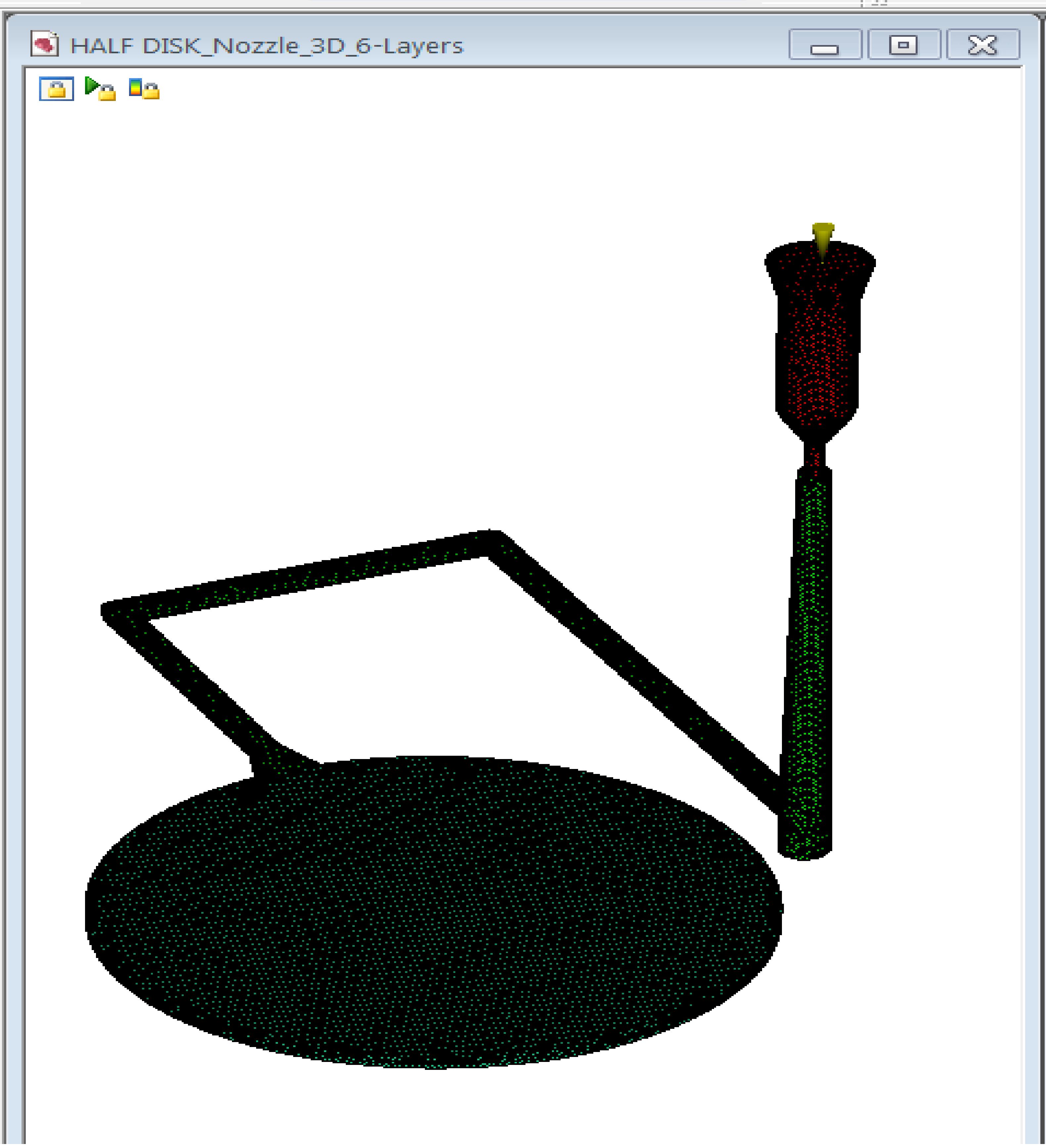
Process Set-up for Analysis

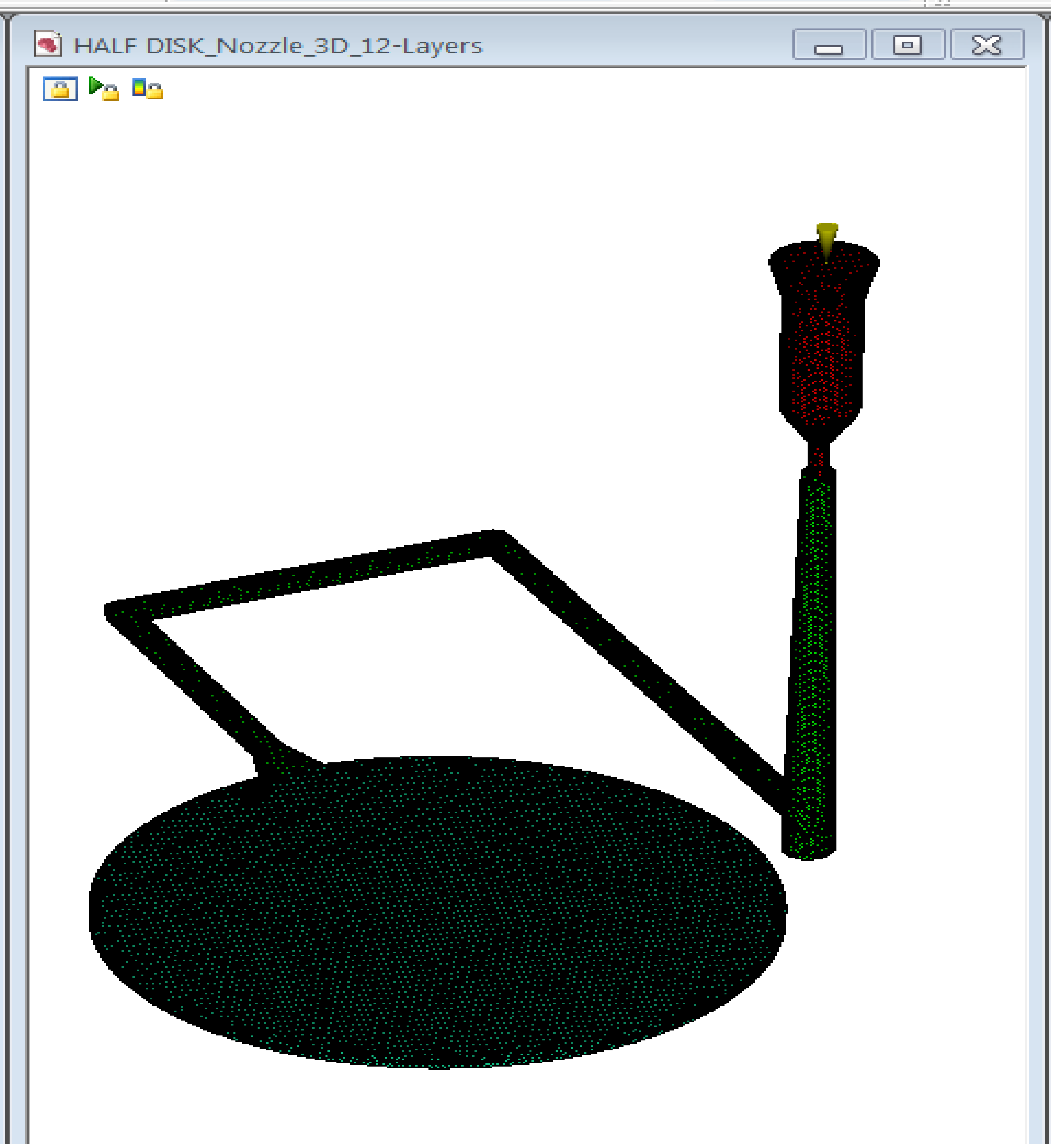
The following parameters were used to run the analysis:

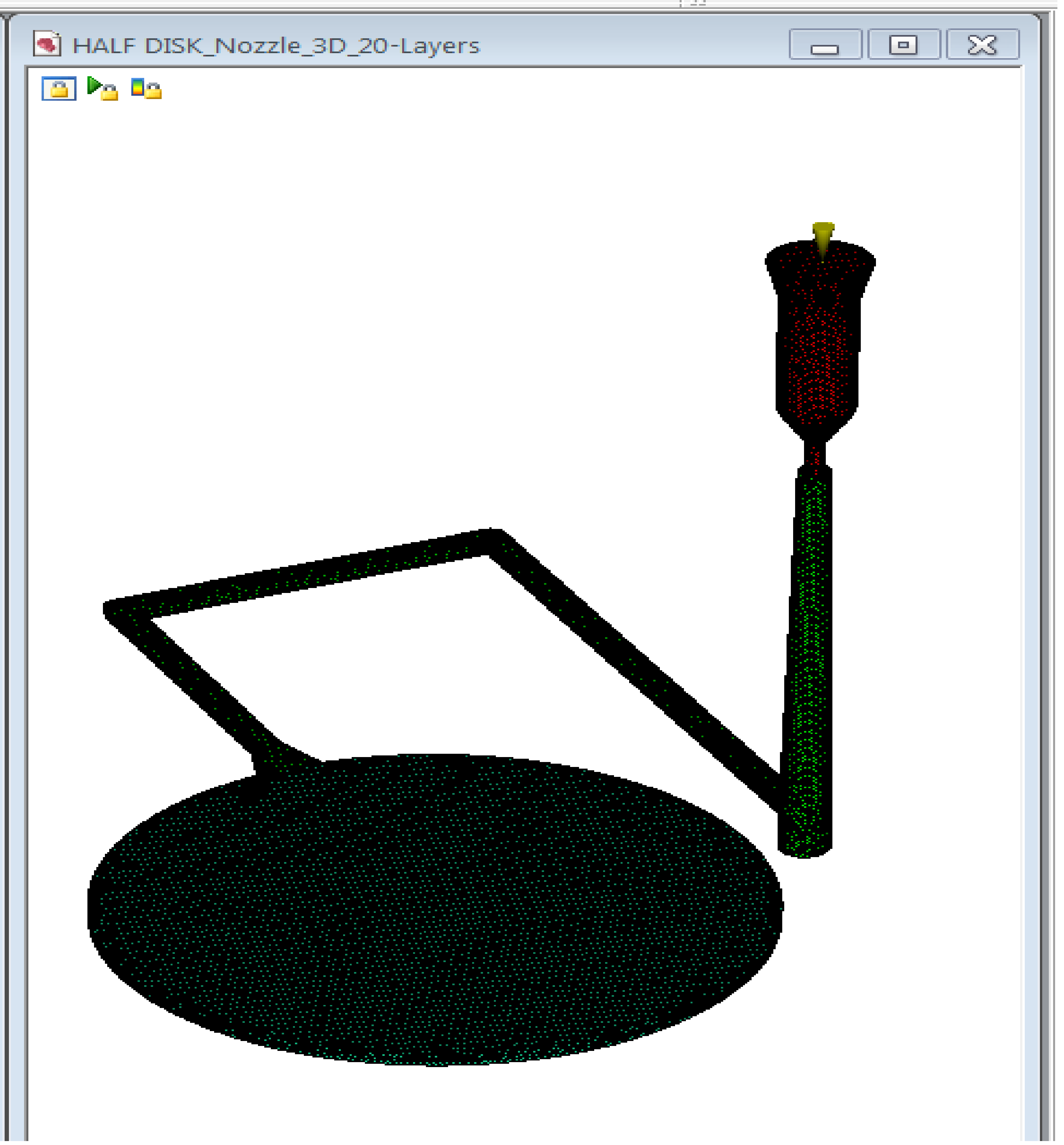
Material: SABIC Lexan 121R*
-15% Glass Fiber Filler
Melt Temperature: 560° F
Mold Temperature: 180° F
Injection Time: 1.0 seconds
V/P Switchover: 99% full parts



