## Introduction

The performance of two identical pumps was compared, one filled with water, the other a glycerine solution. In the case of the water, different cases were considered where throttle location was changed as was impeller speed.

## 4.1 Determination of ratio of viscosity

A comparative value for the viscosity of the glycerine solution (subscript, s) can be obtained using the relationship below:

$$\frac{\mu_w}{(\frac{T\rho}{L})_w} = \frac{\mu_s}{(\frac{T\rho}{L})_s}$$

| | Time taken for calibration cylinder to empty, T (s) | Density, ρ (kgm-3) | Length of tube, L (m) | Tρ/L | Temperature, °C | Dynamics Viscosity, μ (Nsm-2) |
|---|---|---|---|---|---|---|
| **Water** | 54.5 | 1000 | 10 | 5450 | 20.9 | 0.001 |
| **Solution** | 281 | 1170 | 2 | 164385 | 20.9 | 0.030162385 |

**Table 1: Determining a comparative value for the viscosity of the glycerine solution.**

## 4.2 & 6.4

For the water pump, the fluid was throttled at the outlet, at full speed (49.5Hz) and then at half speed, and the pressure rise across the pump at different flow rates was measured. This process was then repeated when throttling at the inlet. The same measurements were taken when throttling at the outlet for the glycerine solution experiment, however here the speed of the pump was allowed to vary.

Using the relationship,

$$\dot{m} = 0.193\sqrt{\Delta p_{vent}}$$

We were able to determine we were able to take measurements at about 10 approximately evenly spaced flow rates. The flow rates, Q, and pressure rises across the pump, $\Delta p$, were obtained and then non-dimensionalised:

Non dimensional pressure rise: $C_p = \frac{\Delta p}{\rho N^2 D^2}$ Non-dimensional flow rate: $C_Q = \frac{Q}{ND^3}$

Where $\rho$ is the density of the fluid, N is the rotational speed of the impeller and D is the impeller diameter.

The relationship between these for all five of the tests are shown in Figure 1.

