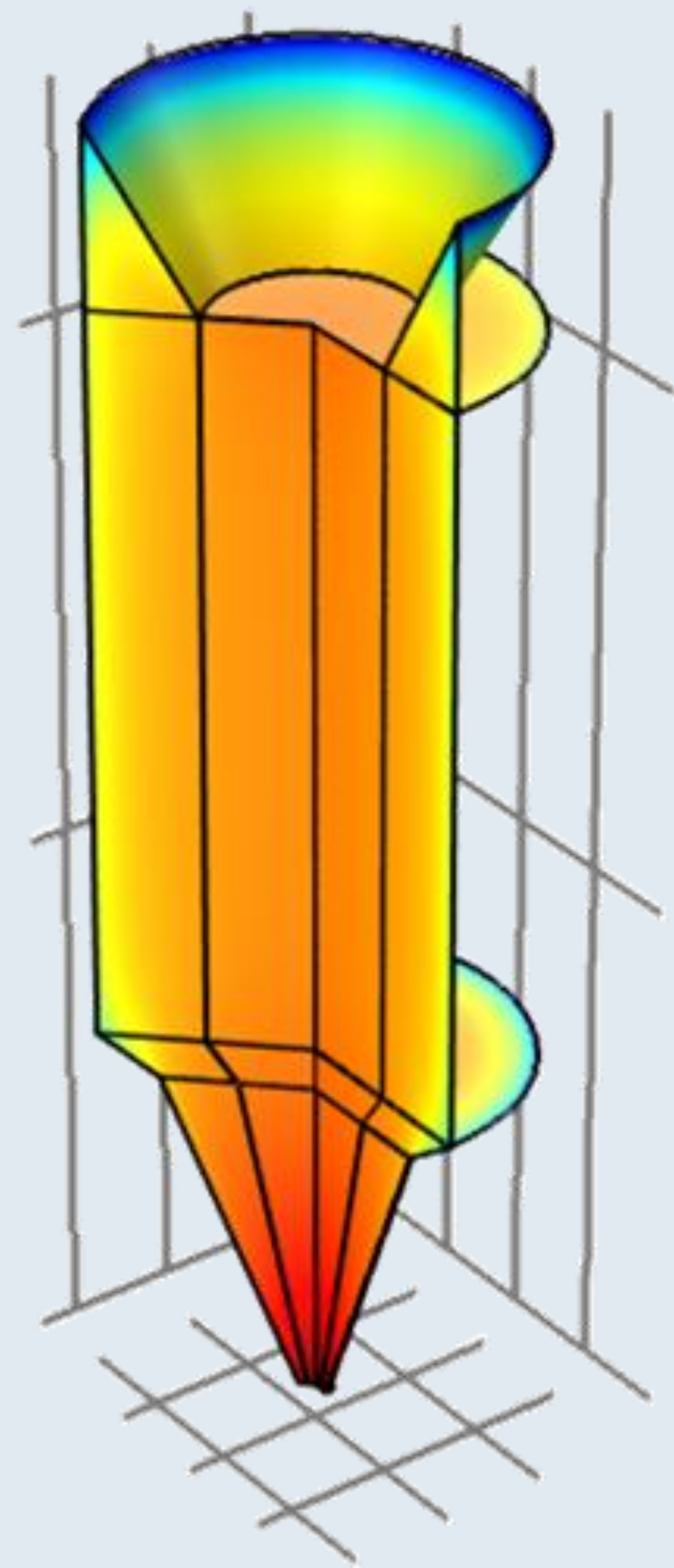




Velocity profile of gelled emulsions in a syringe.

Computational and Rheological Analysis of Gelled Emulsions for 3D Food Printing Applications

Computational Fluid Dynamics (CFD) to investigate the extrusion behavior of various gelled emulsions formulations within a 3D printing system.