Machine nozzle, cold sprue, cold runner, & part are represented







6 Layers
565,500 Elements

12 Layers
1,157,600 Elements

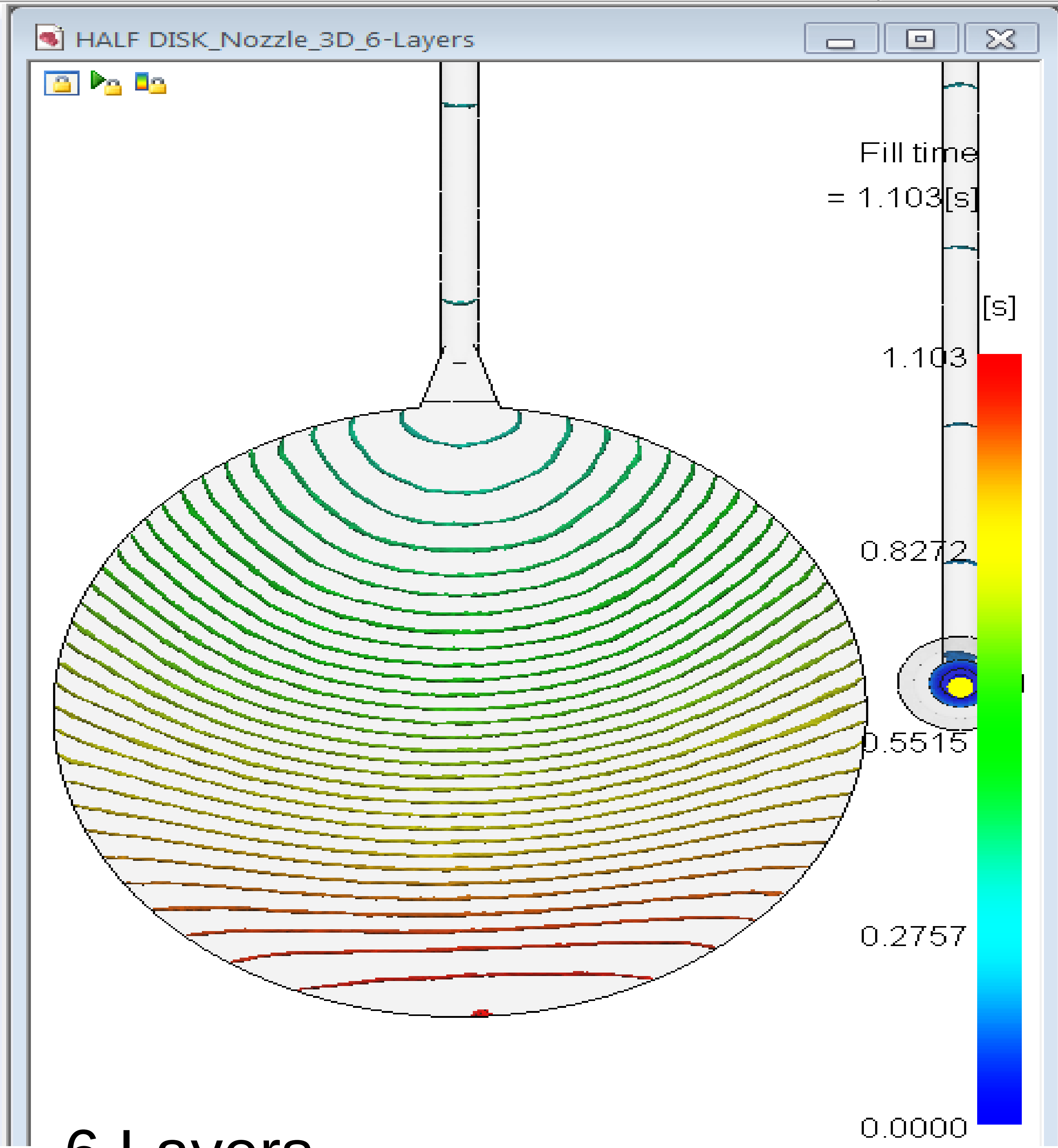
20 Layers
2,097,213 Elements

Fill Time

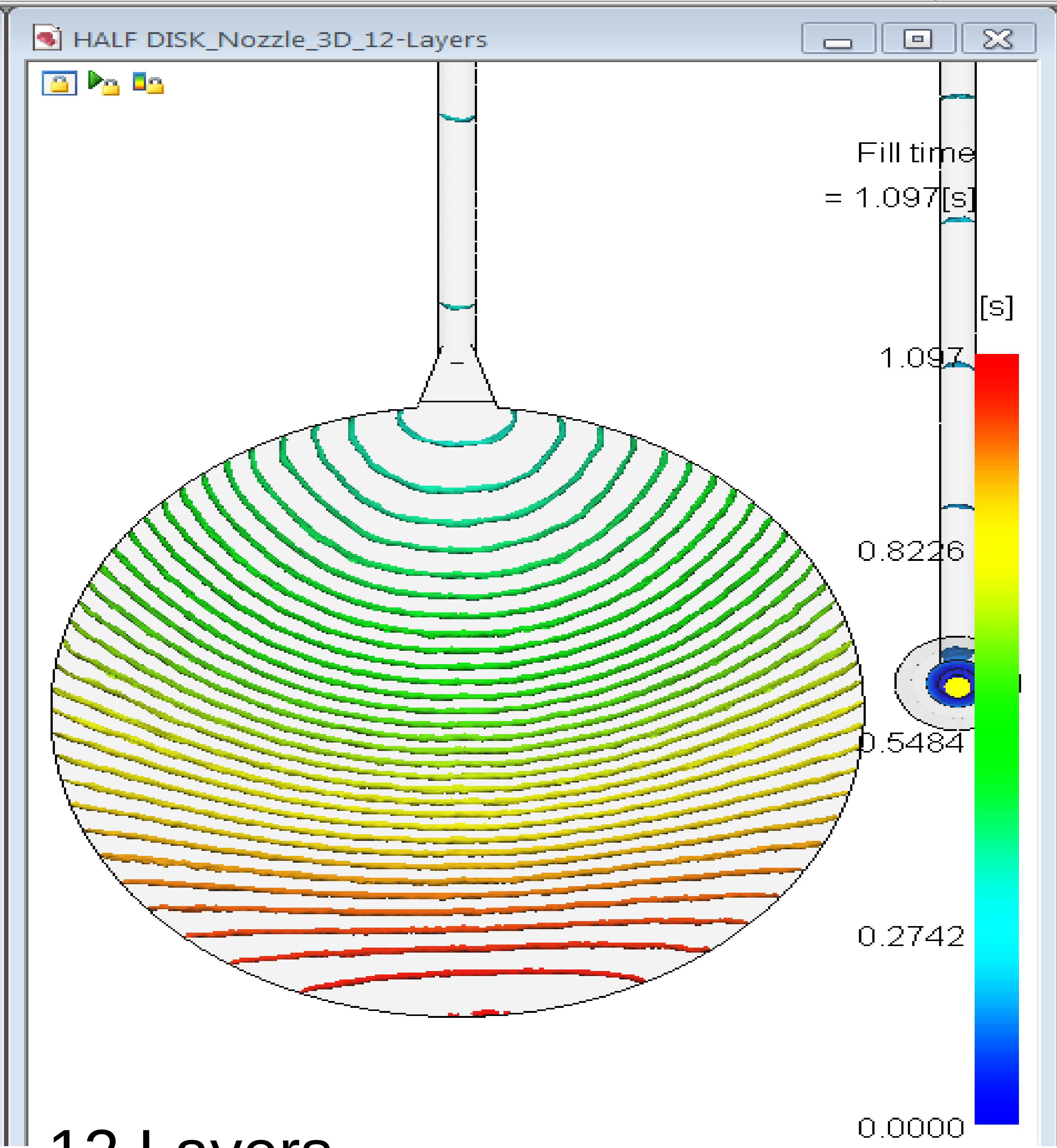
All models exhibit similar filling patterns with the perimeter flow lagging behind the center. All models predict a “flat” flow front near the end of fill.

Fill Time

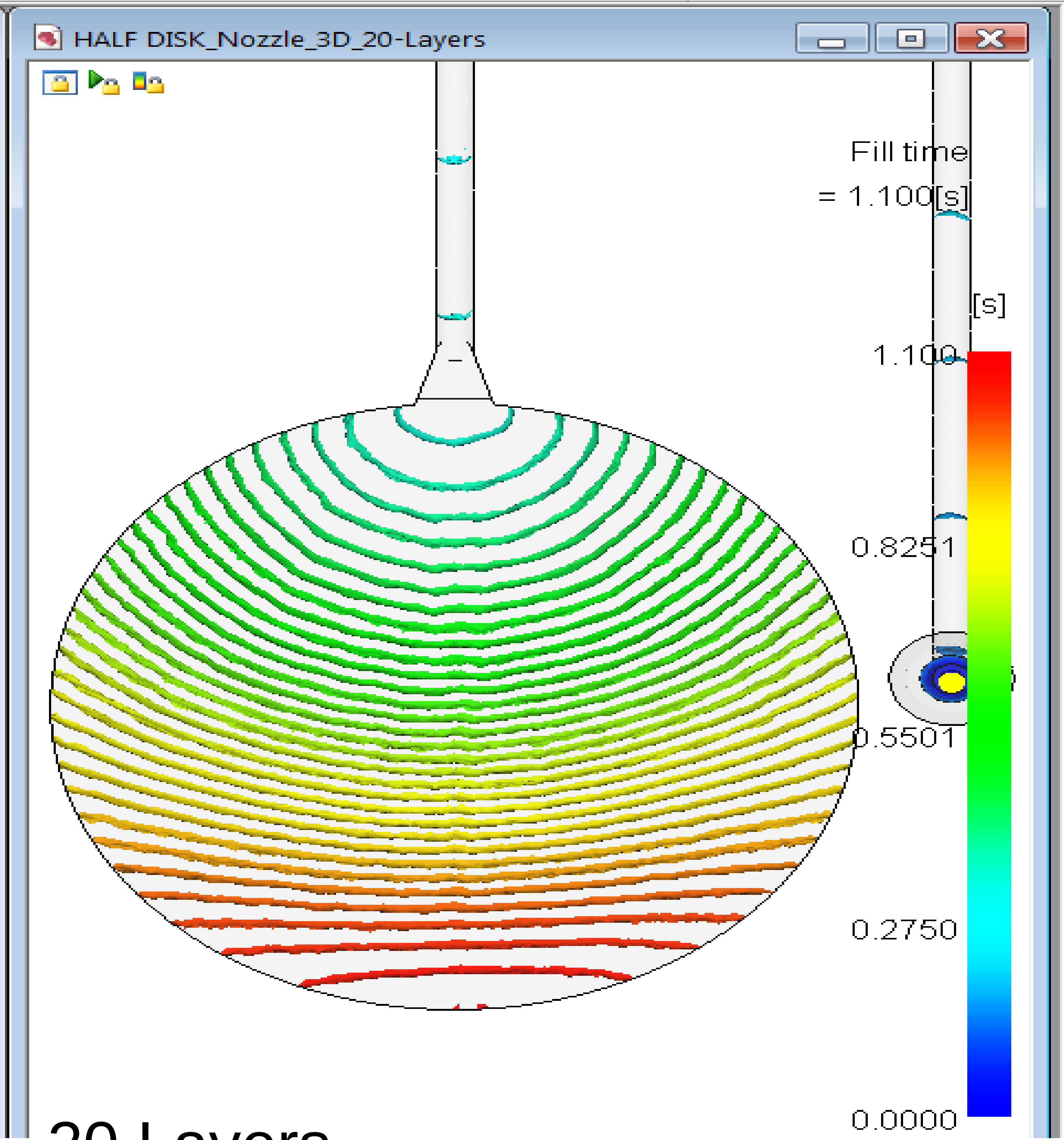
All models exhibit similar filling patterns with the perimeter flow lagging behind the center. All models predict a “flat” flow front near the end of fill.



6 Layers



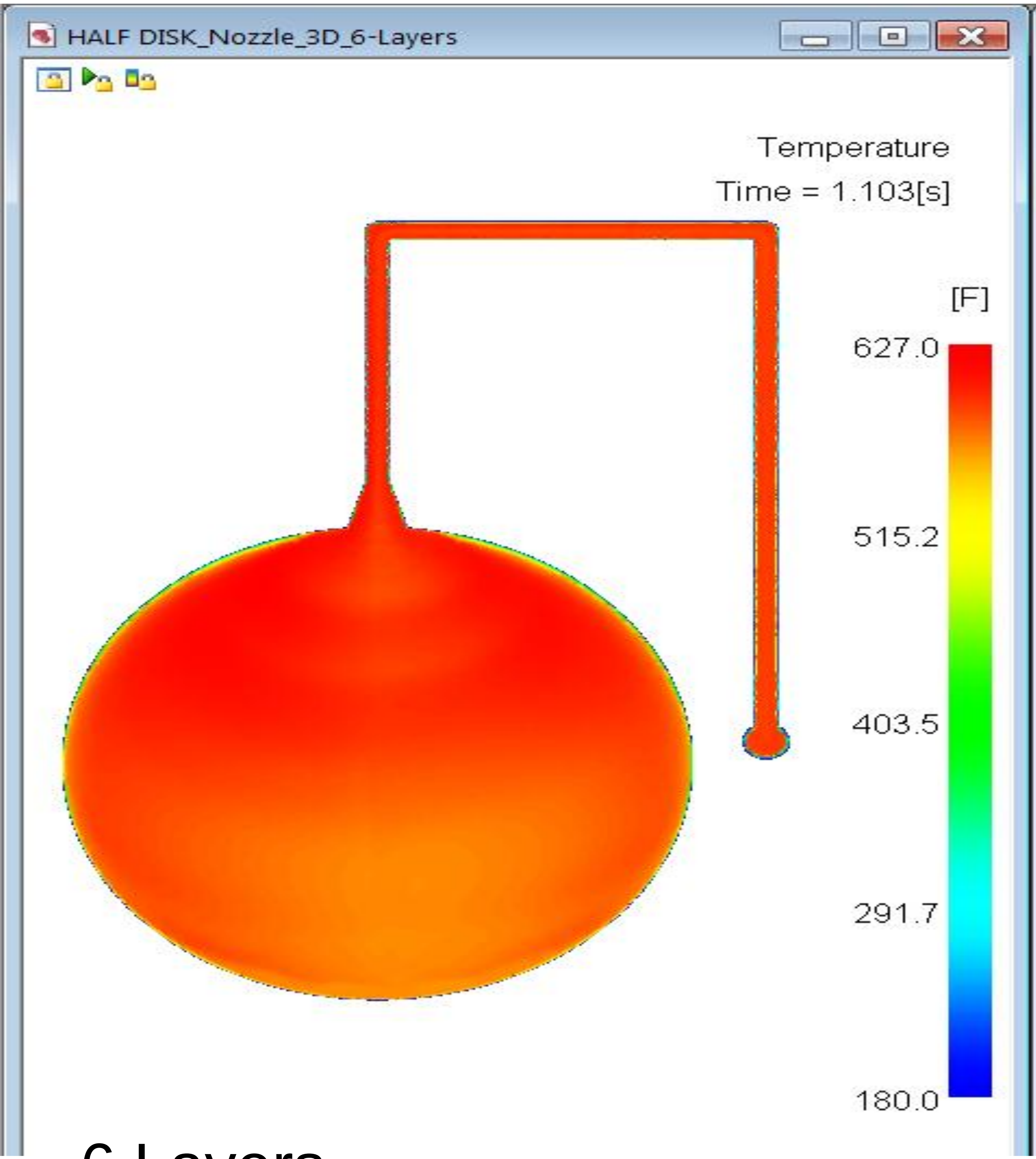
12 Layers



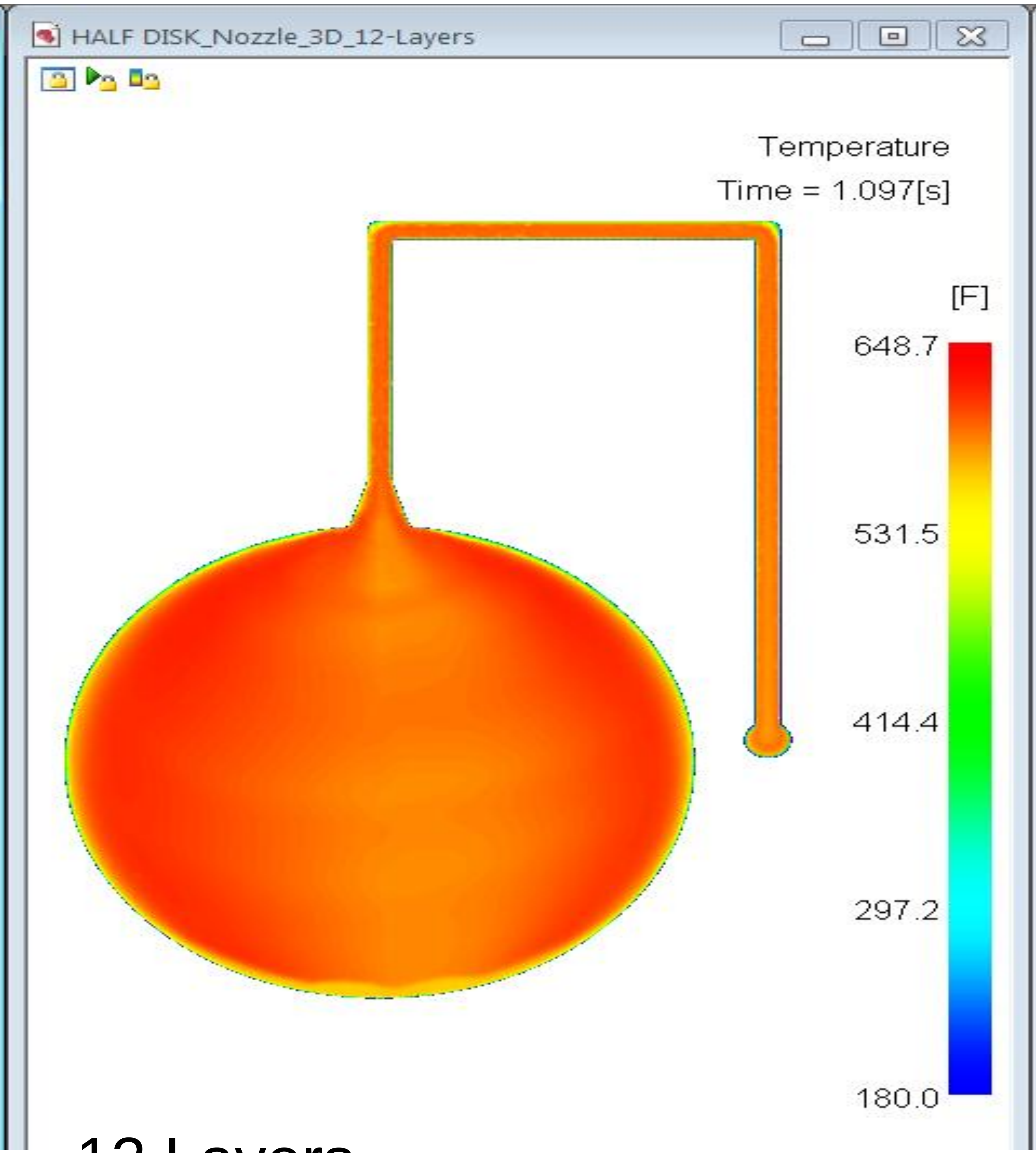
20 Layers

Temperature (default range)