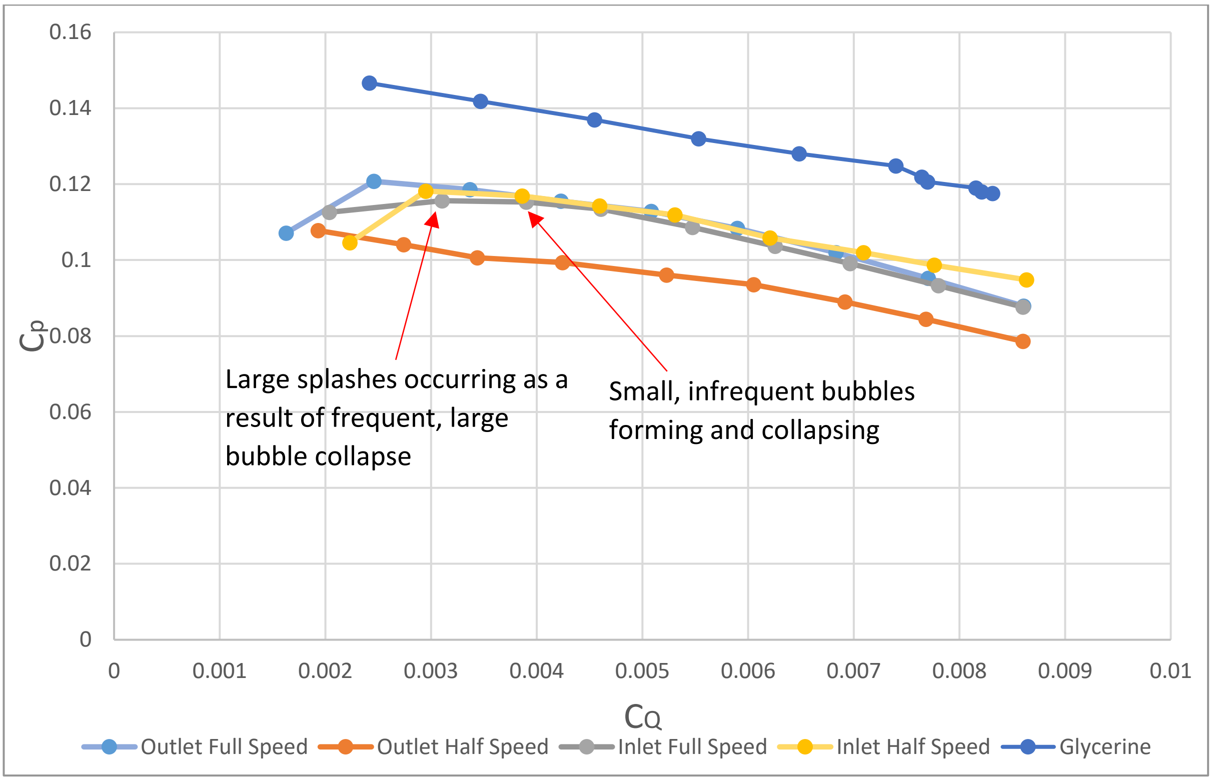



**Figure 1: Dependency of dimensionless pressure rise on dimensionless flow rate for the 5 different test.**

As the inlet was throttled, there was a further drop in pressure. For the full speed flow, cavitation commenced when the pressure drop across the venturi was about 9.6kPa ($C_p$=0.000115288 and $C_Q$=0.003899659). This initially just looked like a series of infrequent and random sparks which occurred towards the leading edge of the impeller. These were small vapour bubbles being formed and then collapsing very quickly. By the time the pressure drop across the venturi reached 6.1kPa ($C_p$=0.000115649 and $C_Q$=0.003102269) very large splashes were occurring very frequently (again towards the leading edge of the impeller). These points are shown in Figure 1, and the actual cavitation is illustrated in Figures 2 and 3.

From inlet to exit, the flow diverges meaning that there is an increase in static pressure as the velocity relative to the impeller decreases. There is also an increase in pressure as the radius increases as the impeller is rotating. Together this means that the lowest pressure is on the leading edge of the impeller. By looking at the meridional view in Figure 4, in travelling from the eye to the impeller blades, the flow must turn from axial to radial very sharply. This curvature means that the lowest pressures will be found on the outer edges of the eye.

