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Simulation of a Downsized FDM Nozzle

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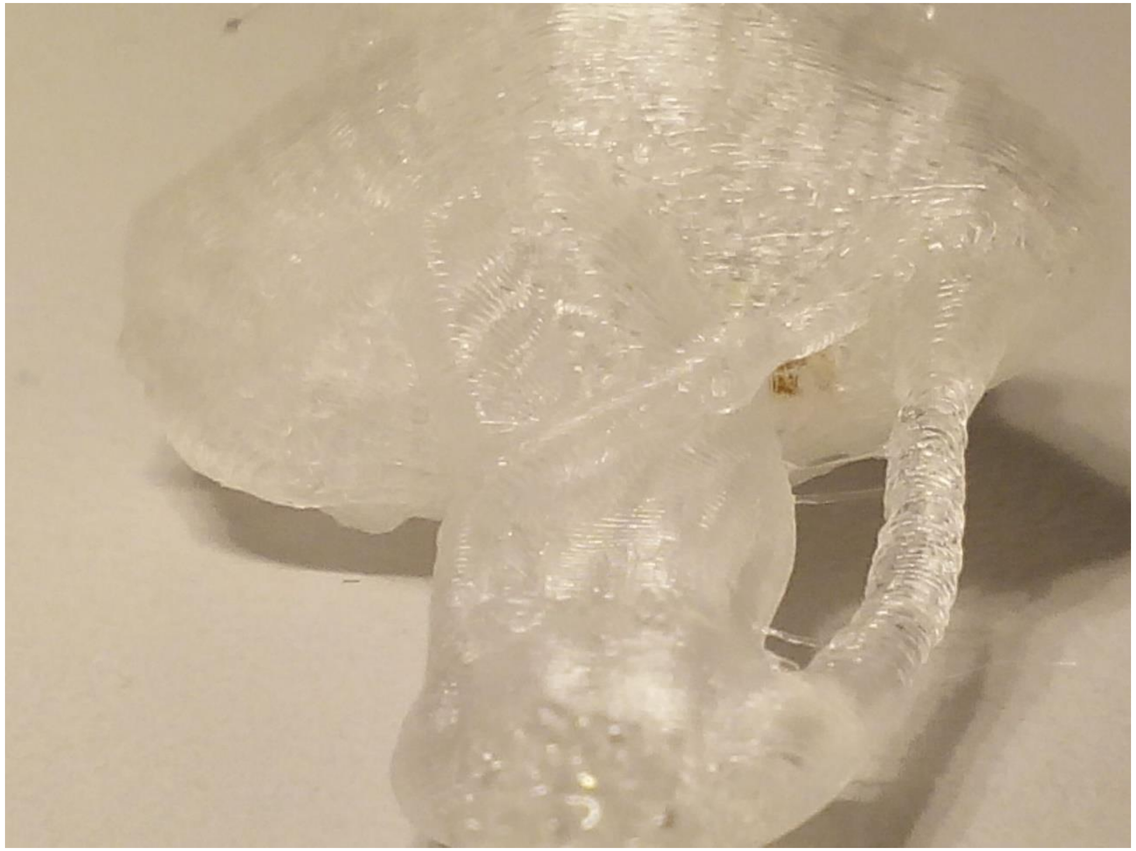
Introduction

- Fused deposition modeling (FDM)
- Surface quality dependent on:
  - layer thickness,
  - road width and
  - printing speed.

- Simulation of an E3D v6 HotEnd Extruder
  - Different diameters
  - Pressure dependent fluid flow



Implementation in COMSOL Multiphysics

- **Geometry** based on the original extruder:
  - Heatsink (aluminum)
  - Heatbreak (steel)
  - Heater bock (aluminum)
  - Nozzle (brass)
  - Additional fan

