

Design of Machines and Mechanical Systems (PC-BTM711)

Session 27

Module 7: Design of Centrifugal Pump

Session Outcomes

- Introduce centrifugal and positive displacement pumps
- Perform design calculations for main components of centrifugal pump
 - Motor selection
 - Impeller shaft
 - Impeller body

SELF-STUDY

Pumps

Rotodynamic

Positive Displacement

Centrifugal (Radial)

Mixed flow (semi-axial)

Axial (Propeller)

Reciprocating

Rotary

Single stage

Multi stage

Volute

Diffuser

Closed

Semi-closed

Opened

Piston

Diaphragm

Gear

Screw

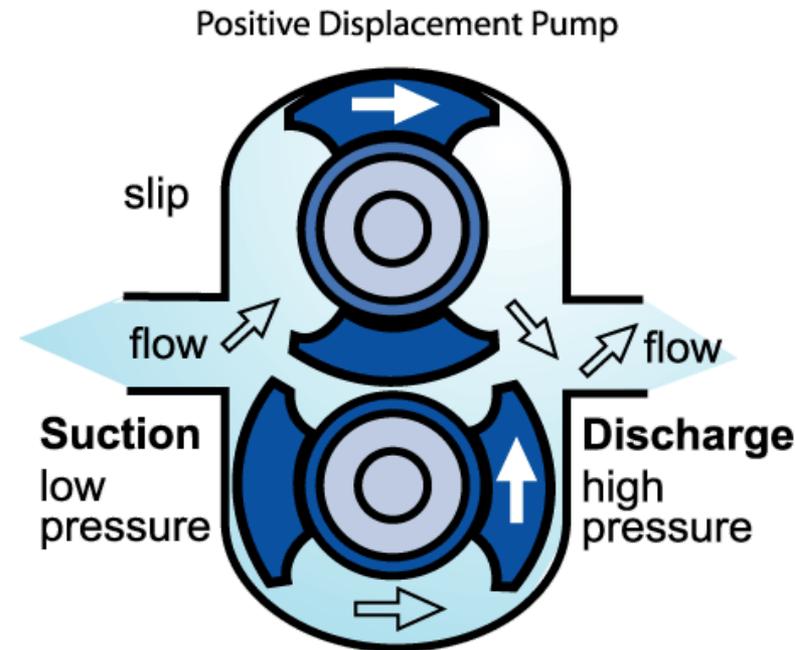
Sliding vane

Lobe

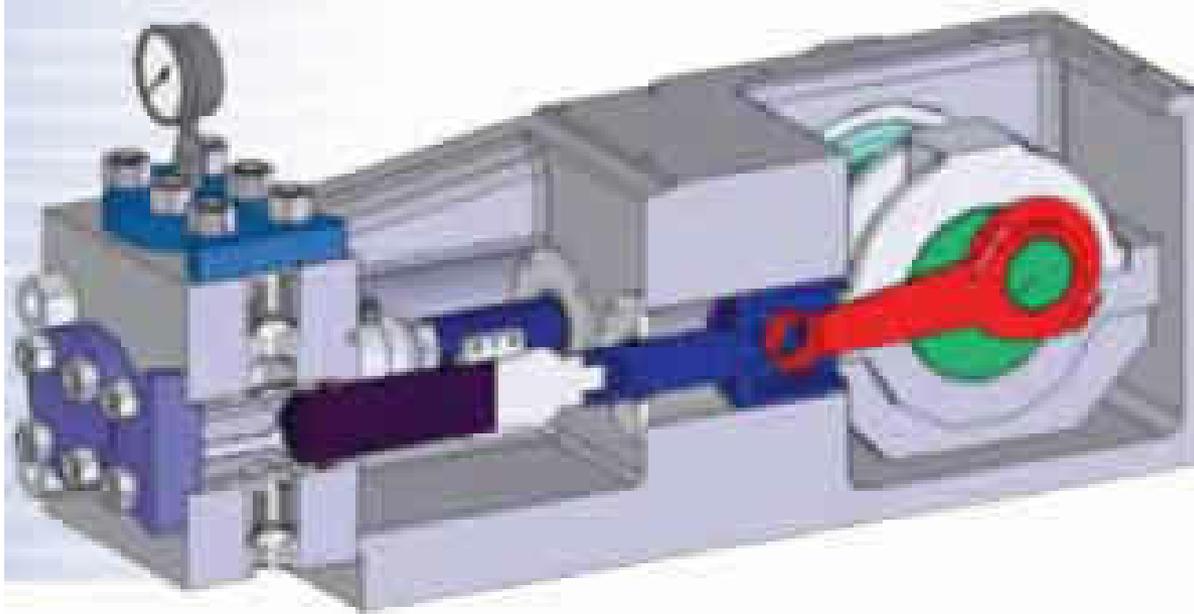
Peristaltic

Positive Displacement Pumps

- Liquid is allowed to flow into the pump as the cavity on the suction side expands and the liquid is forced out of the discharge as the cavity collapses.
- This principle applies to all types of positive displacement pumps.
- Lobe, Gear, Diaphragm, Screw, Vane, Peristaltic etc.



Reciprocating Piston Pump



Typical applications: Full range of liquid types including low viscosity chemicals, high particle content slurries and high viscosity materials.

Diaphragm Pump

- Using a diaphragm to push and pull the product through a chamber.
- Applications: Thick pulps, sewage, sludge, acid and alkaline solutions, oils.



Gear pumps

- For each revolution of an internal gear pump, (below) the gears have a fairly long time to come out of mesh allowing the spaces between gear teeth to completely fill and not cavitate.
- External gear pumps (below)
- Two gears come into and out of mesh to produce flow.
- Uses two identical gears rotating against each other.
- Reduced speeds with high-viscosity liquids results in greater efficiency.

Applications: Handle viscous as well as watery-type liquids.

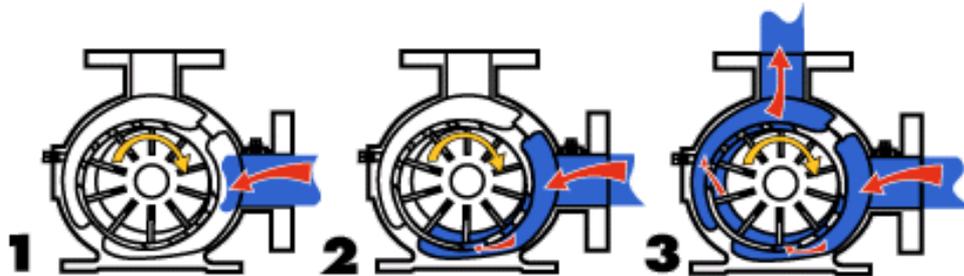
Screw pump



Applications: Transport of viscous fluids with lubricating properties. They are suited for a variety of applications such as fuel-injection, oil burners, hydraulics, fuel, lubrication, circulation, etc.

