PH-203

Vacuum Sciences & Techniques...

End Semester Assignment

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Question 1:-

Answer 1:- Jet Pump is an integral part of the petrochemical and edible Oil industry:

In Petrochemical Industry

→ Low maintanence, reliability and high accuracy makes them accessible and available for different process at different times.

→ As jet pumps do not have movable parts, the unnecessary heat can be reduced ~~which~~ which otherwise could result in explosion

→ Major suction flows to the ~~[illegible]~~ time of 2 to 3 million m^3/h with at suction pressure of under 50 mbar cann't be created so accurately with other pumps.

In Oil Industry:

→ Low maintainance, reliability and high accuracy makes them more accessible.

→ They are used to refine and depolarise edible oil.

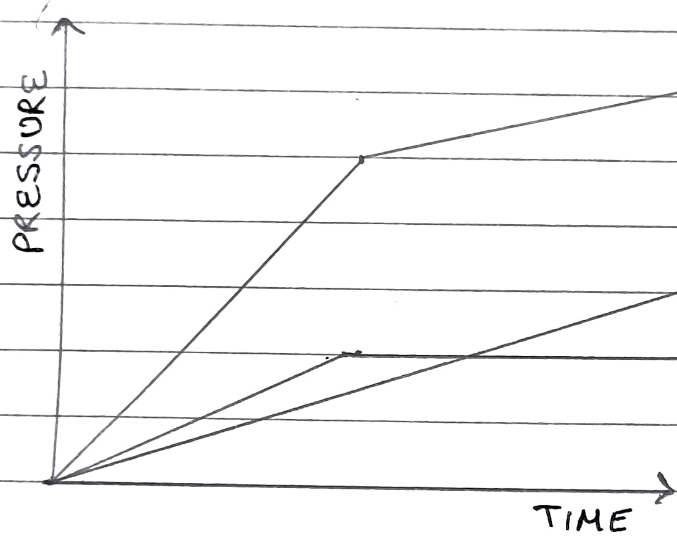
→ They effitevely remove the water vapours.

→ They are used in combination of mechanical pumps to operate in the factory for operations like bleaching, drying etc.

Question 2:-

Answer 2: The lack detection in vacuum chamber aims to localise a leak and determine the total or local rate.

Ideally, a vacuum chamber should maintain the low pressure once the vacuum pumps are switched off. However, the pressure in a real system rises with time: Leaks decrease the efficiency of the system.



(Pressure increase due to various factors)

Depending on the size of leak, various methods can be used. eg

1. Pressurized Soap Bubble Test
2. Flexible Tape technique
3. Ultrasonic detector
4. Helium leak detector
5. Krypton 85 test
6. Foam - spray test

All the methods of vacuum leak detection are pretty good but one method which is the most accurate is the "Helium Leak Detection".

HELIUM LEAK DETECTION :

It is also known as a Mass spectrometer Leak Detector. The tracer gas, helium, is introduced to a test part that is connected to the leak detector. The helium leaking through the test part enters through the system and this partial pressure is measured and results are displayed on a meter.

There are two main parts to leak test parts using helium : vacuum testing (outside in) and pressure testing (inside-out)

Question 3:-

Answer 3:-

Given: Density of oil $\rho = 1000\ Kg/m^3$

Initial pressure of pump (P_i) = 800 Torr = 800×133.32 Pa = 106657.92 Pa

Final pressure of pump (P_f) = 2×10^{-3} Torr = $2 \times 10^{-3} \times 133.32$ Pa = 0.266 Pa

To find: Jet velocity

As we know, the pumps follows the Bernoulli's equation:

$$P_o + \rho g h + \frac{1}{2}\rho v_o^2 = \text{constant}$$

Assumptions
1) jet velocity v_o
2) initial velocity $= 0$
3) height of the system is same throughout.