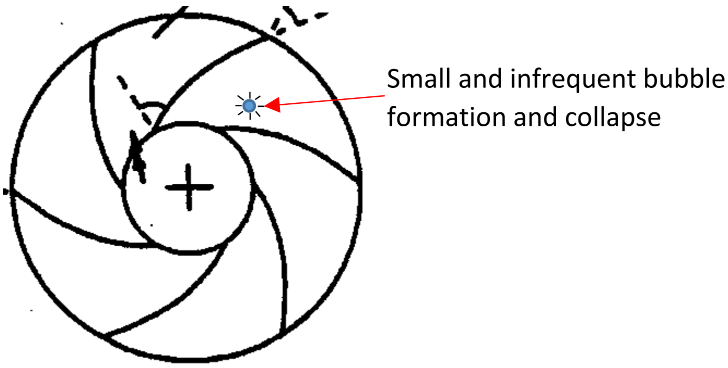



**Figure 2: Cavitation at $\Delta P_{vent}$ = 9.6kPa the in impeller**

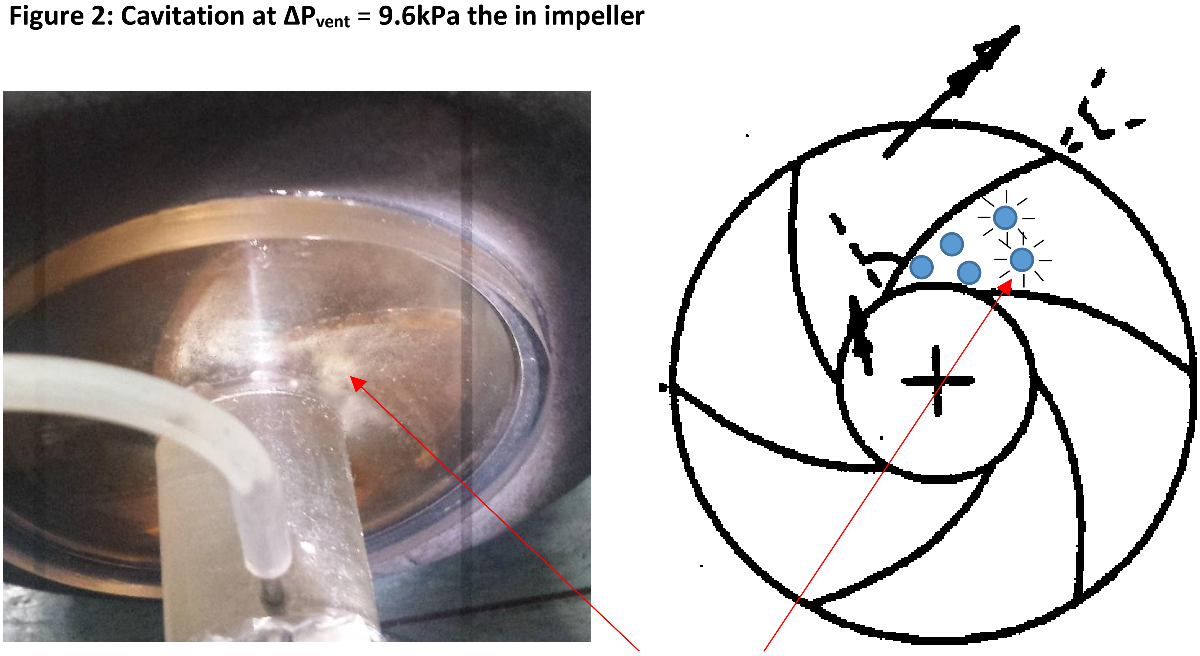



**Figure 3: Cavitation at $\Delta P_{vent}$ = 6.1kPa the in impeller**

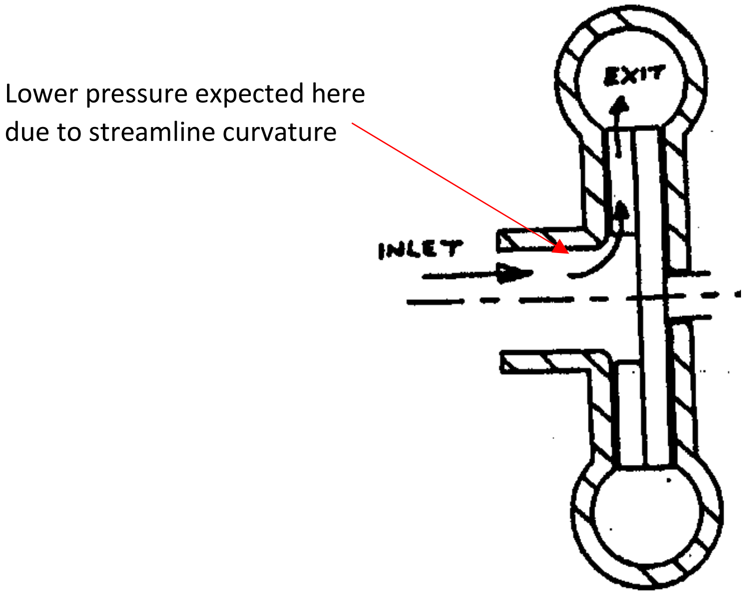



**Figure 4: Meridional view of impeller**

**6.1**

| | Angle (°) | Radii (mm) | Height (mm) |
|---|---|---|---|
| **Inlet** | 59 | 14 | 6 |
| **Outlet** | 46 | 39.75 | |

As the impeller rotates anticlockwise, it does work on the fluid in order to increase the component of its angular momentum about the centre of the impeller. This is done by the convex surface exerting a torque on the fluid. Thus, by Newton's third law, the fluid also exerts a torque on the convex surface of the impeller, resulting in high pressure here. This is shown in Figure 5.

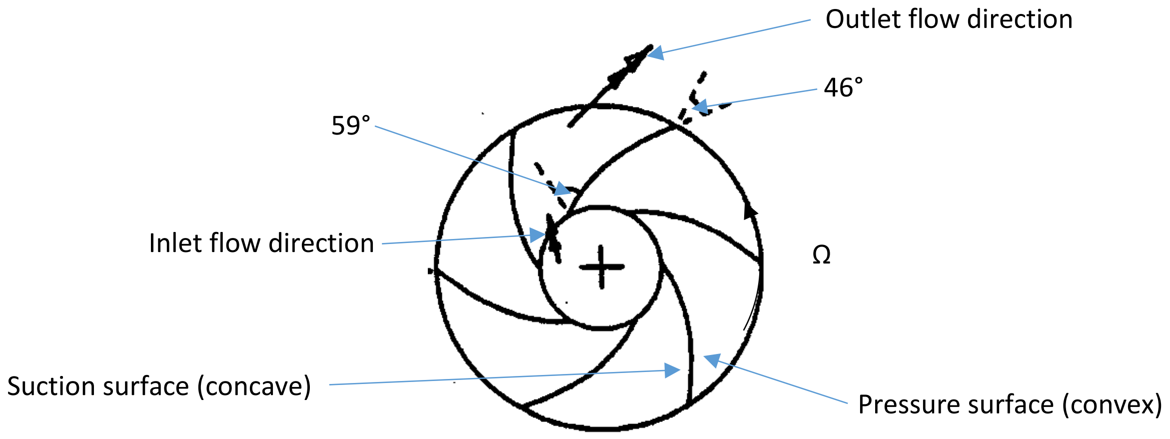
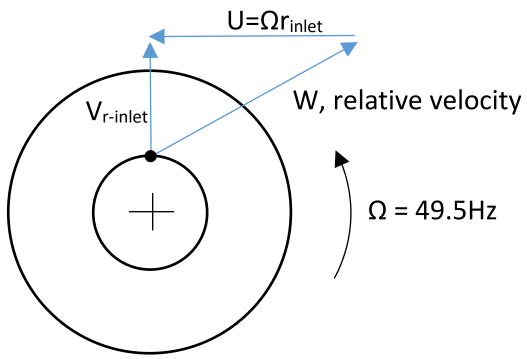



