TVET CURRICULUM DEVELOPMENT, ASSESSMENT AND CERTIFICATION COUNCIL (TVET CDACC)

Qualification Code	**:**	071606T4MCT
Qualification	**:**	Mechatronics Technician Level 6
Unit Code	**:**	ENG/OS/MC/CC/07/6
Unit of Competency	**:**	Apply Fluid Mechanics Principles

WRITTEN ASSESSMENT ASSESSOR'S GUIDE

INSTRUCTIONS TO ASSESSOR

1. Marks for each question are indicated in the brackets.
2. Answers provided are model answers.

SECTION A: (40 MARKS)

1. List two reciprocating pumps classified according to:
   a. Contact of water (2 Marks)
      i. ***Single-acting pump***
      ii. ***Double-acting pump***

(Award 1 mark for each correct response)

   b. Number of cylinders provided (2 Marks)
      i. ***Single cylinder pump***
      ii. ***Double cylinder pump***
      iii. ***Triple cylinder pump***

(Award 1 mark for each correct response, any 2)

2. What are the two methods of performing dimensional analysis? (2 Marks)
   i. ***Rayleigh Method.***
   ii. ***Buckingham π-Method***

(Award 1 mark for each correct response)

3. State three properties of a fluid (3 Marks)
   i. ***Density.***
   ii. ***Viscosity.***
   iii. ***Temperature.***
   iv. ***Pressure.***
   v. ***Specific Volume.***

(Award 1 mark for each correct response, any 3)

4. Outline four main parts of a centrifugal pump (4 Marks)
   i. ***Impeller***
   ii. ***Casing***
   iii. ***Delivery pipe***
   iv. ***Suction pipe with a foot valve and a strainer***

(Award 1 mark for each correct response)

5. State three types of impellers found in centrifugal pump (3 Marks)
   i. ***Open impeller***
   ii. ***Semi-closed impeller***

iii. ***Closed impeller***

(Award 1 mark for each correct response)

6. State the principle of homogeneity in dimensional method? (2 Marks)

Principle of Homogeneity states that dimensions of each of the terms of a dimensional equation on both sides should be the same

(Award 2 marks for the correct statement)

7. Outline two important functions of a multistage pump (2 Marks)
   i. ***To produce a high head***
   ii. ***To discharge a large quantity of liquid***

(Award 1 mark for each correct response)

8. What are the three fundamental dimensions of model analysis? (3 Marks)
   i. ***Length***
   ii. ***Mass***
   iii. ***Time***

(Award 1 mark for each correct response)

9. State two methods of calculating major losses in fluids moving through pipes (2 Marks)
   i. ***Darcy-weisbach formula***
   ii. ***Chezy's formula***
10. Name the three efficiencies of a centrifugal pump (3 Marks)
   i. ***Manometric efficiency***
   ii. ***Mechanical efficiency***
   iii. ***Overall efficiency***

(Award 1 mark for each correct response)

11. Outline four factors which affect viscosity in fluids (4 Marks)
   i. ***Temperature***
   ii. ***Chemical Composition***
   iii. ***Colloid Systems***
   iv. ***Colloid Systems***

(Award 1 mark for each correct response, any 4)

12. State four types of flows in fluid mechanics (4 Marks)

i. ***Steady and unsteady flow.***
ii. ***Uniform and non-uniform flow.***
iii. ***Laminar and turbulent flow.***
iv. ***Compressible and incompressible flow.***
v. ***Rotational and irrotational flow.***

(Award 1 mark for each correct response, any 4)

13. List four advantages of reciprocating pump over centrifugal pumps (4 Marks)

i. ***Reciprocating pump can deliver the required flow rate very precisely.***
ii. ***It gives a continuous rate of discharge.***
iii. ***It can deliver fluid at very high pressure.***
iv. ***No priming is needed in the reciprocating pump.***
v. ***Efficiency of a reciprocating pump is 10% to 20% greater than the efficiency of a centrifugal Pump.***

(Award 1 mark for each correct response, any 4)

SECTION B: (60 MARKS)

14.