$\Rightarrow P_i + \cancel{\rho g h_i} + 0 = P_f + \cancel{\rho g h_f} + \frac{1}{2}\rho v_o^2$ (as height is same)

$$P_i = P_f + \frac{1}{2}\rho v_o^2$$

$$\frac{2(P_i - P_f)}{\rho} = v_o^2$$

$$v_o = \sqrt{\frac{2(P_i - P_f)}{\rho}}$$

$$= \sqrt{\frac{2(106657.92 - 0.266)}{1000}} = 14.605 \text{ m/s}$$

$\rightarrow$ $\boxed{\text{Jet Velocity} = 14.605 \text{ m/s}}$

Question 4:-

Answer 4:-

Given: length of cylinder = 0.3 m
diameter of cylinder = 0.25 m

Surface Area (A) $= \pi l d + \frac{\pi d^2}{4}$

$= \pi(0.3)(0.25) + \pi\frac{(0.25)^2}{4}$

$= 0.2847\, m^2$

The getter screen is sprayed with N_2 to cool it down and coated with deposited titanium providing a constant fresh surface

Given: for N_2; $s = 1$
$\bar{c} = 470$ m/s

Pumping speed $= sA\frac{\bar{c}}{4}$

$= 1 \times 0.2847 \times \frac{470}{4} = 33.45225\, m^3/s$

$=$ ~~33.45~~ 33452.25 L/s

$\boxed{\text{Pumping speed} \doteq 33452.25\ L/s}$

Question 5:-

Answer 5:-

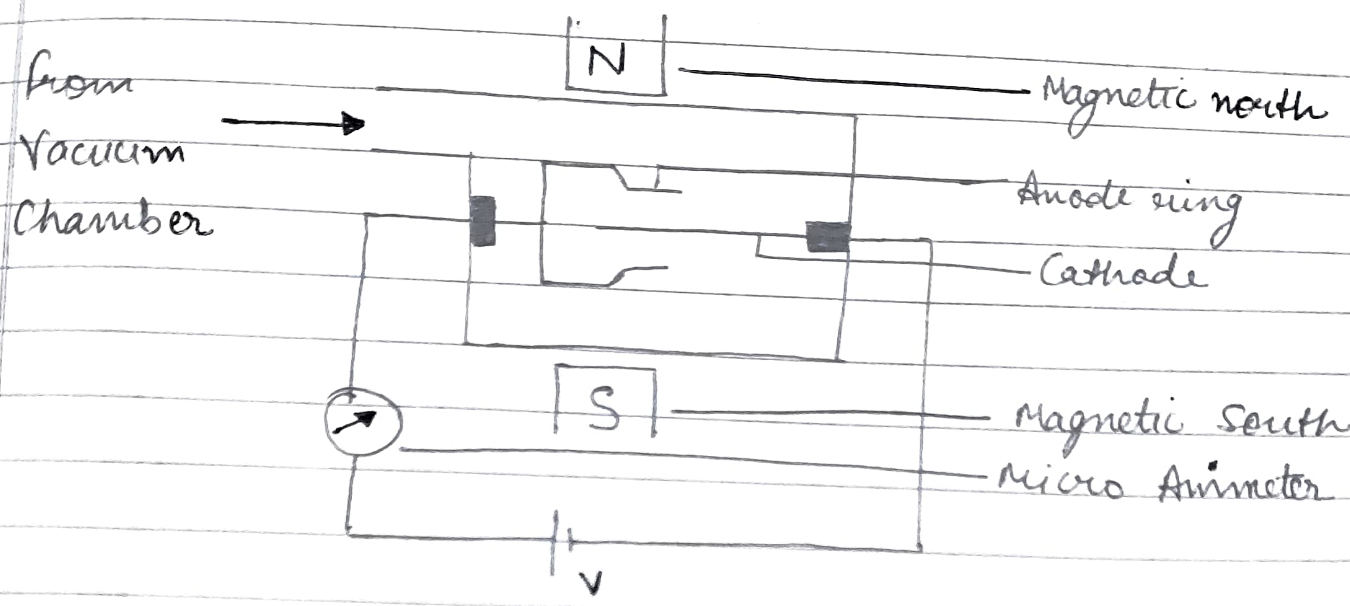
Vaccum Gauges can be classified as:

Vacuum Gauges
- Gas Independent
  - Liquid Wall
    - U Tube
    - McLeod
  - Elastic element
    - Diaphragm
      - Strain
      - Capacitance
    - Bourdon
    - Capsule/Dial
- Gas Dependent
  - Molecular Viscosity
    - Spinning Rotor
  - Energy Transfer
    - Pirani
    - Thermocouple
  - Ionisation
    - Hot cathode
      - Extractor
    - Cold cathode
      - Penning
      - Inverted magnetron

Based on type of measurement, vacuum gauges can be classified into 2 categories.
1) Mechanical (direct) vacuum gauges
2) Indirect measuring vacuum gauges.

