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OLLSCOIL NA hÉIREANN, GAILLIMH

THE NATIONAL UNIVERSITY OF IRELAND, GALWAY

WINTER EXAMINATIONS, 2000

2nd Year Industrial Engineering and Information Systems Examination

HYDRAULICS (EH 204)

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Attempt *any* **four** questions: (Time: 2 hours)

(The Handout of Tables and diagrams provided may be useful in one or more questions)

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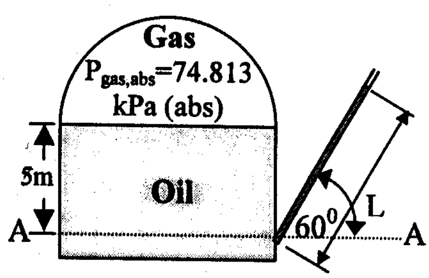
1. (a) Very *briefly*, what do you understand by each of the following terms;
absolute pressure, **gauge pressure,** **atmospheric pressure** ? *[1 mark]*

(b) Show that the **gauge pressure at depth** h below the open surface of a liquid at rest is $P_h = \rho g h$, where ρ is the mass density of the liquid and g the acceleration due to gravity. *[2 marks]*

(c) Taking the specific gravity (relative density) of mercury (Hg) as s = 13.6, the density of water as $\rho_{water} = 10^3 kgm^{-3}$ and the atmospheric pressure as $P_{atm} = 101.3\ kPa$, express the atmospheric **pressure head** in metres of
(i) mercury (ii) water. *[2 marks]*

(d) If the *atmospheric pressure* is $101.3 kPa$ (abs.) and the *absolute pressure* at a point Y below the static liquid surface in a water tank is $130.73\ kPa$ (abs.), how deep below the water surface is the point Y? *[2 marks]*

(e) (i) If, for the accompanying sketch, the *absolute pressure* of the gas *above* the oil in the sealed tank is $P_{gas,abs.} = 74.813\ kPa$ (abs.), what is the **absolute pressure in the tank at the level AA**, at depth $H_A = 5m$ *below the* oil surface?
Take the density of the oil as $\rho_{oil} = 900 kgm^{-3}$. *[1 mark]]*



(ii) **Determine also the length L to which the oil extends in the inclined pipe shown (not to scale) in the diagram,** the pipe being inclined at 60° to the horizontal, the entry to the pipe being located at the level AA. *[2 marks]*

2. (a) Show how the **Bernoulli equation for steady flow of an ideal fluid** can be used to derive an expression of the form

$$Q_{theoretical} = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gH}$$

for a **Venturi Meter** involving a **local constriction** of the pipe, from area A_1 at the inlet section to the area A_2 at the throat section of the meter, H being the drop in the piezometric head between the inlet and throat sections, g the acceleration due to gravity and K a constant. *[5 marks]*

(b) Explain, *in one sentence*, how the above theoretical expression can be modified, by using a constant **coefficient of discharge** (C_d), to give a corresponding expression for the **actual discharge** (Q_{actual}) for the flow of a **real (rather than ideal) fluid**, thereby facilitating the use of the equipment as a **discharge meter.** *[1 marks]*

(c) Explain, *very briefly*, how you verified the form of the expression for Q_{actual} and also determined the value of C_d for the **Venturi Meter in the Hydraulics Laboratory**. *[4 marks]*

3. (a) State the **Bernoulli equation for steady flow of an ideal fluid.** *[1 mark]*

(b) Show that, for an **ideal fluid**, the **discharge from a large reservoir** over a **sharp-edged rectangular weir** is given by the formula

$$Q_{theoretical} = \frac{2}{3} B \sqrt{2g}\, H^{\frac{3}{2}}$$

where B (in m) is the width of the weir, H (in m) is the difference in elevation between the free surface level in the reservoir and the weir crest, g is the acceleration due to gravity (in m^2s^{-1}) and $Q_{theoretical}$ has the units of m^3s^{-1}. *[3 marks]*