**Figure 5: Impeller dimensions, high pressure and low pressure surfaces**

**6.1**

For maximum flow at inlet when the outlet is throttled:

| $\dot{m}$ ($kgms^{-1}$) | $r_{inlet}$ (m) | θ (rad) | h (m) | ρ ($kgm^{-3}$) | $V_{r\text{-}inlet}$ ($ms^{-1}$) |
|---|---|---|---|---|---|
| 1.3175 | 0.014 | $2\pi$ | 0.006 | 1000 | 2.496269494 |




$V_{r\text{-}inlet}$ = 2.50 m/s

U = 4.35 m/s

W = 5.02 m/s

Re = $1.4 \times 10^5$

**Figure 6: Velocity triangle at leading edge for maximum flow**

Using exactly the same method, but using the dynamic viscosity for glycerine shown in Table 1, the Reynolds number for the glycerine solution was found to be: Re = $5.3 \times 10^3$.

**6.3**

Cavitation begins when the local static at the inlet, $p_{in}$, falls below that of the saturation vapour pressure of the liquid, $p_v$.

$$C_{cav} = \frac{p_{in} - p_v}{\rho N^2 D^2}$$

In theory, we would expect cavitation to occur when this value falls below zero, however our measured values of $p_{in}$ are larger than expected as we do not take into account things like pressure loss due to streamline curvature (shown in the meridional view inn Figure 4).

The average temperature during this experiment was about 21°C, at which the saturated vapour temperature, $p_v$, is 0.02492bar (from steam tables).

Using the fact that the discharge is at atmospheric pressure (measured to be 760mmHg), and accounting for the loss in pressure head before discharge and pressure rise across the pump, an estimate of the absolute inlet pressure, $p_{in}$, for each measurement was obtained.

A plot of $C_{cav}$ vs $C_Q$ is shown below in Figure 7.

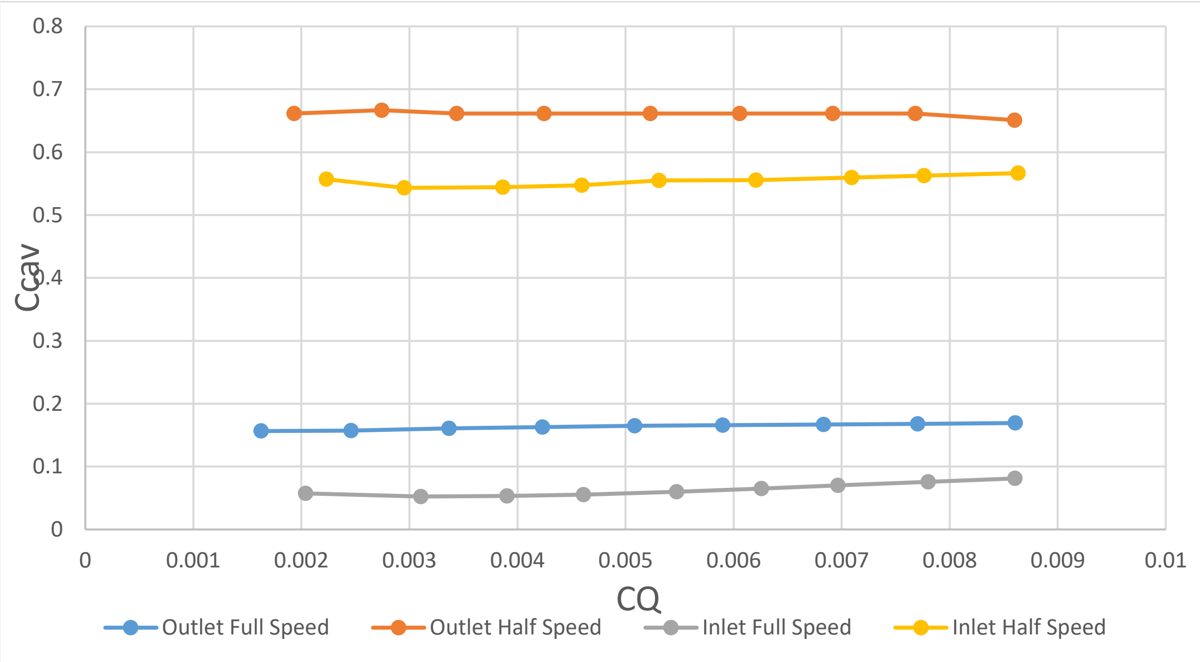



**Figure 7: Dimensionless cavitation number vs dimensionless flow rate for each of the cases in the water pump experiment.**