1) Mechanical (direct) vacuum gauges:
They measure force exerted by gas or momentum transfer to measure pressure (direct). They measure pressure by using some form of mechanical deformation of tubes or diaphragms exposed to difference in pressure.
eg. Mcleod Gauge, Bourden tube, manometer, capacitance vacuum manometer, molecular momentum gauges, viscous friction gauges etc.

2) Indirect measuring Vacuum Gauges:
They measure some gas property from which pressure or number density can be obtained. The properties include ionisation rate, thermal conductivity, optical emission etc. They basically measure a physical effect which is proportional to vacuum pressure.
eg. Pirani gauges, hot cathode ionisation vacuum gauges and cold cathode ionisation gauges which include Penning gauge, inverted magnetron etc.



Penning Gauge Block Diagram.

⇒ For an Ion gauge

Given → $P = 10^{-10}$ Torr

Emission Current $(I_e) = 10^{-9}A$

Average Sensitivity $(S) = 2$

We know, Filament Current $(I_+) = SI_eP$

$$I_+ = SI_eP$$

$$I_+ = 2\times10^{-9}\times10^{-10}A$$

$$\rightarrow I_+ = 2\times10^{-19}A$$

⇒ $\boxed{\text{Filament Current} = 2\times10^{-19}A}$

Question 6:

Answer 6: The cryopump shown consists of the following parts:

1) First Stage Cryoarray: This part of the cryopump is the location where gases with high boiling point are removed through adsorption. It shields the second stage. Its temperature ranges between 50K to 80K and it is used primarily for condensing gases.

2) Second stage Cryoarray: This part of the cryopump is used to condense lower boiling point gases like N_2 and Ar ie light gases. Activated charcoal is used for cryosorption. The effective surface area provided by activated charcoal is about 8000 feet^2/cm^3. The temperature range is around 10K to 20K

3) First stage Can: This is an outer covering to first stage cryoarray and is cooled by liquid nitrogen. It provides radiant shielding to pump and is where gases with high boiling point condense.

4) Relief Valve: Cryopump can trap large amounts of gases due to which degassing and regassing is required. This leads to warming of the pump which may increase pressure to ~~simulate~~ mega pascal ranges. To prevent an

explosion in such cases, cryopumps are provided with relief valve which lets high pressure gases out.

5) Pump Body: The pump body is the external covering of the entire pump. It is there to prevent any leakage by providing a vacuum sealing which separates it from atmosphere to retain pressure.

6) Remote Temperature Monitor: It is used to monitor cryopump operating temperature. It works with the help of silicon diodes sensor to control temperature functions. It is necessary to control desired temperature for condensation.

7) Expander Module: In condensation by Joule Thompson expansion of gas for cooling. This provides for expansion of surface area. This helps in reaching the low temperature desired.

8) Regeneration Purge Tube: Gases can be redirected into the cryopump through this unit to break vacuum inside which is useful to warm the gases during degreasing/regreasing.

9) Hydrogen Vapour Bulb Thermometer: It is used for measuring the temperature of cooled surface along with remote temp. monitor by acting as a thermocouple.

