3 Scale Up

Objectives of the experiment

a) To study the unit operation of mixing and to investigate the power requirement for agitating liquids.

b) To design a large scale agitated system (details given in section 6) using design data obtained experimentally in small scale studies with geometrically similar systems.

Equipment

a) 0.29 m I.D. bench-scale glass tanks containing fluids of different physical properties.

b) 4 baffles, 10% of tank diameter.

c) A 1.1KW variable speed motor.

d) A 0-6Nm shaft-mounted torque/speed transducer for measuring impeller speed and the reaction torque on the motor. (Check the bearings/torque transducer for friction).

e) Two impellers with diameters 0.075m and 0.1m.

f) Hydrometers, thermometer.

Materials and Data

Glycerol/water mixtures are the main liquids for the experiments. Density and viscosity charts are supplied.

3.1 Introduction

Dimensional analysis is extensively employed when scaling objects from model to prototype in a wide range of industries from aerodynamics to food manufacturing. It simplifies problems greatly as the parameters involved dramatically decrease. The scale invariance of the dimensionless frame further results in a reliable scale up. In this study, our aim was to create a large mixing vessel using this technique on experimental model data. The dimensionless groups used for this experiment were the Reynolds number and the Power number. Geometric similarity was ensured by maintaining a constant ratio in the length dimensions between model and prototype. Other dimensionless groups on the other hand were ignored due their irrelevance to the system. For example, as the mixer vessel had baffles there was no vortex formation and thus the Froude number was neglected.

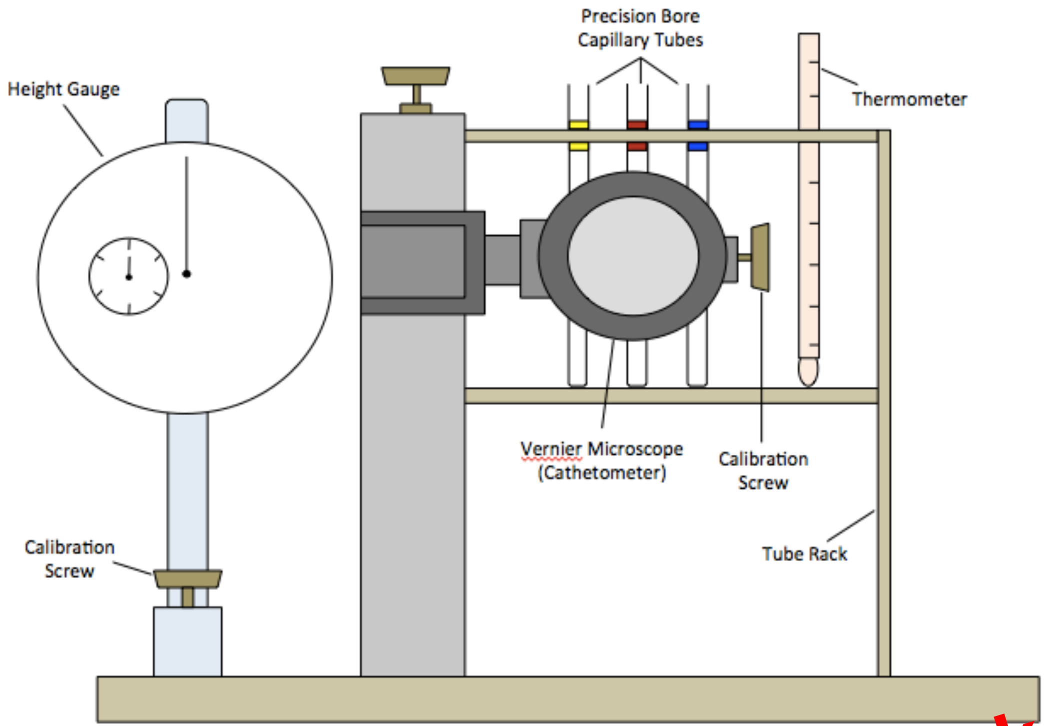
The Power Number is a dimensional number, relating the ratio of force applied on to the impeller to the inertial force. It is a function of 5 parameters N, D, ρ, μ and g where N is the rate of rotation of the impeller, D is impeller diameter, ρ is fluid density and μ is fluid viscosity. Thus in not using dimensional analysis, 5 separate experiments must be conducted in order to determine the effects on P when each parameter is changed as P= f(N, D, ρ, μ, g). This is clearly a time consuming and costly exercise. However, we must still conduct experiments on the prototype and

