Liquid Film Motor

Kuan-Wei Hu (胡冠維), Kai-Chieh Ma (麻凱傑)

TA: Shao-Yu Huang (黃少瑜), Kuan-Nan Lin (林冠男), Li-Jie Xiao (蕭力捷)

Instructor: Yu-Jung Chen (陳俞融)

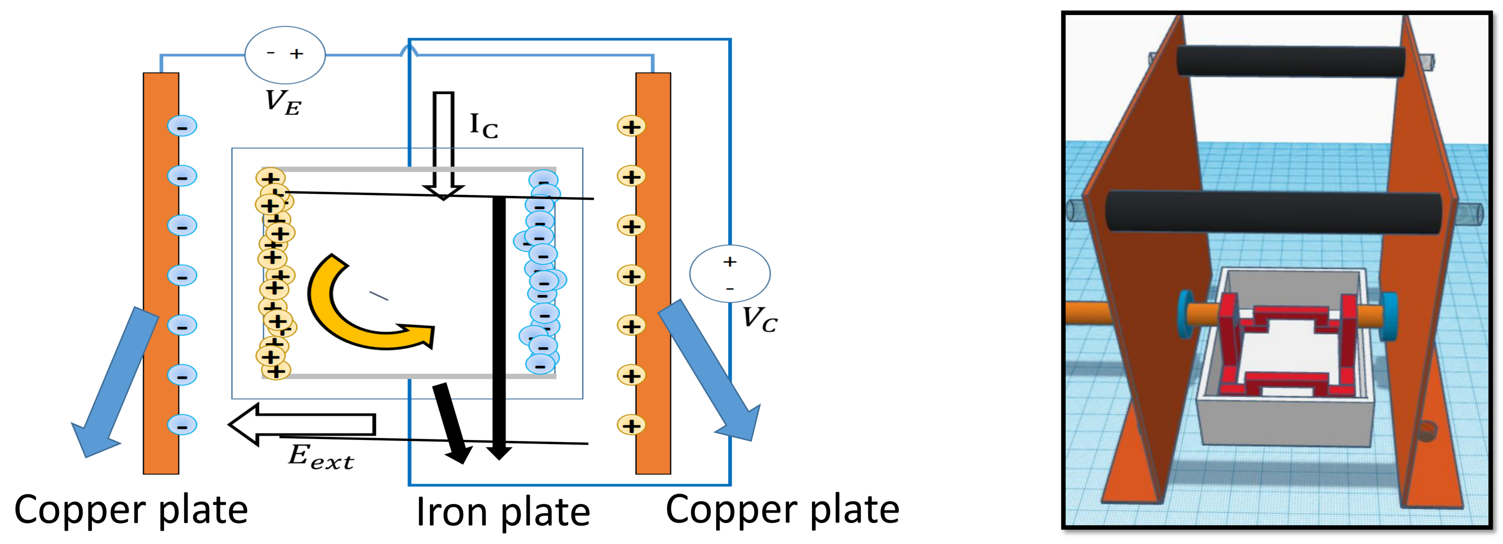
Department of Physics, National Central University, Jhong-li 32054, Taiwan

I. Introduction

Rotation of liquid film motor is driven by conducted current I_C and strong external electric fields across it. Under the external electric field provide by V_E, oppositely charged ions on the film are separated to form two conductive bands. When the film is connected to a current I_C, electrons are released by negative ions at the positive electrode and go into the circuit, while the electrons provided by V_C neutralize the positive ions by attracting them to the negative electrode. By repeating the process, the moving of ions causes the film to rotate. This is the so-called liquid film motor.

II. Apparatus for Experiment

We use a frame with a rectangular hole at the center and two iron plates on the sides of the hole as electrodes and form a film by rotating the frame to make it contact with the liquid beneath. In addition, two copper plates are used to provide a uniform electric field, and the PIV method is used to measure the flow field on the film.