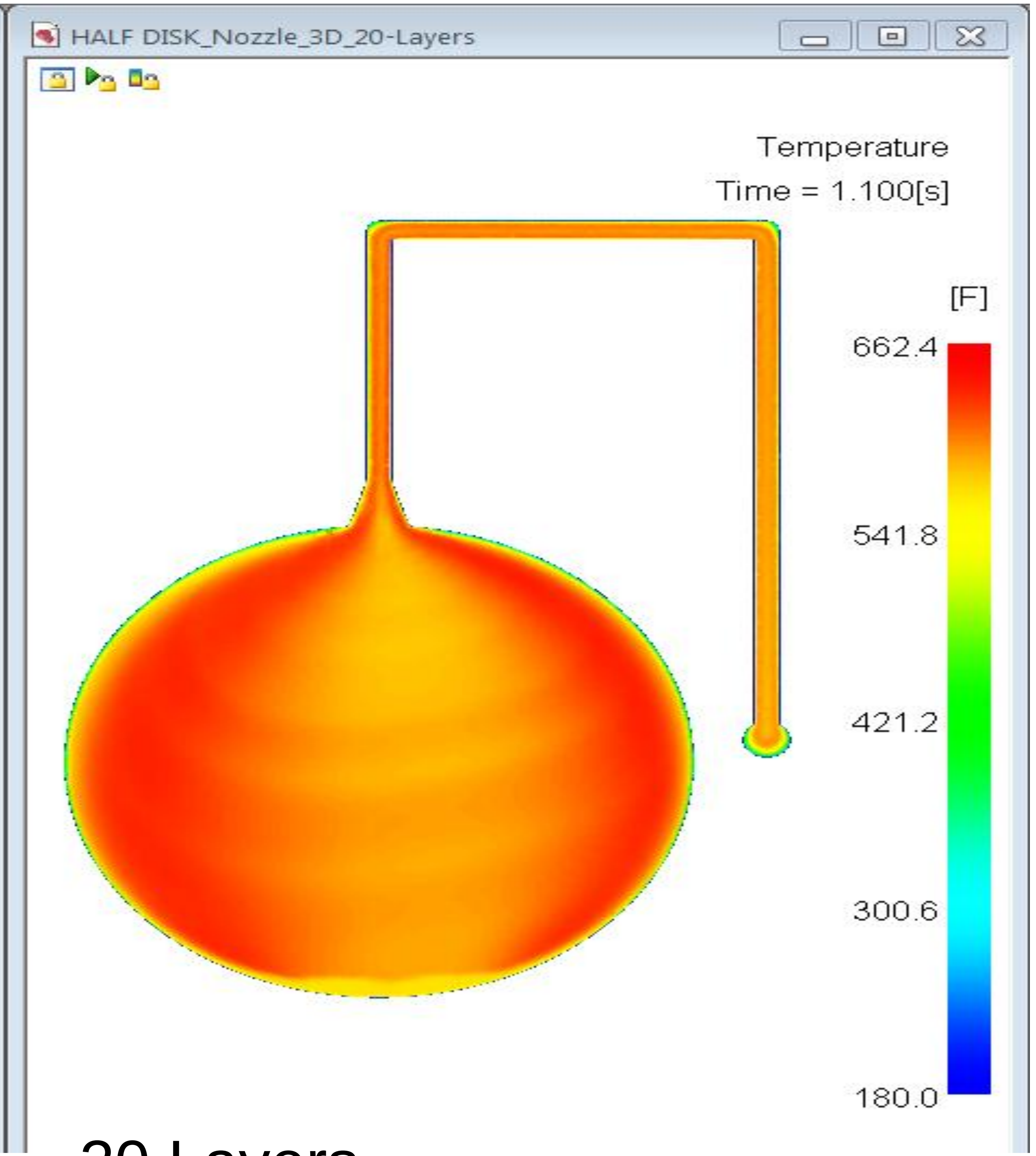
More layers though the thickness provided predictions with hotter maximum temperatures and shows biasing the perimeter of the disk.



6 Layers



12 Layers



20 Layers

Temperature (scaled 500F)

More layers though the thickness provided predictions with hotter maximum temperatures and shows biasing the perimeter of the disk.

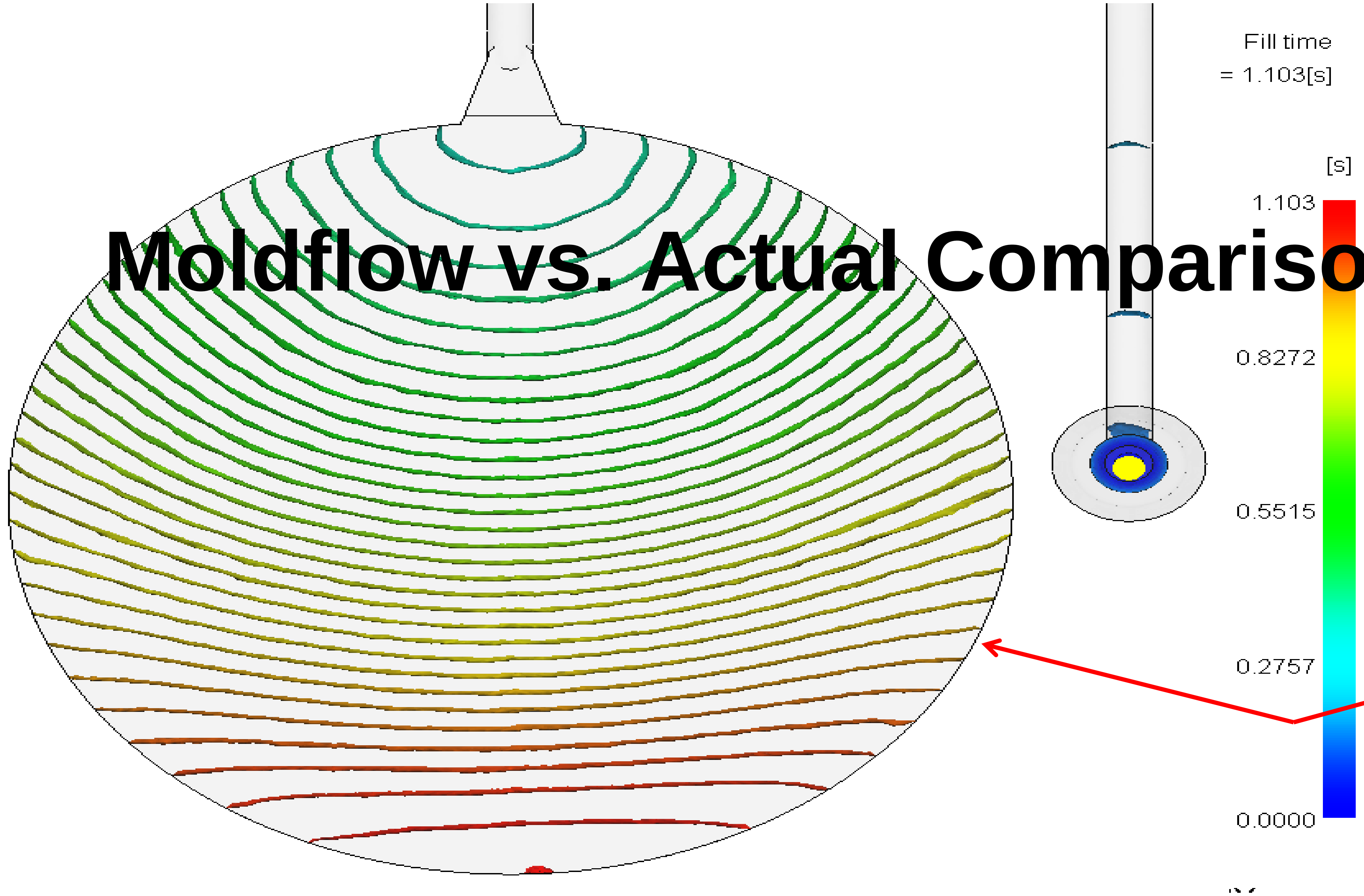
6 Layers 12 Layers 20 Layers

Temperature (scaled 560F / Melt Temp)

More layers though the thickness provided predictions with hotter maximum temperatures and shows biasing the perimeter of the disk.

Moldflow vs. Actual Comparison

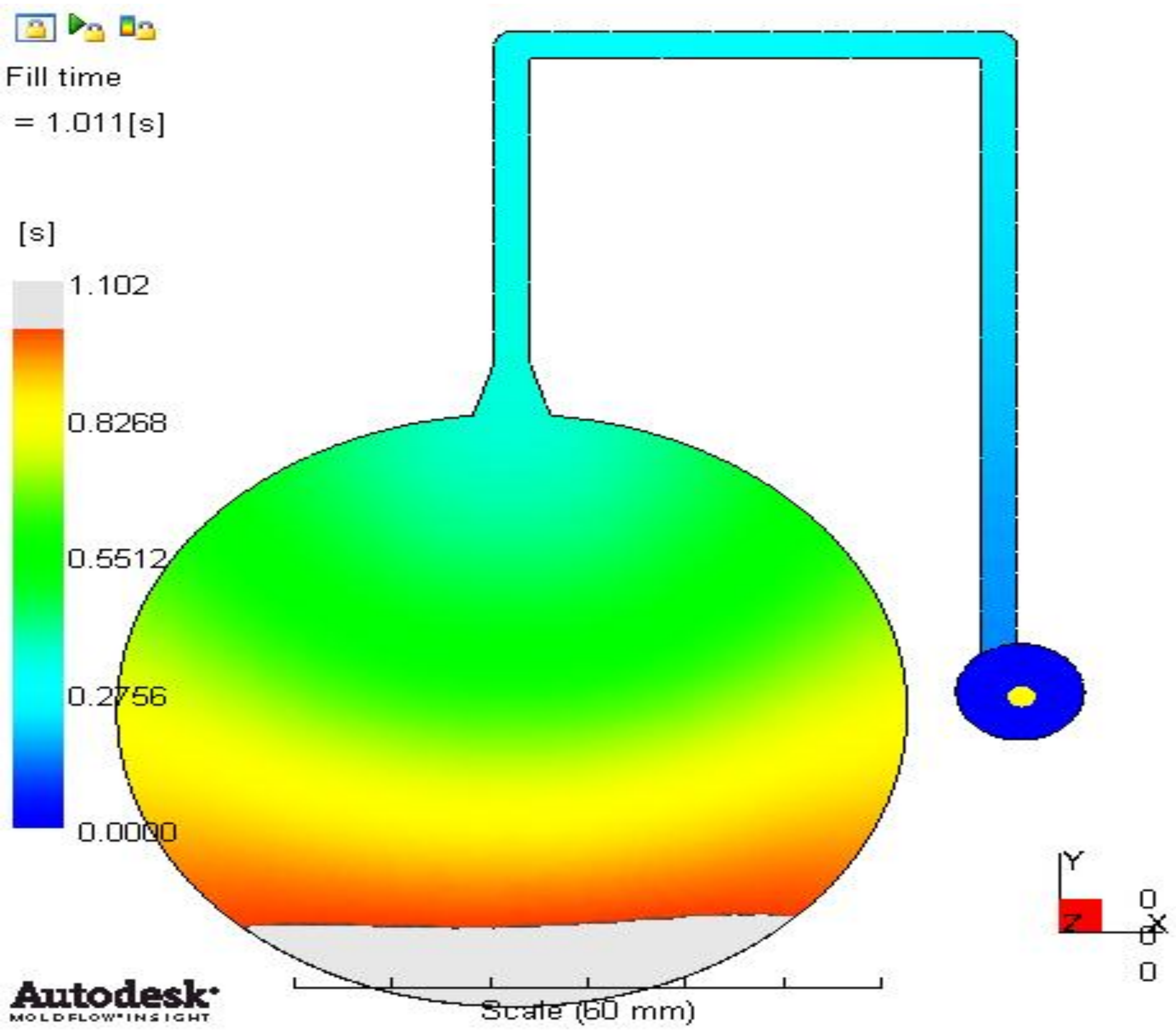
The simulation is not picking up on the shear induced “racetrack” filling effect.



