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Design Methodology for Hydraulic Ram Pump

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ABSTRACT: The hydraulic ram pump is simple in design but it not implemented in the remote areas of India despite of its low cost. So here we have decided to come up with the design methodology. There are lot many problems that we have faced during calculations and in the actual performance and now giving the rough idea of proceeding to the calculations.

KEYWORDS: Design, calculations, PVC pipes, Air vessel, Waste valve, Hydraulic ram pump, Length, Diameter, Wall thickness.

I. INTRODUCTION

The basic formulas that we used was from the books related to hydraulic machines. The inertia pressure has to be considered while designing the pump. The wall thickness has to be calculated from this. The main problem in design of pipe is to decide the diameter. But in case of hydraulic ram pump we have L/D ration from (150-1000) and the length may be up to 8 meters. By taking into account this ration we can easily decide the Diameter of pipe which is very important factor. However the design of Air vessel and waste valve is also an important factor. There is no standard method for designing the Air vessel but some standard sizes like 4"*36" or 4"*24" may be used.

II. MATERIALS AND METHOD

The material that we have used for the construction of hydraulic ram pump is Unplasticized PVC pipes because of its low cost and the useful life up to 50 years and there is no problem of corrosion. Unplasticized PVC pipes are strong yet light, their specific gravity being approximately one-fifth of Cast Iron. As a result, these pipes can be easily handled than their metal counterparts. Reasonable care, however, should be used at all times. Since the soundness of any joint depends on the condition of the spigot and the socket, special care must be taken in transit, handling and storage to avoid damage to the ends.

The method for designing the Hydraulic Ram Pump is given below. First of all, all the theoretical calculations must be done before actual fabrication of the pump in order to know about the efficiency which is the important factor in the design. The formulae involved in calculating the velocity of water, the pressure and the discharge are presented in the Paper.

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III. DESIGN CALCULATIONS

We are considering a community consisting 10 people and accordingly designing the pump. In the village the cattle and other animals requires water for washing purpose. Altogether, if a single man requires 10 lit/day, 10 people will require 100 lit/day and including animals it will increase. On this basis we have done all our calculations.

The calculations are done on approximate basis.

Firstly, it is required to determine the total head and full so that a $\frac{L}{D}$ ratio is to be determined.

In our project, we kept fall as 1m and delivery at about 2.5m.

Fall = 1m

Lift = 2.5 m

Dia. of supply pipe = 0.050 m= 2"

Dia. Of delivery pipe= 0.025 m= 1"

Length of pipe = 8 m

Hence $\frac{L}{D}$ ratio = $\frac{8}{0.050} = 160(150-1000)$

Air Vessel = 4"*24"

Dia. Of waste valve=2"

Now,

STEP:1

$$SDR = \frac{d_a}{s} = 50/3 = 16.67 = 17$$

Where;

s = wall thickness

d_a = outside diameter

We have diameter 50 mm diameter

Permissible wall thickness :-

Compressive strength (σ_v) = 50

$$\sigma_{zul} = \frac{\sigma_v}{c_{min}} = \frac{50}{2} = 25 \text{ N/mm}^2$$

$$S_{min} = \frac{P * d_a}{(20 * \sigma_{zul}) + p}$$

$$= \frac{12.4 * 60.2}{(20 * 25) + 12.4}$$

$$= 1.2 \approx 2 \text{ mm}$$

The inertia pressure is given by,

$$P_i = \frac{v}{\sqrt{\frac{g}{w} \left(\frac{1}{k} + \frac{D}{TE} \left(1 - \frac{1}{2m} \right) \right)}}$$

$$= \frac{4.25}{\sqrt{\frac{9.81}{9789} \left(\frac{1}{2.20 * 10^{-9}} + \frac{0.05}{0.003 * 1200 * 10^{-6}} \left(1 - \frac{1}{8} \right) \right)}}$$

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$$=1.24 \text{ N/mm}^2 = 12.4 \text{ BAR}$$

Where,

V= Velocity of water in supply pipe

G= Acceleration due to gravity

K= Bulk modulus of the water

D= Diameter of supply pipe

T= Wall thickness

E= Young's Modulus for the uPVC pipe.