(c) (i) Describe *very briefly* how, using the **following experimental results,**

Head $H(m)$	0.05	0.10	0.15	0.20	0.25	0.30
Discharge Q (m^3s^{-1})	4.55×10^{-3}	12.88×10^{-3}	23.65×10^{-3}	36.42×10^{-3}	50.90×10^{-3}	66.91×10^{-3}

for a weir of width B = 0.3 m, the $Q_{theoretical}$ expression can be modified to give the **actual discharge** Q_{actual} for a real fluid. *[2 marks]*

(ii) Using the above data, *check* if the **coefficient of discharge** for the above weir has the value Cd = 0.65. *[3 marks]*

(iii) State the modification of the above weir formula, to take account of the upstream **'velocity of approach'** to the weir, if the weir is to be installed as a **discharge meter** in an **open channel.** *[1 mark]*

4. Part A : Answer *either* the following **Part A** *or* **Part B** ***(not both!).***

Suppose that an **open tank,** with **vertical side walls,** is **square in plan,** the side walls being of width B metres. If the depth of liquid in the tank is H metres, show that

(a) the **resultant hydrostatic thrust** (T) acting on each side wall is the force

$$T = \rho g A\bar{x} = \tfrac{1}{2}\rho g B H^2$$

where A = the submerged plane area, $\bar{x}$ is the depth to the centroid of A, ρ is the liquid density and g the acceleration due to gravity. *[4 marks]*

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(b) the corresponding **depth of the centre of pressure** is given by the expression

$$\bar{h} = \frac{I_{oo}}{A\bar{x}} = \frac{2^{nd} \text{ moment of area A about the liquid surface}}{1^{st} \text{ moment of area A about the liquid surface}}$$

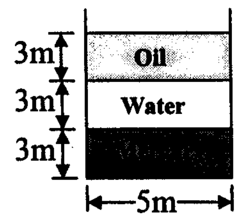
$$= \frac{BH^3/3}{BH^2/2} = \tfrac{2}{3}H \text{ for the case of the tank.}$$

[6 marks]

4. <u>Part B</u> : Answer *either* the above Part A *or* the following Part B *(not both!).*

If the tank referred to in Part A above has width B = 5m and contains **three liquids**, namely,

a 3m depth of **oil** (of relative density $s = 0.96$),
a 3m height of **water** (of density $\rho = 10^3 \text{ kg m}^{-3}$) and
a 3m height of **mercury** (of relative density $s = 13.6$),



calculate

(a) the **liquid pressure** (P_H) at depths H = 3m, 6m and 9m. *[3 marks]*

(b) the **resultant hydrostatic thrust** (T) acting on each wall of the tank. *[3 marks]*

(c) the **depth of the centre of pressure** ($\bar{h}$). *[4 marks]*

5. (a) In the context of **pipe flow**, explain *very briefly* what do you understand by the following terms :

laminar flow **turbulent flow** **Reynolds Number**
friction head loss and **Shock (form) head loss**

[1 mark]

(b) Crude oil, of density ρ = 860 kg m^{-3} and kinematic viscosity $\nu = 18.6 \times 10^{-6} m^2 s^{-1}$, ***flows down*** at the constant rate from one large open reservoir to another through a **pipeline having the following characteristics:**

Pipe	Length L(m)	Diameter D(m)	Absolute roughness k(m)
Pipe No. 1	600.0	0.10	0.03×10^{-3}
Pipe No. 2	500.0	0.20	0.06×10^{-3}

Denoting the sum of the **shock losses in a pipe** by $(\Sigma K)\frac{V_2^2}{2g} = \left[\frac{8(\Sigma K)}{\pi^2 g D^4}\right]Q^2$, and including the loss at the sudden expansion, take $(\Sigma K)_1 = 4.6125$ for pipe No. 1 and take $(\Sigma K)_2 = 6.75$ for pipe No. 2.