Vane Pumps

- Rotating eccentric cam principle
 - Not suitable for high viscosity products
- Used to move light products
 - Fuel
 - Crude
 - Water
 - dispersant



Lobe pump

- Lobe pumps can handle solid mix.
- A gentle pumping action minimizes product emulsification.
- Can operate dry for brief periods of time.

- Can handle vis



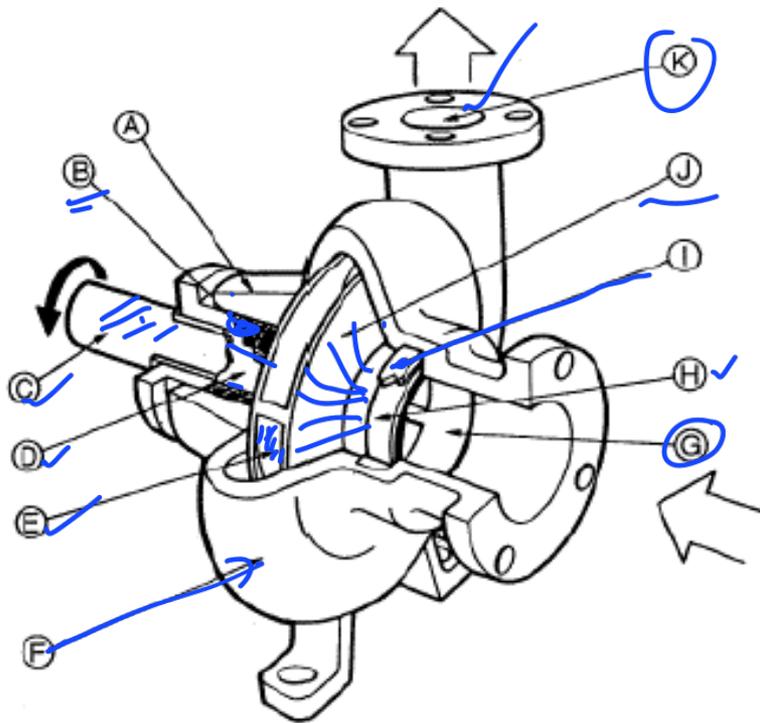
Peristaltic Pump

- A vacuum is created by the rollers compressing the hose and moving along
 - Liquid is drawn into vacuum
- Rollers capture liquid between them and move liquid towards discharge

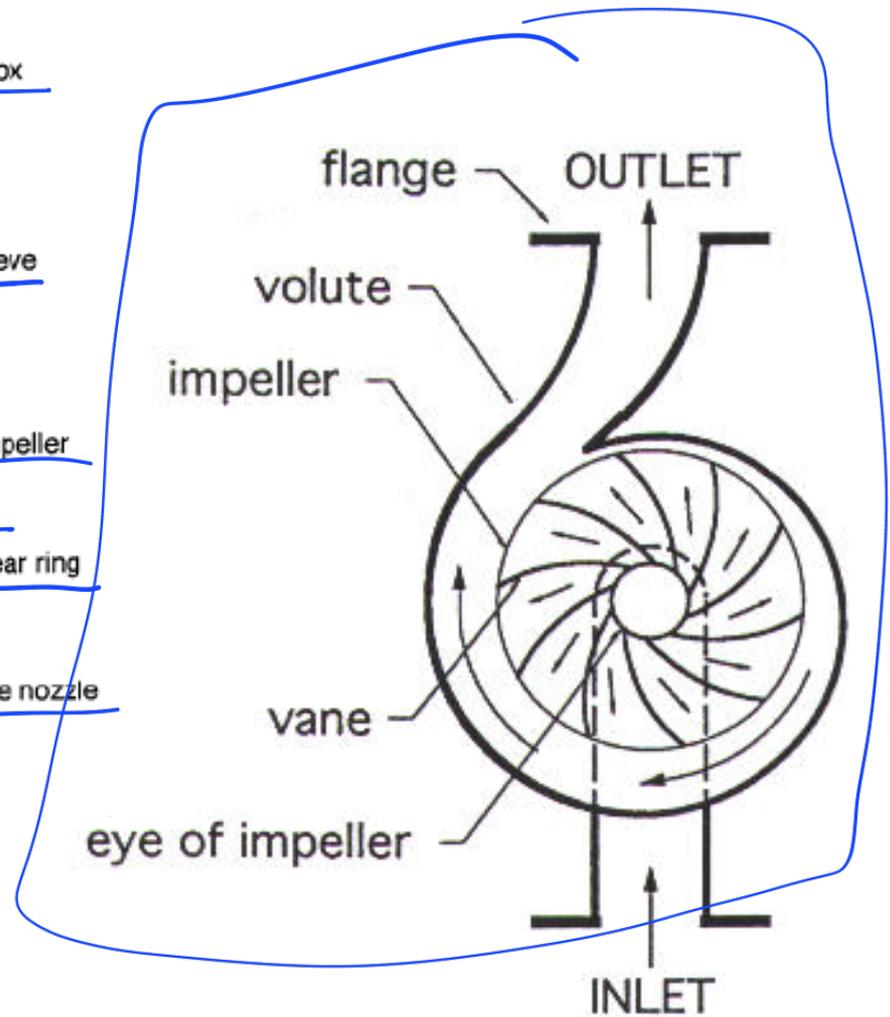


Applications: Corrosive fluids, chemicals, food industry.