STEP:2

$$Q = \frac{\pi}{4} * D^2 * V$$

Where, D = Dia. Of pipe

V = Velocity of water in pipe

& n = No. of strokes of delivery value

$$Q = \frac{\pi}{4} * 0.050^2 * 4.25$$

$$= 8.34 * 10^{-3} \text{ m}^3/\text{sec} \dots \dots \dots (1)$$

STEP:3

First we need to calculate V_{\max} the maximum velocity of water in hydram.

$$V_{\max} = \sqrt{2gH_s}$$

Where,

H_s = height of supply tank from pump = 1m

C_v = Velocity coefficient = 0.96

G= acceleration due to gravity = 9.81 m/sec²

$$V_{\max} = 0.96 * \sqrt{2 * 9.81 * 1} = 4.25 \text{ m/sec}$$

To calculate the velocity of fluid flow in delivery pipe.

$$V_d = \sqrt{2gH_d} = 0.96 * \sqrt{2 * 9.81 * 2.5}$$

$$= 6.72 \text{ m/sec.}$$

Where, H_d = Height of the delivery pipe.

STEP:4

In order to ascertain the nature of flow that whether it is laminar or turbulent.

To find Reynolds's number,

$$R_e = \frac{V_s}{\nu}$$

$$= 4.24 / 0.801 * 10^{-6}$$

$$= 5293383.271 \dots \dots \dots (3)$$

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v = kinematic viscosity and at T= 30° c,
v for water = 0.801* 10⁻⁶ m²/ sec
For smooth pipes,

Blasius suggested that for turbulent flow,

$$f = \frac{0.316}{Re^{0.25}}$$

$$= 0.316 / 5293383.27^{0.25}$$

$$= 0.006.....(4)$$

STEP:5

The Darcy-wersbach formula is the basis of calculating the loss in head for fluid flow in pipes by,

$$1. \text{ Heat loss} = f * \frac{L}{d} * \left(\frac{vd^2}{2g}\right) *$$

$$= 0.006 * \frac{1}{0.050} * \left(\frac{4.25*4.25}{2*9.81}\right)$$

$$= 0.11 \text{ m}.....(5)$$

The velocity of flow in T-junction

$$V_r = \frac{Q}{A_s}$$

$$= \frac{8.34 * 10^{-3}}{\frac{\pi * 0.050^2}{4}}$$

$$= 4.25 \text{ m/sec}(6)$$

Now,

2. Heat loss at T-junction due to sudden enlargement.

$$H_{LT} = \frac{(v_d - v_s)^2}{2g}$$

$$= (6.72 - 4.2)^2 / 2 * 9.81$$

$$= 0.32 \text{ m}(7)$$

3. Friction losses,

$$H_f = k * \frac{v^2}{2g}$$

$$= [k_T + k_{90 \text{ elbow}} + k_{\text{impulse value}}]$$

$$= [(0.42*3) + (0.66*2) + 0.35] * (4.25^2 / 2 * 9.81)$$

$$= 2.7 \text{ m}(8)$$

4. Other losses of head as in pipe fittings

$$H_L = k_t * (v^2 / 2g)$$

Where,

k = resistant coefficient for PVC

$$H_L = 0.42 * (4.25^2 / 2 * 9.81)$$

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$$= 0.38 \text{ m}$$

$$\begin{aligned} 5. \text{Total losses} &= \text{Heat loss} + H_{LT} + H_f + H_L \\ &= (0.11 + 0.32 + 2.7 + 0.38) \\ &= 3.51 \text{ m} \dots\dots\dots(9) \end{aligned}$$

STEP:6

Now, to find acceleration ,

$$\begin{aligned} H - F * \left(\frac{L}{D} * \frac{V^2}{2G}\right) - \text{LOSSES} &= \frac{L}{D} * \frac{dV}{dT} \\ 2.5 - 1 * (8/0.05) * (4.25^2 / 2 * 9.81) - (3.51) &= (8/0.050) * \frac{dV}{dT} \\ 3.77 - 0.0378 &= (15 / 0.076) * \frac{dV}{dT} \\ 1.35 \text{ m / sec}^2 &= \frac{dV}{dT} \dots\dots\dots(10) \end{aligned}$$

STEP:7

Now, drag force is given by,

$$\begin{aligned} F_d &= c_d * A * \rho * \frac{V_t^2}{2g} \\ &= 0.62 * (\pi/4) * 0.050^2 * 1000 * (4.25 / 2 * 9.81) \\ &= 0.26 \text{ N} \end{aligned}$$

STEP:8

The force that accelerate fluid

$$\begin{aligned} F &= m_a = \rho * A * L * \frac{dV}{dT} \\ &= 1000 * (\pi/4) * 0.050^2 * 8 * 1.35 \\ &= 21.2 \text{ N} \dots\dots\dots(11) \end{aligned}$$