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Abstract

Three-dimensional (3D) printing has emerged as a promising technology to produce customized foods tailored to individual sensory preferences and nutritional requirements (Meigui, et al., 2021). Gelled emulsions are particularly attractive as food bioinks due to their soft solid structure and rheological properties. However, the extrusion process subjects the material to high deformation, potentially altering its structure and viscous behavior. In this context, Computational Fluid Dynamics (CFD) is a valuable tool for investigating how processing

parameters affect velocity distribution, local shear rates, and extrusion pressure requirements (Wagner et al., 2025). Nevertheless, modeling these systems remains challenging due to the non-Newtonian nature of food materials (Abbaoui, et al., 2024). Despite these challenges, CFD can provide valuable insights for optimizing processing conditions and extrusion geometries, thereby supporting the development of more efficient and controlled 3D food printing processes.

P: Pea protein (20% w/w) + sunflower oil (10% w/w)

PG: P + Guar gum (G) (1% w/w)

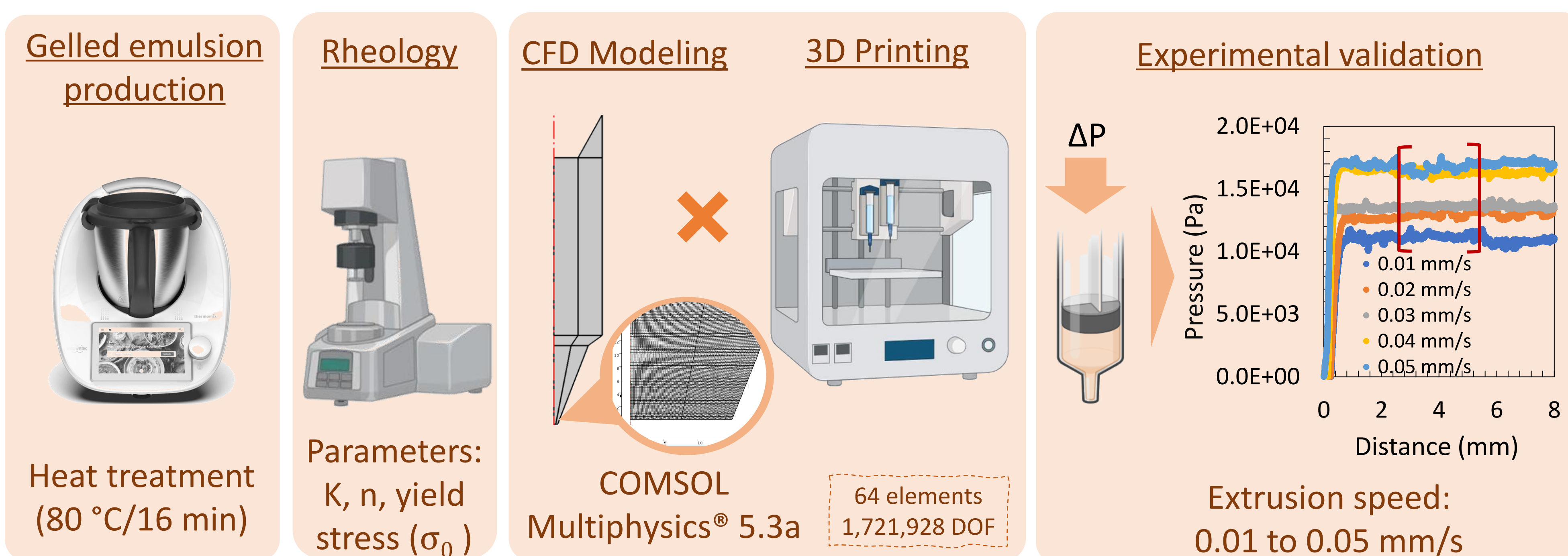


FIGURE 1. Methodology: gelled emulsion production, characterization, CFD modeling and experimental validation.