a. Define 'slip' as used in reciprocating pumps (1 Mark)

It is the difference between the theoretical discharge and actual discharge of the pump

(Award 1 mark for the correct response)

b. State the reasons that causes negative slip in reciprocating pumps (3 Marks)

i. The delivery pipe is short
ii. Suction pipe is long
iii. The pump is running at high speed

(Award 1 mark for each correct response)

c. The cylinder bore diameter of a single-acting reciprocating pump is 150 mm and its stroke is 300 mm. the pump runs at 50 r.p.m. and lifts water through a height of 25 m. the delivery pipe is 22 m long and 100 mm in diameter. Find the theoretical discharge and the theoretical power required to run the pump. If the actual discharge is 4.2 litres/s, find the percentage slip. Also determine the acceleration head at the beginning and middle of the delivery stroke. (16 Marks)

(iii) The percentage slip

The percentage slip is given by,

$$\% \text{ slip} = \left(\frac{Q_{th} - Q_{act}}{Q_{th}}\right) \times 100 = \left(\frac{4.4175 - 4.2}{4.4175}\right) \times 100 = \mathbf{4.92\%. \ Ans.}$$

(iv) Acceleration head at the beginning of delivery stroke.

The acceleration head in the delivery pipe is given by equation (20.15) as :

$$h_{ad} = \frac{l_d}{g} \times \frac{A}{a_d} \omega^2 r \times \cos\theta$$

where a_d = Area of delivery pipe $= \frac{\pi}{4} \times (0.1)^2 = 0.007854$

$$\omega = \text{Angular speed} = \frac{2\pi N}{60} = \frac{2\pi \times 50}{60} = 5.236$$

$$r = \text{Crank radius} = \frac{L}{2} = \frac{0.3}{2} = 0.15 \text{ m}$$

Solution. Given :

Dia. of cylinder, $D = 150 \text{ mm} = 0.15 \text{ m}$

$\therefore$ Area, $A = \left(\frac{\pi}{4}\right) \times 0.15^2 = 0.01767 \text{ m}^2$

Stroke, $L = 300 \text{ mm} = 0.3 \text{ m}$

Speed of pump, $N = 50$ r.p.m.

Total height through which water is lifted,

$H = 25 \text{ m}$

Length of delivery pipe, $l_d = 22 \text{ m}$

Diameter of delivery pipe, $d_d = 100 \text{ mm} = 0.1 \text{ m}$

Actual discharge, $Q_{act} = 4.2 \text{ litres/s} = \frac{4.2}{1000} \text{ m}^3\text{/s} = 0.0042 \text{ m}^3\text{/s}.$

(*i*) *Theoretical discharge* (Q_{th})

Theoretical discharge for a single-acting reciprocating pump is given by equation (20.1), as

$$Q_{th} = \frac{A \times L \times N}{60} = \frac{0.01767 \times 0.3 \times 50}{60} = 0.0044175 \text{ m}^3\text{/s}$$

$$= 0.0044175 \times 1000 \text{ litres/s} = \mathbf{4.4175 \text{ litres/s. Ans.}}$$

(*ii*) *Theoretical power* (P_t)

Theoretical power is given by, $P_t = \frac{\text{(Theoretical weight of water lifted/s)} \times \text{Total height}}{1000}$

$$= \frac{\rho \times g \times Q_{th} \times H}{1000}$$

$$= \frac{1000 \times 9.81 \times 0.0044175 \times 25}{1000} \qquad (\because Q_{th} = 0.0044175 \text{ m}^3\text{/s})$$

$$= \mathbf{1.0833 \text{ kW. Ans.}}$$

$$\therefore \qquad h_{ad} = \frac{22}{9.81} \times \frac{0.01767}{0.007854} \times 5.236^2 \times 0.15 \times \cos\theta = 20.75 \times \cos\theta$$

At the beginning of delivery stroke, $\theta = 0°$ and hence $\cos\theta = 1$

$$\therefore \qquad h_{ad} = \mathbf{20.75 \text{ m. Ans.}}$$

(*v*) *Acceleration head at the middle of delivery stroke.*

At the middle of delivery stroke, $\theta = 90°$ and hence $\cos\theta = 0$.