(top view) *(side view)*

Fig. 1. Experimental set-up sketch

III. Theory

From the view point of energy, the dynamics on the liquid film can be described by the formulae (1):

$$u = \frac{\sigma E}{\rho}, \tag{1}$$

where σ, E, ρ, and u are, respectively, electrical conductivity (reciprocal to resistivity) of the film, electric field across the iron plates, charge density of the film, and the average drift velocity of the ions. Eq. (1) describes the case in which the film is parallel to the ground. More generally, we find the drift velocity is

$$u = \frac{IVL}{nA(qV+mgL\sin\theta)}, \tag{2}$$

where θ is the tilting angle, I, V, are current and voltage of conducted current; L, A, are length and area of the film; and n is the number of ions.

IV. Experimental Results

As the voltage across the film rises, the velocity of charged flow increases, so the velocity of film rotation also increases. In addition, when the film starts to rotate, the film at the edge rotates first, and the shear stress between different circumferences subsequently causes the whole film to rotate. For low voltages, the shear stress is not enough to drive a range of film to rotate fast. Therefore, there is a positive correlation between velocity and voltage (Fig. 2).

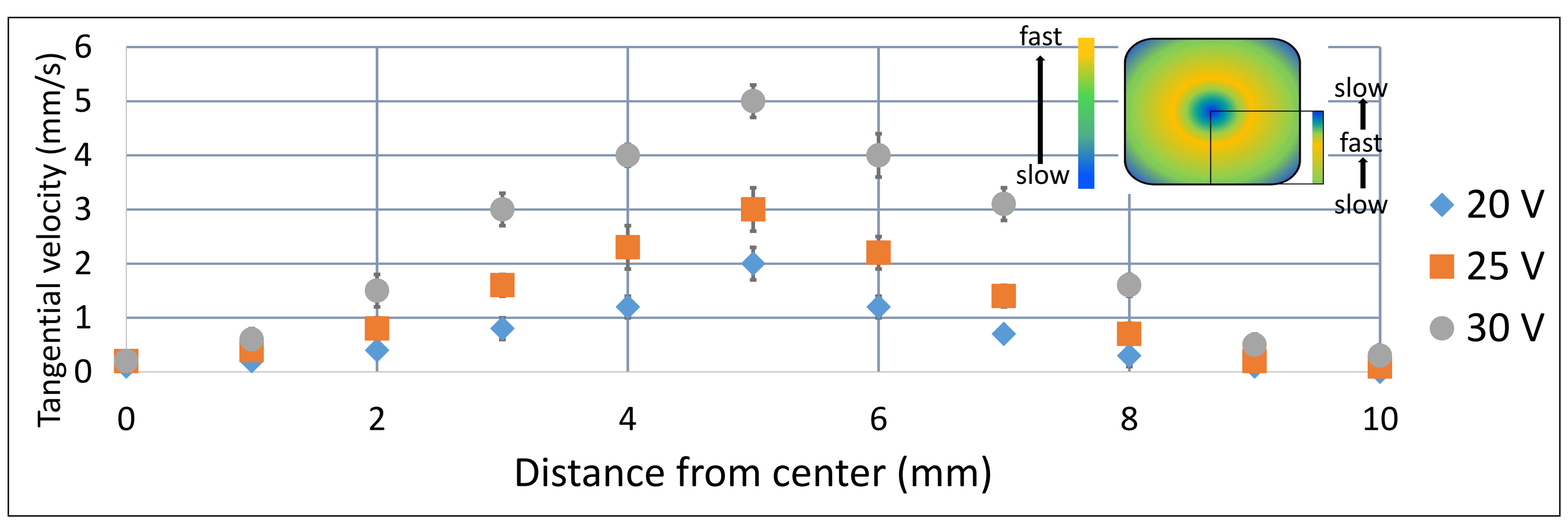


Fig. 2. Compares the tangential velocity under different voltages

The velocity is conductivity-independent (Fig. 3) due to significant effect of collisions, which cause the cancelation of velocities, between the ions.