Implementation in COMSOL Multiphysics

- **Material** properties of the polymer:
  - ABS polymer
  - Cross-WLF model (Shin et al. 2013)

$$\eta(T,\dot{\gamma}) = \frac{\eta_0(T)}{1+(\eta_0(T)\dot{\gamma}/\tau)^{1-n}}$$

$$\eta_0(T) = D_1 \exp\left[\frac{-A_1(T-T_r)}{A_2+(T-T_r)}\right]$$

$$\tau = 3.48 \times 10^4\,\mathrm{Pa}$$

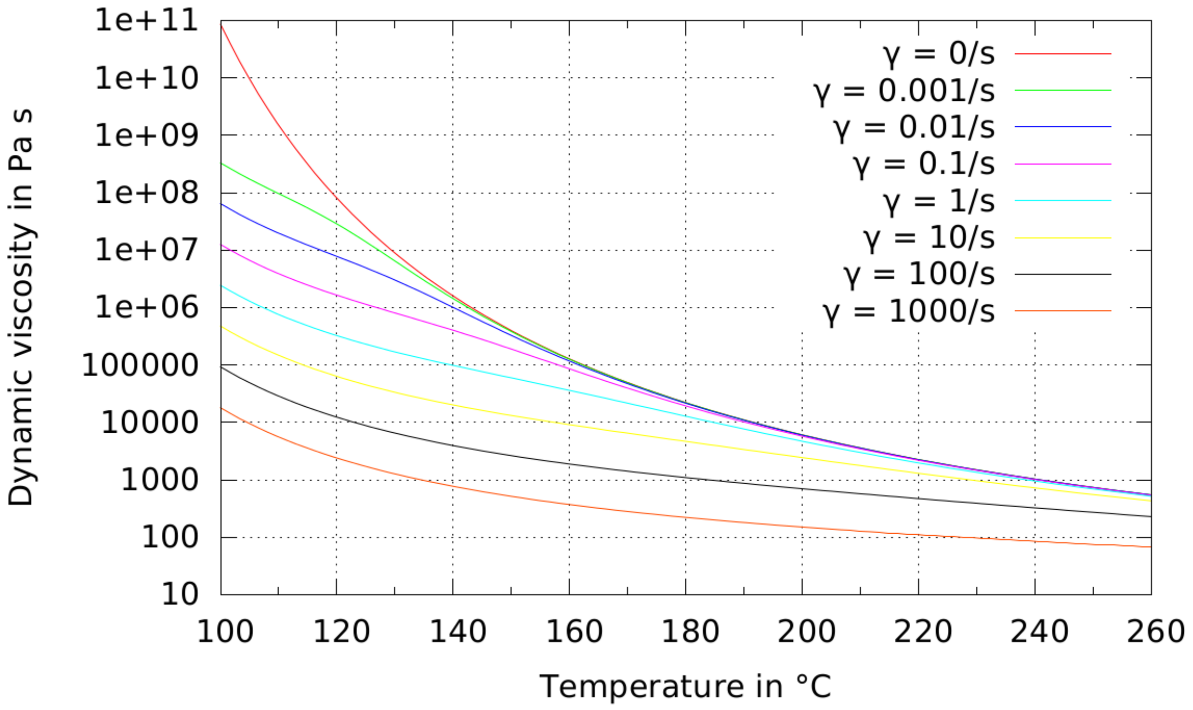
$$n = 0.289$$

$$D_1 = 8.62 \times 10^{11}\,\mathrm{Pa\,s}$$

$$T_r = 373.15\,\mathrm{K}$$

$$A_1 = 24.96$$

$$A_2 = 51.6\,\mathrm{K}$$



Implementation in COMSOL Multiphysics

- **Heating and cooling**:
  - Electric heating
  - Heat source up to 25W
  - Overall heat transfer coefficient