Results

The rheological behavior (apparent viscosity η_{ap} ; consistency coefficient K ; behavior index n ; yield stress σ_0) was incorporated into the CFD model, varying the mass flow rate (and consequently, the shear rates $\dot{\gamma}$) (Equation 1). Guar gum increased K and η_{ap} (Figure 2), while its greater structural breakdown and lower recovery resulted in more printing defects (Figure 3). Experimental and simulated pressure drops were compared for model validation (Figure 4), followed by sensitivity analysis to assess the contribution of each parameter to pressure drop (Figure 5). Shear rate and velocity profiles within the syringe were also evaluated (Figure 6).

$$\eta_{ap} = \frac{\sigma_0 (1 - e^{-\alpha(\max(0.01, \dot{\gamma}))})}{\max(0.01, \dot{\gamma})} + k \cdot \max(0.01, \dot{\gamma})^{n-1} \quad (\text{Equation 1})$$

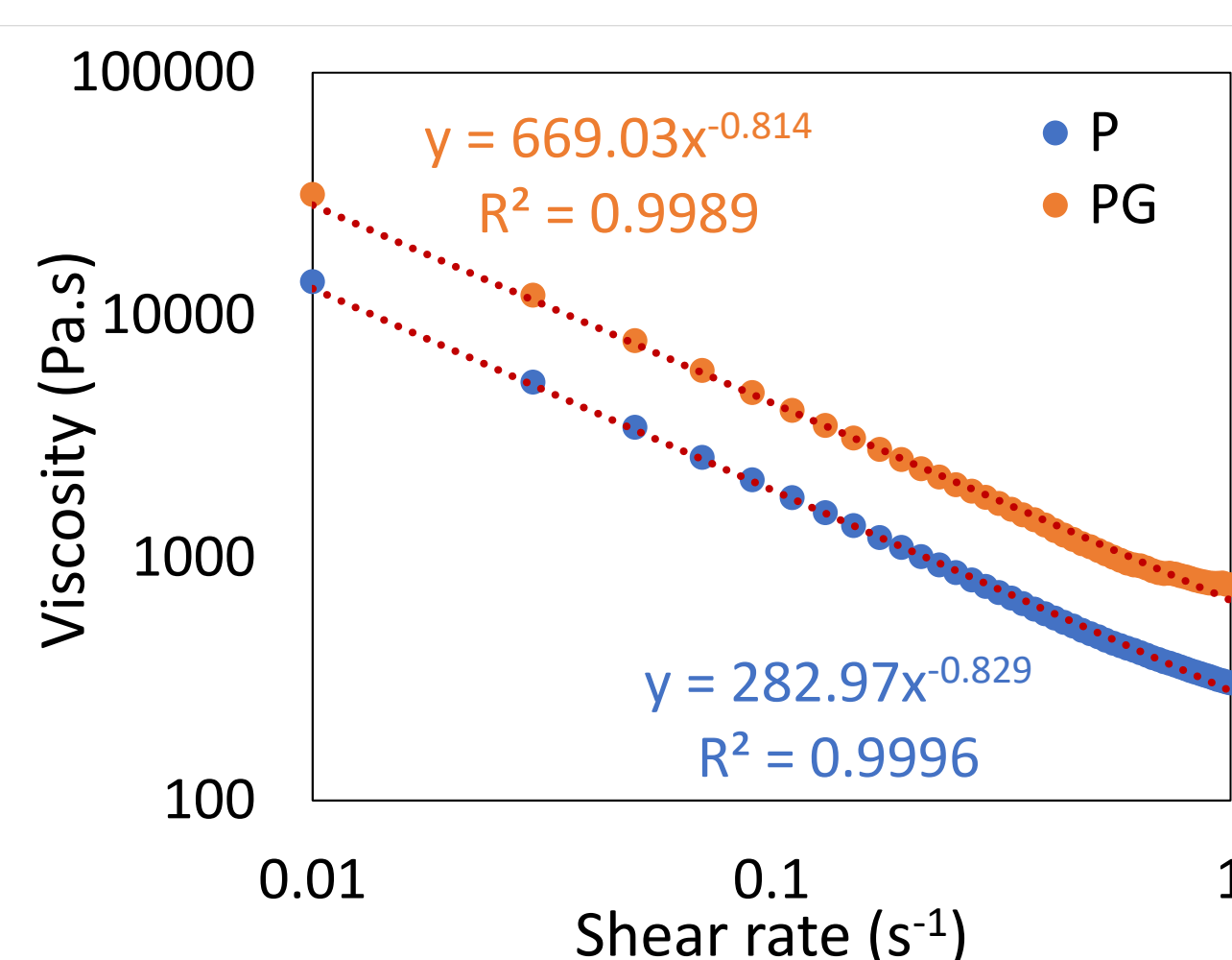


FIGURE 2. Flow curves.

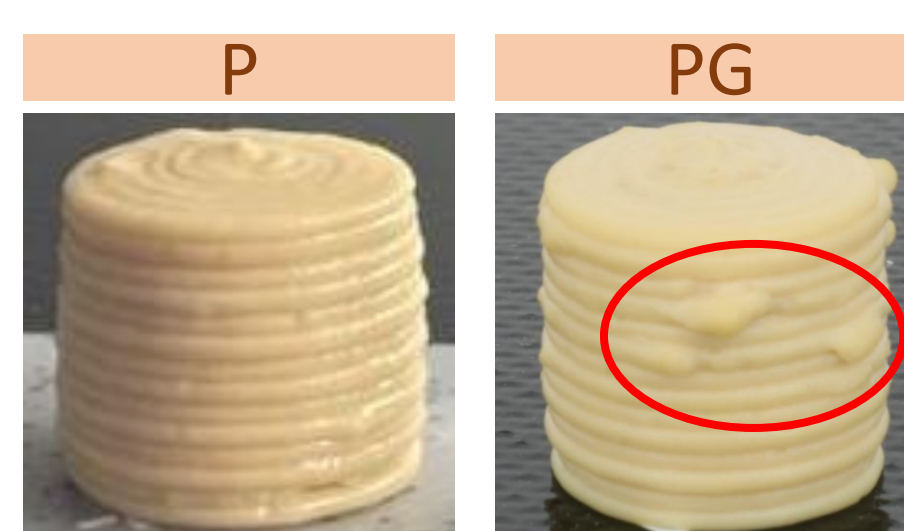


FIGURE 3. Printing quality P and PG in 0.01 mm/s.