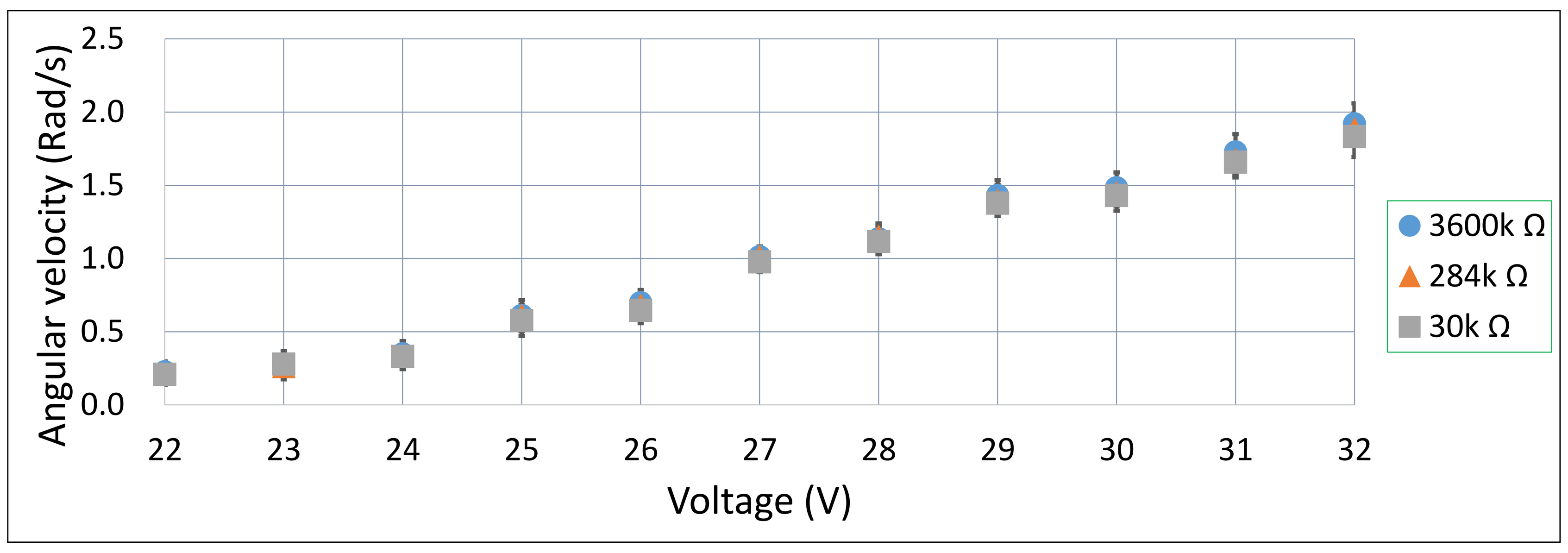


Fig. 3. Angular velocity of film under different conductivities.

When the concentration of glycerol increases, the threshold voltage of the film also increases due to the rising of the viscous force on the film. In addition, the higher the glycerin concentration, the slower the rising rate of angular velocity is (Fig. 4 & Fig. 5).

