Simulation of a Downsized FDM Nozzle

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Introduction: Size and surface roughness are key issues in additive manufacturing technologies. For the aim of downsizing a fused deposition modelling (FDM) extruder, simulations give an insight into the physical parameters and processes within the nozzle in terms of heat transfer and fluid flow.

Background: Simulations were performed on a model inspired by the E3D HotEnd v6 extruder. The extruder contains a nozzle, heater block, heatbreak and heatsink additionally cooled by a fan. The diameter is located in the sub-mm region allowing to reduce the size and surface roughness of the additively manufactured product.

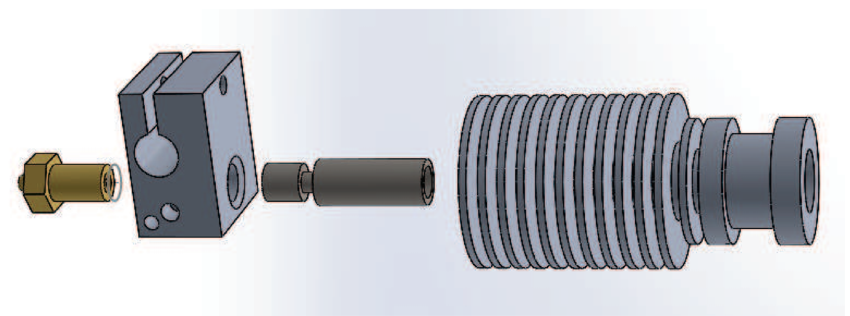

Figure 1. E3D HotEnd extruder in an explosion view

Model: The model contains a heat source (up to 25W), heater block (aluminum), nozzle (brass), heatbreak (steel) and heatsink (aluminum), which is additionally cooled by a fan.
ABS is applied as a polymer fluid showing non-linear viscosity behavior. It enters the extruder forced by a pressure difference between inlet and outlet. The flow is laminar and incompressible.

Validation: The simulation results were experimentally validated. This kind of simulations is facing multiple problems respectively connected to the description of the material properties with temperature and pressure dependency.

Heat transfer: The heat distribution was calculated using the „heat transfer" module of COMSOL Multiphyiscs. Fluid flow was calculated using the „laminar flow" module of COMSOL Multiphysics solving the Navier-Stokes equations.

Environment temperature was assumed as 20° C. The fan was simulated by a constant fluid flow of 2550 mm/s extracted from data sheet ot the fan delivered with the E3D HotEnd extruder.

$$\rho \frac{\partial \mathbf{u}}{\partial t} - \nabla \cdot \eta \left(\nabla \mathbf{u} + \left(\nabla \mathbf{u} \right)^T \right) + \rho \left(\mathbf{u} \cdot \nabla \right) \mathbf{u} + \nabla p = 0$$

