SHERIDAN COLLEGE SCHOOL OF APPLIED CHEMICAL AND ENVIRONMENTAL SCIENCES
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# EFFECT OF FLUID VISCOSITY ON AGITATOR POWER CONSUMPTION

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## INTRODUCTION

It is generally understood that the amount of force required to mix a solution increases as the fluid's consistency also increases. In an agitated system, this can be related to how much power, or energy per unit time is consumed to mix a solution depending on the fluid's viscosity. To visually determine how these factors relate to one another, the dimensionless variables of power number and impeller Reynolds number can be calculated and subsequently plotted. [1]

Furthermore, this relationship is particularly significant to industry as the amount of power required to mix a solution directly affects their capital and operational costs. Whether it's selecting an appropriate motor or finding the ideal mixer speed for a given process, the power consumed by a mixer in an industrial process should be minimized while still providing the necessary agitation to facilitate mass and/or heat transfer within the system.

## PROJECT PURPOSE

The objective of this project is to study the change in power consumption of an agitator with fluids of varying viscosities. This relationship can be analyzed by plotting a graph of power number against impeller Reynolds number. Additionally, different types of identically-sized impellers (*Figure 1*) will be used to determine if impeller selection affects this relationship.

(a) (b)

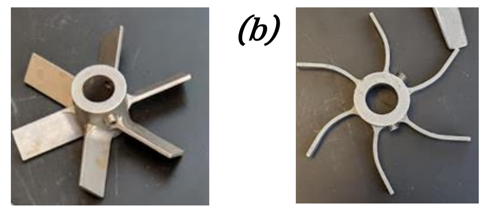

*Figure 1. (a)* Pitched axial impeller. *(b)* Curved blade radial impeller

## METHODOLOGY

When designing the experiment for this project, it was crucial to obtain the necessary data to calculate power number and impeller Reynolds number. As a result, the following variables were recorded for each fluid during testing: power, absolute viscosity, density, rotational speed, and impeller diameter. The temperature was also monitored and maintained around room temperature to minimize variations in fluid behaviour.

The experimental phase of the project can be broken down into three main sections: *Mixing tests*, *Density tests*, and *Viscosity tests*.

To provide the widest variety of results on the results graph, Newtonian and non-Newtonian fluids were selected for testing, as well as two different types of impellers. This resulted in the selection of R.O. water, motor oil, and a 60% (w/w) sugar solution as the test fluids, with axial and radial impeller types. Moreover, the selected mixer speed settings were evenly spaced between the mixer's minimum and maximum speeds for this same purpose.

*Figure 2.* Sugar solution samples of varying compositions

## EQUIPMENT

Analysis of mixing characteristics was conducted using a Lightnin® LabMaster mixer with a covered 20 L PYREX® tank. The tank was anchored to a lab bench where a set of 4 scissor jacks were used to adjust the depth of the impeller within the tank. A pair of 6-inch diameter impellers were used for this experiment: one 6-bladed pitched axial impeller and one 6-bladed curved radial impeller. During the duration of the mixing test, temperature readings were recorded using a thermocouple that was held in place by clamps and a retort stand (*Figure 3a*).

Analysis of fluid density was conducted using various sized hydrometers to determine the sample's specific gravity. Samples were analyzed inside a large test tube while monitoring solution temperature with a thermocouple (*Figure 3b*).

Analysis of viscosity was conducted using a Brookfield viscometer. When the appropriate spindle and torque settings are used, the instrument outputs the sample's absolute (dynamic) viscosity.

(a) (b)

