6 Laboratory Teaching Exercises

6.1 Nomenclature

Name	Sym bol	Units	Definition
Temperature	t	°C	The temperature of the working fluid This is used to obtain the fluid density ρ
Fluid Density	ρ	kg/m^3	The density of the working fluid, i.e. water The density of water varies slightly with the water temperature. Refer to the table in section 6.3 for typical values
Gravitational Acceleration	g	m/s^2	The gravitational force acting on the working fluid. This may be taken as a constant for calculations for this equipment $g = 9.81\ m/s^2$
Flow rate	F	m^3/s	Flow rate produce by the pump. The sensor used depends on the typical range generated by the pump F1 for high flow rate pumps F2 for low flow rate pumps Flow rate is measured in l/min and converted to m^3/s for the calculations (Q=F/60,000)
Pressure	p_{in}	kPa (kN/m^2)	Pressure measured at pump inlet The sensor used depends on the pump under evaluation: p_1 low pressure pump inlet p_3 high pressure pump inlet p_5 axial pump inlet Pressure is measured in kPa (kN/m^2) and converted to N/m^2 for the calculations (Multiply by 1000)

Pressure	p_{out}	kPa (kN/m^2)	Pressure measured at pump outlet The sensor used depends on the pump under evaluation: p_2 low pressure pump outlet p_4 high pressure pump outlet p_6 axial pump outlet Pressure is measured in kPa (kN/m^2) and converted to N/m^2 for the calculations (Multiply by 1000)
Pressure	p_o	kPa (kN/m^2)	Maximum Outlet Pressure measured at outlet of Cyclic pumps only (Diaphragm pump or Plunger pump) using sensor p_4. Pressure is measured in kPa (kN/m^2) and converted to N/m^2 for the calculations (Multiply by 1000)
Pump Speed	N	RPM	Speed of rotation of the motor/pump shaft. Speed is indicated as a percentage of the maximum pump speed For the Centrifugal pump(s), Axial pump and Turbine pump, maximum speed is 2800 RPM Therefore actual speed N = x% x 2800 RPM For the Gear pump, Flexible Impeller pump, Plunger pump and Diaphragm pump, maximum speed is 1400 RPM Therefore actual speed N = x% x 1400 RPM
Torque	T	Nm	The force which causes rotation of the motor/pump shaft Torque is measured in mNm and converted to Nm for the calculations (Divide by 1000)
Volume Flow Rate	Q	m^3/s	The volume flow rate produced by the pump(s). Measured in l/min and converted to m^3/s (Q=F/60000)
Static Head	H_s	m	System head change resulting from a change in static pressure between the pump inlet and pump outlet $H_s = \frac{(p_{out} - p_{in})}{\rho g}$

Velocity Head	H_v	m	System head change resulting from a change in flow velocity between the pump inlet and outlet $H_v = \frac{(V_{out} - V_{in})^2}{2g}$ where V_{in} = fluid velocity at inlet in m/s V_{out} = fluid velocity at outlet in m/s Note: On C3-MKII the working fluid is incompressible and the inlet and outlet pipework have the same cross sectional area so the change in flow velocity is negligible and hence $H_v \approx 0$.
Elevation Head	H_e	m	System head change resulting from a difference in elevation between the sensors at the inlet and outlet of the pump. These positions are fixed for the C3-MKII and hence the value of H_e is constant for any given pump. H_e Centrifugal pump(s) = 0.440 m H_e Gear pump = 0.040 m H_e Axial flow pump = 0.170 m H_e Flexible impeller pump = 0.440 m H_e Turbine pump = 0.040 m H_e is ignored when testing the Diaphragm and Plunger pumps
Total Head	H_t	m	Total difference in system head between the inlet and outlet of the pump(s). $H_t = H_s + H_v + H_e$
Maximum Outlet Head	H_O	m	Maximum head at the outlet of the Cyclic pumps only (Diaphragm and Plunger pumps). $H_s = \frac{p_o}{\rho g}$
Mechanical Power Input	P_m	W	Mechanical power input to the impeller from the motor. $P_m = \frac{2\pi NT}{60}$ (N in RPM, T in Nm)

Hydraulic Power Output	P_h	W	Hydraulic power imparted to the working fluid by the impeller. $P_h = \rho g Q H_t$ or $\rho g Q H_o$ for Cyclic pumps
Overall Efficiency	E_o	%	The overall efficiency is an indication of the proportion of the power input to the pump from the motor that is transferred as useful work to the working fluid. $E_o = 100\% \times \frac{\text{Hydraulic power absorbed}}{\text{Mechanical power supplied}}$ $E_o = 100 \times \frac{P_h}{P_m} \%$
Volumetric Efficiency	E_v	%	Positive displacement pumps have a theoretical ideal volume of fluid which they can pump in a single rotation of the impeller(s) or single cycle of the plunger / diaphragm. The volumetric efficiency is an indication of the losses in the pump due to internal leakage / leakage past ball valves etc. (the losses usually increase with pressure) $E_v = 100\% \times \frac{\text{Actual volume flow rate}}{\text{Ideal volume flow rate}}$ $E_v = 100 \times \frac{Q}{Q_{ideal}} \%$

The relevant measurement sensors for each pump are described in the teaching exercises as well as in the pump specifications section (see page 26).

6.2 Table – Change in Density of Water with Temperature

The following table lists the density of pure water at different temperatures. If a thermometer is not available then the approximate ambient temperature should be assumed. Any error in the actual density will be small and will not seriously affect the performance characteristics obtained.

Temperature	**Density**
°C	**Kg/m^3**
4	999.9
6	999.9
8	999.8
10	999.7
12	999.5
14	999.2
16	998.9
18	998.6
20	998.2
22	997.8
24	997.3
26	996.8
28	996.2
30	995.6
32	995.0
34	994.4
36	993.7
38	993.0
40	992.2
42	991.4
44	990.6
46	989.8
48	988.9
50	988.0