$$\nabla \cdot \mathbf{u} = 0$$

Equation 1. Incompressible Navier-Stokes equation

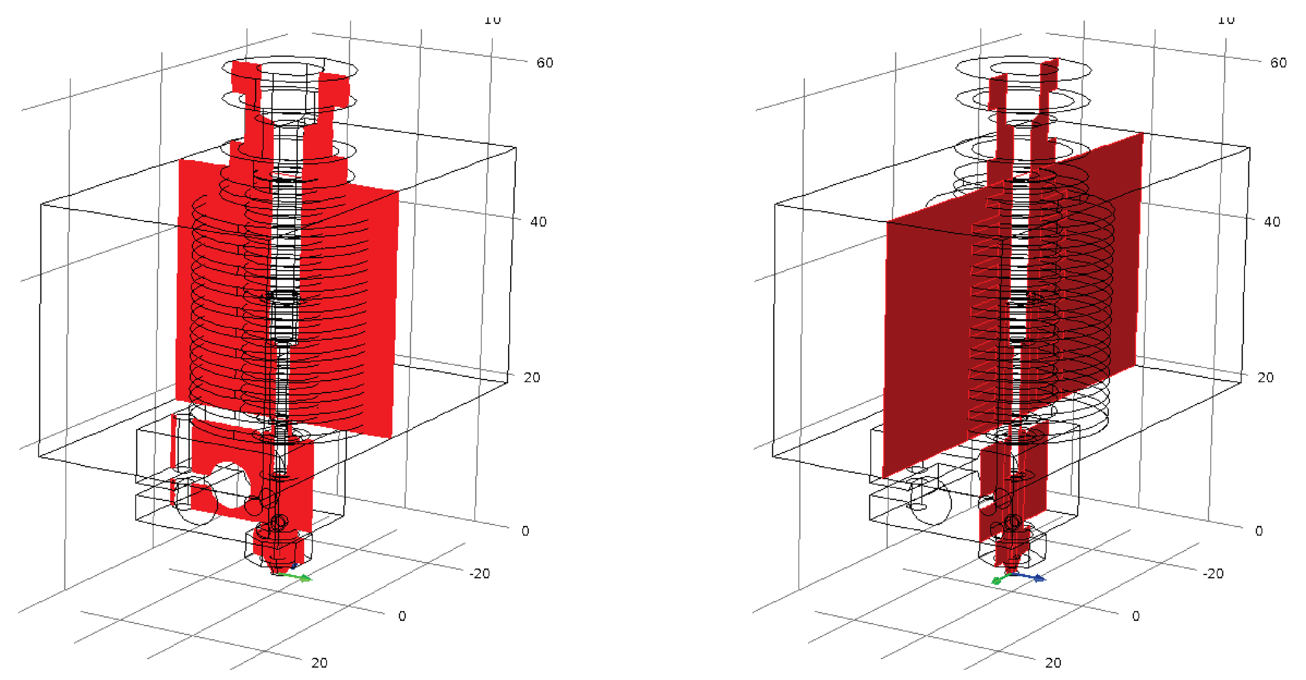

Figure 2. COMSOL geometry for the extruder and fan

Results: The simulations show a temperature gradient and the functionality of the heatbreak. Temperature and pressure have major influence on the flow inside the nozzle. The temperature reaches a stationary value before 600s, fluid flow before 2s. The polymer outflow is approximately quadratically dependent on the pressure difference.

Experiments could conclude a total heat transfer coefficient of 15W/(m²K).

