Electronic Supplementary Material (ESI) for Nanoscale

Electronic Supplementary Information II for:

Dynamics of catalytic tubular microjet engines: dependence on geometry and chemical environment

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1. Calculation of the Reynolds number of microjet moving in the solution

For an object moving in fluid with a velocity of v, the Reynolds number, which is the ratio of the inertial forces to the viscous forces, is given by $Re=\rho vD/\mu$, where D is the dimension of the object, ρ and μ are the density and viscosity of the fluid respectively. In our case, we use ρ=1000 kg/m^3 and $\mu=1\times10^{-3}$ Pa·s for H_2O_2 solution with relatively low concentration. For a moving microtubular jet with a diameter of 10 μm in the H_2O_2 solution, we found that the velocity of microjet is normally less than 2 mm/s. Correspondingly, the Reynolds number can be estimated as $Re=\rho vD/\mu$=0.02, which means the catalytic motion of our microjet is at very low Reynolds number.

2. Estimation of the displacement of the microjet and the bubble after separation

After the separation of the microjet and the expelled bubble (t=t′), the microjet acquires an initial velocity of v_j(t′). From now on, the frictional force (F_{jet}) is the only force applied to the microjet, which decelerates the microjet motion. According to the Newton's second law we have

$$\frac{d^2 s_j(t)}{dt^2} = F_{jet}/m = -\frac{2\pi\mu L}{(\ln(\frac{2L}{R_j}) - 0.72)m} \cdot \frac{ds_j(t)}{dt}$$

where m is the mass of the microjet, $s_j(t)$the moving distance after the separation. Corresponding boundary conditions are:

$$s_j(t') = 0; \left.\frac{ds_j(t)}{dt}\right|_{t=t'} = v_j(t').$$

The initial velocity at separation $v_j(t')$ is estimated to be 1 mm/s according to our experiment, and therefore, for a microjet composed of Ti/Co/Pt (15/15/5 nm in thickness) with a length of 100 μm and a diameter of 10 μm, the solution of the Newton's second law is:

$$s_j(t) = 1\times10^{-9} - 1\times10^{-9}\cdot e^{-9.2\times10^4\cdot(t-t')}.$$

From our microscopy observation, we know that the moving time after separation can last tens of microseconds until velocity decrease to 0, which suggests that the moving distance of the microjet after separation is less than 1 nm.

As for the moving distance of the bubble after separation, similar estimation method can also be engaged except for different form of drag force: $F_{bubble} = -6\pi\mu R_b v_b(t)$. For a bubble with a diameter of 10 μm and a initial velocity at separation of 1 mm/s, the moving distance $s_b(t)$ after separation can also be estimated as

$$s_b(t) = 7\times10^{-11} - 7\times10^{-11}\cdot e^{-1.4\times10^7\cdot(t-t')},$$

which means that the movement of the bubble after separation is far more less than 1 nm. Thus we can reach the conclusion that the displacement of the microjet and the bubble after the separation can be neglected.

3. Example of experimental velocity calculation

The velocity of the microjet during catalytic motion can be estimated by tracking the trajectories of microjets recorded in the video. Each experimental velocity value represents the average of the velocities for 5 microjets taken over a certain time interval. For example, the video in Supporting

Information I shows the trace of a microjet over the course of 2 s. The accumulated distance is 950 μm by measuring the still images captured from the video and thus the velocity is calculated to be 475 μm/s.