  - Cooling by electic fan
  - Flow of 2550mm/s

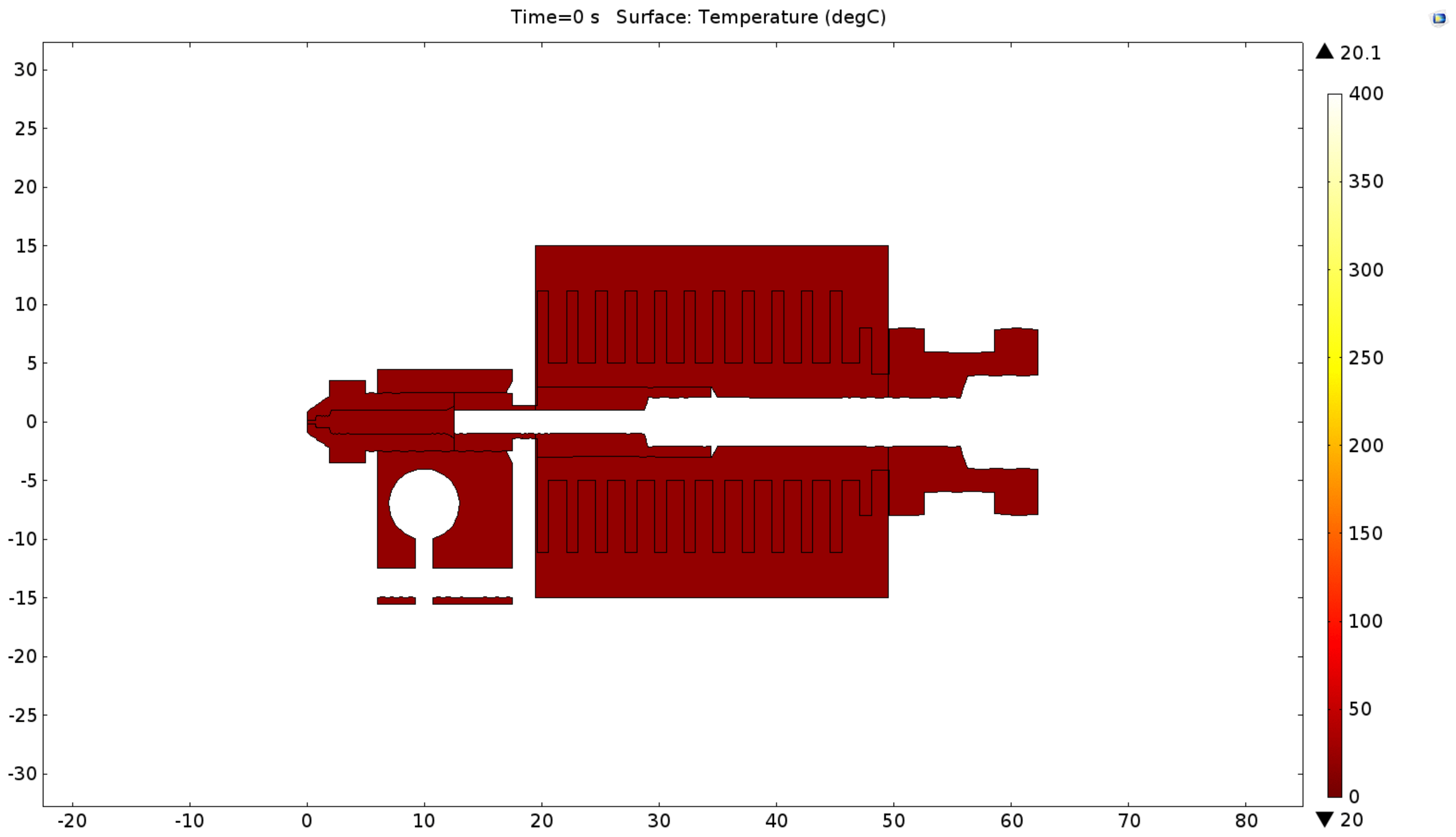
$$\rho C_p \mathbf{u} \cdot \nabla T = \nabla \cdot (k \nabla T) + Q$$

- **Fluid flow**:
  - Low Reynolds number
  - Pressure difference between inlet and outlet of 3 .. 12atm
  - 1.75mm filament
  - Melting process in heatbreak

$$\rho(\mathbf{u} \cdot \nabla)\mathbf{u} = \nabla \cdot \left[-p\mathbf{I} + \eta \left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T \right) - \frac{2}{3}\eta(\nabla \cdot \mathbf{u})\mathbf{I} \right] + \mathbf{F}$$