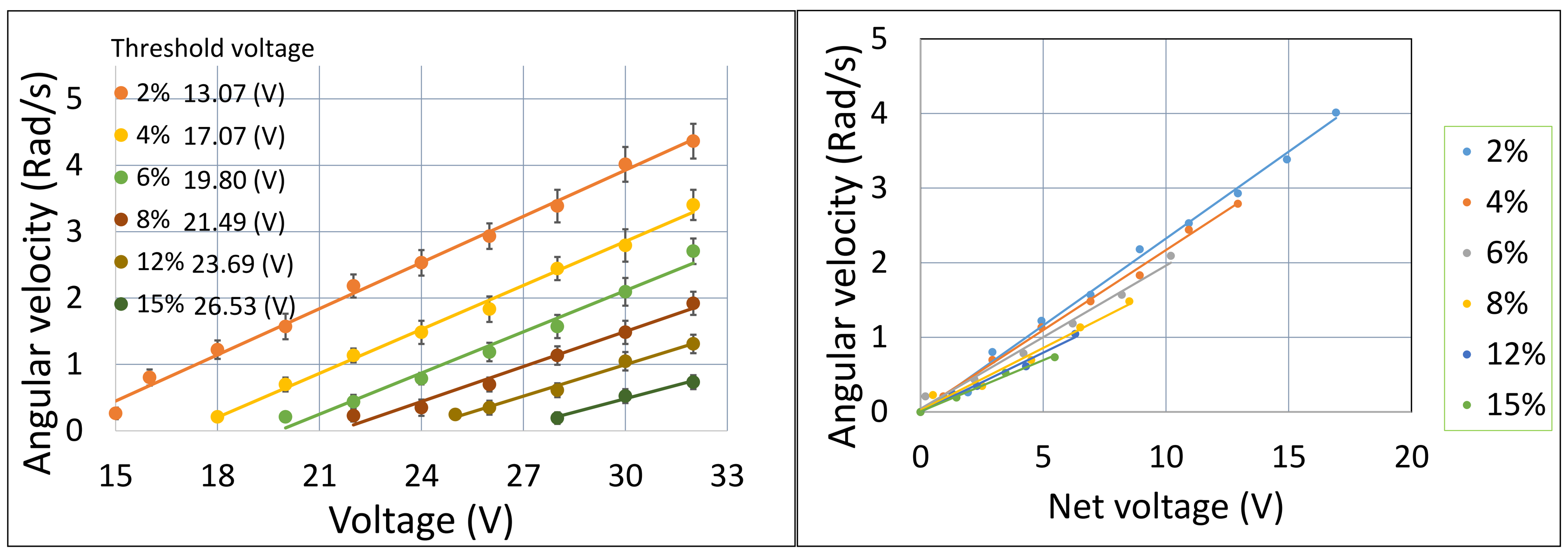


Fig. 4. Angular velocity of film under different concentrations.

