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Numerical analysis of high viscous non-Newtonian fluid flow using the MPS method

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Introduction

Behavior of high viscous non-Newtonian fluid flow is analyzed using the MPS (Moving Particle Simulation) method [1]. The power-law model is used as the constitutive equation of a non-Newtonian fluid in the MPS method. Furthermore, the gravity and the viscous terms in the momentum equation are implicitly solved high viscous fluid model. With this model, we compared the behavior of Newtonian fluid in the shear flow field.

Calculation method

In this study, purely viscous non-Newtonian flow was assumed. The equations of continuity and motion are written as

$$\nabla \cdot \mathbf{u} = 0 \tag{1}$$

$$\rho \frac{D\mathbf{u}}{Dt} = -\nabla p + \eta \nabla^2 \mathbf{u} + \rho\, \mathbf{g} \tag{2}$$

where **u** is the velocity vector, ρ is the density, t is the time, p is the pressure, η is the shear viscosity and **g** is the gravity vector. The Power-law model was used as the constitutive equation of a non-Newtonian fluid. The Power-law model and shear rate $\dot{\gamma}$ are written as

$$\eta = \eta_0 \dot{\gamma}^{n-1} \tag{3}$$

$$\dot{\gamma} = \sqrt{\mathbf{D} : \mathbf{D}} \tag{4}$$

$$\mathbf{D} = \frac{1}{2}\left\{\langle \nabla \mathbf{u} \rangle + \langle \nabla \mathbf{u}^t \rangle\right\} \tag{5}$$

where η_0 is the zero-shear viscosity, n is a Power-law index and **D** is the deformation tensor. MPS method, the differential operator vector ∇ of scalar quantities ϕ at particle i is given by weighted averaging as

$$\langle \nabla \phi \rangle_i = \frac{d}{n_0} \sum_{j \neq i} \frac{(\phi_j - \phi_i)}{|r_j - r_i|^2}(r_j - r_i) w_{ij} \tag{6}$$

Similarly, the laplacian operator ∇^2 is written as

$$\langle \nabla^2 \phi \rangle_i = \frac{2d}{\lambda n_0} \sum_{j \neq i} (\phi_j - \phi_i) w_{ij} \tag{7}$$

where d is the number of spatial dimensions, n_0 is an initial particle number density, r_i and r_j are the positions of particles i and j, w_{ij} is the weight function and λ is parameter.

Calculation

Figure 1 shows shear viscosity η as a function of the shear rate $\dot{\gamma}$ for Power-law fluid 1 (n = 0.6), Power-law fluid 2 (n = 0.2) and Newton fluid (n = 1) at zero-shear viscosity $\eta_0 = 10\ \mathrm{Pa \cdot s}$ in the calculation model. Figure 2 shows the calculation model of plane Poiseuille flow. Figure 3 shows calculation results of plane Poiseuille flow at various elapsed times for each fluid. A Newtonian fluid (n = 1) flow the familiar parabolic profile as shown in Fig. 3. As the Power-law index n decreases, the velocity becomes more and more flattened in the center. From these results, good agreement is obtained the theoretical fluid behavior for each fluid.

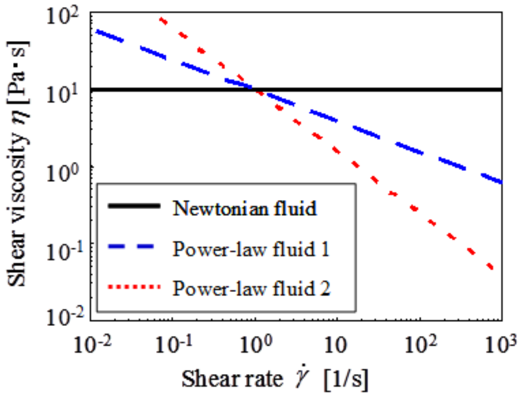

Fig. 1 Shear viscosity as a function of shear rate for each fluid.

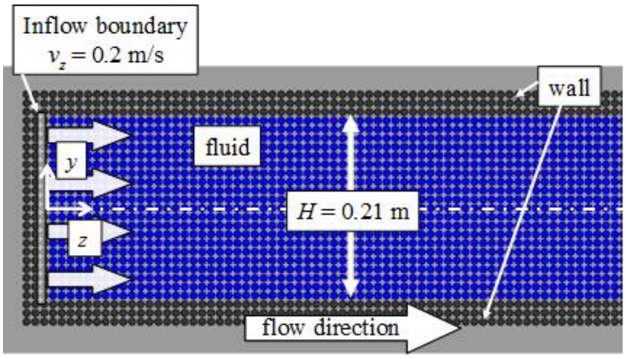

Fig. 2 Calculation model of plane Poiseuille flow.

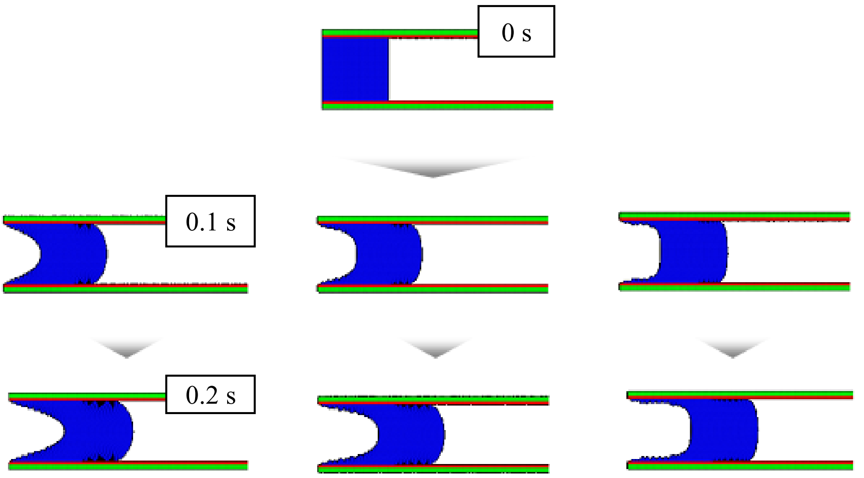

Fig. 3 Plane Poiseuille flow at various elapsed times for each fluid.

Conclusion

In this study, we discussed to predict the behavior of high viscous non-Newtonian fluid using the MPS method. The calculation results obtained are in good qualitative agreement with the behavior of non-Newtonian fluid.

References

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