Assuming that the ***steady*** **difference between the reservoir oil surface levels** is H_s = 7.09 m, **check *fully* the following computer output solution for the discharge** *Q* in the pipes:

Pipe No.	Discharge (m^3s^{-1})	Velocity (ms^{-1})	Coefficient of Friction 'f'	Relative Roughness (k/D)	Reynolds No.	Flow Type
1	5.84345×10^{-3}	0.74401	0.04021	0.3×10^{-3}	4000	Turbulent (just!)
2	5.84345×10^{-3}	0.18600	0.03200	0.3×10^{-3}	2000	Laminar (just!)

where the Reynolds No. is $Re = \frac{\rho V D}{\mu} = \frac{VD}{\nu} = \frac{4Q}{\pi D \nu}$

[9 marks]

6. Crude oil, of density ρ = 860 kg m^{-3} and kinematic viscosity $\nu = (\mu/\rho) = 18.6 \times 10^{-6}$ m^2 s^{-1}, *flows down* from one open tank into another by means of a **straight vertical pipe** of length L = 10 m, diameter D = 0.01 m and absolute roughness $k = 0.03 \times 10^{-3}$ m. The entry to the pipe is "*bell-mouthed*" and a valve (K = 0.19) is fitted at mid-length. The bottom of the pipe is *well below* the oil surface level in the lower tank. Assuming that the pipe flows full and the entry (but not the exit) head loss is negligible and **assuming also that the flow is laminar, check** if

   (a) the **discharge for a steady oil surface level difference** of H = 12 m in the tanks is given by $Q = 0.1524 \times 10^{-3} m^3 s^{-1}$ *[5 marks]*

   (b) this **discharge is consistent with the assumption of laminar flow.** *[3 marks]*

   (c) the **ratio of the sum of the shock losses to the friction loss** is 0.0194. *[2 marks]*

7. (a) In the context of **pump-pipeline system analysis and pump selection,** what (*very briefly!*) do you understand by *each* of the following terms;

   manometric head-discharge curve, efficiency-discharge curve and **system curve** ?

   (b) **A constant-speed pump, having the manometric head-discharge relation** $H_p = AQ^2 + BQ + C$, for Q in litres per second and H_P in metres, where A = -0.0017, B = - 0.4500 and C = 60.3289
   (as determined by non-linear regression using empirical data for the pump)
   is installed in a pumping station for the purpose of delivering sewage to a settling tank through a 0.2 m diameter µPVC pipeline, 2.5 km in length, the static lift involved being $H_s = 15.0$ m.

   The *effective* absolute roughness of the pipe is $k = 0.15 \times 10^{-3}$ m, the kinematic viscosity of the sewage is taken as $\nu = (\mu / \rho) = 1.14 \times 10^{-6}$ $m^2 s^{-1}$ and an allowance is made for form (i.e. shock) losses amounting to $(\Sigma K)V^2/2g = 10.0\ V^2/2g$.

   The **pipe system curve data, and the pump characteristics** (manometric-head/discharge and efficiency/discharge data), are tabulated in Tables A and B.

Table A: Data for the pipe system curve, for a static head lift H_S = 15.00m.

Discharge (litre/sec)	Reynold's no.	Friction factor 'f'	Head loss (m)		Static head (m)	Pump manometric head (m)
			friction	shock		
0.05	279	0.03353	0.0001	0.0000	15.00	15.0001
15.25	85128	0.02184	3.2767	0.1200	15.00	18.3967
27.75	154904	0.02058	10.2215	0.3974	15.00	25.6189
31.00	173059	0.02040	12.6437	0.4960	15.00	28.1397
37.46	209107	0.02011	18.2032	0.7241	15.00	33.9272
41.89	233836	0.01996	22.5898	0.9055	15.00	38.4953
62.50	348884	0.01951	49.1652	2.0156	15.00	66.1809
77.40	432057	0.01932	74.6700	3.0912	15.00	92.7613
81.00	452153	0.01929	81.6237	3.3855	15.00	100.0092
97.87	546352	0.01915	118.3225	4.9431	15.00	138.2656

