Dynamic behavior of an Elastic Capsule in the Viscous Shear Flow

o Chanyi Song1, KAIST,
Dept. of Mechanical and Aerospace Engineering Systems, Daejeon, Republic of Korea,
songchanyi@kaist.ac.kr
Soo Jai Shin2, KAIST, soojai_shin@kaist.ac.kr
Hyung Jin Sung3, KAIST, hjsung@kaist.ac.kr
Keun-Shik Chang4, KAIST, kschang@kaist.ac.kr

The unsteady deformation of a two-dimensional elastic capsule in the viscous shear flows is investigated numerically. The capsule has the structure of a liquid enclosed by a deformable membrane. In this paper, the capsule is deformed without any translation in the simple and oscillating shear flows; then it is translated while deforming in the Couette flow. An immersed boundary method (IBM) is used to solve this fluid-structure interaction problem. Here the fluid shear force deforms the capsule in equilibrium with the membrane elasticity. It is studied the capsule deforming to a steady state through transition in the simple shear flow. In the oscillating shear flow, the capsule was deformed in a quasi-steady periodic pattern but had a phase lag. In the Couette flow, the capsule was deformed and simultaneously lifted up, presenting diverse trajectories depending on the membrane elasticity and Reynolds number.

1. Introduction

The purpose of the present study is to investigate the effect of interfacial elastic modulus on dynamic motions and flow induced transient deformation of elastic capsules under the shear flows. In this study, it is extended the capsule mechanics from the simple shear flow to the oscillating shear flow to look into the inertia effect in the unsteady flow. The capsules in the Couette flow are also included with a question how their trajectories differ depending on the fluid dynamic and structural parameters; Reynolds number (Re=0.05~40), the dimensionless shear rate(G=0.0005~0.05), and the oscillation frequency(f_f=0.2 and 1.0.).

2. Numerical Method

An immersed boundary method (IBM) has been used to solve the fluid-structure interaction problems[(1)]. The flow field is calculated in an Eulerian grid system by solving the Navier-Stokes equations that include the momentum forcing term from the structural part. In contrast, the capsule dynamics is determined by solving the structural equation of motion formulated in a Lagrangian coordinate, with uniform grid distributed on the membrane. The structural equation includes the momentum forcing term from the viscous shear flow. These equations are simultaneously solved at each time step to generate the flow-structure interaction.

3. Simple Shear Flow

It is used the Taylor deformation parameter(D_{xy}) to quantitatively measure the deformation of the capsule. The steady capsule is more deformed for higher G than lower G. It means that the capsule is more compliant to the viscous shear force if the elasticity is smaller. Higher Reynolds number also makes the capsule more deformed. D_{xy} oscillates before the shape of capsules reach the steady state. The transition time is shorter for lower Re. The inclination angle(θ) of capsule shows the oscillatory behavior of the transient capsule response and the steady state of the capsule. The results from the D_{xy} and θ, show the inertia effect. The tank-treading motion is shown in this calculation. The period T_m of tank-treading motion is increased with Re and G.

4 Oscillating Shear Flow

The high frequency flow allows less capsule deformation than the low-frequency flow does because the structural elasticity cannot respond fast enough to the oscillating fluid shear stress. For the lower frequency, the oscillating flow is slow enough for the elastic capsule to fully respond. The mean values of the quasi-steady D_{xy} are the same for the two frequencies even though the wave patterns are quite different. There is a phase difference between the driving oscillating flow and the motion of the responding elastic capsule with G. Also, the subharmonic patterns of D_{xy} are appeared.

5 Couette Flow

The elastic capsules move to downstream due to the flow. The time-dependent trajectory of the capsule affected by membrane elasticity and Reynolds number. The capsule with large elasticity moves faster than the capsule with small elasticity. Here the capsule speed is influenced by the lift force in the Couette flow because the closer to the upper wall, the faster the flow moves. Generally speaking, the lift force is proportional to the inclination angle for an elongated body. The different moving motion of the capsule due to membrane elasticity may be used for capsule separation.

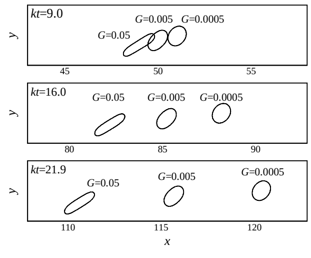

Fig. 1 The position of the capsules in Couette flow

Bibliography

(1) Huang, W.-X., Shin, S. J., and Sung, H. J., "Simulation of flexible filaments in a uniform flow by the immersed boundary method," J. Comput. Phys., 226 (2007), pp. 2206-2228.