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Stokes flow around a rolling cylinder

Extended abstract

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Micropumps are a necessary device for microfluidics. Many solutions are possible and technical devices are numerous. In this paper, we have developed an analytical solution for the peristaltic technique in microchannels that enlighten some physical limitations. We have then compared this solution to a numerical one that also provides results when no theoretical results were found. The squeezing of the wall, in the peristaltic technique, is represented by the corner formed by a rolling cylinder on a wall (cf. fig.1).

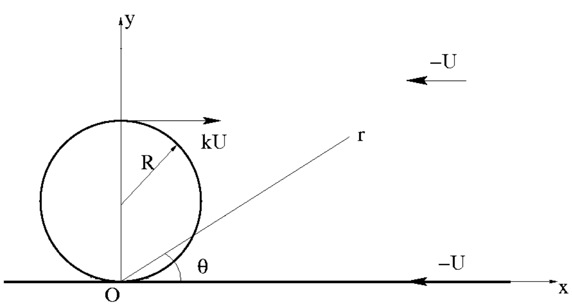

Figure 1: Notations: r, θ are the polar coordinates; R is the radius of the cylinder; $-U$ the upstream velocity; k the ratio between the linear velocity on the cylinder and U

An analytical solution of the Stokes flow has been formulated when the contact is perfect between the wall and the cylinder. This leads us to find :

$$\psi = -\frac{U \sin\theta}{r}(r - 2R\sin\theta)\left[r - 2(1+k)R\sin\theta\right]$$

Numerical and analytical results are highly correlated and, for the case k=1 (same translation velocity for the cylinder and the wall), the streamlines show a vortex above the cylinder:

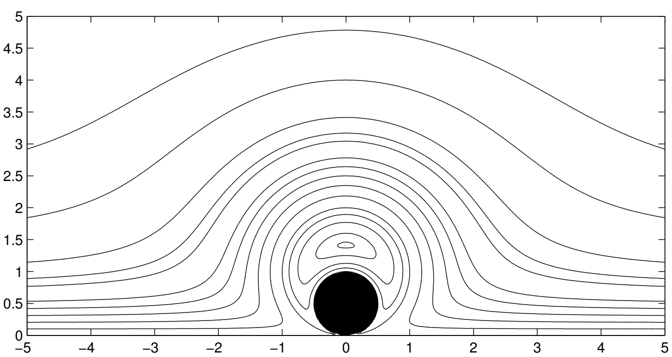

Figure 2: Streamlines for k=1: non slip condition at the contact point

It has been shown that, in this case, cavitation or compressibility effects are produced necessarily downstream the contact point. In the case of a liquid, the cavitation has been observed experimentally by Seddon and Mullin [1]. Numerical simulation leads to the same results and allows the study of the influence of a gap between the wall and the cylinder. A plot of the pressure applied in the gap for different size of interstice (h/R) shows the drop-off of the pressure as the interstice size increases.

This figure depicts that compressibility or cavitation may appear in a zone where pressure tends to non physical values, leading to a lift that separates the cylinder from the wall, regardless of its weight, until these effects are suppressed. This phenomenon clearly has many consequences in a wide range of applications in microfluidics since it establishes, for example, that peristaltic micropumps must necessarily have leaks or generate bubbles ...

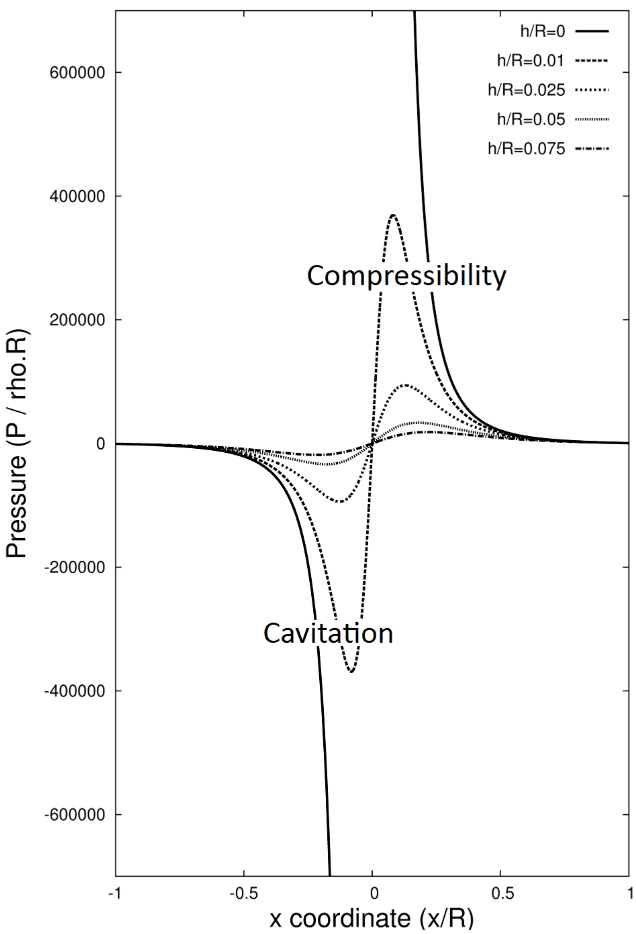

Figure 3: Maximum and minimum dimensionless pressure as a function of the size of the interstice

References

[1] James R. T. Seddon and Tom Mullin, *Reverse rotation of a cylinder near a wall.* PHYSICS OF FLUIDS, Volume 18, 2006.