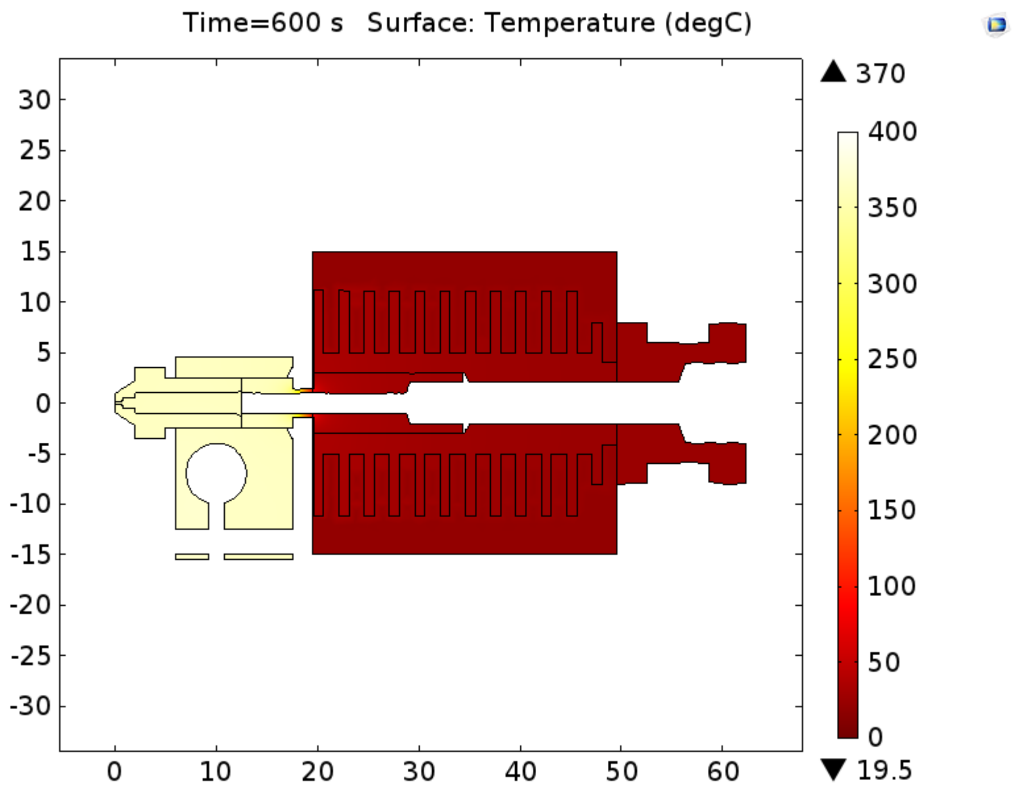
$$\nabla \cdot (\rho \mathbf{u}) = 0$$

Simulation Results

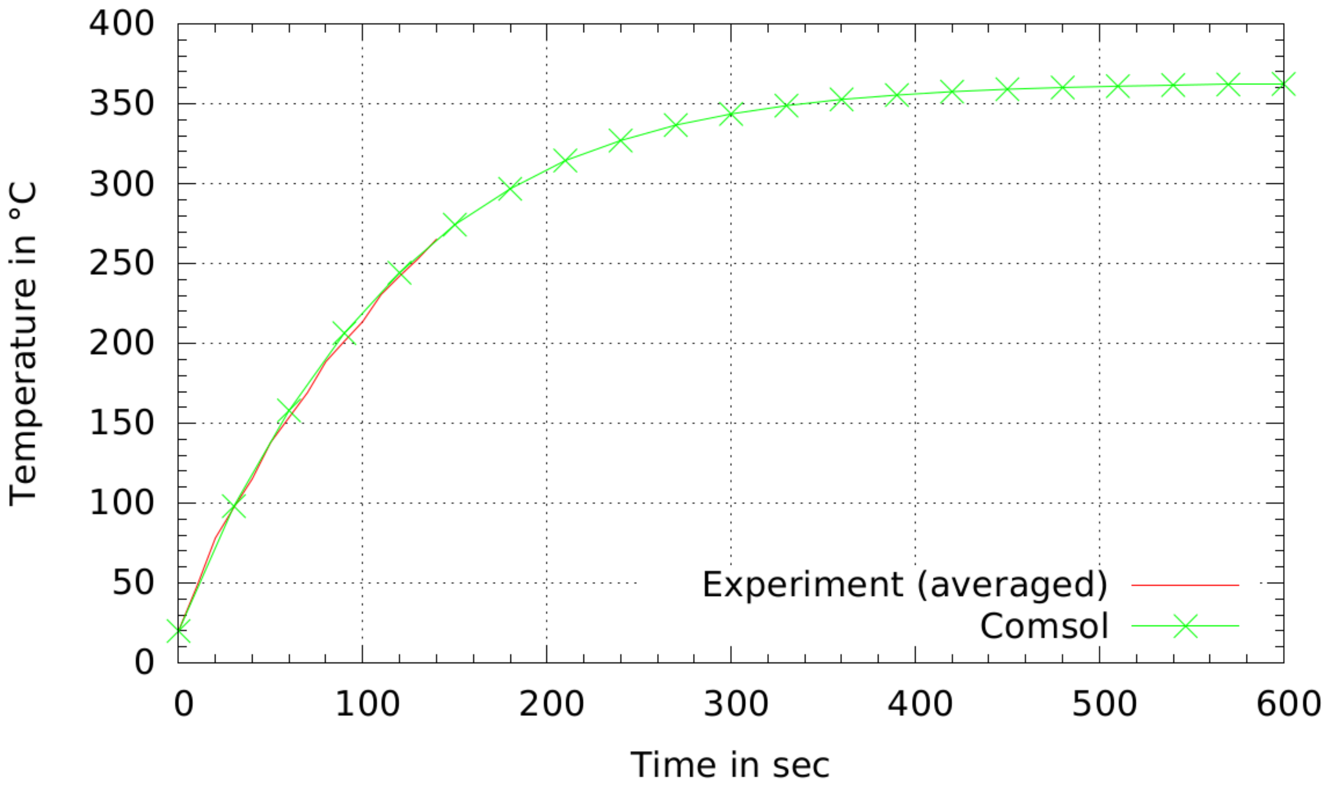


Simulation Results

- Heating with 25W



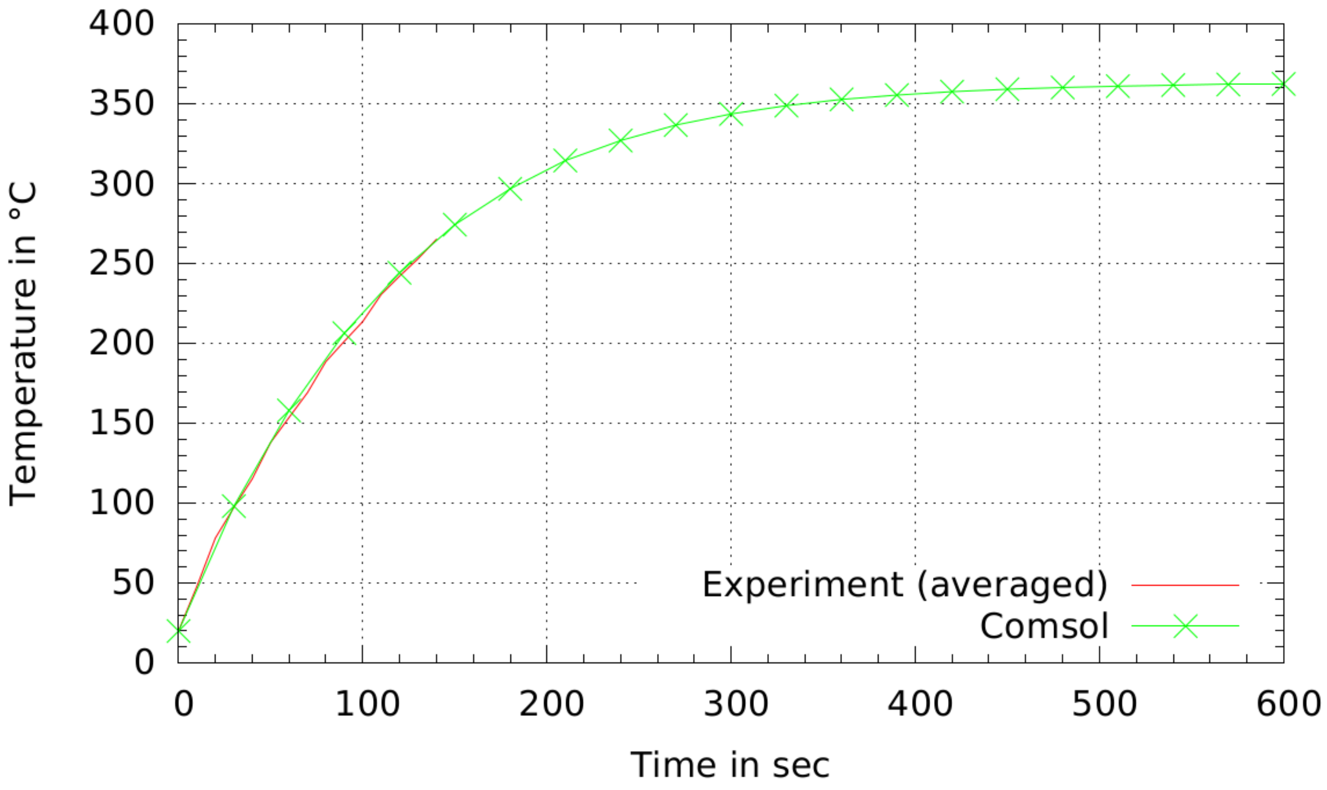
