Micro-objets déformables sous écoulement: Dynamique de vésicules et capsules

Gwenn Boëdec et Julien Deschamps

IRPHE
Institut de Recherche sur les Phénomènes Hors Équilibre

Aix-Marseille université
Centrale Marseille
Vesicles and capsules

Liquid droplet surrounded by a deformable membrane

Vesicles

Capsules

20 µm

50 µm
Encapsulation and vectorization

Protection, transport and release
Food industry, cosmetology, medical therapy…

Encapsulation of living cells within double emulsion droplets produced by flow focusing

Choi et al., Lab on Chip, 2016
Rheology of suspensions

Single object  Pair interaction  Collective motion, rheology

Lac et al, JFM, 2007

Doddi & Bagchi, PRE, 2009
Fahraeus-Lindqvist effect

Pries et al., American Journal of Physiology, 1992

Pries et al., American Journal of Physiology, 2005
Model system for red blood cells

Blood in vessels

RBC membrane constitution

Cytoskeleton
Spectrin network
Schematic view of RBC membrane

Byers et al., PNAS, 1985
Lipidic bilayer → vesicle

Spectrin network → polymeric capsule
Vesicle: model system for cells

Modelization of living cells behavior

Static equilibrium shapes

Bud formation of vesicle while subjected to elongation flow

Seifert, Advances in physics, 1997

Kantsler et al., 2005

Cell free layer, Margination

Grandchamp, PRL, 2013

Shapes and migration in Poiseuille flow

Self diffusion of RBC jet

Tahiri et al., Microvascular research, 2013
Lecture 1: Basic notions, modelization

Fluid and flow descriptions
Interfacial mechanics for vesicles and capsules
Coupling conditions

How to describe such complex system?
Lecture 2: Dynamics of vesicles and capsules in unbounded shear flow

Keller Skalak Model → tumbling and tank-treading dynamics

Single object in shear flow

Keller Skalak model
Lecture 2: Dynamics of vesicles and capsules in unbounded shear flow

Real phase diagram for vesicles

Phase diagram for vesicles
Lecture 2: Dynamics of vesicles and capsules in unbounded shear flow

Real phase diagram for capsules

Phase diagram of an elastic capsule in shear flow with the tumbling and tank-treading regimes as a function of the viscosity contrast $\epsilon$ and the inverse dimensionless shear rate $\chi^{-1}$. These solid lines guide the eyes separating the tank-treading (circles), tumbling (crosses) and transient region (diamonds) for our simulation. Dashed lines indicate the phase diagram due to Skotheim & Secomb (2007) for the same parameter set. In the region between the dashed lines intermittent motion is predicted. We have not found conclusive evidence for this kind of motion, but rather found transient dynamics from tumbling to tank-treading. The numbers correspond to following figures, where parts of the phase diagram are examined closer.

Geometrical parameters: $a_2 = a_3 = 0.9a_1$, elastic parameters: $\nu = 0.333$, $\tilde{\kappa} = 0.01$, $\tilde{C}_0 = 1$.

Nevertheless high-order modes accumulate numerical errors during the simulation run, in particular at large shear rates, thereby limiting the maximum simulation time.

Phase diagram

Our numerical results for the overall phase diagram are summarized in figure 4, where the dynamical behaviour is plotted as a function of the inverse dimensionless shear rate $\chi^{-1}$ and the viscosity contrast $\epsilon$. At low shear rates, the hydrodynamic forces are too small to overcome the energy barrier present for a tank-treading motion due to the shape memory effect. Therefore, capsules tumble at low $\chi$, while an oscillating tank-treading behaviour is stable at large $\chi$. We also observe transient dynamics from tumbling to tank-treading for large viscosity contrast $\epsilon$, which will be discussed below. Although this transient dynamics might be taken as an indication of intermittent motion, we could not find conclusive evidence during the time of our simulation runs. In particular, we never observed a transition from tank-treading to tumbling. Also shown in this figure is the phase diagram for the analytic model by Skotheim & Secomb (2007). The qualitative agreement, apart from the apparent lack of intermittent behaviour, seems to be rather good, given the crude dynamics implemented in the reduced analytical model. Only at large viscosity contrast do pronounced differences in the shape of the phase diagram start to feature. Closer inspection of the data reveals significant oscillations of the axis lengths, which are fixed.

Kessler et al., JFM, 2008

Phase diagram for capsules

Tumbling

Intermittent

Tank-treading

Fig. 6(d)

Fig. 6(b)

Fig. 6(a)

Fig. 6(c)

Transitent
Lecture 3: Lift velocity and pearling instability

Vesicle/capsule dynamics near a plane wall

Lift of a vesicle with gravity

Abkarian et al., PRL, 2002
Lecture 3: Lift velocity and pearling instability

Tubular vesicle pearling instability

Pearling instability
Destabilization of a tubular vesicle