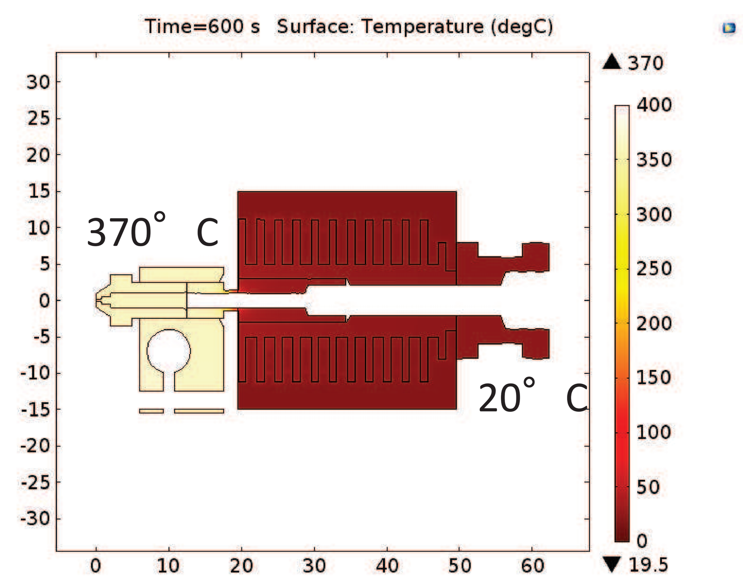

Figure 3. Heat distribution with 25 W heating

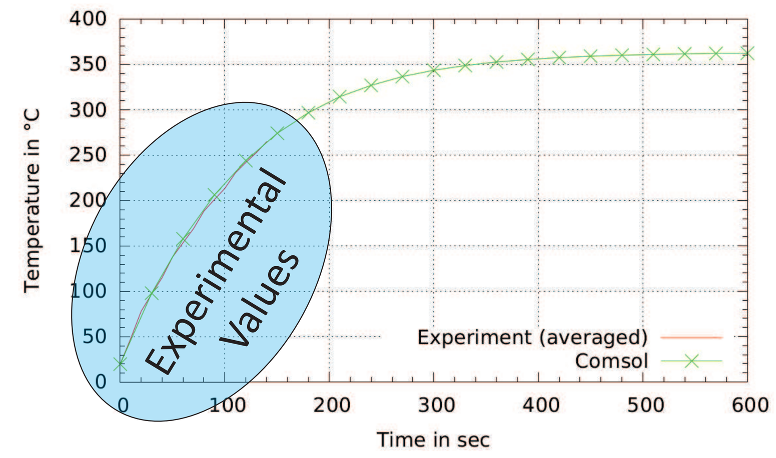

Figure 4. Heating process at suitable heat flux of 15 W/(m²K)

Variable	Values	Units
Heating	15, 25	W
Overall heat transfer coefficient	10, 15, 20, 25, 30	W(m²K)
Pressure difference	3 to 12	atm
Nozzle diameter	250, 350, 400	µm

Table 1. Variations

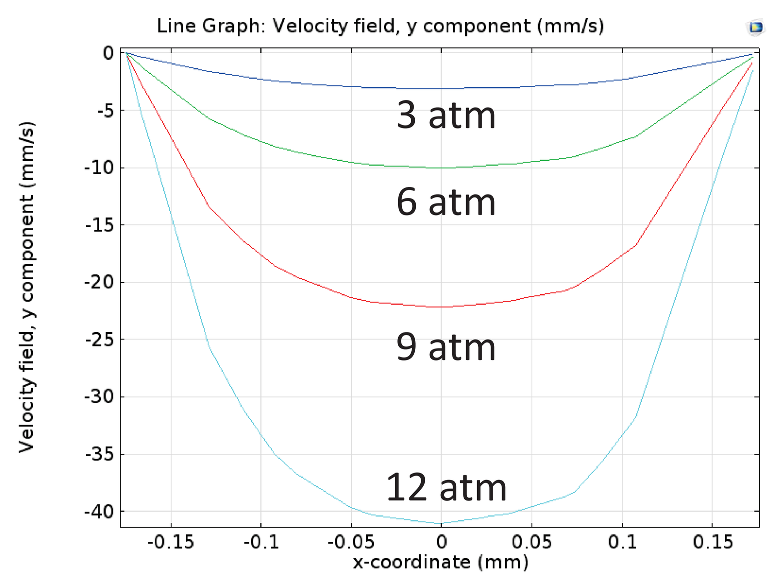

Figure 5. Fluid flow at pressure differences of 3 to 12 atm

Conclusions: Simulations show realistic behavior comparable to values stated in the manual. The nozzle is heated up to 231° C at 15 W(m²K) and 15 W heating. Fluid flow varies between 3.5 and 44.0 mm/s at the exit.
Properties are significantly influenced by the nozzle diameter, temperature and pressure difference. Heat distribution shows a characteristic gradient from the nozzle tip to the heatsink from 230° C to room temperature. The temperature gradient has a large change in the heatsink causing the polymer to melt quickly and prevent polymer degradation. Fluid flow is controlled by a pressure difference between the inlet and outlet causing a characteristic parabolic velocity distribution.
Fluid velocity is quadratically depending on the pressure difference between inlet and outlet which can be expected due to the quadratic dependence of the surface area and Bernoulli equation.

References:

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