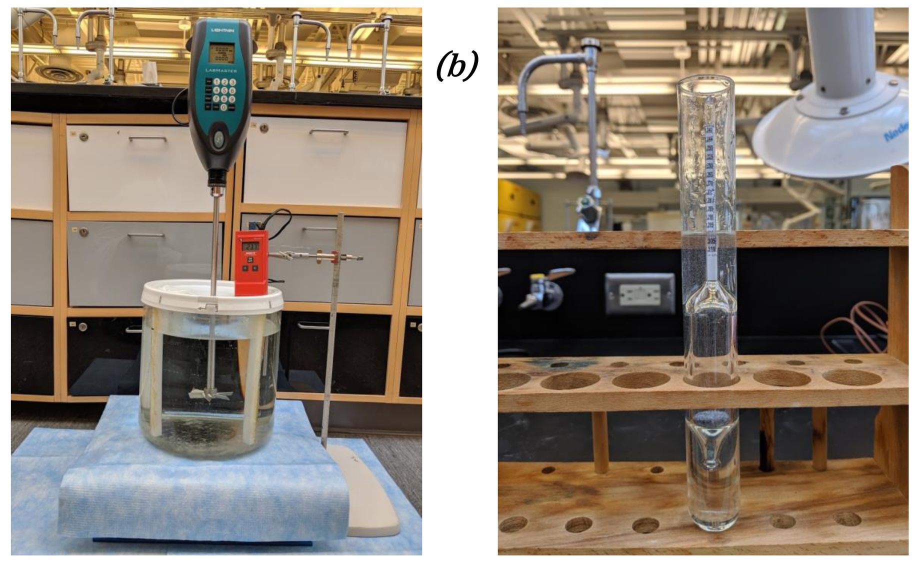

*Figure 3. (a)* Mixing test set-up. *(b)* Specific gravity tests with hydrometers.

## PROCEDURAL ISSUES

While performing the experimental trials, several issues arose that hindered our project's progress, some of which were:

1. <u>Mixer limitations:</u>
   Due to the use of a lab-scale portable mixer, it was not able to provide enough power to agitate the solution at a wide variety of flow regimes. The mixer's limited speed range was further reduced by constant error outputs during testing. Also, at the lowest speed settings, the mixer would display power readings of 0 as it could only output whole numbers. Instead, power consumption had to be calculated using RPM and torque values.
2. <u>Extreme viscosity of cornstarch suspension:</u>
   The viscosity of the desired cornstarch suspension produced favorable non-Newtonian fluid properties but due to the underpowered agitator, it was unable to adequately agitate the suspension for the mixing tests. This fluid was then removed from the project altogether.
3. <u>Fluid spillage:</u>
   Originally, the experiment was designed to replicate ideal mixing conditions however, since the mixing tank did not have the correct dimensions, liquid frequently spilled during testing, particularly at high mixing speed settings. Consequently, the fluid volume in the tank had to be reduced, and a lid was made from a 5-gallon bucket.

## RESULTS

Following the end of the laboratory component of the project, the experimental data was immediately tabulated on Excel to calculate the respective power number and impeller Reynolds number values for each test run of every liquid.

The results of these calculations were plotted against one another for all fluids tested (*Figure 4*). This was done for ease of comparison of experimental data trends between different fluid types. Separate graphs were additionally plotted for individual fluids for further analysis of axial and radial impeller performance between trial runs.