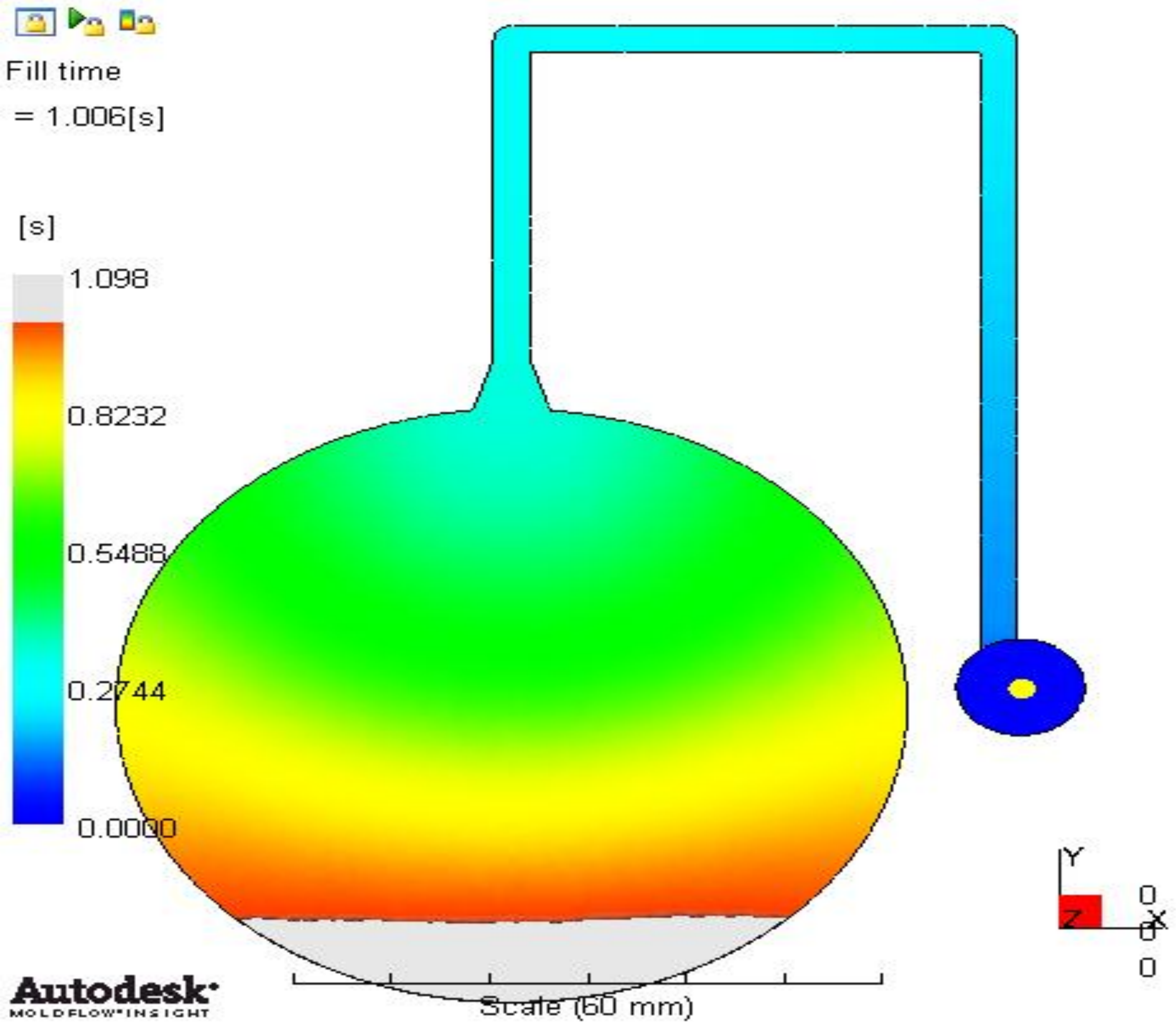
Initial Analysis

- Race-track effect not observed in Simulation

6 Layers



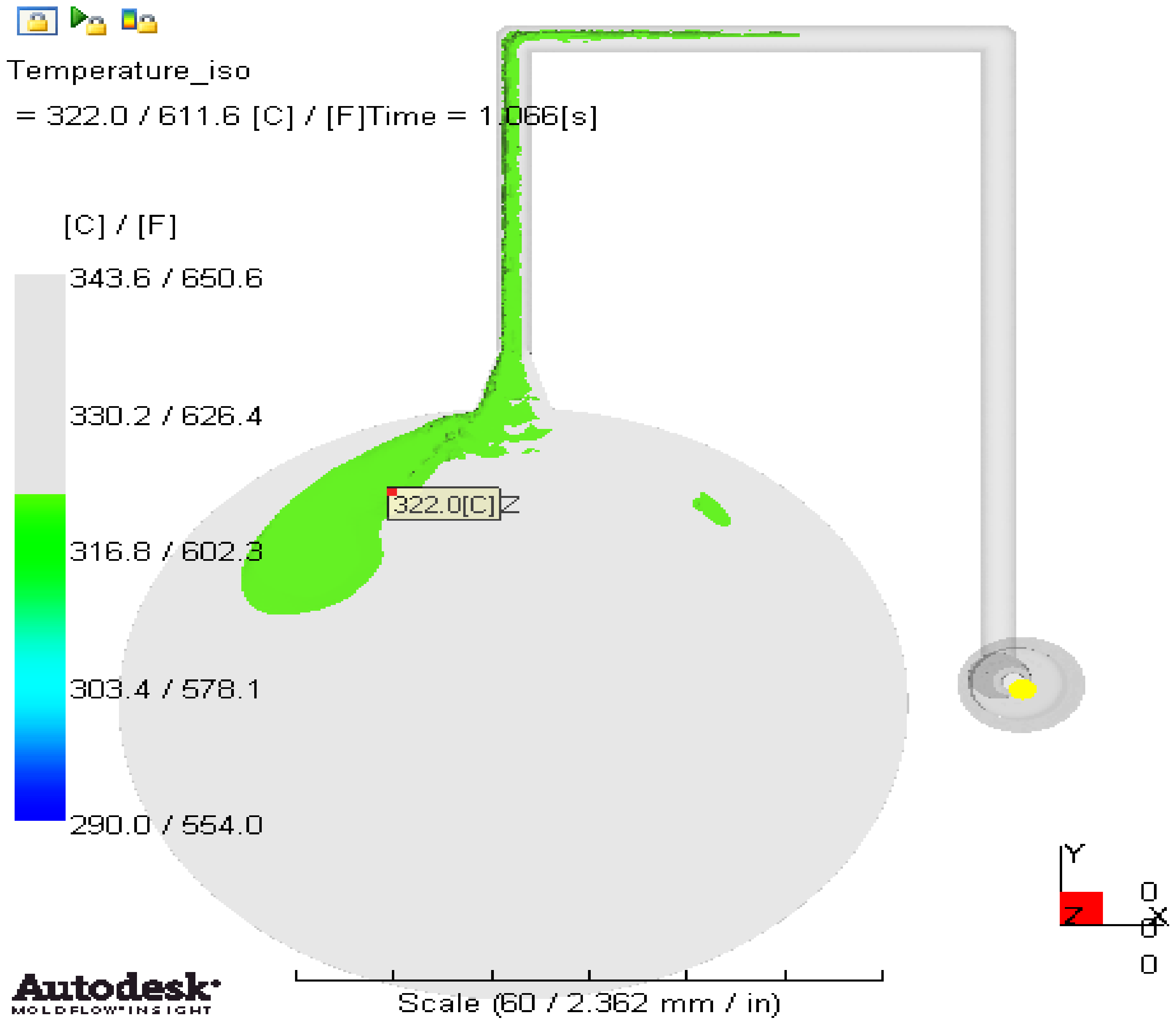
16 Layers



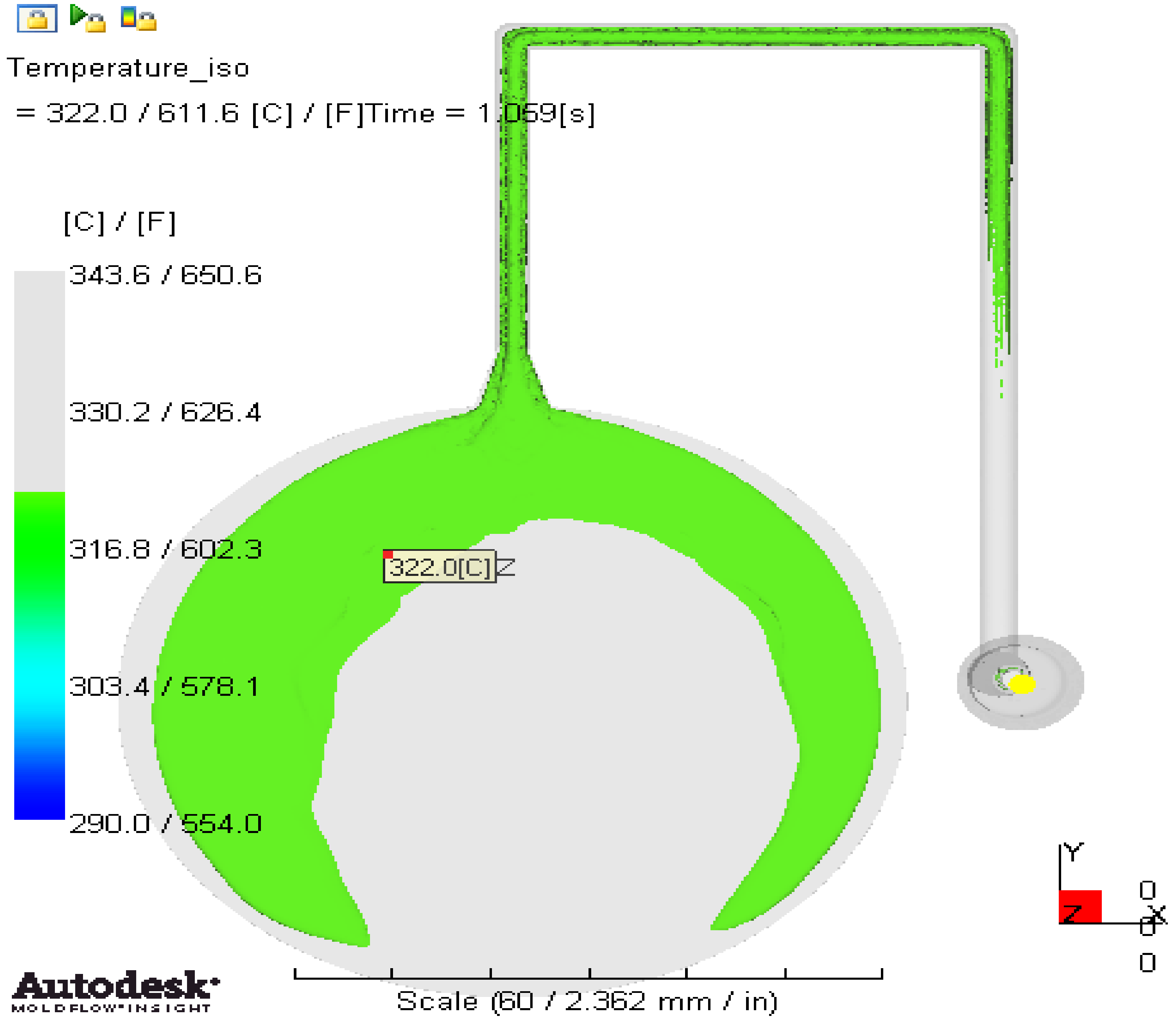
Initial Analysis

- Some shear heating observed
  - Melt inlet is at 293° C (560K)
  - Iso-surface plot of polymer above 320° C (661K)