STEP:9

Pressure at point is obtained by dividing F by area

$$\begin{aligned} P_3 &= \frac{F}{A} = \frac{21.2}{\frac{\pi}{4} * 0.050^2} = 10.797 \text{ K N/m}^2 \\ &= 0.010 \text{ BAR} \end{aligned}$$

STEP:10

$$\begin{aligned} P &= \rho * g * Q * h \\ &= 1000 * 9.81 * 2.5 * 1000 * 1.93 * 10^{-3} \end{aligned}$$

$$P = 47.33 \text{ KW}$$

STEP:11

TO CALCULATE EFFICIENCY

$$t_1 = L_1 * \frac{V_{\max}}{(H_d - h) * g}$$

This formula is based on the empirical relationship between head of supply and the length of supply, it is suggested that,

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$$L_1 = 2.5 * H$$

$$L_1 = 2.5 * 1$$

$$= 2.5\text{m}$$

$$t_1 = 2.5 * \frac{4.25}{(2.5-1)*9.81} = 0.722 \text{ sec}$$

$$t_2 = L_2 * \frac{V_{\max}}{(H_d - h) * g}$$

$$= 1 * \frac{4.25}{(2.5-1)*9.81} = 0.28 \text{ sec}$$

Where,

L_1 = Length of supply based on empirical head and length of supply

L_2 = Length of pump

t_1 = Time taken for impulse valve to close or delivery valve to open

t_2 = Time taken for delivery valve to close

H = supply head

H_d = Height of tank from river

V_{\max} = maximum velocity

One beat is equal to $t_1 + t_2$

$$1 \text{ beat} = 0.722 + 0.28$$

$$= 1.010 \text{ sec}$$

Since n is the no. of beats/min

$$n = \frac{60}{1.010} = 59.4 \approx 59$$

STEP:12

We then calculate the flow rate of the water flowing at waste valve

$$Q_w = \pi * r^2 * L * \frac{n}{60}$$

Where,

Q_w = flow rate of waste water

R= the radius of waste valve

L= length of hydram

n= 59

$$Q_w = \pi * (0.025/2)^2 * 1 * 59/60$$

$$= 1.93 * 10^{-3} \text{ m}^3/\text{sec}$$

To find the head loss coefficient (M)

$$M = \frac{f * L * V * V}{2 * g * D} = \frac{0.011 * 4.25 * 4.25 * 1}{2 * 9.81 * 0.050} = 0.2$$

STEP:13

Next, we will find vol. of waste water $(\text{vol})_w$

$$(\text{Vol})_w = \frac{L_s * A_s * M}{M} \log \left(\frac{1}{1 - \mu} \right)$$

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We have,

H_d = height of delivery tank = 2.5m

L_d = Length of delivering pipe from hydrant = 2.5m

d_d = dia of delivery pipe = 0.076

L_s = length of supply pipe = 15m

d_s = dia of supply pipe = 0.0508

$$V_{max} = 4.25 \text{ m/sec}$$

$$\begin{aligned} \mu &= \frac{M \cdot V_{max}^2}{2 \cdot g \cdot H_d} \\ &= \frac{0.2 \cdot 4.25^2}{2 \cdot 9.81 \cdot 2.5} \\ &= 0.07 \end{aligned}$$

$$\begin{aligned} (\text{Vol})_w &= \frac{L_s \cdot A_s \cdot \log\left(\frac{1}{1-\mu}\right)}{M} \\ &= \frac{1 \cdot \frac{\pi}{4} \cdot 0.050^2}{0.2} \cdot \log\left(\frac{1}{1-0.07}\right) \\ &= 0.3 \text{ liter} \end{aligned}$$

Then we calculate the volume of delivery water $(\text{Vol})_d$

$$\begin{aligned} (\text{Vol})_d &= \frac{L_d \cdot A_d \cdot \ln(1+\beta)}{M} \\ &= \frac{2.5 \cdot \frac{\pi}{4} \cdot 0.025^2}{0.2} \cdot \ln(1+0.07) \\ &= 0.415 \text{ liter} \end{aligned}$$

$$\begin{aligned} \beta &= \frac{M \cdot (V_{max})^2}{2 \cdot g \cdot H_d} \\ &= \frac{0.2 \cdot (4.25)^2}{2 \cdot 9.81 \cdot 2.5} \\ &= 0.07 \end{aligned}$$