$$\therefore \qquad h_{ad} = 20.75 \times 0 = \mathbf{0. \text{ Ans.}}$$

(Award 16 marks for the correct working, steps with the correct answer)

15.

a. A centrifugal pump having outer diameter equal to two times the inner diameter and running at 1000 r.p.m. works against a total head of 40 m. the velocity of flow through the impeller is constant and equal to 2.5 m/s. the vanes are set back at an angle of 40^{o} at outlet. If the outer diameter of the impeller is 500 mm and the width at outlet is 50 mm, determine:

i. Vane angle at inlet

ii. Work done by the impeller on water per second

iii. Manometric efficiency

(14 Marks)

Speed, $N = 1000$ r.p.m.

Head, $H_m = 40$ m

Velocity of flow, $V_{f_1} = V_{f_2} = 2.5$ m/s

Vane angle at outlet, $\phi = 40°$

Outer dia. of impeller, $D_2 = 500$ mm $= 0.50$ m

Inner dia. of impeller, $D_1 = \dfrac{D_2}{2} = \dfrac{0.50}{2} = 0.25$ m

Width at outlet, $B_2 = 50$ mm $= 0.05$ m

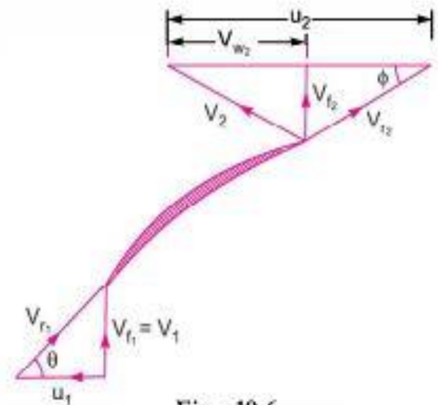

Fig. 19.6

Tangential velocity of impeller at inlet and outlet are

$$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.25 \times 1000}{60} = 13.09 \text{ m/s}$$

and $$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.50 \times 1000}{60} = 26.18 \text{ m/s.}$$

Discharge is given by, $Q = \pi D_2 B_2 \times V_{f_2} = \pi \times 0.50 \times .05 \times 2.5 = 0.1963 \text{ m}^3/\text{s}$.

(*i*) **Vane angle at inlet** (θ).

From inlet velocity triangle $\tan\theta = \dfrac{V_{f_1}}{u_1} = \dfrac{2.5}{13.09} = 0.191$

$\therefore$ $\theta = \tan^{-1} .191 = 10.81°$ or **10° 48′**. **Ans.**

(*ii*) **Work done by impeller on water per second** is given by equation (19.2) as

$$= \frac{W}{g} \times V_{w_2} u_2 = \frac{\rho \times g \times Q}{g} \times V_{w_2} \times u_2$$

$$= \frac{1000 \times 9.81 \times 0.1963}{9.81} \times V_{w_2} \times 26.18 \qquad \ldots(i)$$

But from outlet velocity triangle, we have

$$\tan\phi = \frac{V_{f_2}}{u_2 - V_{w_2}} = \frac{2.5}{(26.18 - V_{w_2})}$$

$$\therefore \quad 26.18 - V_{w_2} = \frac{2.5}{\tan\phi} = \frac{2.5}{\tan 40°} = 2.979$$

$$\therefore \quad V_{w_2} = 26.18 - 2.979 = 23.2 \text{ m/s.}$$

Substituting this value of V_{w_2} in equation (*i*), we get the work done by impeller as

$$= \frac{1000 \times 9.81 \times 0.1963}{9.81} \times 23.2 \times 26.18$$

$$= \mathbf{119227.9 \text{ Nm/s.}} \quad \textbf{Ans.}$$

(*iii*) **Manometric efficiency** (η_{man}). Using equation (19.8), we have

$$\eta_{man} = \frac{gH_m}{V_{w_2} u_2} = \frac{9.81 \times 40}{23.2 \times 26.18} = 0.646 = \mathbf{64.4\%}. \textbf{ Ans.}$$