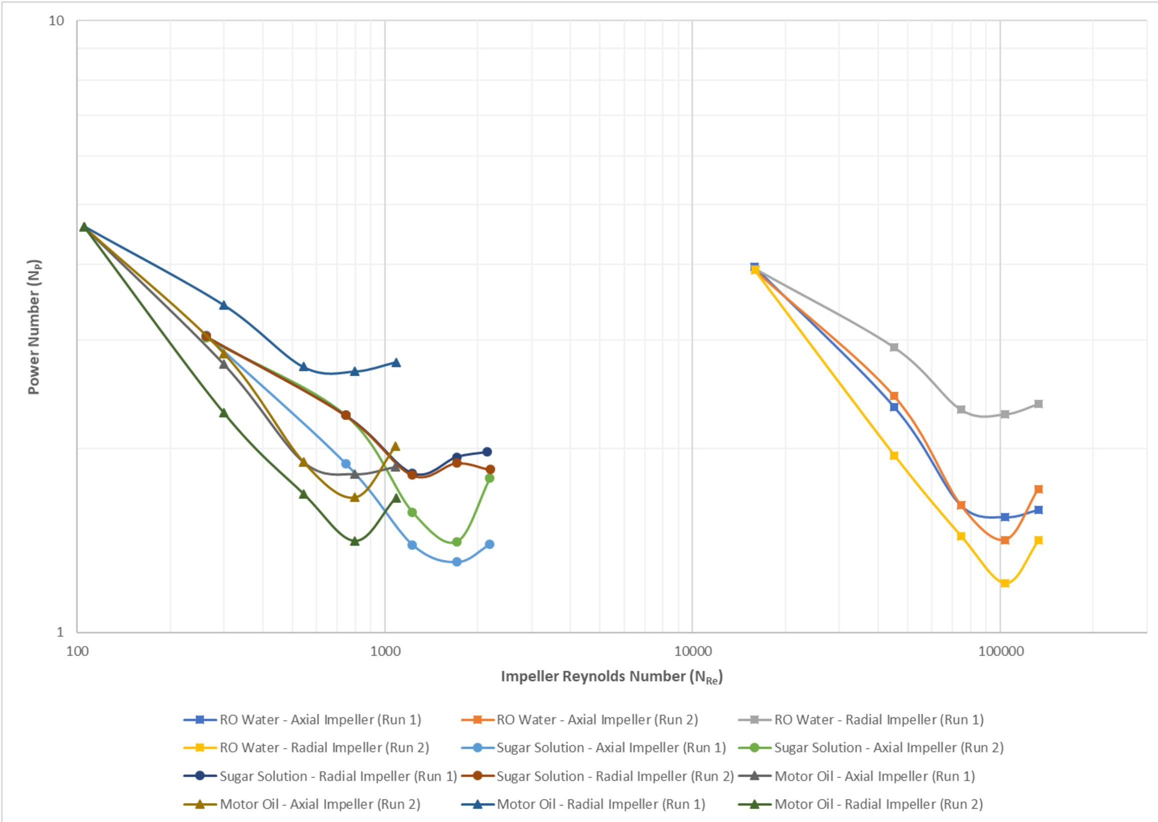


*Figure 4.* Plot of Power Number vs. Impeller Reynolds Number for Various Fluids

## EXPERIMENTAL ANALYSIS

Analyzing the experimental data depicted in Figure 4, it is immediately evident for each fluid used in this experiment, the power number generally decreases with respect to an increase in the impeller Reynolds number. This indicates that as system increases in turbulence, the mixer experiences less resistance from the fluid, allowing for faster rotational speeds with smaller increases in power. However, this trend is untrue for the right-most data point of every fluid as nearly every line curves back upward. This behavior is not completely understood however it is speculated that at higher speed settings, the formation of a small vortex within the mixing tank causes the mixer to consume more power to achieve the desired mixing conditions.

Out of each fluid tested, only R.O. water was able to obtain fully turbulent mixing conditions ($N_{Re} > 10{,}000$) in every single test trial. [1] In comparison, nearly all the trials for motor oil occurred with a laminar flow regime ($N_{Re} < 1{,}000$) except for its trial at the 1250 RPM setting. [1] For the sugar solution, its data was split between the laminar and transitional flow regimes. [1]

Moreover, when comparing the mixing performance between axial and radial impellers for each fluid, in general, axial impellers demonstrated more consistent results as they produced nearly identical results for every liquid tested at each speed setting, whereas the radial impeller was more susceptible to variances in power output.

## CONCLUSIONS

As a result of this project, it was verified that power consumption of an agitator is affected by fluid viscosity. It was also determined that, in general, the increase in power consumption decreases the more turbulent the mixing tank is, as a result of higher rotational speeds. Furthermore, the effect of impeller type on this relationship was inconclusive due to the irregularity of most of the radial impeller test data. Additional testing would be required to form an accurate conclusion.

Thus, for a given agitation system and fluid, it can be concluded that the optimal mixing conditions to minimize power consumption can be determined experimentally.

## FUTURE RESEARCH

In future iterations of this project, it is suggested that the focus be shifted towards designing an impeller for a given mixing process involving a single fluid to optimize power consumption.

Alternatively, students can also attempt to continue this research by testing more non-Newtonian fluids as this project primarily focused on used Newtonian fluids for testing. However, it is recommended that thixotropic or shear thinning fluids are used to avoid the power limitations of the provided agitator as these non-Newtonian fluids should become easier to mix as the stresses applied by the mixer increase with rotational speed. [1,2]

## INDUSTRIAL APPLICATIONS

Agitators serve a multitude of applications in industry and come in various types and sizes depending on the type of process. The main objective of these agitators is to produce flow, promote heat transfer, and/or maintain fluid uniformity within the tank. Common industries where agitators are often used are: [3,4]

- Oil & Gas
- Chemical manufacturing
- Paint, Ink, & Coatings
- Pharmaceuticals & Bio-tech
- Cosmetics
- Food & Beverage
- Wastewater
- Pulp & paper

*Figure 5.* Mixing tanks used in the cosmetics industry. [5]

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