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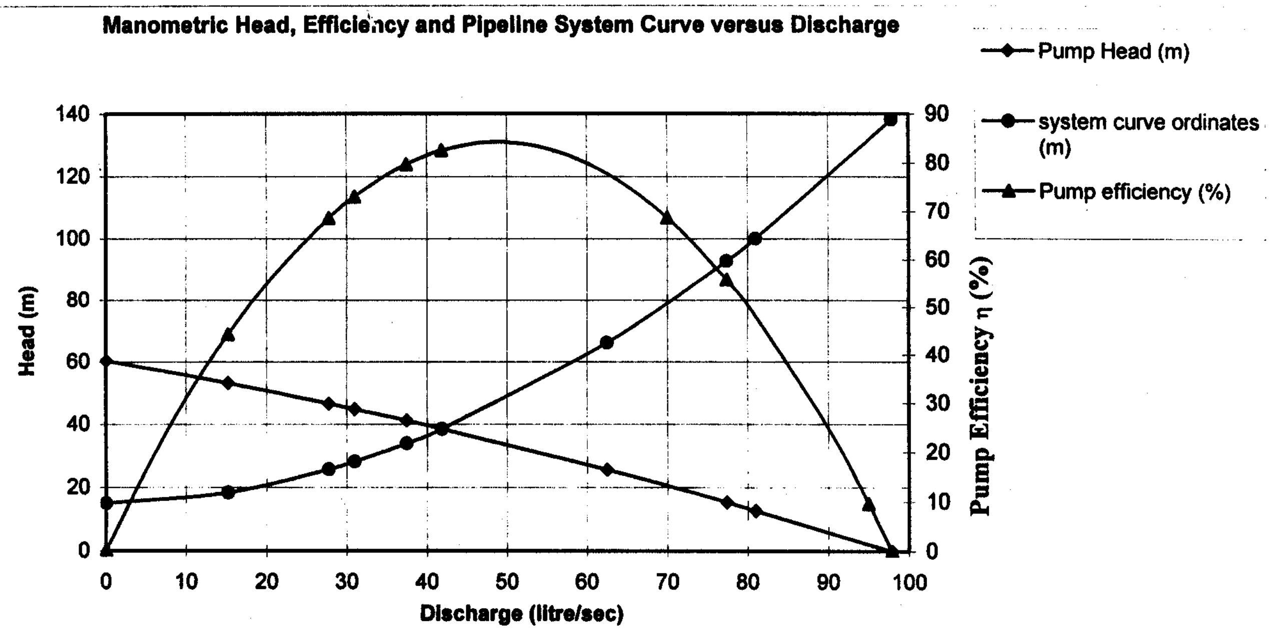
Table B : The Pump Characteristics and the Pipeline System Ordinates:

Discharge (litre/sec)	0.05	15.25	27.75	31.00	37.46	41.89	62.50	77.40	81.00	97.87
Pump Manometric Head (m)	60.3064	53.0711	46.5323	44.7439	41.0864	38.4953	25.5633	15.3146	12.7252	0.0000
System Curve Ordinates (m)	15.0002	18.3967	25.6189	28.1397	33.9272	38.4953	66.1809	92.7613	100.0092	138.2656
Pump Efficiency η (%)	0.17	44.35	68.50	72.98	79.66	82.55	77.83	55.78	48.11	0.00

These data are also shown plotted in the accompanying graph.



Note that a separate version of the accompanying figure is provided with this Examination Paper for submission with your Examination Answer Book.

(a) Using the **enlarged version of the above Figure** provided separately with this examination question paper, determine ***graphically*** the **discharge** Q in the pipe and the **pump head** H_P delivered to the pipeline. *[2 marks]*

(c) **Check analytically** your solution for the **discharge Q** in the pipe. *[3 marks]*

(d) **Estimate the power consumption** (in watts) **of the pump.** *[5 marks]*

Note that a separate version of the figure for Question No. 7 is provided with this Examination Paper for submission with your Examination Answer Book.