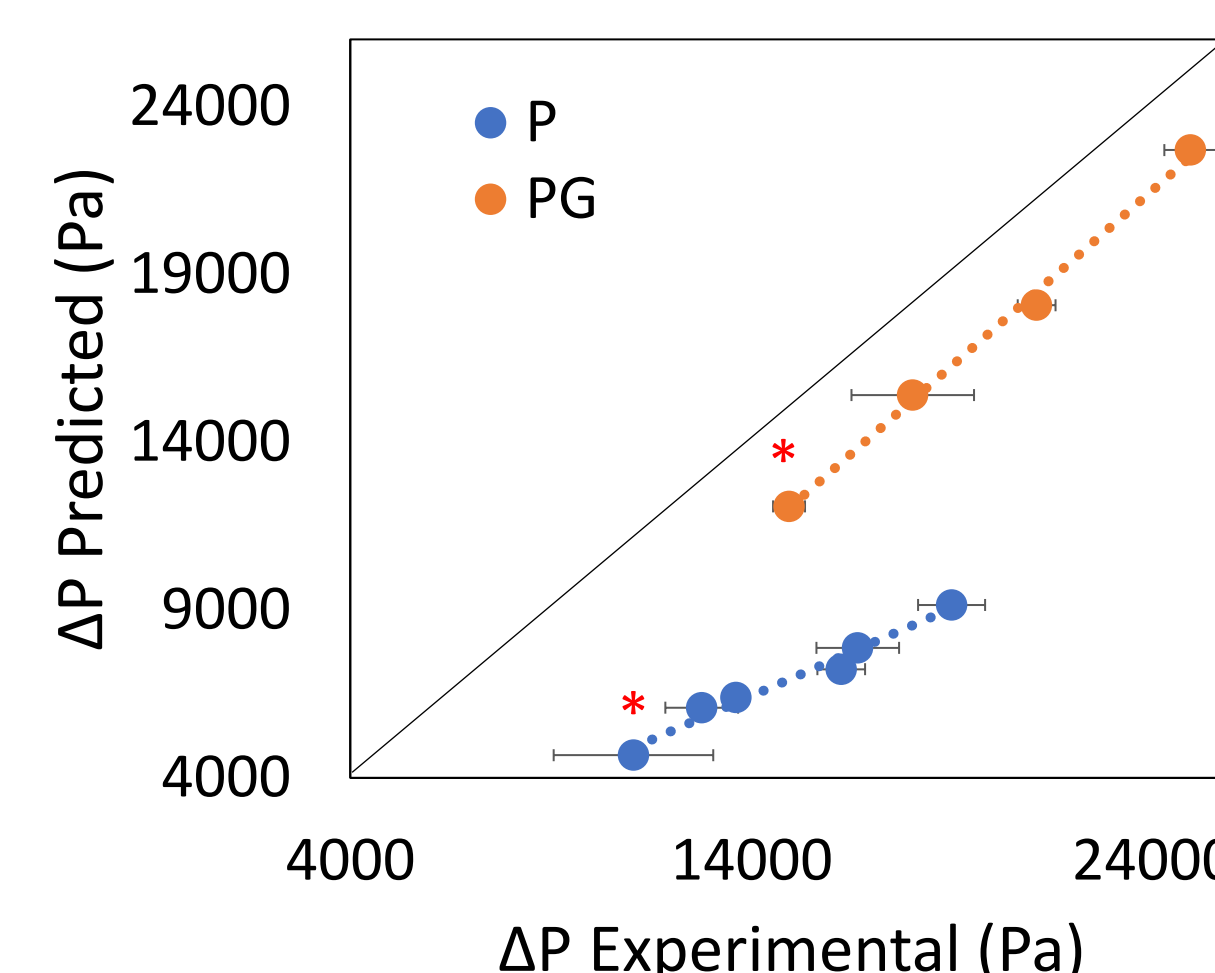


FIGURE 4. ΔP observed vs. simulated.