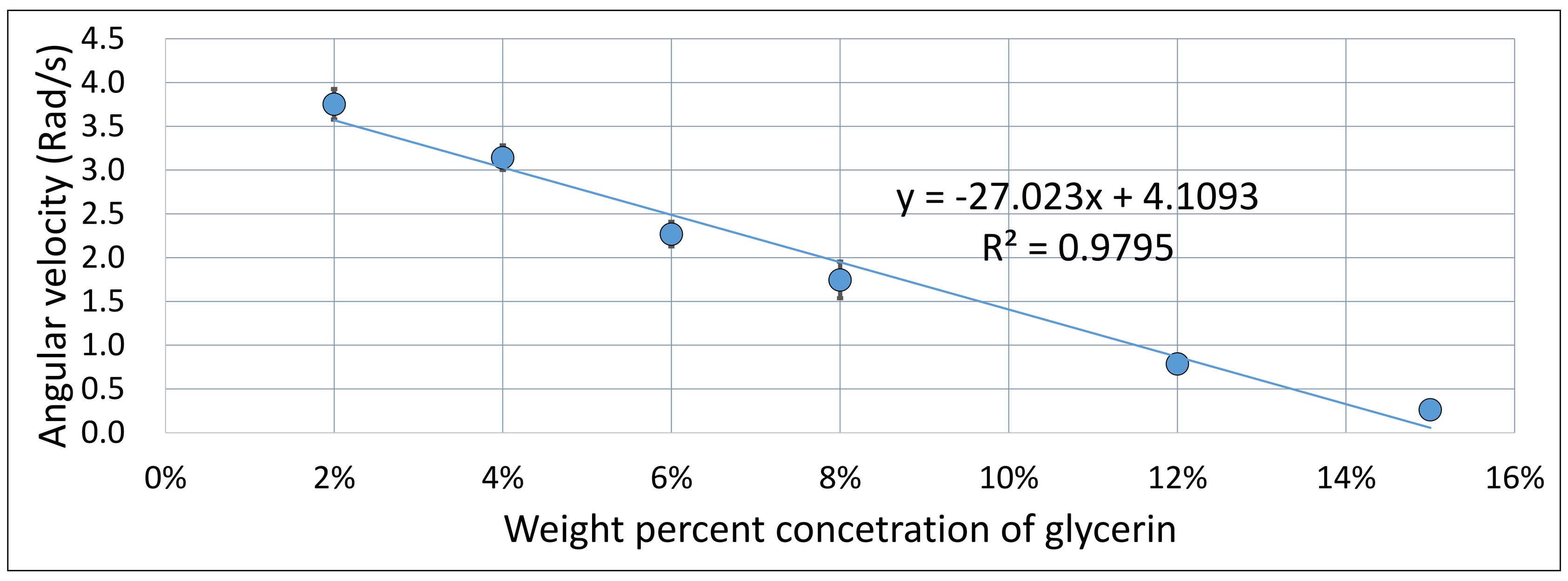


Fig. 5. Angular velocity of film under different glycerin weight percentage concentrations.

As the tilting angle of the frame gets larger, gravity plays a significant effect. Initially, the velocity of upward rotation becomes slower and that of downward becomes faster. Nevertheless, both velocities eventually becomes smaller (Fig. 6). The experimental result agrees with our theoretical prediction Eq. (2).

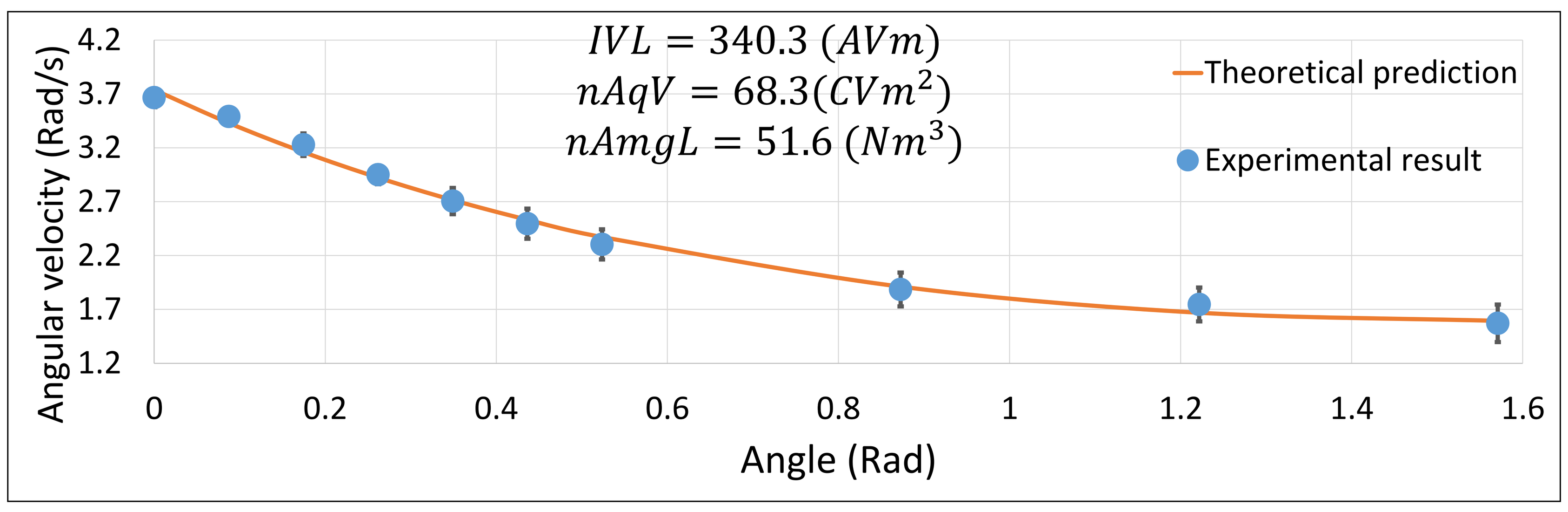


Fig. 6. Angular velocity of film under different tilting angles.

V. Conclusion

1. From Fig. 2, Fig. 3, and Eq. (1), we deduce u ∝ E and ρ ∝ σ.
2. From Fig. 4, the threshold voltage increases as the concentration of glycerin increases.
3. From Fig. 6, the angular velocity decreases as the tilting angle of frame increases and agrees with our prediction Eq. (2).

Reference:

[1] R. M. Namin, PhysRevE.92.033002.