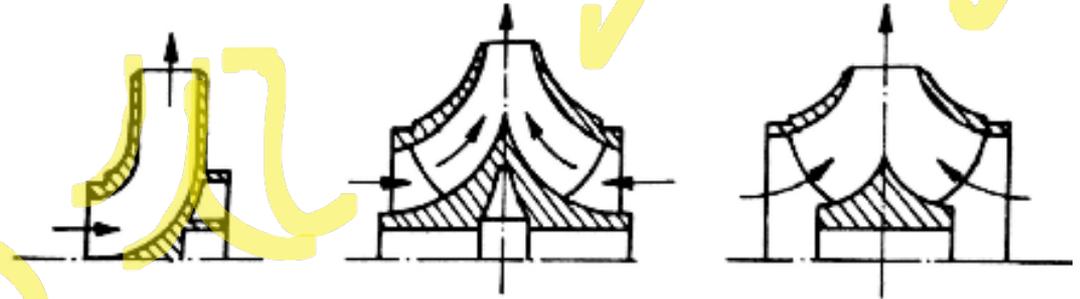
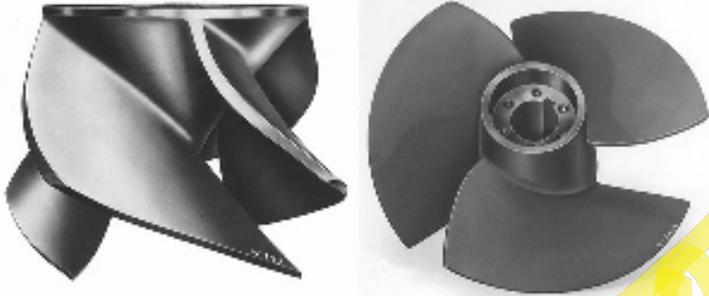
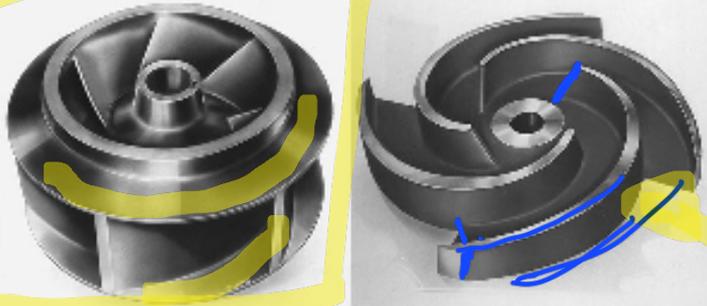
Centrifugal pump terminology



- A Stuffing Box
- B Packing
- C Shaft
- D Shaft Sleeve
- E Vane
- F Casing
- G eye of Impeller
- H Impeller
- I Casing wear ring
- J Impeller
- K Discharge nozzle



Closed, Semi-closed and Open Impellers

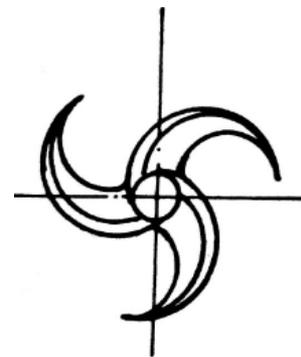


(a) CENTRIFUGAL - SINGLE - SUCTION RADIAL TYPE

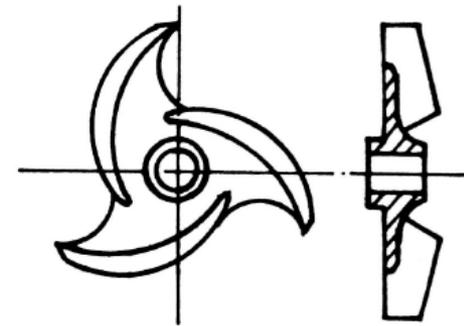
(b) CENTRIFUGAL - DOUBLE - SUCTION

(c) MIXED - FLOW DOUBLE - SUCTION

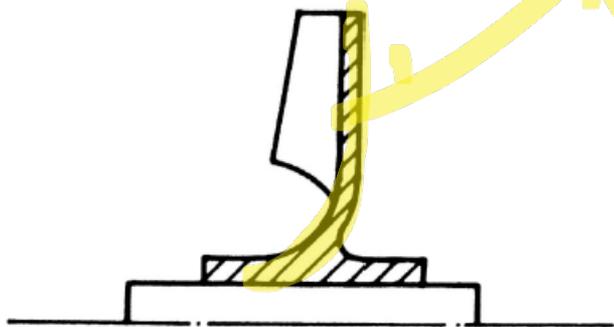
Closed Impeller (for pure liquids: water, oil, acid, alkali)



WITHOUT SHROUD



WITH PARTIAL SHROUD

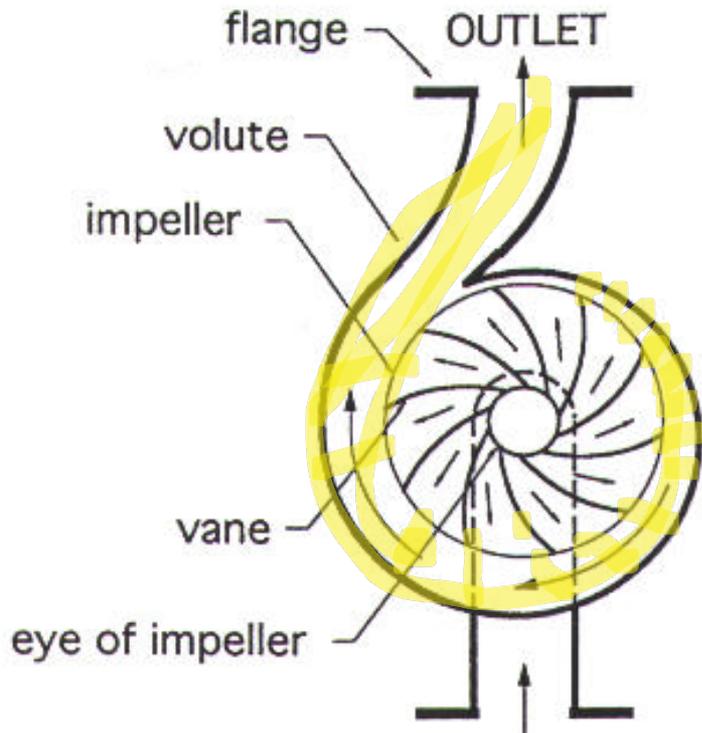


Semi-closed Impeller

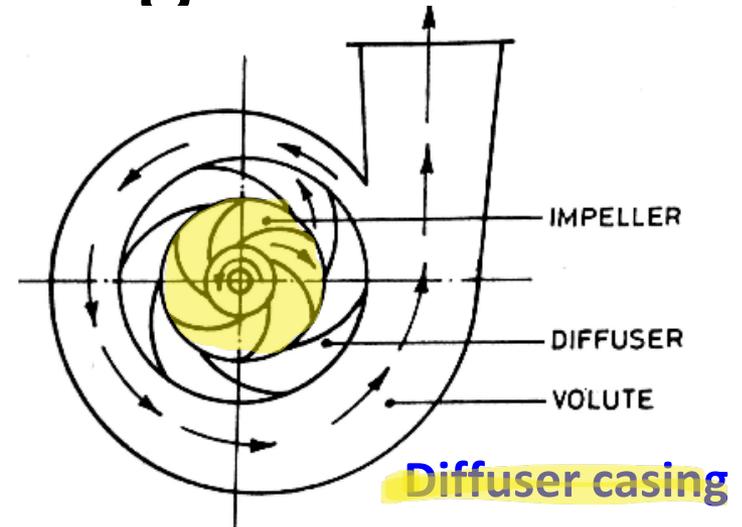
(limited debris: sewage water, paper pulp)