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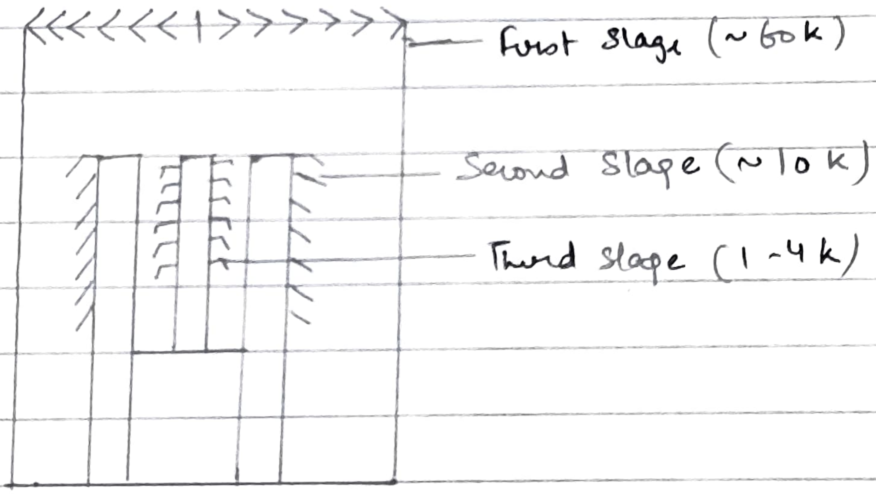
Adding A Third Stage Cryoarray:

A third stage cryoarray arrangement can be put below the second stage cryoarray. To maintain excessively low temperature required, we can use an excessive cooling mechanism like Rhodium cooling using liquid Helium which can bring the temperature as low as 1K - 4K. At these temperatures all gases may condense. The arrangement looks like this.



Cryoarray Arrangement.

Advantages:

1) Due to huge surface areas, larger amount of gas can be pumped out
2) Sticking probability may rise close to 1 due to such low temperatures. This pump arrangement may come in handy in fusion reactors where high vacuum and excessive cooling is needed.

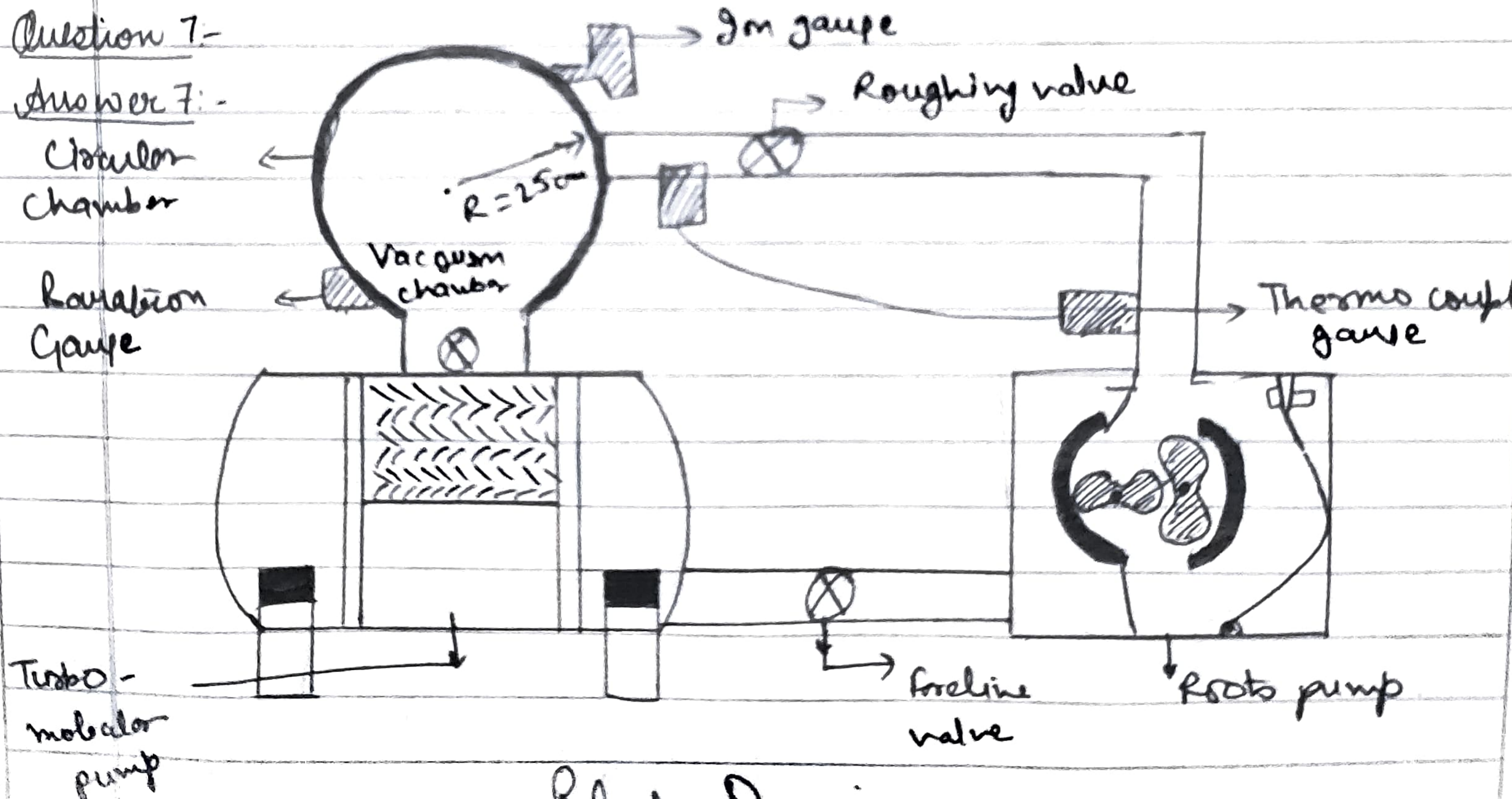
3. Gases with low boiling point like H_2 and He can also be trapped in a third stage and pressure of around 10^{-9} torr cand be achieved.