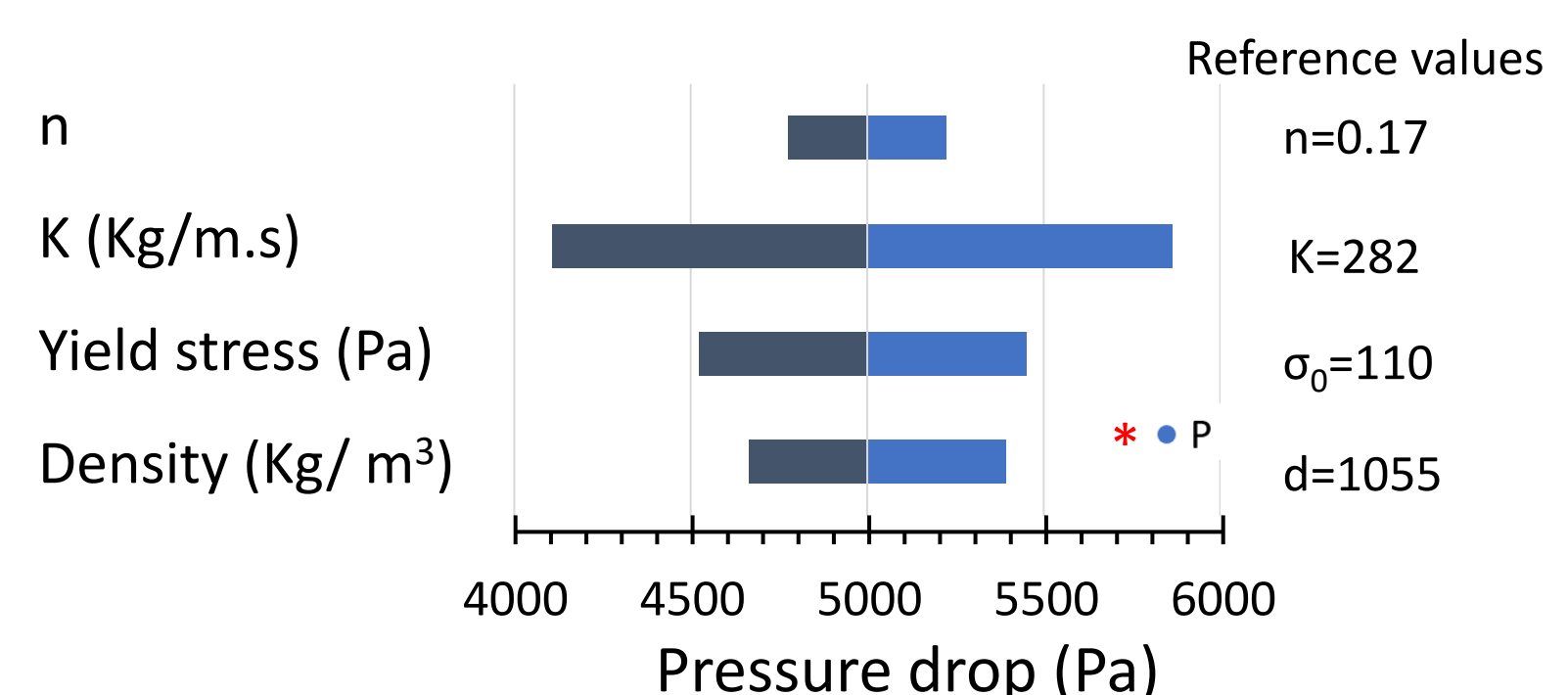


FIGURE 5. Sensibility test varying parameters in 25%.