Open Impeller (slurry and liquid with large solid particles)

Volute and Diffuser Casing

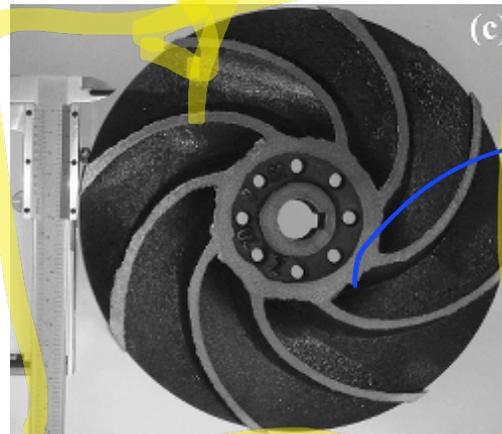


Volute casing



Diffuser casing

Diffuser increases the efficiency of centrifugal pump by allowing a more gradual expansion and less turbulent area for the liquid.



SELF-STUDY

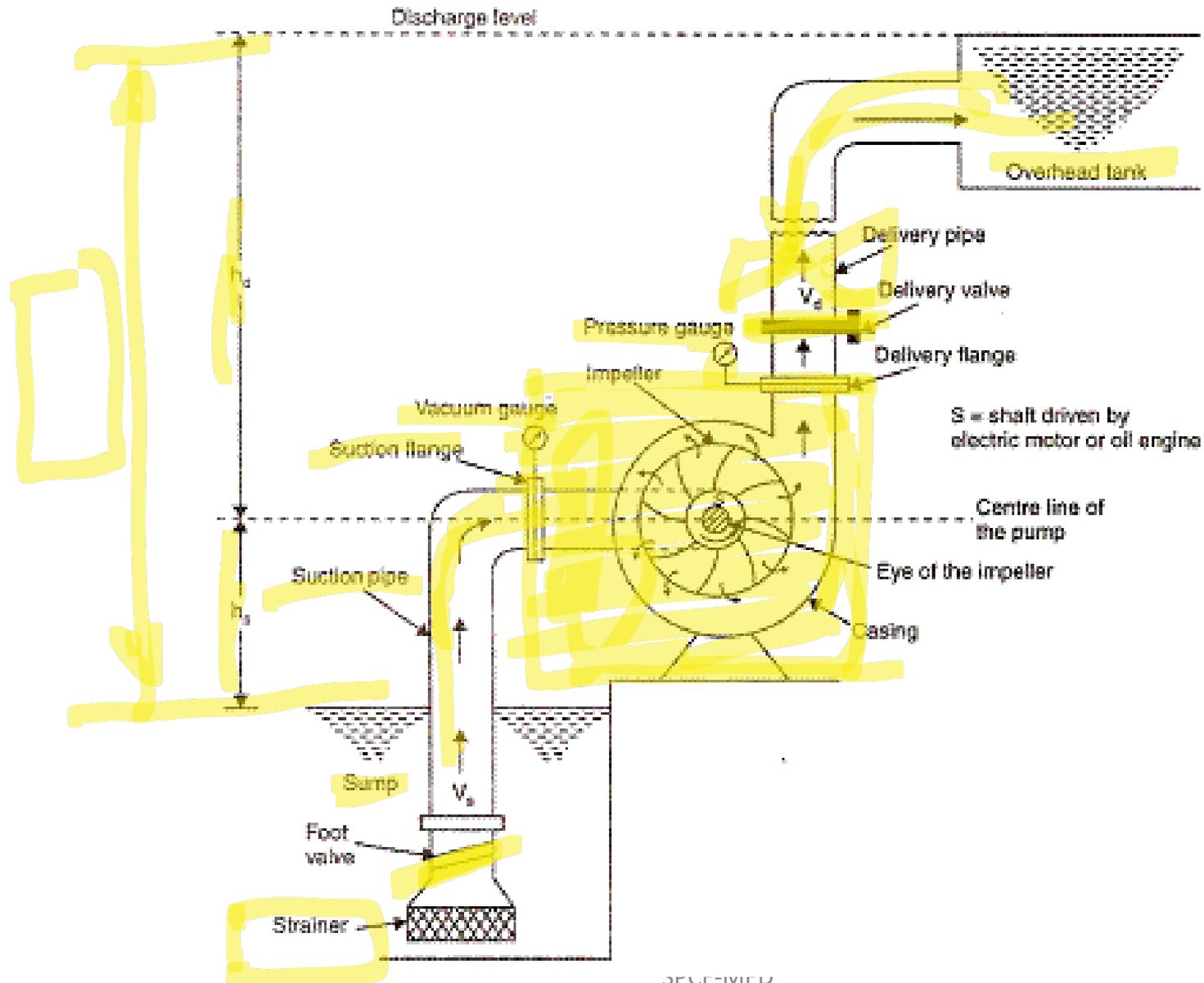
Comparison of Centrifugal and PD pumps



Positive Displacement Pump	Centrifugal Pump
Low flow rates (400 lpm)	High flow rates (as high as 1200,000 lpm)
High pressure (300 atm.)	Moderate pressure (few atm.)
Priming is rarely required	Priming is always required
Pulsating flow	Steady flow
Non-uniform torque	Uniform torque
Constant flow rate irrespective of pressure or head demand	Flow rate changes with change in head
High initial cost (reciprocating pump)	Low initial cost
High maintenance cost (reciprocating pump)	Low maintenance cost
Large floor space for same capacity (reciprocating pump).	Compact design
More noise (reciprocating pump)	Less noise

Design of Centrifugal Pump

Centrifugal Pump System



Design Specification

- A centrifugal pump is to be designed for following specification.
 - Total head = 50 m
 - Discharge = 100 m³/hr
 - Liquid = water at 25°C

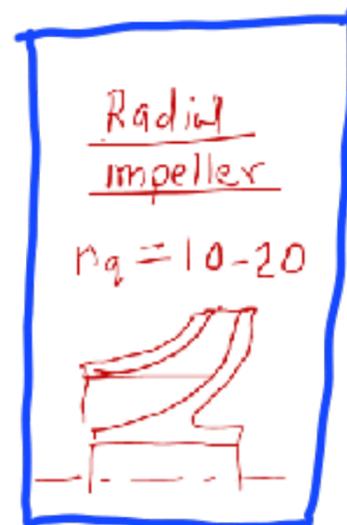
The pump is directly connected to electric motor. Select suitable motor for pump and design impeller shaft, impeller and casing with volute profile.