Clearly the dimensionless cavitation number is considerably lower for full speed case (i.e. 49.5Hz) than for half speed case. This makes sense as for the same $p_{in}$, $N^2$ will be much larger for the full speed case, resulting in a significantly lower $C_{cav}$. As we decrease $C_Q$ by throttling, this reduces the pressure at the inlet, resulting in a decrease $C_{cav}$. This is not down to N (as this was kept roughly constant for the high and low speed case). There appears to be very little difference between throttling at the inlet and outlet.

**6.5**

Due to the pressure rise across the pump, the pressure at the inlet is significantly lower than that of the outlet. Thus a decrease in pressure by throttling at inlet is enough to make the local static pressure lower than the saturated vapour pressure, resulting in cavitation. Similar pressure rises across the pump are achieved by throttling at the outlet, however due to this pressure rise, the decrease in pressure at the outlet does not cause the local static pressure to drop below the saturated vapour pressure at any point. The difference in inlet pressure when throttling at the inlet compared to the outlet is shown in Figure 7, where for a given rotor speed and flow rate, throttling at the inlet gives the lower cavitation number. Despite this difference the pump still causes the same pressure rise, as can be seen in Figure 1.

**6.6**

- The pump uses the rotational kinetic energy of the impeller blade to do work on the fluid and increase its pressure. If the flow rate is increased (without a corresponding increase in impeller rotational speed) then the pressure rise must decrease as less work is done on each volume of fluid moving through the impeller.
- The Reynolds number for the throttling the water at the outlet (for a full speed impeller) was approximately $1.4 \times 10^5$. As we don't have the relative roughness, all we can say is that this is either on the edge of the transition zone, or it is in the turbulent zone (using Figure 3 in the hand out). Here, the skin friction coefficient is almost entirely independent of Reynolds Number. The greater viscosity of the glycerine solution, resulted in a Re = $5.3 \times 10^3$. This is still in the laminar region. Here the friction factor is lower, and leading to a larger pressure rise in the pump, due to the lower friction factor and hence lower pressure loss.
- When the rotor speed was increased, cavitation increased. As the flow velocity at the inlet to the impeller is increased, the pressure, $p_{in}$, must decrease, resulting in increased cavitation. Change in cavitation with throttle location had been described above. If the flow rate is decreased (but impeller speed kept constant) then the radial component of the flow velocity will decrease (with the transverse component kept constant). Therefore the inlet angle of flow will decrease: shown below:

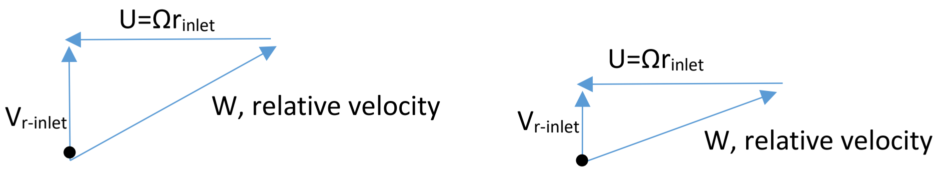



**Figure 8: Velocity triangles for different flow rates**

**6.7**

The high viscosity of glycerine means that its Reynolds number is significantly below that of the water flow. The discharge coefficient of a low Reynolds number flow does not remain constant, meaning that the degree of pressure recovery will vary. Therefore, the mass flow rate we obtain from the Venturi will be less accurate for the glycerine flow than for the higher Reynolds number water flow. Venturi meter allows you to relate mass flow rate to pressure.

**Conclusion**

- The lowest pressure in the impeller was towards the leading edge of the blade and at the edge of the eye (due to the flow curvature).
- The convex side of the blade is the high pressure surface due to the fact that the impeller is rotating and doing work on the fluid to increase its rotational component of velocity.
- Cavitation occurred at high impeller speeds when throttling at the inlet as this meant that the local static pressure dropped below that of the saturated vapour temperature. These trends with impeller speed and throttle location can be seen in Figure 7.
- The high viscosity of the glycerine solution means a lower Re, hence lower friction factor and hence a greater pressure rise in the pump for a given flow rate.