6 Layers

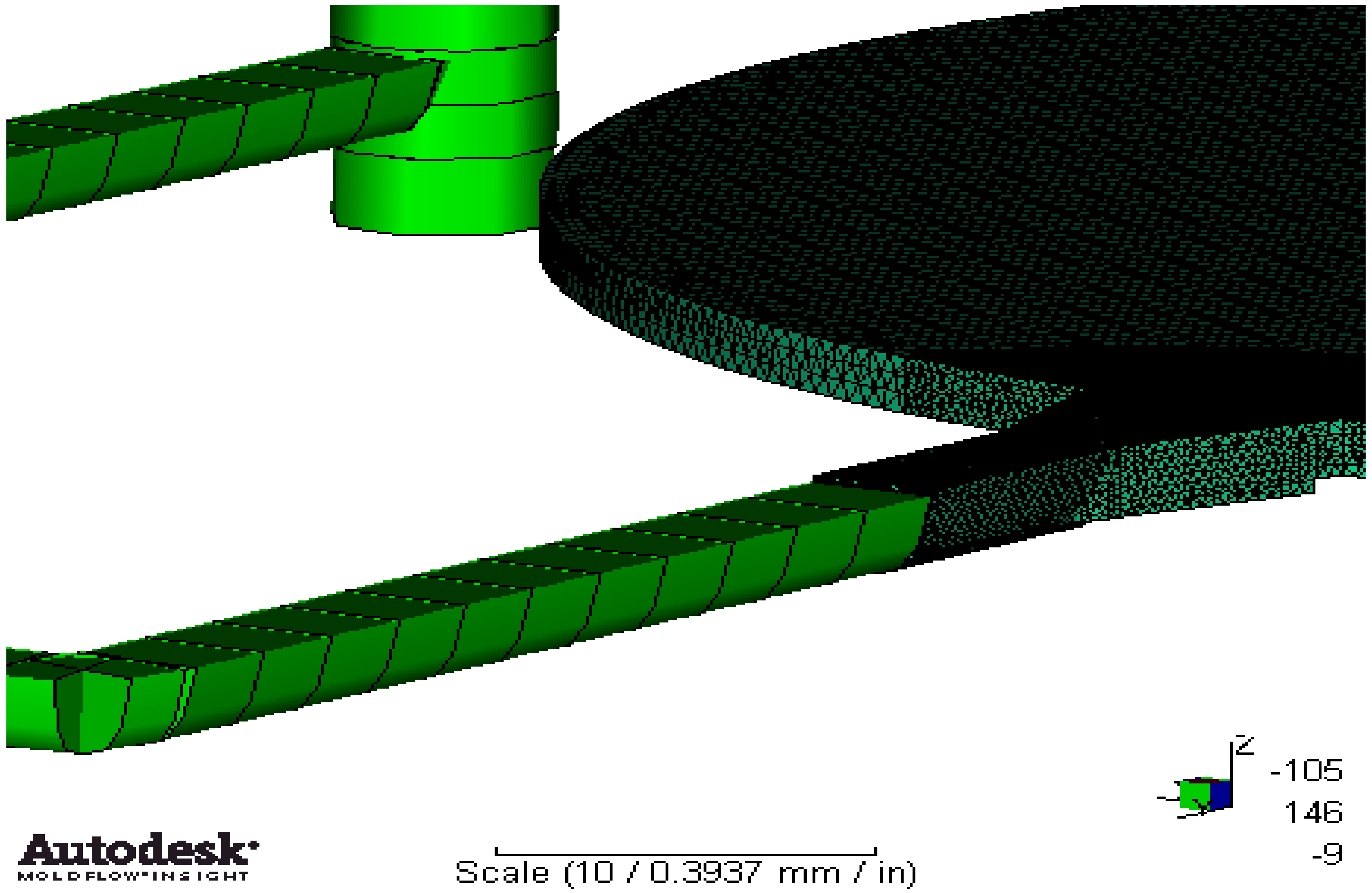


16 Layers



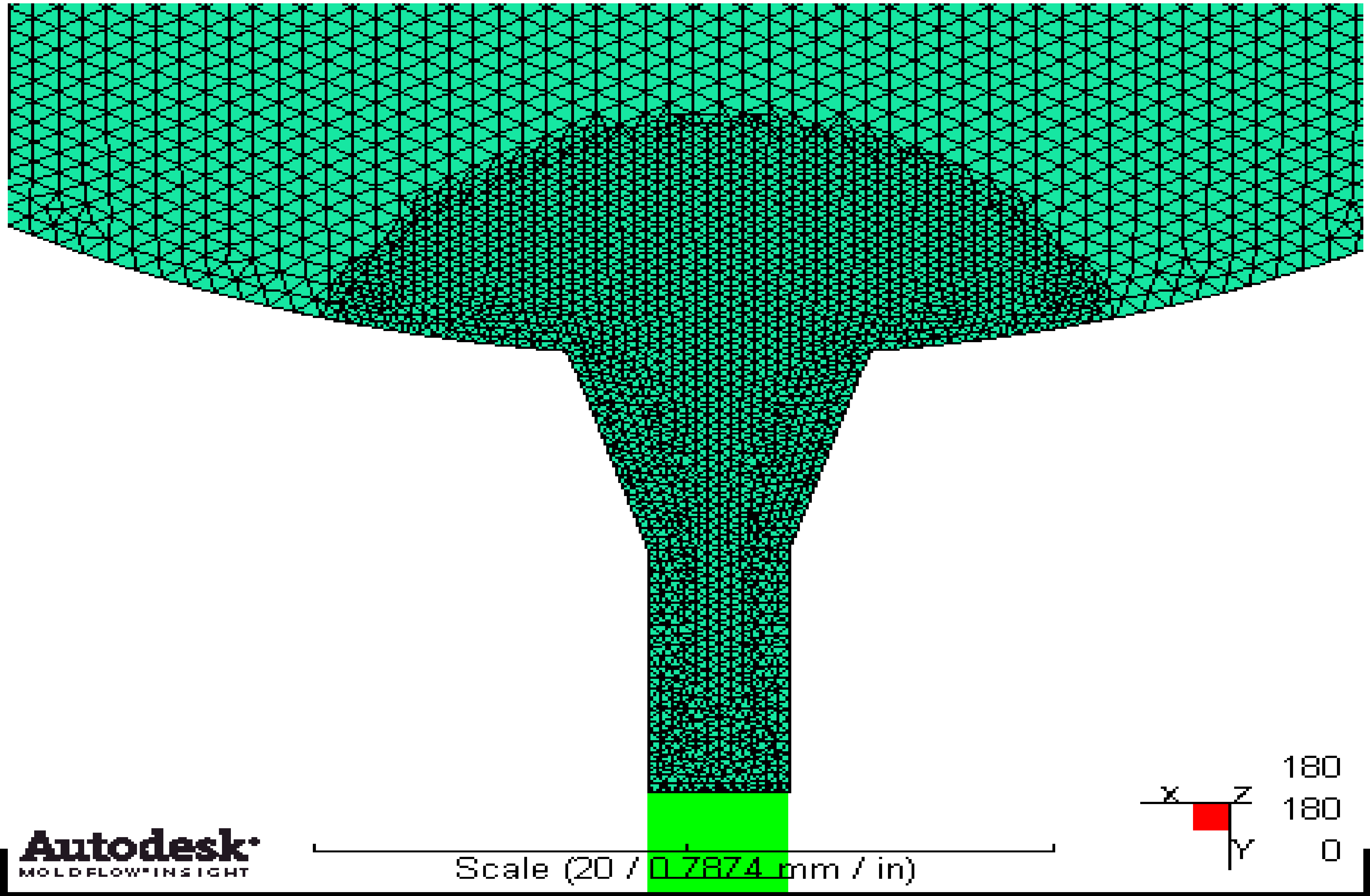
Model Feed System as Beam Elements

- Beam Elements ensure less false diffusion between layers/laminates
  - Can use up to 20 laminates in radial direction
  - VERY computationally efficient
  - Assign same U-Shape
- Beam elements are valid so long as the flow remains one-dimensional
  - No branching
- Use tetrahedral elements at the gate



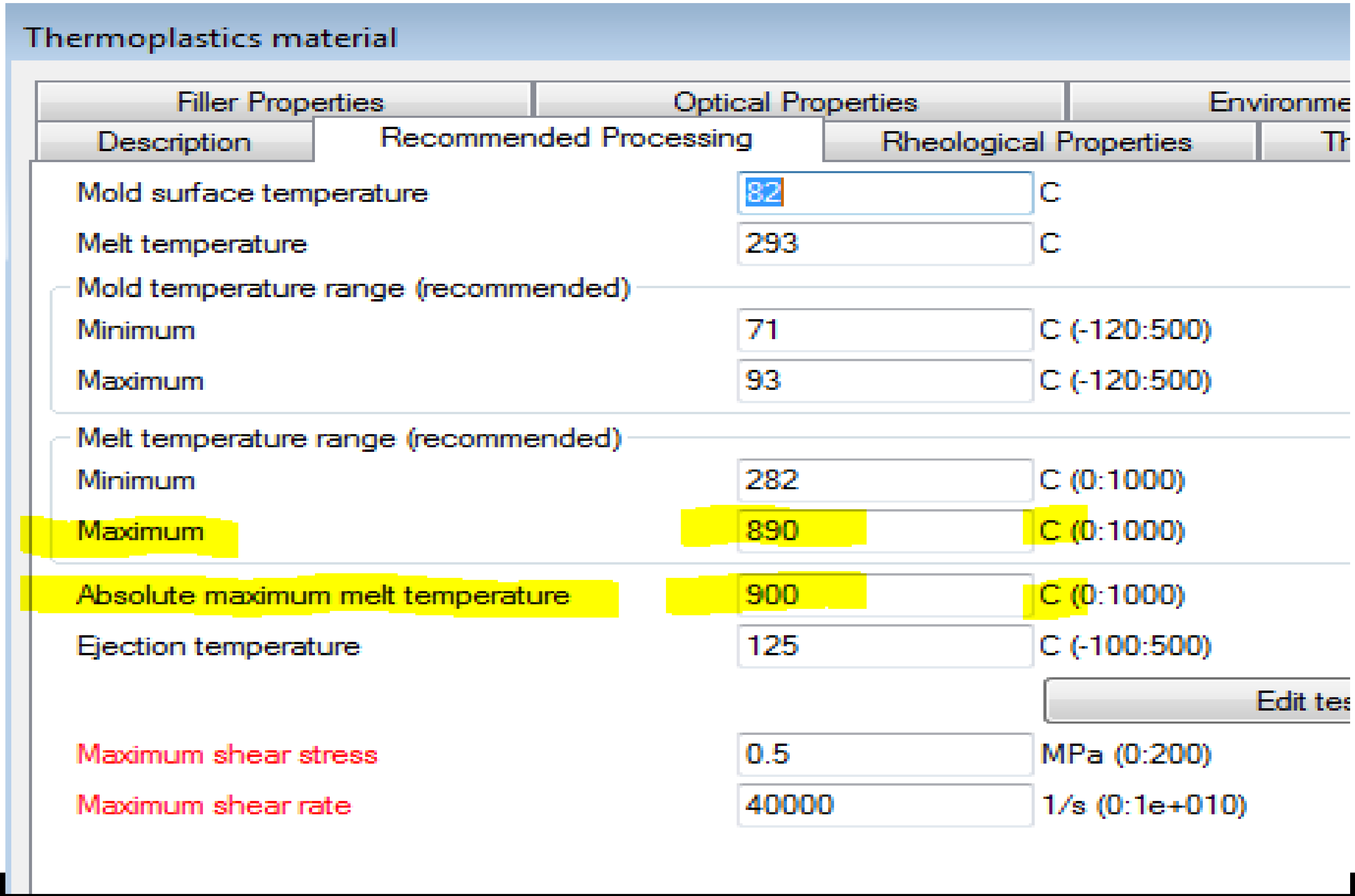
Refine Gate Mesh

- Use “Remesh Tetra” tool to refine the gate mesh size to 0.37 mm
  - Gate has 20 layers of element through thickness
  - Cavity mesh has 12 layers through thickness



Avoid Temperature Cap Limit

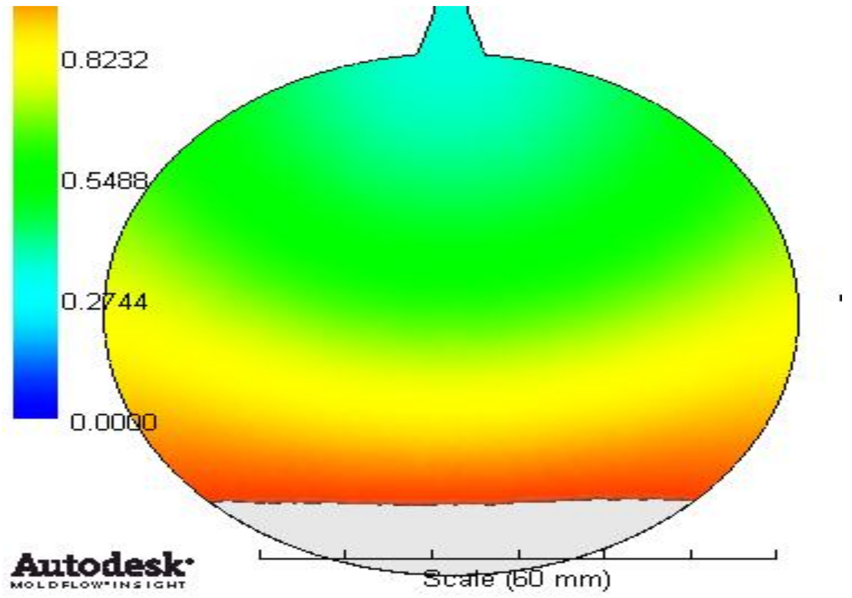
- Allow shear heating to increase melt temperature practically without limit by raising the absolute maximum melt temperature