(Award 14 marks for the correct working, steps with the correct answer)

b. An oil of specific gravity of 0.7 is flowing through a pipe of diameter 300 mm at the rate of 500 litres/s. find the head loss due to friction and power required to maintain the flow for a length of 1000 m. take v=0.29 stokes (6 Marks)

Sp. gr. of oil, $S = 0.7$

Dia. of pipe, $d = 300 \text{ mm} = 0.3 \text{ m}$

Discharge, $Q = 500 \text{ litres/s} = 0.5 \text{ m}^3\text{/s}$

Length of pipe, $L = 1000 \text{ m}$

Velocity, $V = \dfrac{Q}{\text{Area}} = \dfrac{0.5}{\frac{\pi}{4}d^2} = \dfrac{0.5 \times 4}{\pi \times 0.3^2} = 7.073 \text{ m/s}$

$\therefore$ Reynolds number, $R_e = \dfrac{V \times d}{\nu} = \dfrac{7.073 \times 0.3}{0.29 \times 10^{-4}} = 7.316 \times (10)^4$

$\therefore$ Co-efficient of friction, $f = \dfrac{.079}{R_e^{1/4}} = \dfrac{0.79}{\left(7.316 \times 10^4\right)^{1/4}} = .0048$

$\therefore$ Head lost due to friction, $h_f = \dfrac{4 \times f \times L \times V^2}{d \times 2g} = \dfrac{4 \times .0048 \times 1000 \times 7.073^2}{0.3 \times 2 \times 9.81} = 163.18 \text{ m}$

Power required $= \dfrac{\rho g \,.\, Q \,.\, h_f}{1000}$ kW

where ρ = density of oil $= 0.7 \times 1000 = 700 \text{ kg/m}^3$

$\therefore$ Power required $= \dfrac{700 \times 9.81 \times 0.5 \times 163.18}{1000}$ = **560.28 kW. Ans.**

(Award 6 marks for the correct working, steps with the correct answer)

16.

a. A horizontal pipe line 40 m long is connected to a water tank at one end and discharges freely into the atmosphere at the other end. For the first 25 m of its length from tank, the pipe is 150 mm diameter is suddenly enlarged to 30 mm. the height of water of water level in the tank is 8 m above the centre of the pipe. Considering all losses of head which occur, determine the rate of flow. Take f=0.01 for both sections of the pipes. (16 Marks)

Total length of pipe, $L = 40 \text{ m}$

Length of 1st pipe, $L_1 = 25 \text{ m}$

Dia. of 1st pipe, $d_1 = 150 \text{ mm} = 0.15 \text{ m}$

Length of 2nd pipe, $L_2 = 40 - 25 = 15 \text{ m}$

Dia. of 2nd pipe, $d_2 = 300 \text{ mm} = 0.3 \text{ m}$

Height of water, $H = 8 \text{ m}$

Co-efficient of friction, $f = 0.01$

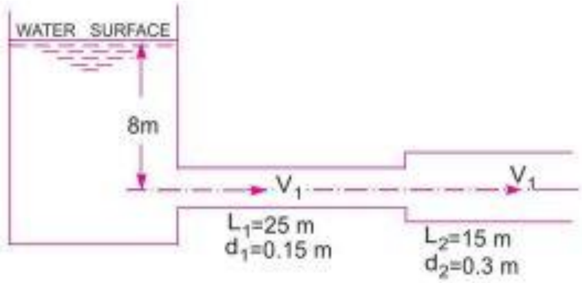

Fig. 11.5

$$0 + 0 + 8 = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + 0 + \text{all losses}$$

or
$$8.0 = 0 + \frac{V_2^2}{2g} + h_i + h_{f_1} + h_e + h_{f_2} \qquad ...(i)$$

where h_i = loss of head at entrance = $0.5\,\frac{V_1^2}{2g}$

h_{f_1} = head lost due to friction in pipe 1 = $\frac{4 \times f \times L_1 \times V_1^2}{d_1 \times 2g}$

h_e = loss head due to sudden enlargement = $\frac{(V_1 - V_2)^2}{2g}$

h_{f_2} = Head lost due to friction in pipe 2 = $\frac{4 \times f \times L_2 \times V_2^2}{d_2 \times 2g}$