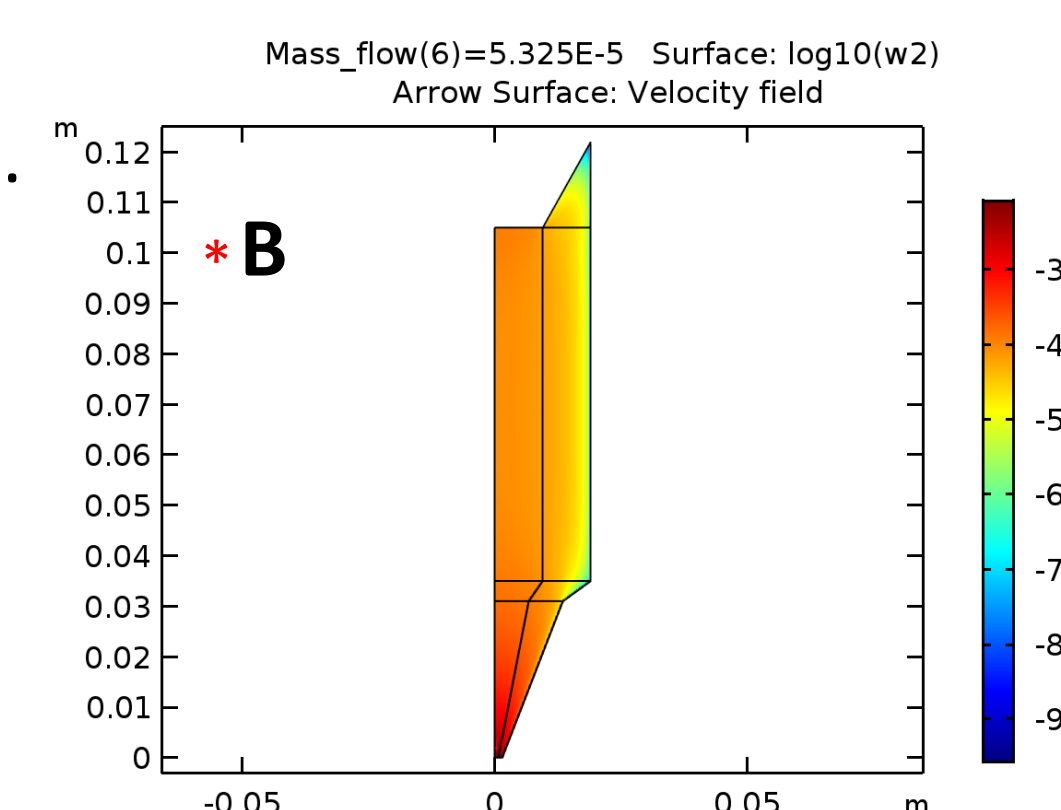
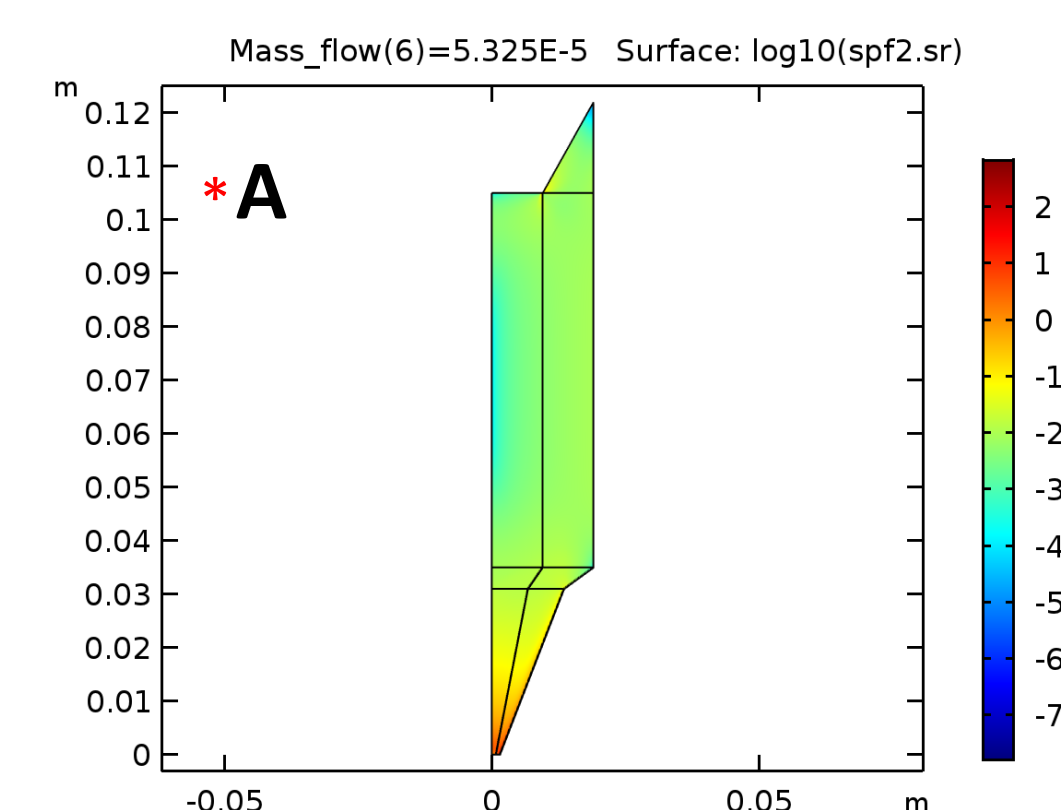


FIGURE 6. Shear rate (A) and velocity profile (B) of P and PG.

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