P1_7 Medical Nanobot Locomotion Methods within a Fluid

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Abstract

The following paper discusses the motion and mechanisms behind the motion of a nanoscale robot within a fluid and compares it to that of a larger object moving through the same fluid by considering the impeding forces to motion that the nanobot has to overcome. The fluid considered is water in which it is found that the apparent viscosity of a fluid is highly dependent on the length scale of the object attempting to move through it. This leads to a nanoscale object experiencing a much larger viscosity compared to a macro scale object in the same fluid.

A Nano-Doctor's Commute

With the advances in technology, nanobots (autonomous robotic devices on the nanoscale) are becoming more and more a reality with increased research into areas including medical nanobots. Medical nanobots are a special type of nanobot that concern the idea of being able to use a nano-scale machine acting as an *in vivo* robotic doctor. This nano-doctor would not only be capable of diagnosing an illness, but also being able to travel to the source of the problem and make the delivery of drugs in a small but much largely effective dose compared to the macro scale world around us.

At this current point in our technological era, there are several issues that are yet to be overcome with designing and creating a medical nanobot that can act in such a way described above. However, one area that can be considered theoretically without so much issue is how a medical nanobot can move about a fluid and whether a similar motion to that of a human swimming within water (or even a propeller on a ship) would be a suitable method of locomotion through water at the nanoscale.

Moving through a Fluid

To consider the methods of propulsion through a fluid at the nano-scale, first need to understand propulsion methods in the macro world. When a person swims through water, there motion forward throughout the fluid is largely due to overcoming the inertia of the fluid, that is, the resistance of the fluid being put into motion. Now, consider a person swimming through, say treacle, suddenly propelling oneself becomes more difficult as a much larger amount of energy would be required to move through the fluid since the treacle is much more viscous. To understand the effects on motion of an object immersed with a more viscous fluid, we consider the forces acting on the object as it attempts to propel itself through the fluid. By considering the transfer of momentum between the object and fluid, the inertial impeding forces, $F_{inertial}$, can be shown to be [1];

$$F_{inertial} \propto \rho a^2 v^2, \quad (1)$$

where, ρ is the density of the fluid, a is the size of the object (radius of spherical object) or length scale, and, v is the objects speed. By considering the rate at which adjacent layers of a fluid are forced to move over each other, an equation for the viscous impeding forces, F_η [1] has the form;

$$F_\eta \propto \eta a v, \quad (2)$$

where, η is the viscosity of the fluid. By dividing Eq. 1 by Eq. 2, a quantity called the Reynolds number, Re, is discovered;

$$Re = \frac{av\rho}{\eta}, \quad (3)$$

where all symbols have the same definitions as above. The Reynolds number is an important ratio within fluid mechanics as it helps us to describe which of the two impeding forces of motion through a fluid, inertial and viscous, have a greater effect on an objects motion. If the Reynolds number is large ($Re \gg 1$), inertial force dominates; if the

Reynolds number is small ($Re \ll 1$), viscosity force dominates motion of an object in the fluid. The Reynolds number also allows us to consider a stationary or flowing fluid, as it is the same regardless of each type of flow.

Water isn't Viscous. Or is it?

By using Eq. 3 it can be determined which impeding force has a larger effect on a nanoscale object's motion through a fluid. This is done by comparing the Reynolds number of a human through water to that of a bacterium (a largely considered nanobot-like object [2]) through water, leading to the consideration of objects at different length scales, a.

Using the viscosity of water as 8.9x10^{-4} Nsm^{-2} and velocity of human motion to be 1 ms^{-1} and bacterium motion to be 5x10^{-5} ms^{-1}, and finally the human and bacterium sizes are taken to be, 0.5 m and 10^{-6}m respectively [2]. These values give us a Reynolds number at the macro scale (human through water) of Re_{macro}~5.6x10^{5} and at the bacterium (nano) scale of Re_{nano}~5.6x10^{-5} (both using a density of water equal to 1000 kgm^{-3}). This results in a staggering difference of 10 orders of magnitudes apart for the macro and nanoscale sizes.

Since Re_{nano} is much smaller than one, this tells us that it is mainly the impedance force of viscosity that has a much larger affect on bacterium (our pseudo-nanobot) motion compared to the inertial force. Leading on from this knowledge, it can also be deduced that, for objects with a size on the nanoscale, water has a very high apparent viscosity.

Alternative Method of Swimming in High-Viscosity Situations

Now that it has been concluded that an object with a size on the order of nanometres will have a very tough journey throughout a fluid such as water due to experiencing a higher viscosity compared to a much larger object, an alternate method of locomotion (providing more energy) is certainly required.

Using a bacterium again as our pseudo-nanobot, an alternate method to moving through a "non-viscous fluid" (in reality all fluids are viscous) at the nanoscale can be suggested, that is, flagella. Flagella are corkscrew like attachments that biological systems have developed over millions of years of evolution to overcome this high-viscosity problem. They move in a rotational motion that allows them to smoothly move throughout a high-viscosity fluid with an incredibly high efficiency. Researchers from the Micro/Nanophysics Research Laboratory at Australia's Monash University have even managed to design man-made flagella in the form of a piezoelectric ultrasonic resonant motor [3] that works in the same way to move a nano/micro scale object through a fluid.

Conclusion

It has been deduced that even though some fluids may not be very viscous in regards to the motion of a macro scale object (Re_{macro}~5.6x10^{5} for a human through water), the apparent viscosity of the fluid is very sensitive to the size scale of the object (Re_{nano}~5.6x10^{-5} for a bacterium through water) and thus alternative means of motion is required at smaller (nano) scales. Thus, when designing a nanobot for use within a body, careful decisions in regard to the methodology of locomotion of the nanobot is required or else the risk of a nanobot becoming "stuck" or "exhausted" is entirely possible.

References

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