Modified specific speed, $n_q = \frac{n\sqrt{Q}}{H^{3/4}}$

$n =$ pump speed in rpm

$Q =$ Flow rate in m^3/s

$H =$ pump head , m



Francis type

$n_q = 20-80$



Half axial

$n_q = 80-160$



Propeller (axial)

$n_q = 100-500$



Specific speed (n_s): Speed of rotation of geometrically similar pump of such a size that it ensures a delivery Q of 75 liters/sec at head H of 1 m.

$$n_s = 3.65 n_q$$

(A) Selection of Pump Speed
Assuming the impeller type as 'radial'

$$n_q = 10$$

$$\therefore 10 = \frac{n \times \sqrt{100/3600}}{(50)^{3/4}}$$

$$\therefore n = 1128 \text{ rpm.}$$

We select a motor with 1500 rpm

$$\therefore n_q = \frac{1500 \times \sqrt{100/3600}}{50^{3/4}}$$

$$\therefore (n_q)_{\text{actual}} = 13.3$$

$$P = \frac{\gamma Q H}{1000 \eta_0} \quad \text{in kW}$$

γ in kg/m^3

Q in m^3/s

H in m

$$\eta_0 = \eta_p \times \eta_m \times \eta_{\text{mech}}$$

(B) Power requirement

$$\gamma = 1000 \text{ kg/m}^3 \quad \checkmark$$

$$g = 9.806 \text{ m/s}^2 \quad \checkmark$$

$$Q = \frac{100}{3600} \text{ m}^3/\text{s} \quad \checkmark$$

$$H = 50 \text{ m} \quad \checkmark$$

$$\eta_0 = \underline{0.75} \quad (\text{assumed})$$

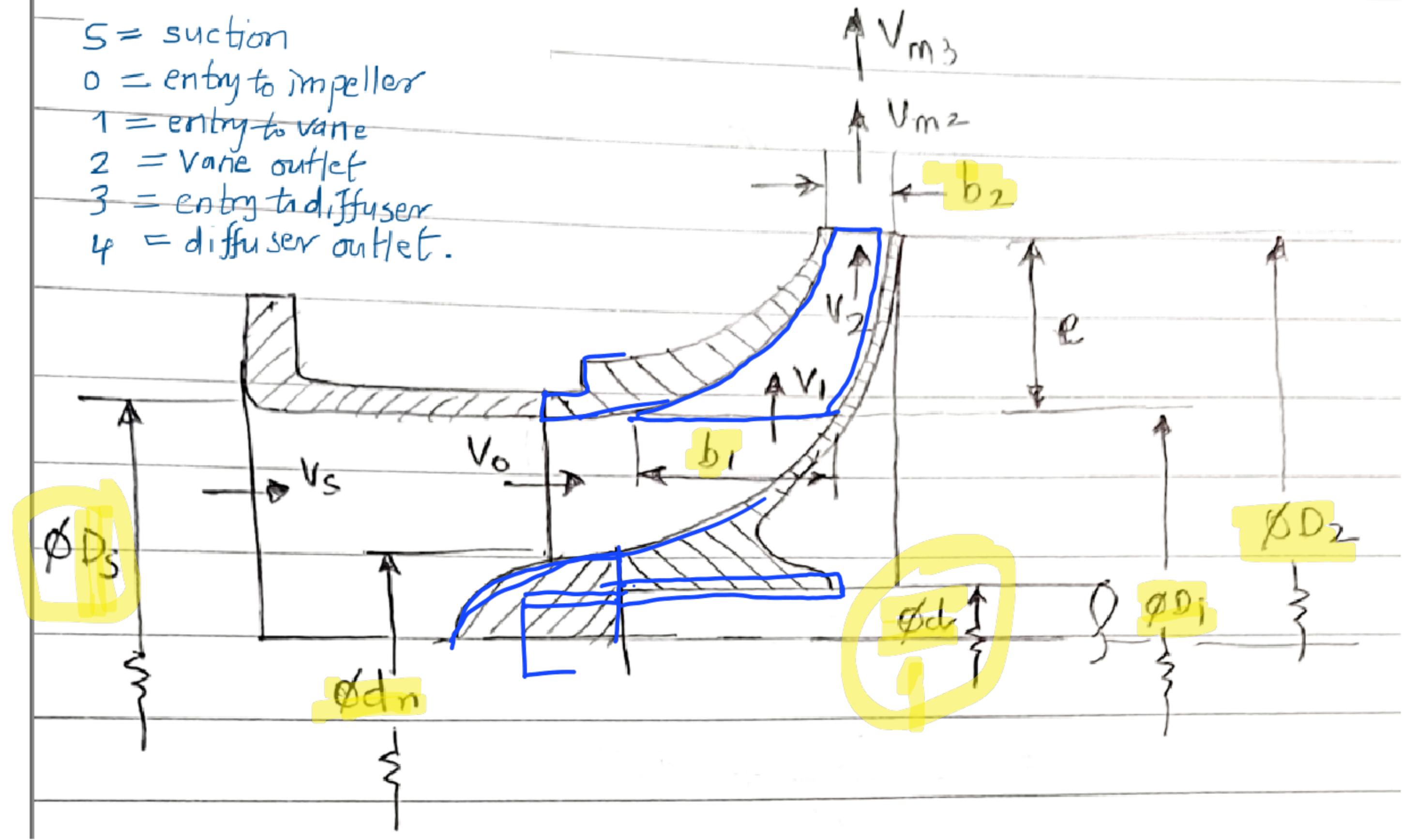
$$\therefore P = \frac{1000 \times 9.806 \times \left(\frac{100}{3600}\right) \times 50}{1000 \times 0.75}$$