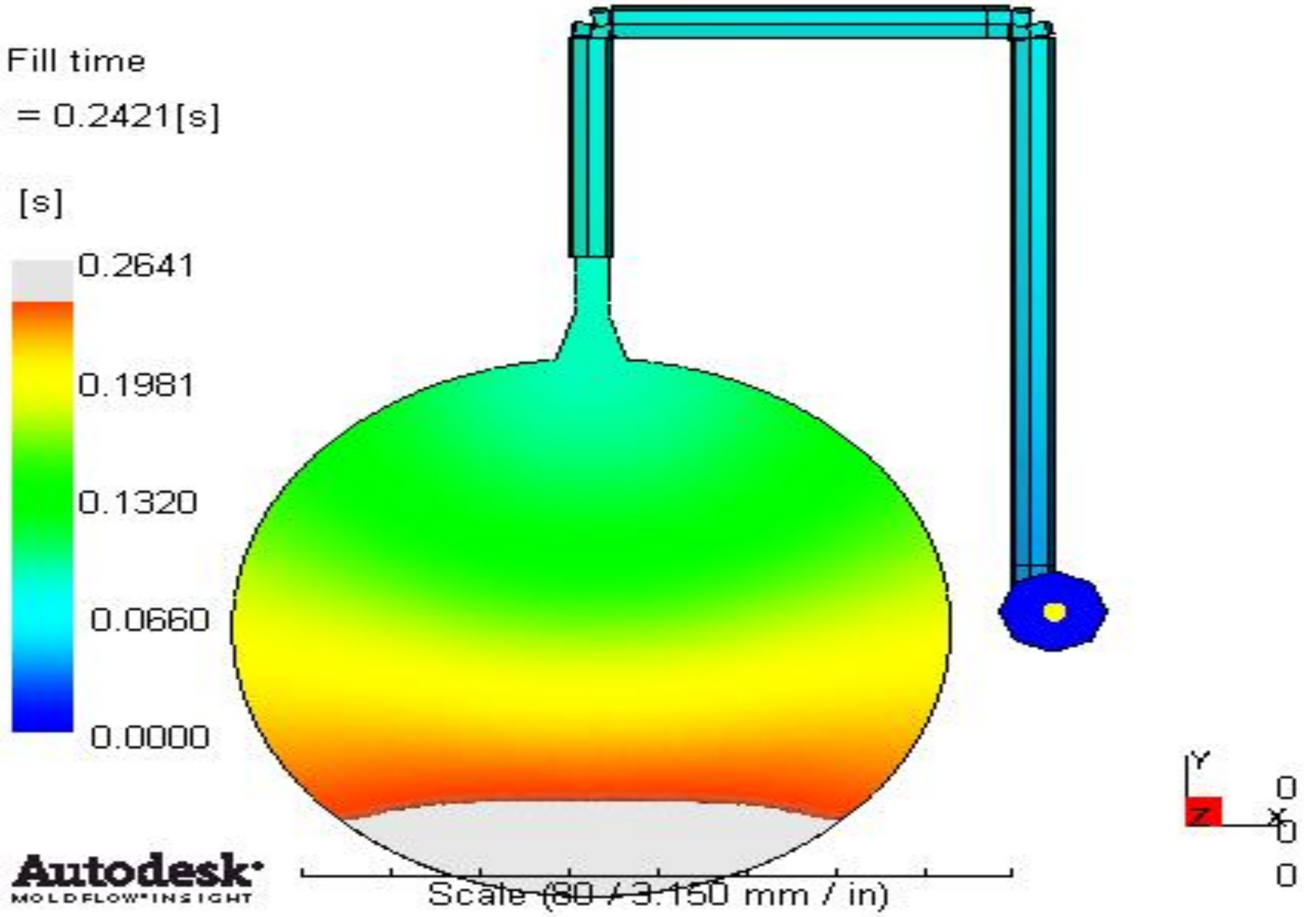
Autodesk University

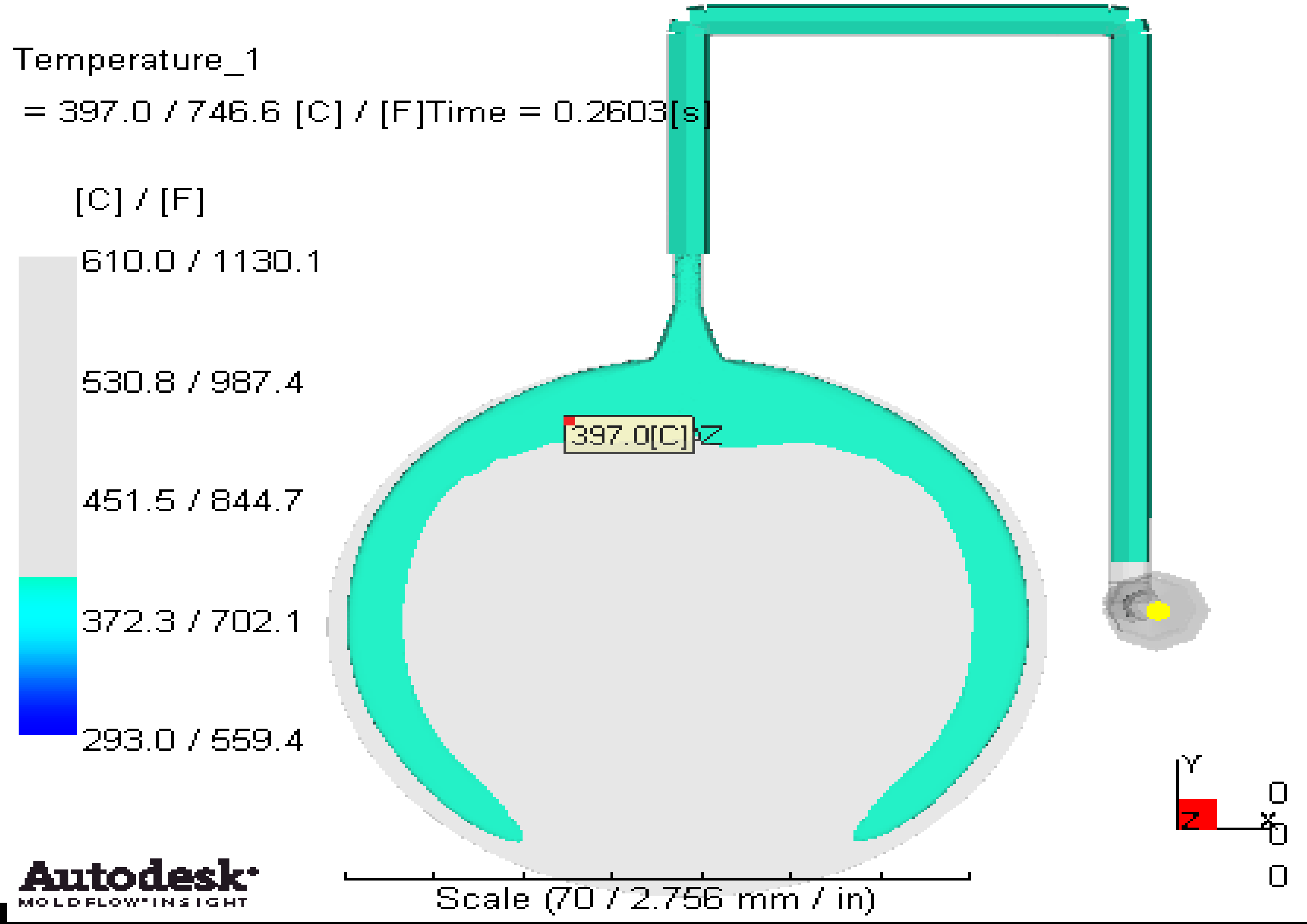
New Prediction

Initial Prediction



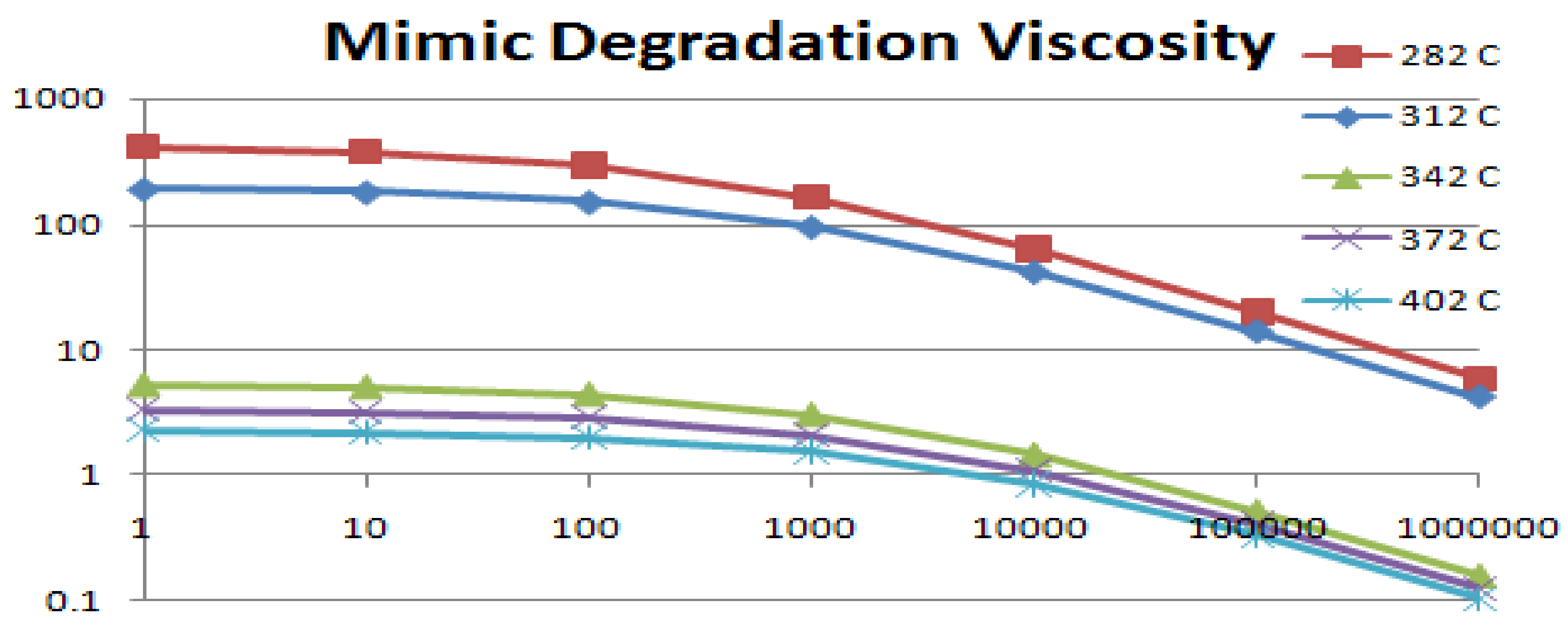
- Fill Pattern shows some race-track effect (better than initial)
  - Not as much as actual moldings
- Temperatures rises very high: up to 610° C (1130K) !
  - Iso-surface shows melt region above 397° C (747K)

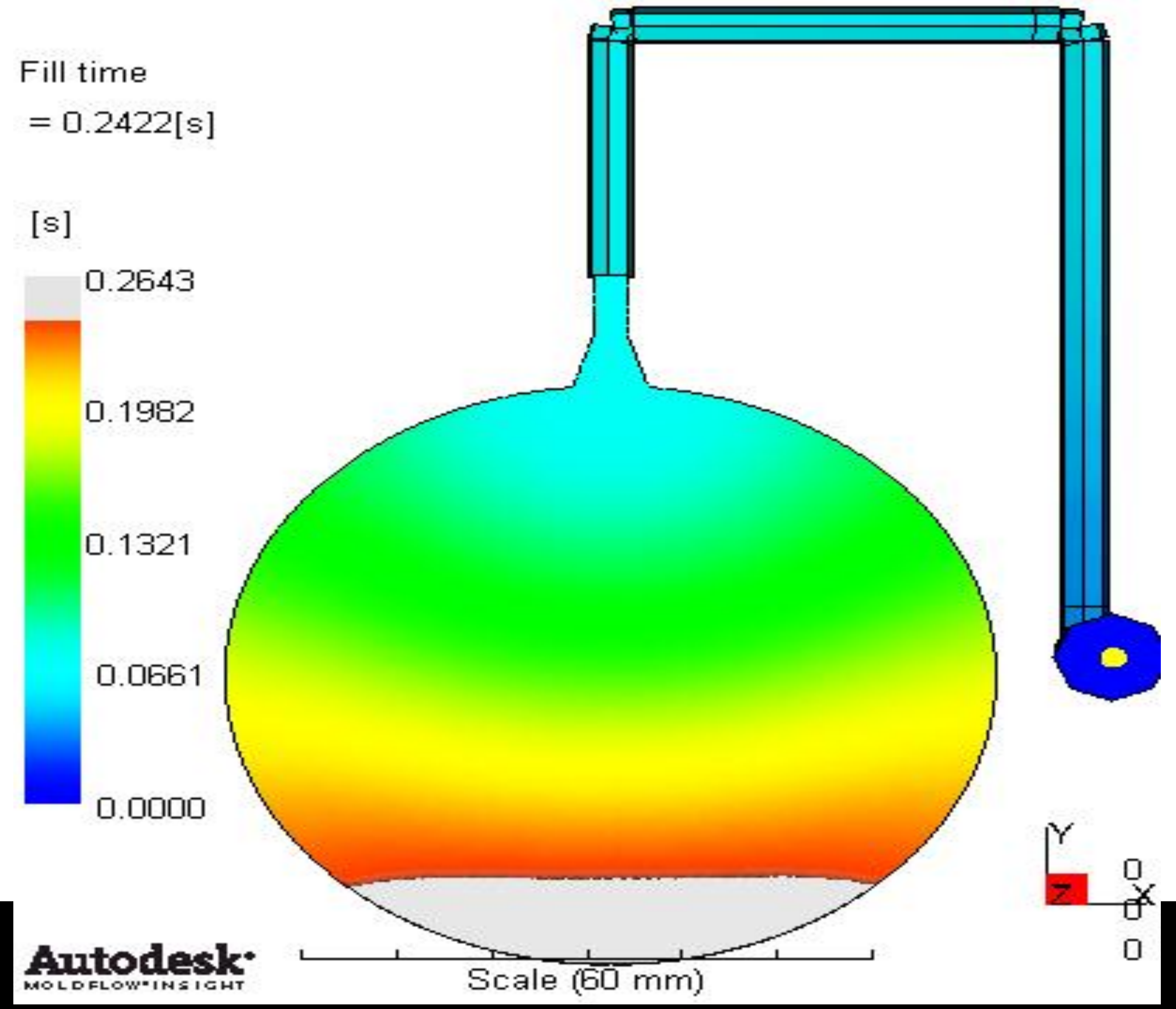


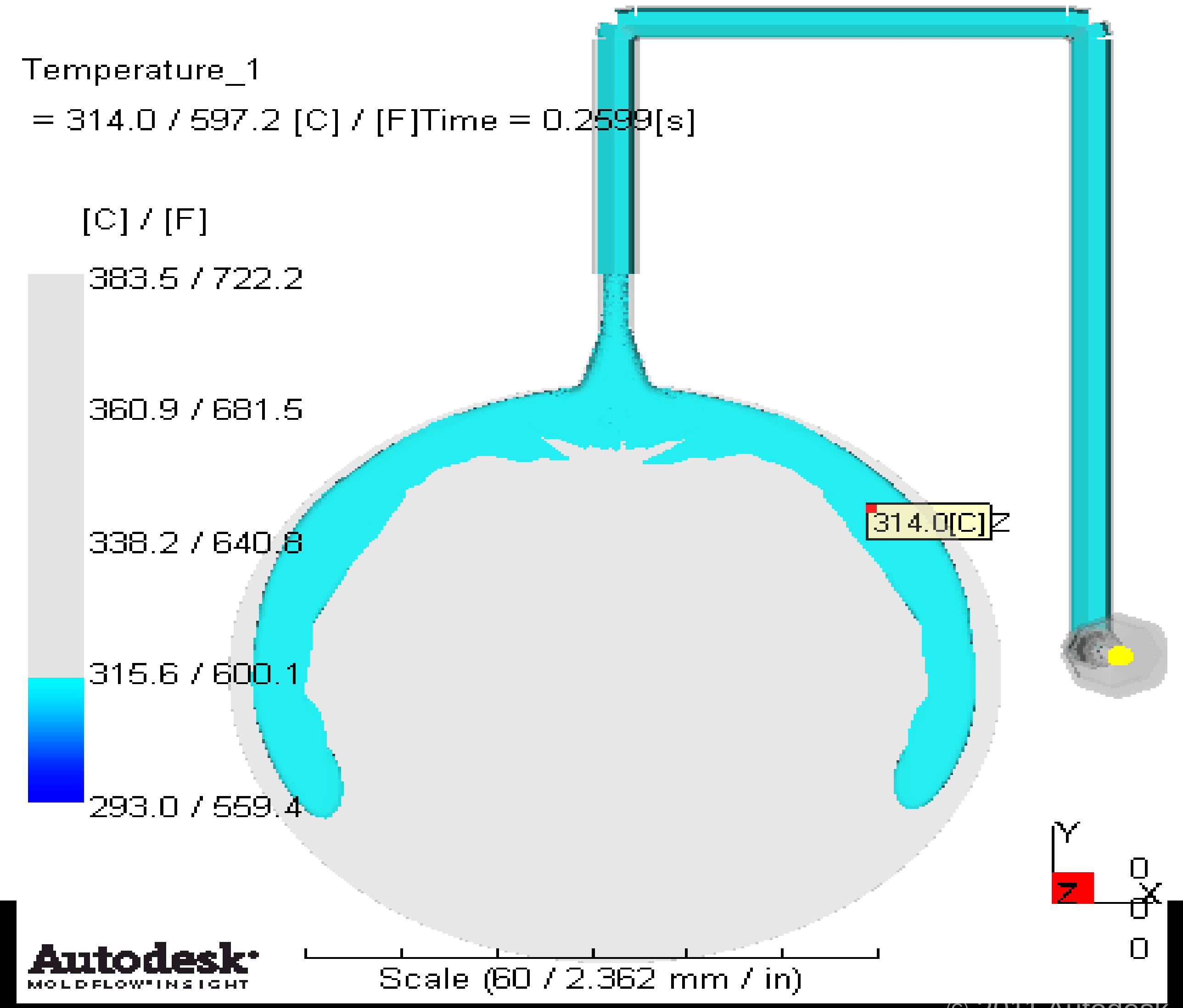


Are such high temperatures realistic?