Disadvantages:

1. Large volumes of gases increase risk of explosion.
2. Regular maintenance must be needed to keep a check on cooling systems.
3. The arrangement is highly expensive because of the usage of expensive materials like Rhodium.

Question 7:-

Answer 7:-



Block Diagram.

As per the block diagram drawn:
The appropriate chamber should be a circular chamber with radius 25cm.
For the design, the components used are:

(A) PUMPS:

1. Turbomolecular Pump:
Turbomolecular pump is best suited for this since the volume of the chamber is small and high pumping speed may not be needed. It has the capacity to bring down the pressure to 10^{-8} Torr when used as a main pump. This pump is very clean and is comparitevely less expensive then the other pumps who perform the same function
A mechanical roughing and backing pump is required which gives a boost to the progess by effictively reducing initial pressure and make the air cleaner.

2. Roots Booster Pump:
It is a backing pump and it can easily lower the pressure to 10^{-4} mbar. This pump is advantageous because
1) it has long service life
2) it has not contacting part therefore less heat production is there.

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3. It does not require any lubrication therefore it provides clean and oil free pumping, which helps to increase efficiency and reduce pumping cost
4. It is very quiet and compact

(B) VALVES :

1. Foreline Valve:
This will be a mechanical valve present between the turbomolecular pump and scroll pump. This valve will prevent air flow from turbomolecular pump to scroll pump during roughing pre-evacuation.

2. Roughing Valve:
This valve will be a mechanical valve which will be used to control when the scroll pump must act as a roughing pump to pre-evacuate the chamber

3. Gate Valve:
This valve will be a mechanical valve which will be placed between the chamber and turbomolecular pump. This will control the pumping through turbomolecular pump.

4) Other Valves:

Other air / mechanical valves may be added in the system to have an even better control on gas flow.

(C) VACUUM GAUGES USED

We must use indirect gauges.

1. Ion gauge:

We will use an ion gauge to measure pressure within the vacuum chamber. A direct gauge cannot be used since the pressure will drop very low to 10^{-8} Torr. Ion Gauge measures high range of pressure and will measure even minor changes in pressure

2. Thermocouple Gauge

It will be used to measure pressure during pre-evacuation. ie the roughing stage.

3. Baratron Gauge

It will be used to identify when we need to start up our turbomolecular pump. A Baratron gauge measures true pressure (F/A) and can give an accurate idea when the turbomolecular pump must be started after roughing.

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SEQUENCE OF OPERATION

1. First of all we will ensure that are valves are intact and in working condition to provide sufficient Safety measures. Safety measures for pumps will also be seen.

2. The Intiation

→ Roughing valve will be opened and foreline and gate valve will be closed

→ Then we will start the root pump which will approximately reduce the pressure to 10^{-2} Torr.