$$= \underline{18.15 \text{ kW}}$$

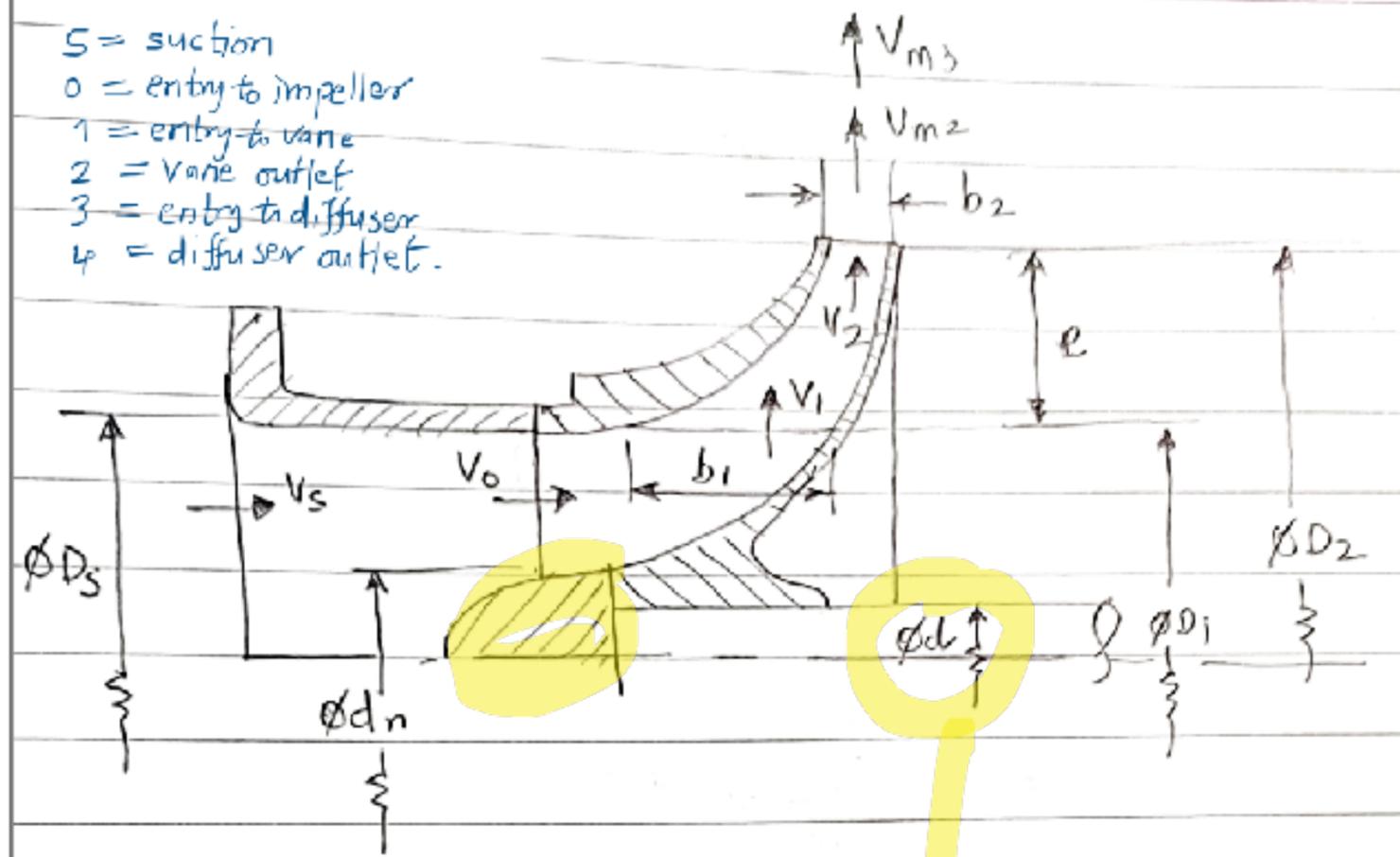
Motor selected = $\underline{18.5 \text{ kW}}$ @ $\underline{1500 \text{ rpm}}$

Pumps
by 'Sahu'

- S = suction
- 0 = entry to impeller
- 1 = entry to vane
- 2 = vane outlet
- 3 = entry to diffuser
- 4 = diffuser outlet.



- S = suction
- 0 = entry to impeller
- 1 = entry to vane
- 2 = vane outlet
- 3 = entry to diffuser
- 4 = diffuser outlet.



(c) shaft design

$$\begin{aligned} \text{Torque, } m_t &= \frac{1000 \text{ (kW)}}{(2\pi n/60)} \\ &= \frac{1000 \times 18.5}{(2\pi \times 1500/60)} \\ &= 117.8 \text{ Nm} \end{aligned}$$