- In reality, the material will degrade at such high temperatures
  - This results in reduced molecular weight
  - This will cause an irreversible viscosity decrease
  - Lower viscosity would mean less shear heat is generated above degradation temperature
  - Modify viscosity to mimic degradation (Not based on measurements)
    - Racetrace effect without excessive temperatures (Isosurface at 314° C (597K))



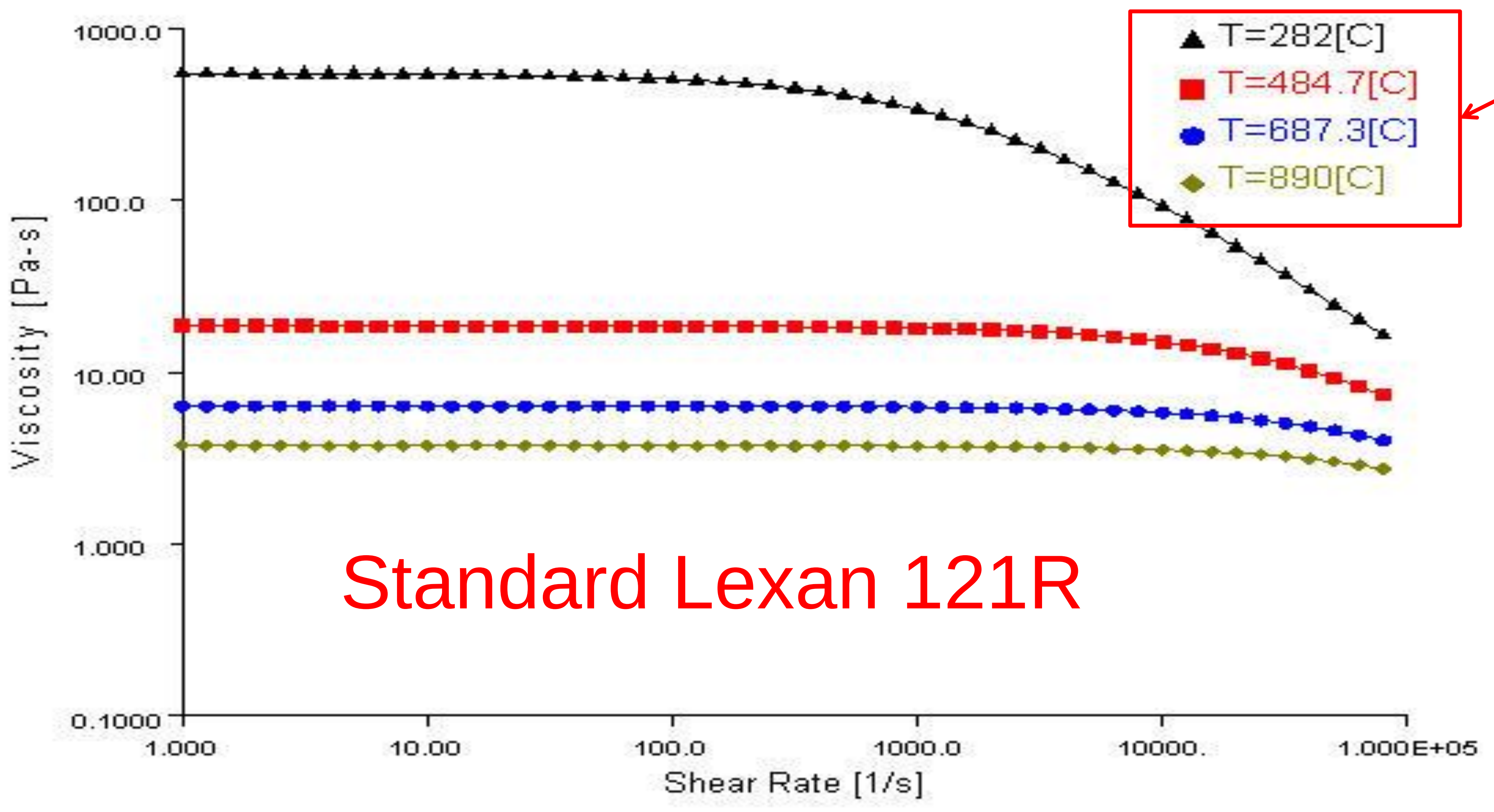


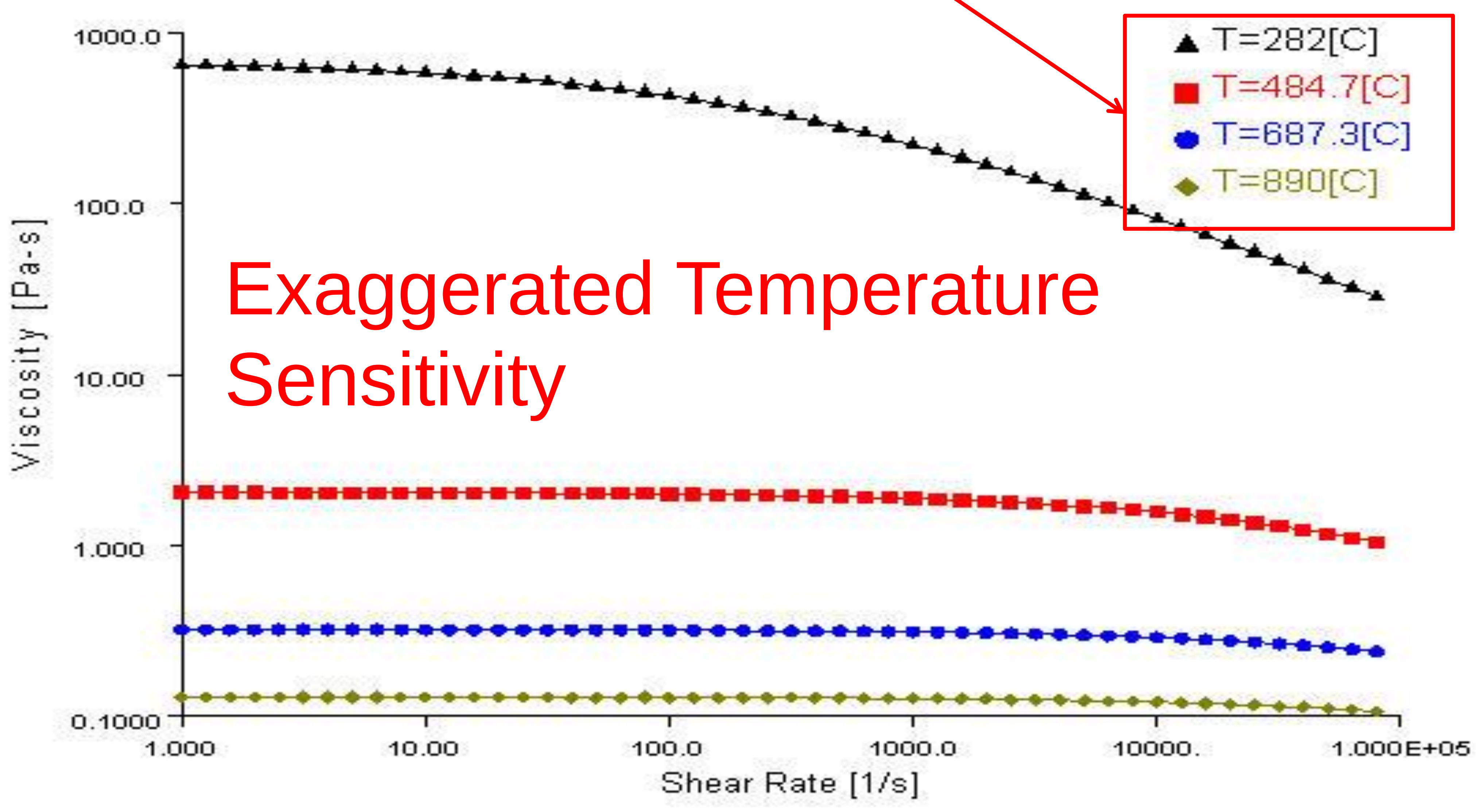


Viscosity Sensitivity to Temperature

- What if the viscosity's temperature sensitivity is greatly exaggerated (sensitivity study)