→ ~~[illegible]~~ Now foreline valve and gate valve will be opened and roughing valve will be closed.

→ Thermocouple gauge will be used to measure the pressure in roughing stage while baratron gauge will continousely measure the pressure inside the vacuum chambers.

→ As soon as the pressure in the roughing pump will be acheived, the valves will be switched.

3. Final stage:

The turbomolecular pump will bring down the pressure to 10^{-8} torr. This pressure will be monitored by the ion gauge constantly. Once the required pressure is achieved. pumps and valves are close.

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TIME REQUIRED TO ACHIEVE VACUUM

⇒ Volume of sphere $= \frac{4}{3}\pi r^3$

$= 65476.19\ cm^3 = 65.48\ l$.

Time required ⇒

$$t = \frac{V}{S} \ln\left(\frac{P_i}{P_f}\right)$$

P_i = initial pressure
P_f = final pressure.

ROOTS PUMP (ROUGHING PUMP)

Roots vacuum pump can be operated at high speed due to the contactless operating methods. For this process, the ideal speed for the roots pump is 30 l/s

$s = 30\ l/s$, $P_i = 760$ torr, $P_f = 10^{-2}$ torr

$$t = \frac{V}{S} \ln\left(\frac{P_i}{P_f}\right)$$

$$t = \frac{65.48}{30} \ln\left(\frac{760}{10^{-2}}\right)$$

$t = 24.52$ seconds.

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TURBO MOLECULAR PUMP

$s = 100$ l/s $\quad P_i = 10^{-2}$ Torr $\quad P_f = 10^{-8}$ Torr.

$$t = \frac{v}{s} \ln\left(\frac{P_i}{P_f}\right)$$

$$t = \frac{65.48}{100} \ln\left(\frac{10^{-2}}{10^{-8}}\right)$$

$$t = 9.03 \text{ seconds}$$

$\Rightarrow$ Total time $= 24.52 + 9.03$
$= 33.55$ sec
≈ 34 sec.

But this time has to be combined with the startup time of the pump which accounts for 4 – 4:30 minutes for the process.

So, the total process takes upto 5 minutes in total to complete.

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MATERIAL USED FOR CHAMBER

For spherical chamber, we need a high vacuum created in the chamber. For this we first of all make sure that the tensile strength of the material used is high. For these reasons, and also because we need to look inside the chamber for the coating, we will have to use an optical material which can sustain in vacuum. We will use hard glass of proper tensile strength for the chamber.

CYLINDERICAL CHAMBER

Now, if we use a cylindrical chamber instead of a spherical chamber, keeping the volume of the chamber same. The dimensions will be

radius = 25 cm

height = ~~33.33cm~~ 33.33 cm.

We know, that when the amount of stress rises on the corners and edges, the tensile strength of the material that is used must be greater than the previous. The pumping speed may be reduced a bit if leaking of corners take place.

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Question 8:-

Answer 8:-

Correction in the question: The diameter increases not decreases from top to bottom

Answer:

1) The diameter of the caps increases from top to bottom in such a way that the annular pump surface between the individual conical system and the wall of the pump body decreases from one stage to the another.
The advantage of this is that the vapour expansion is less in the stages of the forline vacuum side and therfore a higher static pressure ratio is obtained. This results in the higher toleration of the pressure on the fore-vacuum side. Hence the first stage of the diffusion pump has the highest pumping speed and the lowest compression Ratio; which in turn allows the engine to higher engine loads on the pump and consumption of less amount of fuel.

2) If the diameter of the Caps is reversed:
→ If it is reversed, the result will be very less air intake and lower probability of diffusion because the intake area of the pump on top surface of the

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pump body will be reduced to a significant amount.

→ Now, as the higher diameter cap is at the top, the speed of nozzle jet is also heavily reduced because of the increase in the area of the cap. and decrease in the jet pressure. Therefore less momentum will be imparted on the incoming gas particles.

→ In diffusion pump, the top jet, becomes unstable at about 0.1 Pa, the middle at about 3 Pa, and the bottom and having the highest diameter at 40 Pa.
Reversing the cap order will ~~expode~~ ~~the~~ expose the smaller cap to high pressure, which may result in breaking of the pump

From all the points, we can say that either the pump may break down, pumping action may fail or pumping speed will be reduced significantly.