$$\tau = \frac{m_t}{\left(\frac{\pi d^3}{16}\right)}$$

$$\therefore 58.3 = \frac{117.8 \times 10^3}{\left(\frac{\pi d^3}{16}\right)}$$

$$\therefore d = 21.75 \text{ mm}$$

$$d \approx 24 \text{ mm}$$

$$\tau_{\text{allow}} = \frac{0.5 \times S_y}{\text{FOS}}$$

$$= \frac{0.5 \times 350^*}{3^*}$$

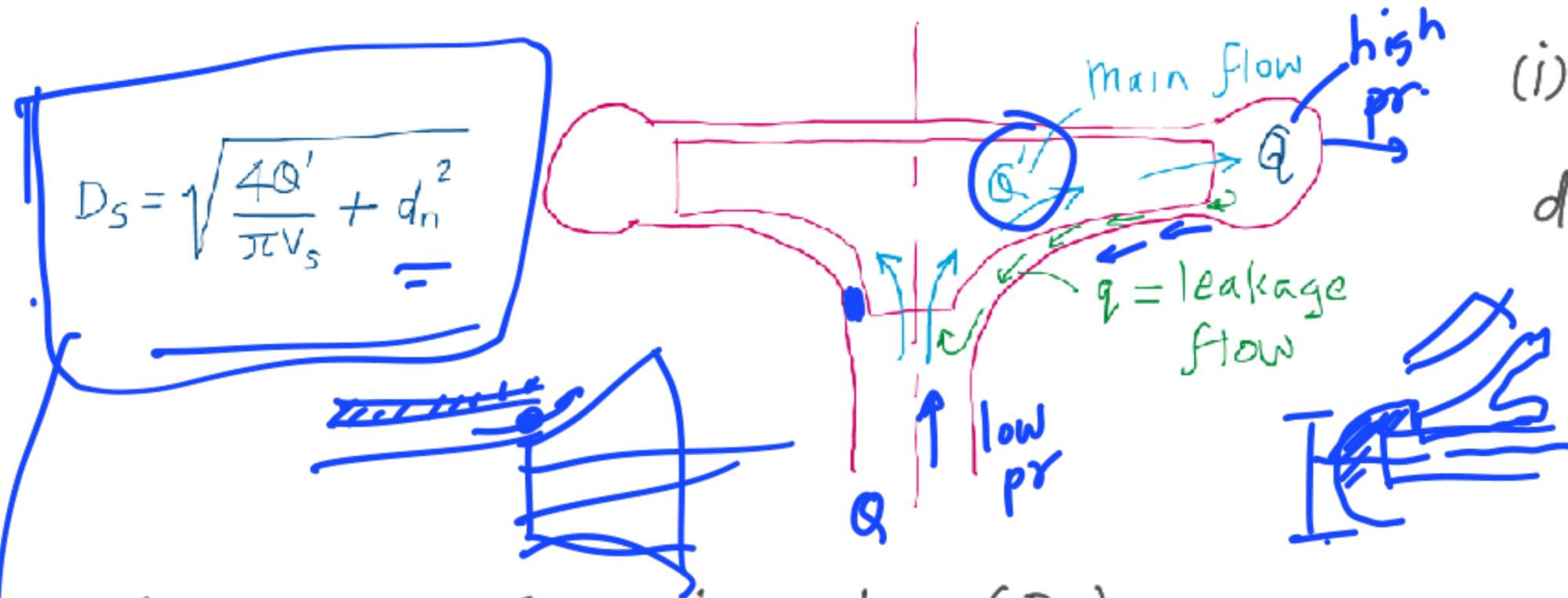
(* assumed)

$$= 58.3 \text{ MPa}$$

(D) Impeller Sizing

(i) Nose diameter

$$\begin{aligned} d_n &= (1.5 \text{ to } 1.6) \underline{d} \\ &= 1.5 \times 24 \\ &= \underline{\underline{36 \text{ mm}}} \end{aligned}$$



(ii) Suction pipe diameter (D_s)

$$\underline{Q'} = 1.06 Q \text{ (6\% leakage assumed)} = 1.06 \times \frac{100}{3600} = \underline{\underline{0.02944 \text{ m}^3/\text{s}}}$$

$$\underline{V_s} = \underline{V_o} = \underline{V \cdot \epsilon}$$

$$V = \sqrt{2gH} = \sqrt{2 \times 9.806 \times 50} = \underline{\underline{31.3 \text{ m/s}}}$$

$$\epsilon = \underline{\underline{0.023 \sqrt{n_q}}} \text{ for } \underline{\underline{n_q < 45}} \Rightarrow \epsilon = 0.023 \sqrt{13.3} = \underline{\underline{0.08388}}$$

$$\therefore \underline{V_s} = \underline{V_o} = 31.3 \times 0.08388 = \underline{\underline{2.625 \text{ m/s}}}$$

$$\therefore D_s = \sqrt{\frac{4 \times \underline{\underline{0.02944}}}{\pi \times \underline{\underline{2.625}}} + \underline{\underline{0.036}}^2} = \underline{\underline{0.1248 \text{ m}}} \quad \therefore \underline{\underline{D_s = 125 \text{ mm}}}$$

(D) contd

(iii) Vane inlet diameter (D_1)

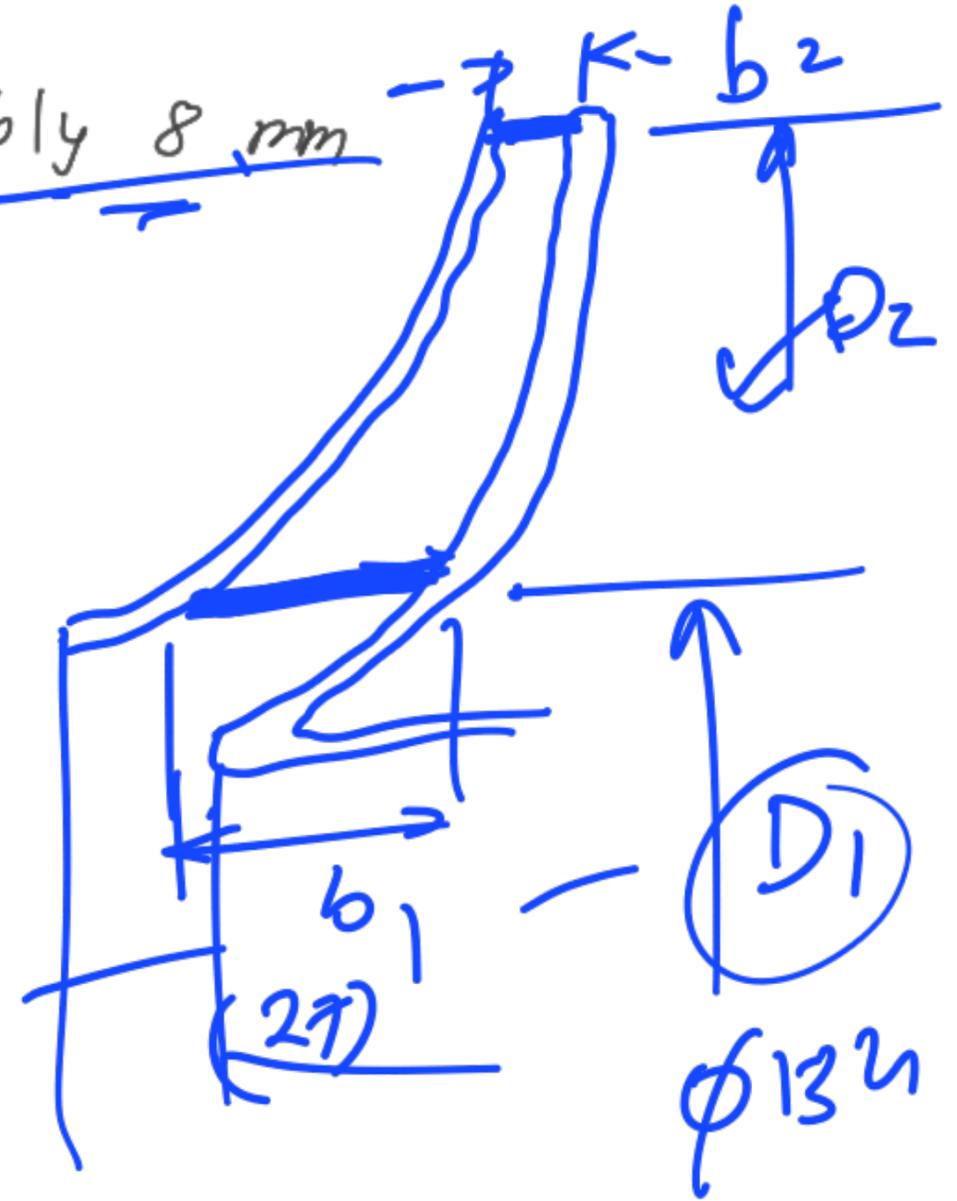
$$D_1 = \widehat{D}_s + (5 \text{ to } 10 \text{ mm}) \text{ preferably } \underline{8 \text{ mm}}$$

$$\therefore D_1 = \underline{134} \text{ mm}$$

(iv) Inlet vane width (b_1)