- Temperature close to the nozzle tip



Simulation Results

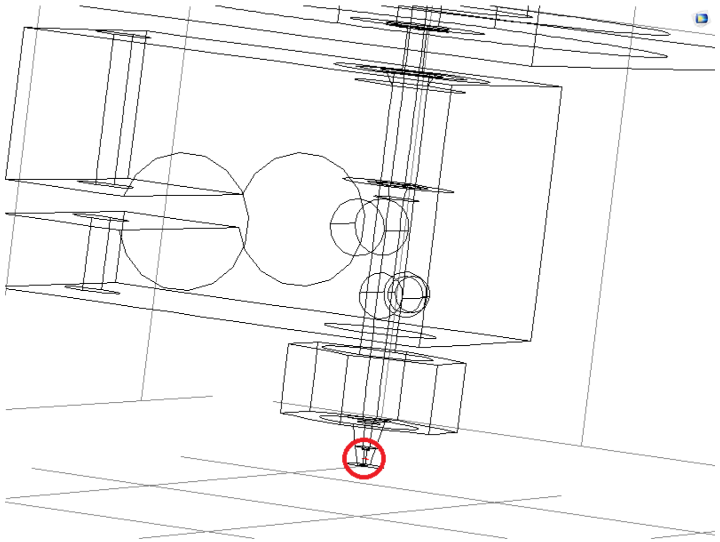
- Calibration via experimental setup
- Ideal temperature at 230° C
- Overall heat transfer coefficient of 15W/(m²K)
- Heat regulation via electrical heating
