Magnetohydrodynamic Cocktail Stirrer

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November 11, 2016

Abstract

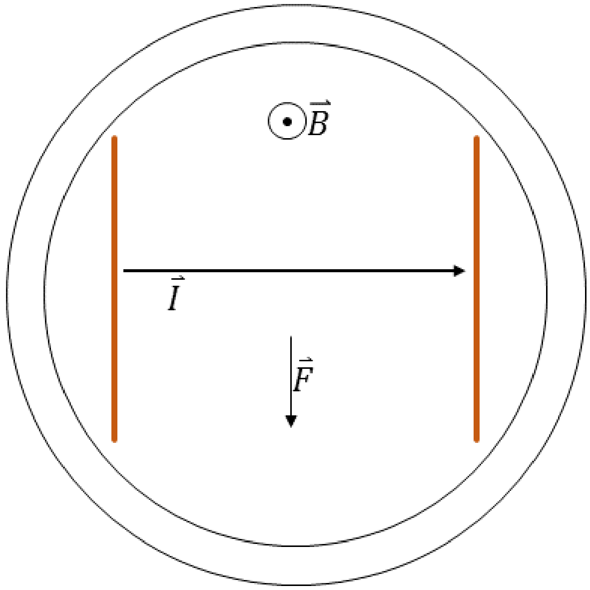

Figure 1: First iteration of contactless stirrer

1 Background

The first attempt at a contactless cocktail was based on a simple application of the Lorentz force. Two copper electrodes placed in a glass tumbler passed a current through the liquid, while a strong magnet (a 2"x1"x3/4" N45 block from United Nuclear Scientific LLC) under the tumbler provided an orthogonal magnetic field (Fig. 1). Assuming time-invariance, the force applied on a differential element $\mathrm{d}V$ in a current field $\vec{J}$ and an orthogonal magnetic field $\vec{B}$ can be found from the element length $\mathrm{d}\ell$ parallel to the current and cross-sectional area $\mathrm{d}A$ normal to the current:

$$\vec{F} = q\vec{V} \times \vec{B} \tag{1}$$

$$\vec{F} = I\vec{\ell} \times B \tag{2}$$

$$I = |J|\mathrm{d}A \tag{3}$$

$$\tag{4}$$

(Valid because $\mathrm{d}A$ is defined to be normal to $\vec{J}$.)

$$\mathrm{d}\vec{F} = |\vec{J}|\mathrm{d}A\mathrm{d}\ell \times \vec{B} \tag{5}$$

Since, in this case, the magnetic and current fields are orthogonal, and since the current field is approximately uniform between the electrodes (simply the total current divided by the electrode area),

$$\mathrm{d}\vec{F} = |\vec{J}||\vec{B}|\mathrm{d}A\,\mathrm{d}\ell \tag{6}$$

$$\vec{F} = \iiint_V |\vec{J}||\vec{B}|\mathrm{d}A\,\mathrm{d}\ell \tag{7}$$

Given an electrode area of A and spacing of L and approximating both the current and magnetic field to be uniform between the electrodes,

$$\vec{F} = |\vec{B}|L \iiint_A |\vec{J}|\mathrm{d}A = |\vec{B}|IL \tag{8}$$

This design did work in principle; the Lorentz force produced a pumping action, where fluid would flow down the centerline between the electrodes and recirculate along the walls of the tumbler. However, since a large current was flowing through a fluid, significant electrolysis occurred, which, in addition to producing potentially dangerous hydrogen and oxygen gas, affected the taste of the cocktail due to the electrolysis products of ethanol.

2 Theoretical Background

Since the basic application of Lorentz force to pumping was effectively validated (and is in fact well studied [1]), the major problem remaining was the electrolysis of the cocktail. As per Faraday's Law of Electrolysis:

$$\dot{m} = \frac{I}{F}\frac{M}{z} \tag{9}$$

Where:

- $\dot{m}$ is the mass of electrolysis products appearing at an electrode per unit time;
- I is the total current flowing into or out of the electrode;
- F is the Faraday constant, 96485 mol/C;
- M is molar mass of the original substance;
- z is the number of valence electrons of the substance.

Since F is a constant and M and z are properties of the substance, in order to minimize $\dot{m}$, I must be minimized. However, pumping force is also directly proportional to I. The central proposal of this project is that currents which circulate entirely within a fluid will not result in electrolysis, because the *net* current flow through the fluid is zero.

The obvious question is how to produce currents without an external EMF source such as a battery. The proposed solution is to use an external, time-variant magnetic field to induce circulating currents (eddy currents) in a conductive fluid.

For the purposes of a first-pass analysis, the following model will be considered:

- The fluid will be a 3" diameter, 3" tall cylinder (based on an approximate cocktail tumbler);
- The fluid will be considered to have electrical resistivity ρ and magnetic properties equal to a vacuum (water is in fact weakly diamagnetic, but this is expected to be a negligible contribution);

Since, at this point, the goal is to find the form of the current field and its dependence on $B_{s,max}$ and ρ, it is not necessary to accurately know the resistivity of an actual cocktail; those values are calculated later in §4.1.

2.1 General Design

While effectively solving the electrolysis problem, this prohibits the simple structure of the original design: since the currents in the liquid now oscillate sinusoidally at 60 Hz, in a static $\vec{B}$ field, the force on a parcel of liquid would also oscillate, producing no net motion. Therefore, the applied magnetic field must oscillate as well, synchronous with the solenoid current. The simplest design of this type would have a second electromagnet mounted orthogonally to the first, and driven from the same power source. However, geometry would require either a single large solenoid outside the axial solenoid, or two smaller solenoids (presumably with ferrous cores) on either side of the tumbler. The first case would require impractical amount of wire to construct, and the second generates a frustratingly weak field through the liquid. Therefore, large permanent magnets were next considered. 3" dia. x 1" thick NdFeB45 magnets from United Nuclear Scientific LLC were chosen based on field strength per dollar ($140 and maximum $\vec{B} \cdot \vec{n}$ of $\approx$0.42 T).

3 Rotor Design

4 Property Measurements

4.1 Cocktail Resistivity

4.2 Rotor Field Measurement

References

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[3] Bowler, John R., and Theodoros P. Theodoulidis. “Eddy Currents Induced in a Conducting Rod of Finite Length by a Coaxial Encircling Coil.” Journal of Physics D: Applied Physics 38.16 (2005): 2861-868. Web. 23 Aug. 2016.