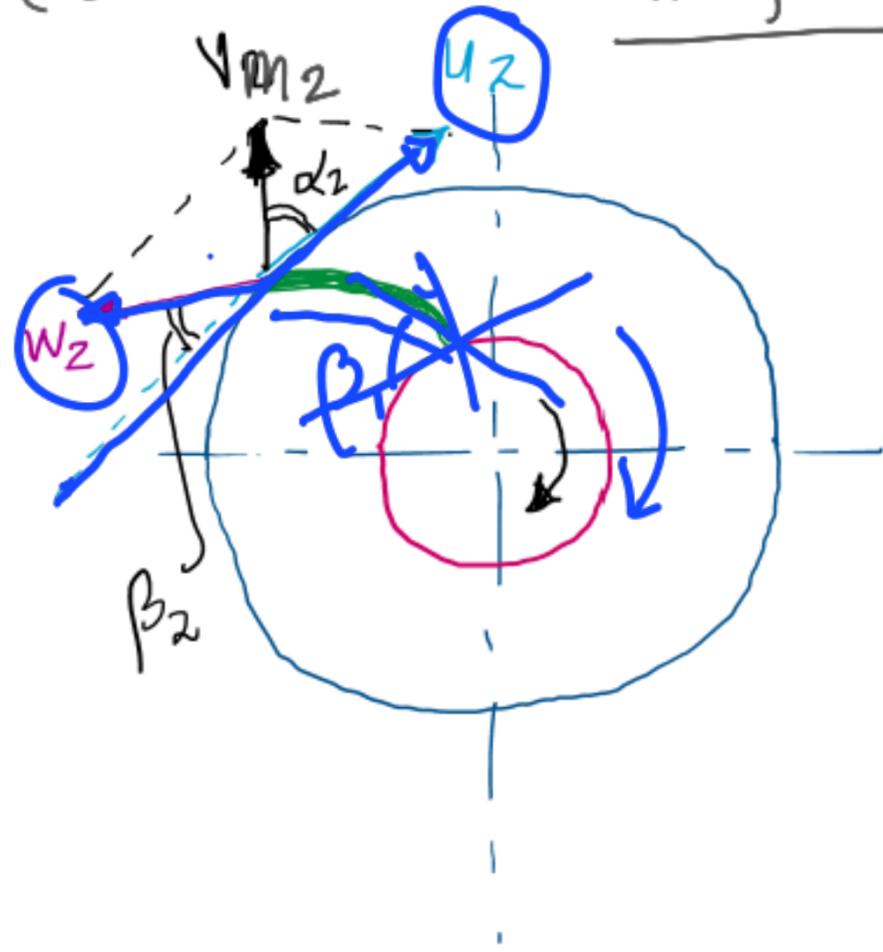
$$b_1 = \frac{Q'}{\pi D_1 V_0}$$
$$= \frac{0.02944}{\pi \times 0.134 \times \underline{2.625}}$$
$$= \underline{0.0266 \text{ m}}$$

$$\therefore b_1 = \underline{27} \text{ mm}$$



(D) contd.

(v) Impeller O.D.

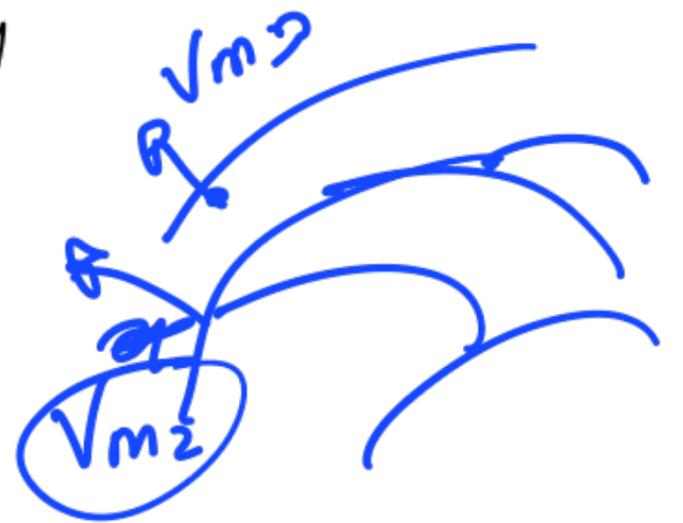


$$D_2 = \frac{2\sqrt{2gH}}{\omega} = \frac{2 \times \sqrt{2 \times 9.806 \times 50}}{\left(\frac{2\pi \times 1500}{60}\right)} = 0.398 \text{ m}$$

$$D_2 = 400 \text{ mm}$$

V_{m3} = absolute diffuser entry velocity
 = (0.8 to 0.9) V_0

V_0 = velocity at entry of diffuser



(vi) Other parameters

β_2 = discharge angle \sim $24^\circ - 28^\circ$, $\boxed{25^\circ \text{ assumed}}$

V_{m3} = abs. diffuser entry velocity = (0.8 to 0.9) \times V_0
 (meridional = radial)
 = $\boxed{0.85} \times 2.625$
 = $\boxed{2.231 \text{ m/s}}$

absolute

V_{m2} = abs. (meridional) vane exit velocity = $\boxed{1.2 V_{m3}} = \boxed{2.6772 \text{ m/s}}$

(D) contd
(vii)

Outlet vane width (b_2)

$$\begin{aligned} b_2 &= \frac{Q'}{\pi D_2 V_{m3}} \checkmark \\ &= \frac{0.02944}{\pi \times 0.400 \times 2.231} \\ &= 0.0105 \text{ m} \end{aligned}$$

\therefore $b_2 = 11 \text{ mm}$ \checkmark