  - 25W → 370° C
  - 15W → 230° C

- Temperature close to the nozzle tip

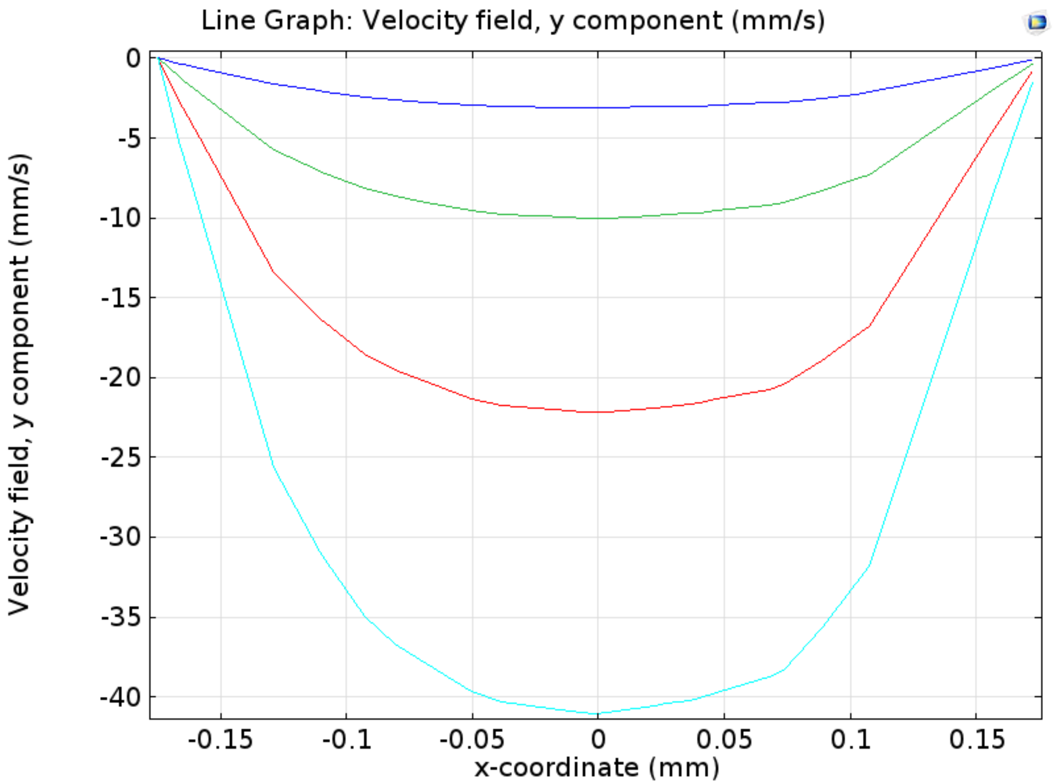


Simulation Results

- Fluid flow via pressure difference between inlet and outlet
- Parabolic velocity distribution