But from continuity equation, we have

$$A_1V_1 = A_2V_2$$

$$\therefore \qquad V_1 = \frac{A_2V_2}{A_1} = \frac{\frac{\pi}{4}d_2^2 \times V_2}{\frac{\pi}{4}d_1^2} = \left(\frac{d_2}{d_1}\right)^2 \times V_2 = \left(\frac{0.3}{.15}\right)^2 \times V_2 = 4V_2$$

Substituting the value of V_1 in different head losses, we have

$$h_i = \frac{0.5\,V_1^2}{2g} = \frac{0.5\times(4V_2)^2}{2g} = \frac{8V_2^2}{2g}$$

$$h_{f_1} = \frac{4\times 0.01\times 25\times(4V_2)^2}{0.15\times 2\times g}$$

$$= \frac{4\times .01\times 25\times 16}{0.15}\times\frac{V_2^2}{2g} = 106.67\,\frac{V_2^2}{2g}$$

$$h_e = \frac{(V_1-V_2)^2}{2g} = \frac{(4V_2-V_2)^2}{2g} = \frac{9V_2^2}{2g}$$

$$h_{f_2} = \frac{4\times .01\times 15\times V_2^2}{0.3\times 2g} = \frac{4\times .01\times 15}{0.3}\times\frac{V_2^2}{2g} = 2.0\times\frac{V_2^2}{2g}$$

Substituting the values of these losses in equation (i), we get

$$8.0 = \frac{V_2^2}{2g} + \frac{8V_2^2}{2g} + 106.67\,\frac{V_2^2}{2g} + \frac{9V_2^2}{2g} + 2\times\frac{V_2^2}{2g}$$

$$= \frac{V_2^2}{2g}\,[1 + 8 + 106.67 + 9 + 2] = 126.67\,\frac{V_2^2}{2g}$$

$\therefore$ $$V_2 = \sqrt{\frac{8.0\times 2\times g}{126.67}} = \sqrt{\frac{8.0\times 2\times 9.81}{126.67}} = \sqrt{1.2391} = 1.113 \text{ m/s}$$

$\therefore$ Rate of flow, $Q = A_2\times V_2 = \frac{\pi}{4}\,(0.3)^2\times 1.113 = 0.07867\ \text{m}^3/\text{s}$ = **78.67 litres/s. Ans.**

(Award 16 marks for the correct working, steps with the correct answer)

b. List four factors that affect the fluid flow (4 Marks)

- ***i. The viscosity, density, and velocity of the fluid.***
- ***ii. Changes in the fluid temperature will change the viscosity & density of the fluid.***
- ***iii. The length, inner diameter, and in the case of turbulent flow, the internal roughness of the pipe.***
- ***iv. The position of the supply and discharge containers relative to the pump position.***
- ***v. The addition of rises & falls within the pipe layout.***

(Award 1 mark for each correct response, any 4)

17.

a. Find the head loss due to friction in a pipe of diameter 300 mm and length 50 m, through which water is flowing at a velocity of 3 m/s using:

i. Darcy formula

ii. Chezy's formula; for which C=60

(10 Marks)

Dia. of pipe, $d = 300 \text{ mm} = 0.30 \text{ m}$

Length of pipe, $L = 50 \text{ m}$

Velocity of flow, $V = 3 \text{ m/s}$

Chezy's constant, $C = 60$

Kinematic viscosity, $\nu = 0.01 \text{ stoke} = 0.01 \text{ cm}^2/\text{s}$

$= 0.01 \times 10^{-4} \text{ m}^2/\text{s}.$

(*i*) **Darcy Formula** is given by equation (11.1) as

$$h_f = \frac{4 \cdot f \cdot L \cdot V^2}{d \times 2g}$$

where 'f' = co-efficient of friction is a function of Reynolds number, R_e

But R_e is given by $R_e = \frac{V \times d}{\nu} = \frac{3.0 \times 0.30}{.01 \times 10^{-4}} = 9 \times 10^5$

