Supporting Text - Estimate of the drag force.

The drag force at a given point under the rotating object was calculated as

$$\tau = \frac{\mu \cdot r \cdot \omega}{h}, \qquad [1]$$

where r is the distance from center of rotation, h is the width of the gap between the object and the surface, μ is the viscosity of the solution (0.84 x 10^{-3} Pa·s), and ω is the rotational rate (2 rpm).

(i) *Drag force between a rotating circular rim and a track.*

The total drag torque T_1 is calculated by integrations with the area of the rim that faced the track.

$$T_1 = \int_0^{2\pi}\int_{R_1}^{R_2} r \cdot \left(\frac{\mu \cdot r \cdot \omega}{h}\right) \cdot r \cdot dr \cdot d\theta$$

$$= \frac{\pi \cdot \mu \cdot \omega \cdot (R_2^4 - R_1^4)}{2h}, \qquad [2]$$

where R_1 and R_2 represent the radii of the inner and outer edges of the rim, respectively. The calculated drag torque is 9 x 10^{-18} N·m, assuming that the gap between the rim and the track surface is 50 nm. The drag torque is 1.8 x 10^{-16} N·m for a 2.5-nm gap.

(ii) *Drag force between a rotating circular disk and a surface.*

The total drag torque between a rotating disk and a surface (T_2) is calculated by integration with the area of the disk.

$$T_2 = \frac{\pi \cdot \mu \cdot \omega \cdot R^4}{2h}, \qquad [3]$$

where R is the radius of the disk. The calculated total drag torque is 6 x 10^{-18} N·m for a 20-μm diameter rotor and a 500-nm gap between the rotor and the surface.