We will compare the Power curve, Po for stirred tank with the Fanning Friction Factor, Cf curve for pipe. Po curve for stirred tank depends on the geometry of the impeller, while the Cf in turbulent flow is affected by relative roughness of the pipe. At the laminar region, there is a linear relationship between Cf and Re at larger range, $100 < Re < 4000$, compared to Po and Re curve which is only valid at small range, $1 < Re < 8$. The similarity that could be observed is that, at low Re numbers, the both the Cf and Po are inversely proportional to Re. At laminar region, the gradient of the Cf graph is steeper compared to Po curve at low Reynolds number. For Cf curve for pipe, there is a transition region between laminar and turbulent flow, where this uncertain region poses difficulty in determining the exact Po number based on Reynolds number. Whereas for Po curve in stirred tank, the Po number can be read from the graph for all Reynolds values without difficulties. The transition region is relatively sharp for Cf curve, but relatively smooth for Po curve. At high Re numbers, both the Cf and Po approached constant values, from Curve 2, at $Re > 2000$, $Po = 4$. This suggests that, friction factor is not affected by Re number when the flow is highly turbulent.

A non-Newtonian fluid is a fluid whose viscosity is dependent on the shear rate, resulting in a gradient of viscosity in the vessel. The mixing of non-Newtonian fluid is expected to be slow. For shear thinning fluid such as ketchup and paint, the viscosity decreases as the shear rate increases. During the start-up of mixing, a higher power is required because it will be hard to get the fluid in motion from its stationary state. During mixing, the shear stress increases, the fluid viscosity decreases, thus allow smoother flows and lower power consumption. For shear thickening fluid such as cornstarch in water (oobleck), the viscosity increases as the shear rate increases. The opposite happens. Initially, mixing is easy. As mixing continues, the fluid is harder to flow. Less power is required initially and the power consumption increases as mixing continues. In particular, the power consumption of Newtonian fluid will be smaller compared to non-Newtonian fluid.

Agitator or mixers used are chosen based on the type of mixing required, vessel capacity and fluid viscosity. Turbines such as the six-bladed disc turbine are used for gas- liquid dispersion in small vessels, liquid-liquid dispersion and for fast competitive chemical reactions. Paddles such as gate paddles are used in shallow, wide tank and fluid of higher viscosity when low shear is adequate. Anchors and helical ribbons are used for non-Newtonian fluid. These impellers has larger diameter and has close clearance to wall, thus allow the entire volume of the vessel to be swept during mixing. Similarly, Z-blade and Banbury mixers are used for high viscosity fluid such as dough, rubber or paste.

Portable mixers that can be clamped on the side or top of vessel are often used for wide range of applications. It provides cost effective solution for small batch mixing. Extruders are usually used in the plastic industries, when the feed contains granular or powdered base polymer is mixed with additives. The extrudate is delivered at high pressure for shaping purposes. Static in-line mixers or 'motionless mixers' operates by pumping the fluid through pipe containing a series of non-moving blades. This mixer is suitable for usage in the laminar or turbulent flow



4.2 Discussion

The diffusion coefficient is the greatest in methanol, followed by ethanol and then acetone. This trend is true for all the 3 values obtained for each organic solvent from the experiment, prediction by FSG method and published literature.

Molecule with lower molecular weight will have a higher mass transfer rate, corresponding to a higher diffusion coefficient value, which reflects the results of the experimental values. Using the Stefan's method for experimental value calculations, the diffusion coefficient of Methanol, Ethanol and Acetone is 2.37 x 10^{-5} m^2s^{-1} , 1.15 x 10^{-5} m^2s^{-1} and 9.12 x 10^{-6} m^2s^{-1} respectively, where methanol has the highest value among all.

The rate of diffusion is afftected by several factors such as pressure, temperature, composition, molecular shape, molecular size, solvent viscosity and etc.. In the experiment, the temperature and pressure is kept constant at room temperature and pressure. However, it is noted that in practical chemical engineering processes, these 2 parameters are usually never constant. Hence, it is important for us to know how these parameters would affect the diffusion coefficient values.

From FSG correlation , D α $\frac{1}{P}$. As pressure, P increases, the molecules become closer together, the mean free path travelled by molecule is shorter. The diffusivity reduces, thus the diffusion coefficient, D is low. Besides that, D α $T^{1.75}$. As temperature, T increases, molecular velocities increases and kinetic energy of

- Experimental apparatus is set up in a sealed box, with constant gas stream passing through the top of tube. This prevents any accumulation of vapor at the top of tube and thus allows the assumption of $x_{A2} = 0$ at the top of tube.
- Using thermocouple probe instead of thermometer to give a more accurate temperature reading
- Real gas equation such as Peng-Robinson equation of state should be used instead of ideal gas equation to inprove accuracy of experimental diffusivity values. Peng Robinson equation of state takes into account the effect of intermolecular forces of attraction between molecules and accounts for the finite volume of gas molecule, of which these are considered negligible in ideal gas law.