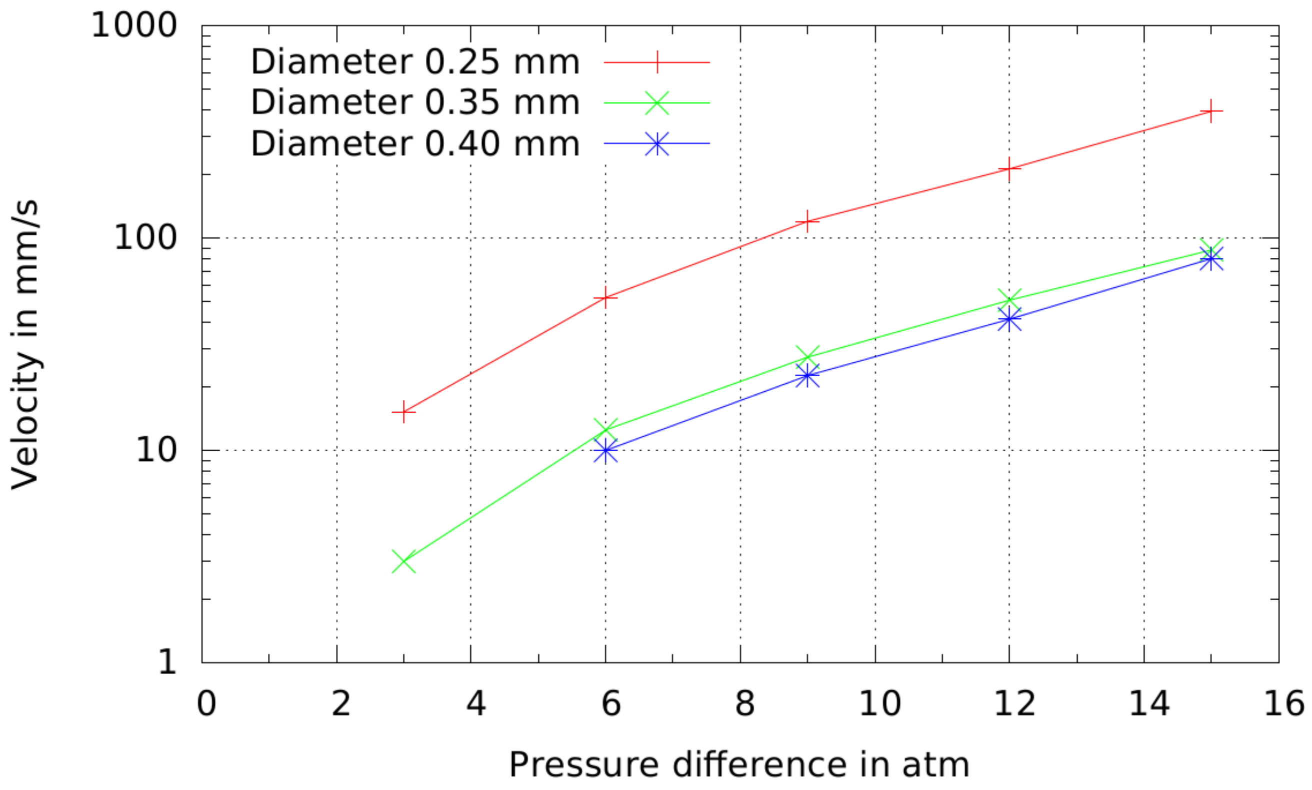
- Pressure differences 3, 6, 9 and 12atm



Simulation Results

- Pressure difference sweep on different diameters:
  - 0.25mm
  - 0.35mm
  - 0.40mm
- Quadratic dependence on diameter

- Diameter dependency



Conclusion

- E3D HotEnd extruder simulated and calibrated via experiments
- Insight into the physical behavior and processes
  - velocity,
  - viscosity and
  - temperature.
- Characteristic temperature gradient from tip to heatsink
- Large change of gradient in heatbreak
- Fluid flow controlled via pressure difference
- Parabolic velocity distribution
- Fluid velocity is quadratically dependent on the pressure difference