Note large temperature range

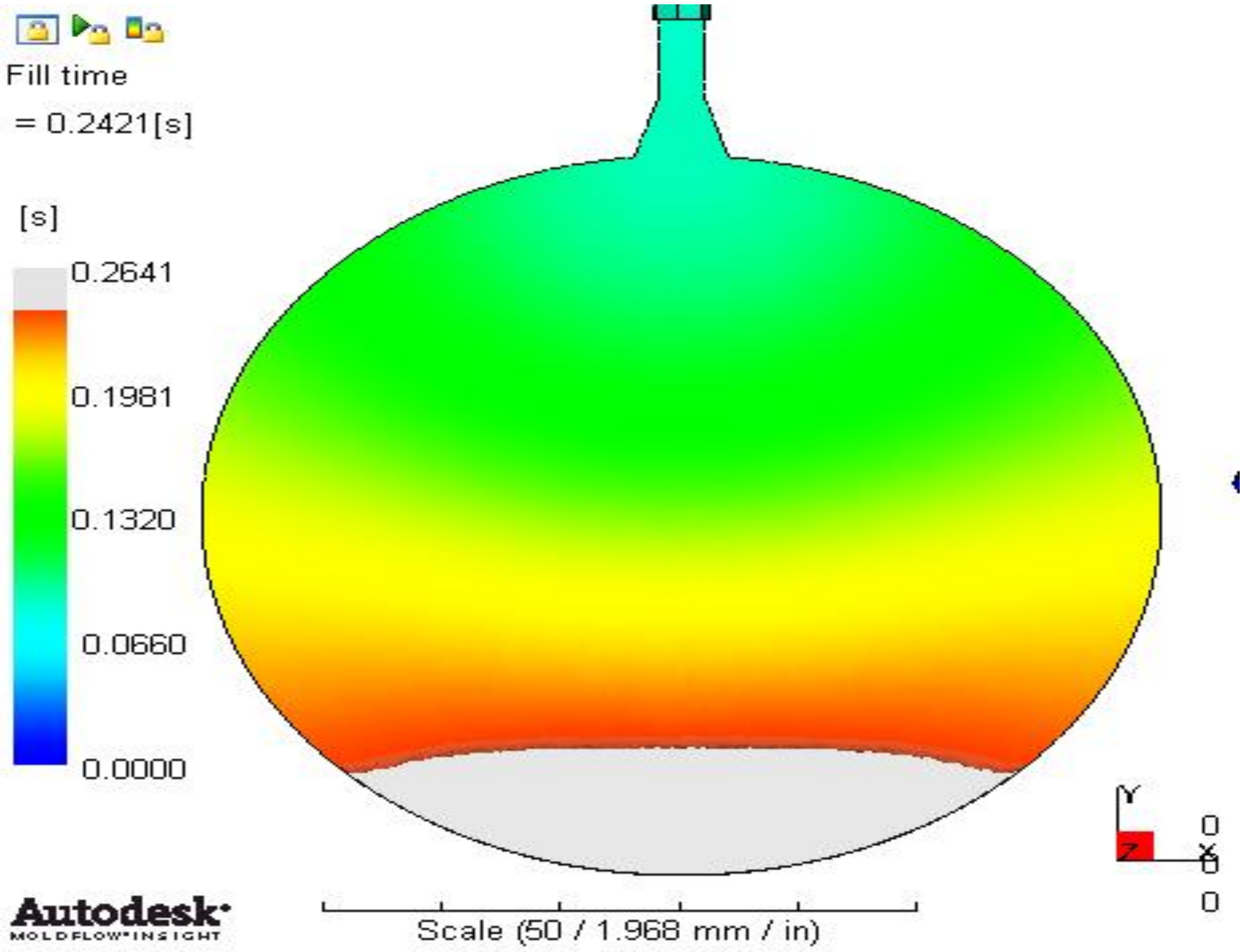




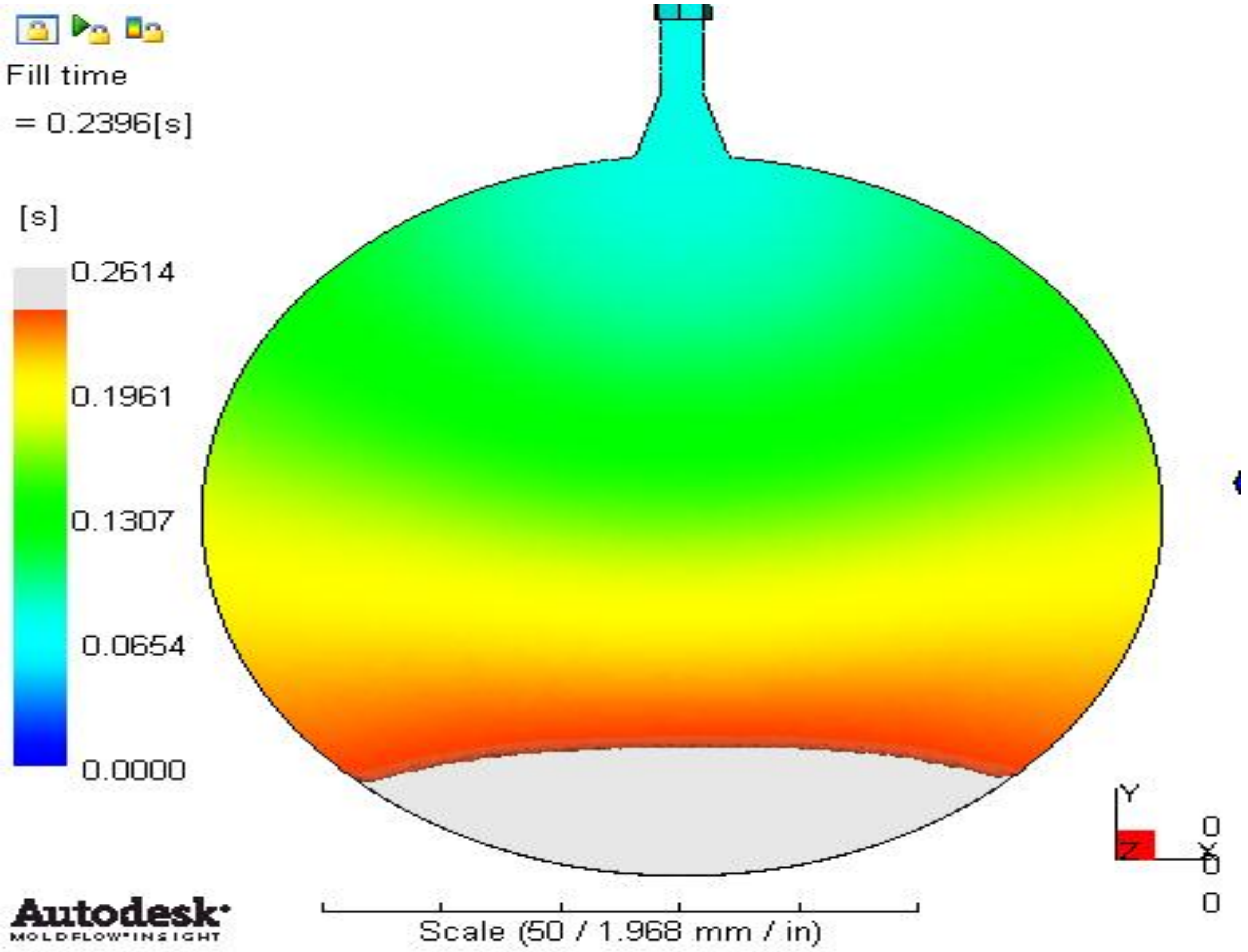
Viscosity Sensitivity to Temperature

- Slight difference in flow front shape

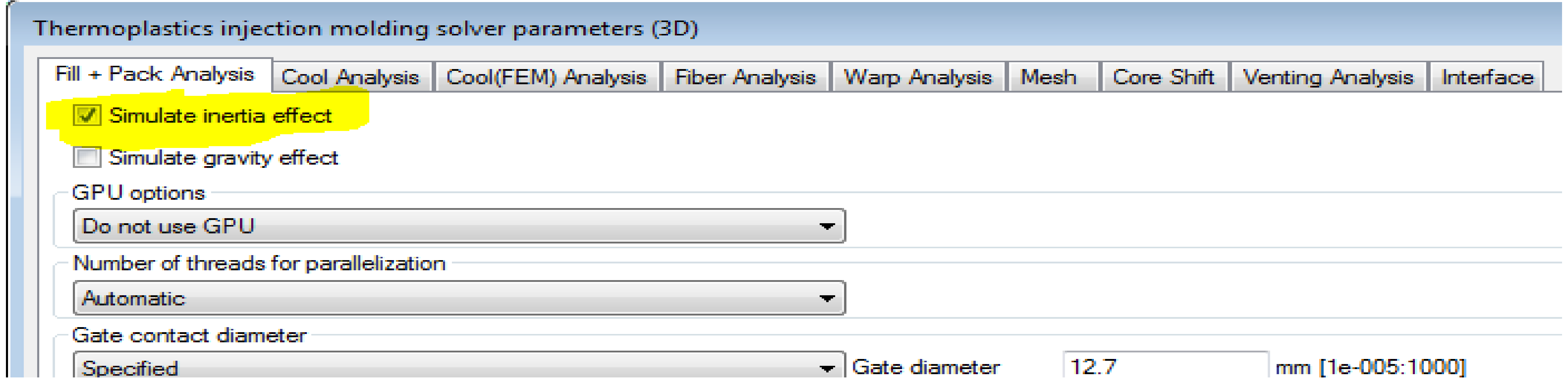
Standard Lexan 121R



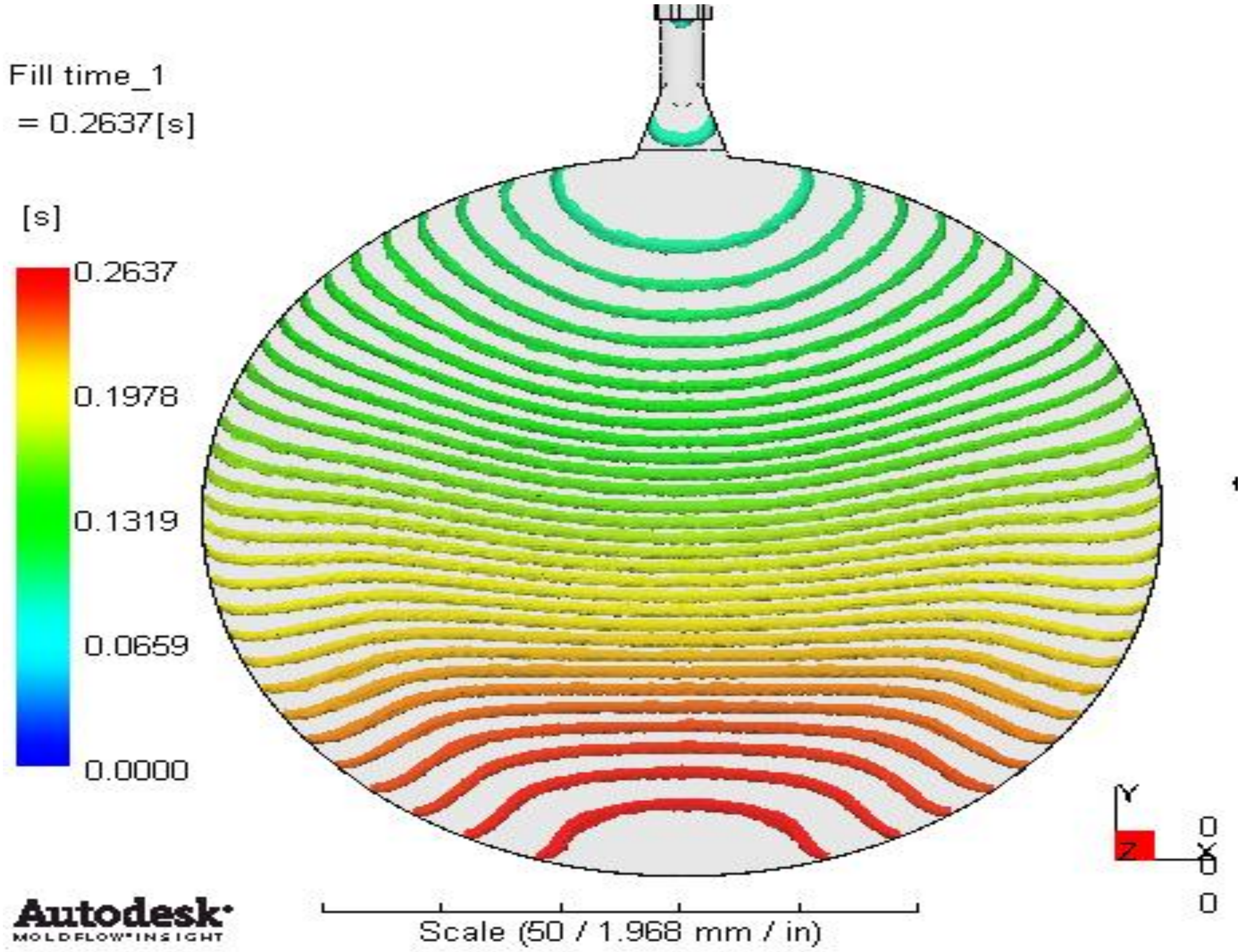
Exaggerated Temperature Sensitivity



Turn on Inertia



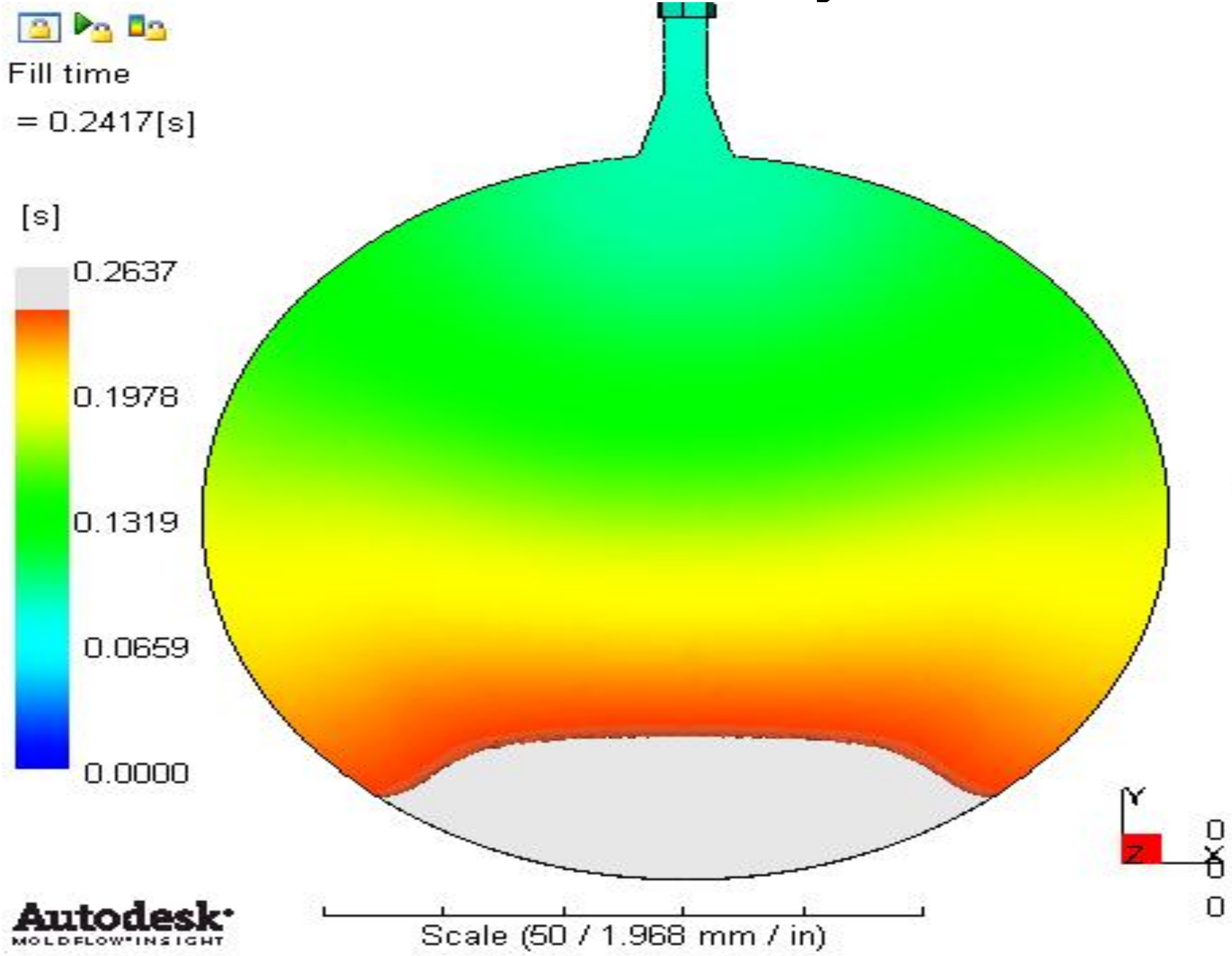
- Include the inertia term in the momentum equation
- Also turns on a more accurate method for calculating the flow front velocity (Longer computation time)
  - Race-track effect is much improved !



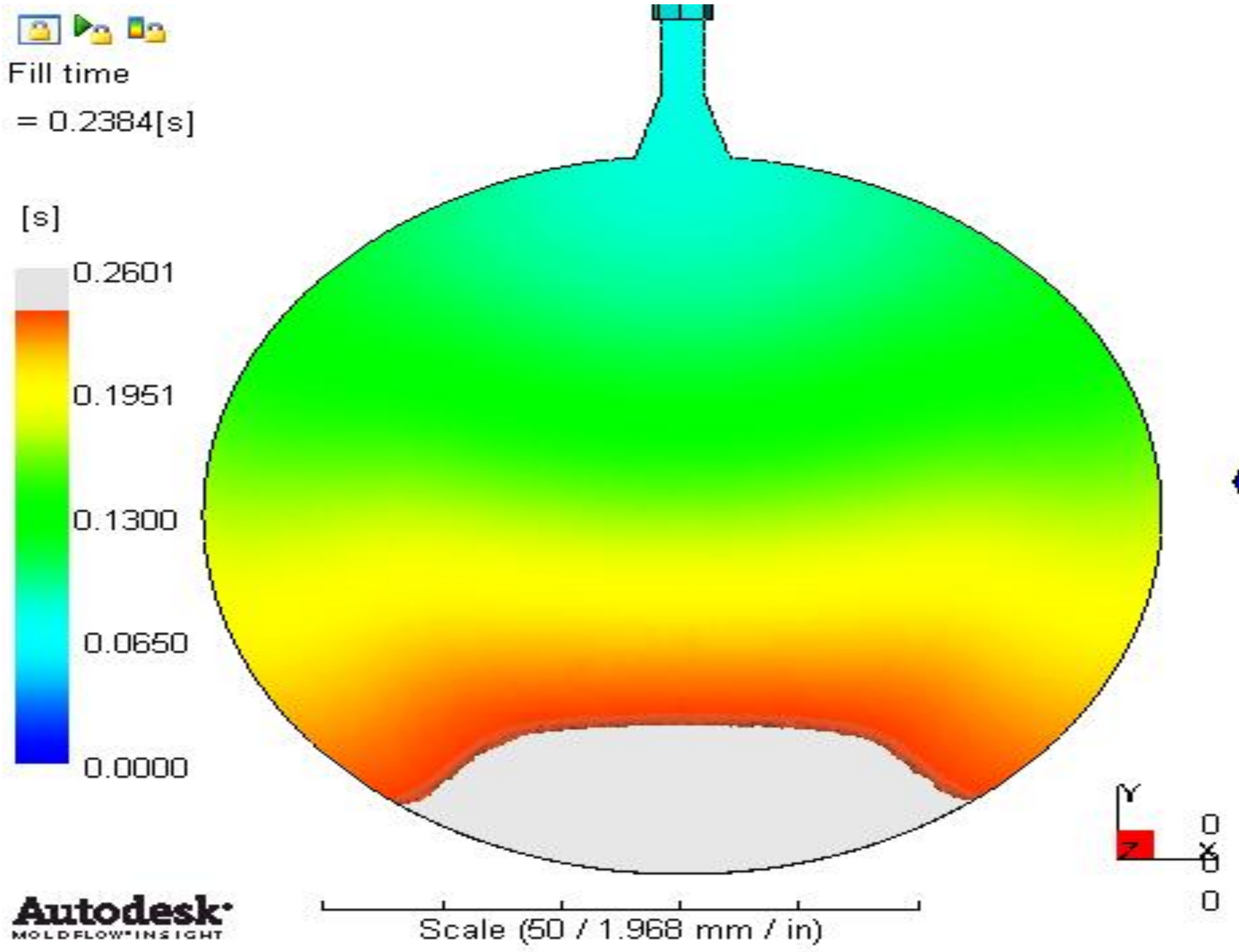
Inertia plus high temperature sensitivity

- Race-track shape is slightly better than with standard viscosity coefficients
  => Accurately modelling the temperature sensitivity will have some effect

Standard Viscosity



Exaggerated Temperature Sensitivity



Conclusions

- Race-Track Effect can be observed when:
  - Correct Flow Rate is applied
    - To have the correct amount of shear heating
  - Beam elements are used to capture shear-heating fully
  - Gate refinement is used
  - Temperature Cap is eliminated
  - Inertia effect is on, enabling accurate flow front velocity calculation
- Temperatures can go unrealistically high, but this may be because material degradation is not being considered which would lower the viscosity

DISK Study

The following parameters were used to run the analysis:

Material: Lexan 121R: Sabic Innovative Plastics

*Moldflow substitute for actual Thermocomp lX04513C material. Substitute was selected based on similar melt flow rate and physical properties

Melt Temperature = 560° F

Mold Temperature = 180° F

Injection time = 0.25 seconds

Dual Domain Mesh = .015” (148,748 elements)

3D Mesh = 20 Layers (4,549,363 elements)