$\therefore$ Value of $f = \frac{0.079}{R_e^{1/4}} = \frac{0.079}{\left(9 \times 10^5\right)^{1/4}} = .00256$

$\therefore$ Head lost, $h_f = \frac{4 \times .00256 \times 50 \times 3^2}{0.3 \times 2.0 \times 9.81} =$ **.7828 m. Ans.**

(*ii*) **Chezy's Formula.** Using equation (11.4)

$$V = C\sqrt{mi}$$

where $C = 60$, $m = \frac{d}{4} = \frac{0.30}{4} = 0.075 \text{ m}$

$\therefore$ $3 = 60\sqrt{.075 \times i}$ or $i = \left(\frac{3}{60}\right)^2 \times \frac{1}{.075} = 0.0333$

But $i = \frac{h_f}{L} = \frac{h_f}{50}$

Equating the two values of i, we have $\frac{h_f}{50} = .0333$

$\therefore$ $h_f = 50 \times .0333 =$ **1.665 m. Ans.**

(Award 10 marks for the correct working, steps with the correct answer)

b. A crude oil of viscosity 0.97 poise and relative density 0.9 is flowing through a horizontal circular pipe of diameter 100 mm and of length 10 m. calculate the difference of pressure at the two ends of the pipe, if 100 kg of the oil is collected in a tank in 30 seconds.

(10 Marks)

Solution. Given : $\mu = 0.97 \text{ poise} = \frac{0.97}{10} = 0.097 \text{ Ns/m}^2$

Relative density $= 0.9$

$\therefore$ ρ_0, or density, $= 0.9 \times 1000 = 900 \text{ kg/m}^3$

Dia. of pipe, $D = 100 \text{ mm} = 0.1 \text{ m}$

$L = 10 \text{ m}$

Mass of oil collected, $M = 100 \text{ kg}$

Time, $t = 30 \text{ seconds}$

Calculate difference of pressure or $(p_1 - p_2)$.

The difference of pressure $(p_1 - p_2)$ for viscous or laminar flow is given by

$$p_1 - p_2 = \frac{32\mu \bar{u} L}{D^2}, \text{ where } \bar{u} = \text{average velocity} = \frac{Q}{\text{Area}}$$

Now, mass of oil/sec $= \frac{100}{30}$ kg/s

$$= \rho_0 \times Q = 900 \times Q \qquad (\because \rho_0 = 900)$$

$$\therefore \quad \frac{100}{30} = 900 \times Q$$

$$\therefore \quad Q = \frac{100}{30} \times \frac{1}{900} = 0.0037 \text{ m}^3/\text{s}$$

$$\therefore \quad \bar{u} = \frac{Q}{\text{Area}} = \frac{.0037}{\frac{\pi}{4} D^2} = \frac{.0037}{\frac{\pi}{4} (.1)^2} = 0.471 \text{ m/s.}$$

For laminar or viscous flow, the Reynolds number (R_e) is less than 2000. Let us calculate the Reynolds number for this problem.

Reynolds number, $R_e{}^* = \frac{\rho V D}{\mu}$

where $\rho = \rho_0 = 900$, $V = \bar{u} = 0.471$, $D = 0.1$ m, $\mu = 0.097$

$$\therefore \quad R_e = 900 \times \frac{.471 \times 0.1}{0.097} = 436.91$$

As Reynolds number is less than 2000, the flow is laminar.

$$\therefore \quad p_1 - p_2 = \frac{32\mu \bar{u} L}{D^2} = \frac{32 \times 0.097 \times .471 \times 10}{(.1)^2} \text{ N/m}^2$$

$$= 1462.28 \text{ N/m}^2 = 1462.28 \times 10^{-4} \text{ N/cm}^2 = \mathbf{0.1462 \text{ N/cm}^2}. \textbf{ Ans.}$$

(Award 10 marks for the correct working, steps with the correct answer)