Taylor Instability

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The Taylor instability is a secondary flow which occurs as a transition from rotary Couette Flow in the annular gap between two coaxial cylinders of differing diameter when the inner cylinder rotates faster than a critical value. Pairs of counter-rotating axisymmetric (toroidal) vortices are formed in the radial and axial directions while the principal flow continues to be around the azimuth (Figure 1.).

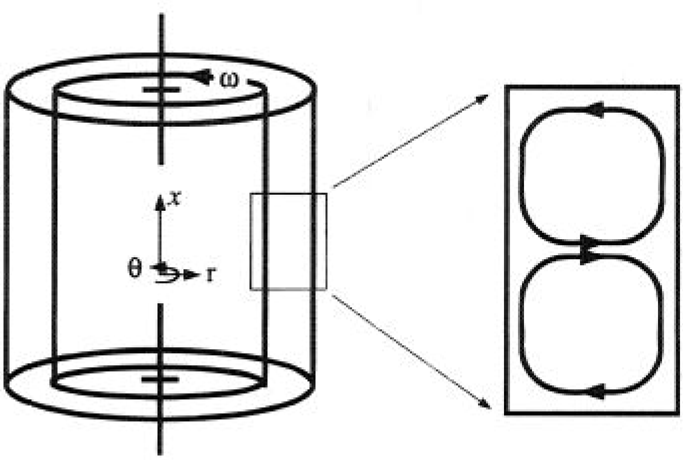

Figure 1. Coaxial cylinder geometry with exploded view of Taylor vortices.

The onset of vortices has been studied experimentally by observing the consequences of their motion: namely to increase the wall shear stress (torque), the rate of heat transfer and the rate of mixing within the fluid. Vortices are generated if the Taylor Number, $Ta = r_i(\rho\omega/\eta)^2(r_o - r_i)^3$ exceeds a critical value, Ta_c, where r_i and r_o are the inner and outer radii, respectively, ρ is the fluid density, η the viscosity and ω the rotational speed. The limiting case, $r_i/r_o \to 1$, was solved theoretically by Taylor to yield $Ta_{c,(r_i/r_o \to 1)}=1695$. For long annuli having a small annular gap, $r_i/r_o \gtrsim 0.8$, the critical Taylor number may be approximated by $Ta_c = \pi^4(1 + r_o/r_i)^2/(4P)$ with $P = 0.0571(1 - 0.652(r_o/r_i - 1)) + 0.00056/(1 - 0.652(r_o/r_i - 1))$.

A multitude of higher order instabilities which are non-axisymmetric and time periodic, occur if the Taylor number is increased further. Superimposed Poiseuille Flow, described by a Reynolds Number $Re = 2\rho u(r_o - r_i)/\eta$, delays the Taylor instability. Rotation reduces the Reynolds number for transition from laminar to turbulent flow and the combined system is described by a regime map (Figure 2).

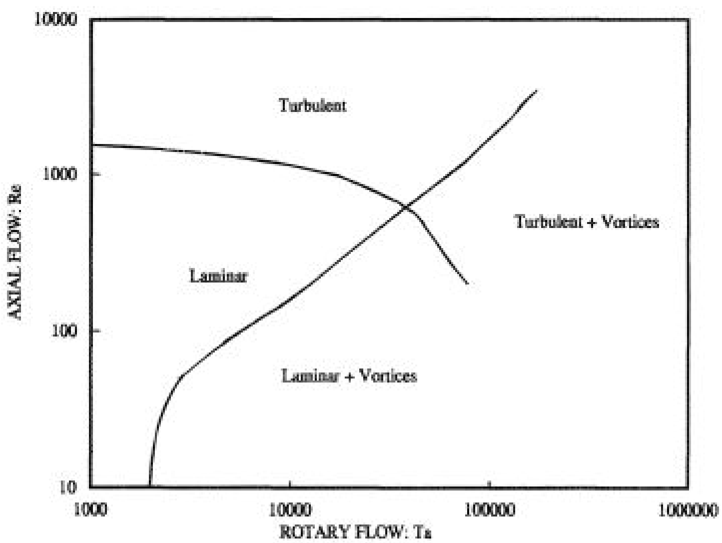

Figure 2. Regime map for Taylor vortices in the presence of an axial flow.

Positioning the axis of the inner cylinder a distance, δ, from the axis of the outer cylinder produces an eccentric annulus and causes the Taylor instability to be delayed by an amount dependent on the eccentricity, $\varepsilon = \delta/(r_o - r_i)$ and given by $Ta_c(\varepsilon) = Ta_c(1 + 2.6185\varepsilon^2 + O(\varepsilon^4))$.

The critical Taylor number is also modified by Non-Newtonian Fluid behavior. The theoretical analysis for a Generalized Newtonian fluid characterized by $\beta = \frac{d\ln(\eta/\eta_o)}{d\ln(\dot{\gamma}/\dot{\gamma}_o)}$ is discussed in Tanner (1985) and the onset of Taylor vortices given by $Ta_c(\beta) = Ta_c(l + 0.505\beta + O(\beta^2))$ for $r_i/r_o \to 1$. The viscosity used in defining the Taylor number for non-Newtonian fluids is $\eta = \eta(\dot{\gamma})$; $\dot{\gamma} = \omega r_i/(r_o - r_i)$.

References

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