3) Length of AB is very high as compared to BC because of two reason.

a) To maintain a constant mass flow, the volume flow rate increases down the stages. The interiors are therefore kept in such a way that the surface between the two nozzles is decreasing stage by stage. Due to this we get low vapour expansion on fore vacuum side which accounts for higher pressure tolerance

b) The oil used in the oil pump have multiple range of molecular weights. Different components have different boiling points and vapour pressures. High vapour pressure components come out from lower nozzles and vice-versa.

For high velocity of gas coming out from the nozzle, it needs to be compressed first. Due to lower vapour pressure its compression chamber must be large to allow max compression.

4) Given: AB = 10 cm, BC = 5 cm, CD = 3 cm

AB is now reduced to 5 cm

An approximate formule of the pumping speed is

$S = 2\pi r r_0 u_2 x_{diff,2}$ r_0 = radius of nozzle

u_2 = velocity

$$x_{diff,2} = \sqrt{\frac{Dy}{u_2}}$$

D = diff. constant of vapour jet
y = length of AB
u_2 = velocity of jet.

from above equations we get $S \propto \sqrt{y}$

$S = K\sqrt{y}$, K being a constant.

Percent change $= \frac{S_{final} - S_{initial}}{S_{initial}} \times 100$

$= \frac{K\sqrt{5} - K\sqrt{10}}{K\sqrt{10}} \times 100$

$= -29.2893\%$.

⇒ There is a reduction is pumping speed of $\boxed{29.29\%}$

5) Advantages:

The advantages are that the pumping speed increases when expansion near the first and second stage is provided in the housing. This increases the contact length between the vapour jet and the pumped gas and thus, increases $x_{diff,2}$ which increases the pumping speed.

Dis advantages:

Now, since the bell shape has more surface area, it requires more cooling to prevent oil vapours to backflow.

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Question 9:-

Answer 9:- Given:

speed of turbo molecular pump = 1200 l/s

momentum of inertia = 1.1×10^{-2} Kg m^2

frequency (f) = 500 Hz

breaking time = 10^{-2} seconds.

As we know;

$$\text{Torque } (M) = 2\pi I \left(\frac{df}{dt}\right)$$

replacing $\frac{df}{dt}$ with $\frac{f}{t}$

$$M = \frac{2\pi \times 1.1 \times 10^{-2} \times 500}{10^{-2}}$$

$$\boxed{M = 3455.75 \text{ Kg } m^2/s^2}$$

Torque for given turbomolecular pump = 3455.75 Nm.

The Safety requirements to be taken care of before operating the pump are:

1. In turbo molecular pumps, the rotors rotate with a very high energy. Due to this, we should not try to immediately shut the rotation down. The breaking system must be calibrated & allowed to function such that the energy is brought down slowly and steadily. This helps prevent failure

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2. Since the pumping speed is greater than 500 lps ; a, a proper coolent must be used for inctance water.
3. Temperature sensors must be installed to monitor functioning during operation.
4. Overloading the pump and insertion of unwanted objects should always be avoided due to high energy which may cause failure.

IMPORTANCE OF TORQUE.

Torque holds an immense importance in the safety operation because it determines the amount of energy we need to provide the rotor of the pump to stop. Large amount of torque required may denote a bad pump design since pump must be shut down slowly and gradually to prevent failure.

→ Pumping speed (s)

S is proportional to the mean circumferential velocity i.e rotational speed and the inlet area A.

Taking the angle of the blades as α

$$s = \frac{1}{4} \times A \times v \times \sin(2\alpha)$$

Thus, pumping speed $\propto$ rotational speed.

Rotational speed $\propto$ Rotations per minute (RPM)

$\Rightarrow$ pumping speed $\propto$ RPM.

RPM is doubled

If RPM is doubled, pumping speed is double.
All the other changes might end up heating the rotors and blades which might in turn can cause other damages to the pump therefore a more advanced and better coolant will be required. The pump also might get unstable at higher speeds.

RPM is halved.

If RPM is halved, pumping speed is halved.
In this case the time required for evacuating the chambers might increase.

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