The delivery flow rate can be calculated as below,

$$Q_d = \frac{Q_w \cdot \text{Vol}_d}{\text{Vol}_w}$$

Where,

Q_d = delivery flow rate (m^3/sec)

Q_w = waste flow rate (m^3/sec)

Obtained earlier = $1.93 \cdot 10^{-3} \text{ m}^3/\text{sec}$

$$\begin{aligned} Q_d &= \frac{1.93 \cdot 10^{-3} \cdot 0.41}{0.3} \\ &= 2.63 \text{ lit/sec} \end{aligned}$$

The efficiency of hydrant can be defined as below, using D'rankine formula,

$$E(\text{rankine}) = \frac{Q \cdot h_d}{(Q + Q_w) \cdot H}$$

$Q = Q_d = 2.63 \text{ lit/sec}$

$Q_w = 0.3 \text{ lit/sec}$

$H_d = 1.5 \text{ m}$

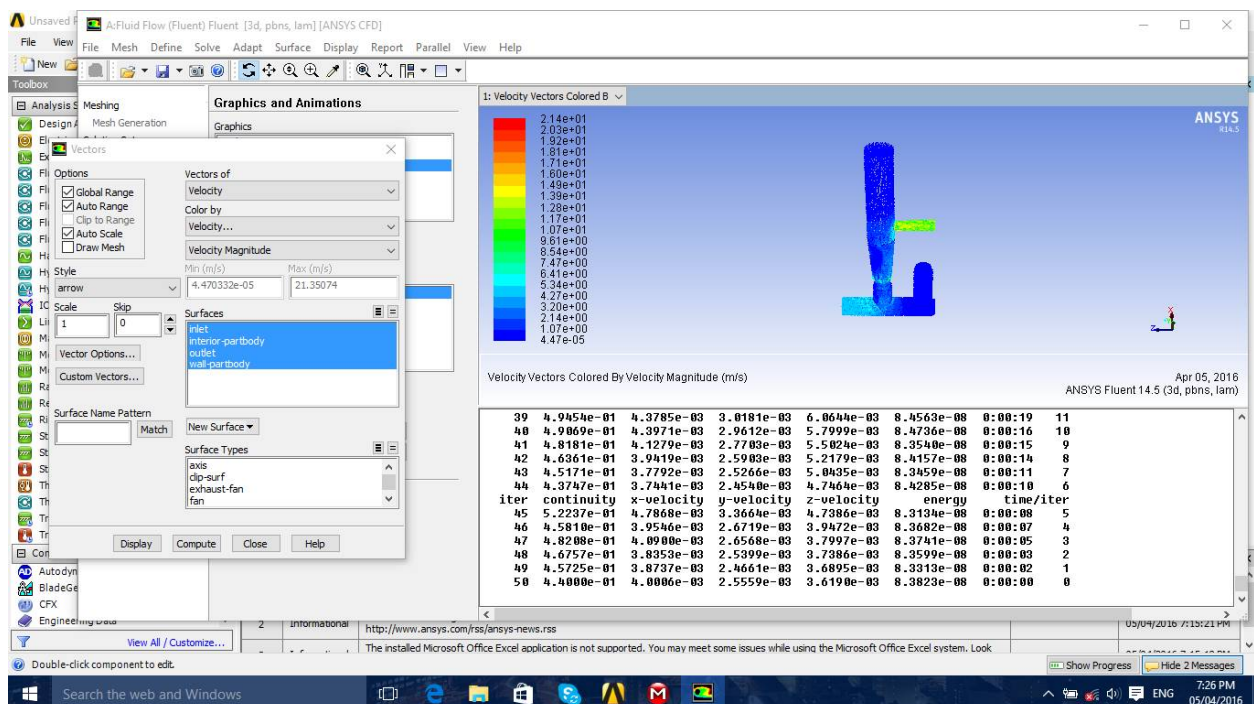
$H = (h_d + h_s) = 1.5 + 1 = 2.5 \text{ m}$

$$E = \frac{2.63 \cdot 1.5}{(2.63 + 1.93 \cdot 10^{-3}) \cdot 2.5}$$

$$= 59.95\%$$

$$= 60\%$$

IV. SIMULATION AND RESULTS



The analysis is done on ANSYS software. It shows the velocity distribution inside the hydram and also shows the minimum and maximum velocity. The analysis is done in (Computational Fluid Dynamics) CFD- FLUENT. At first the prototype has been made and the later considerations have been made according to this. The diameter has been increased in order to work the pump more efficiently and the design has made accordingly.

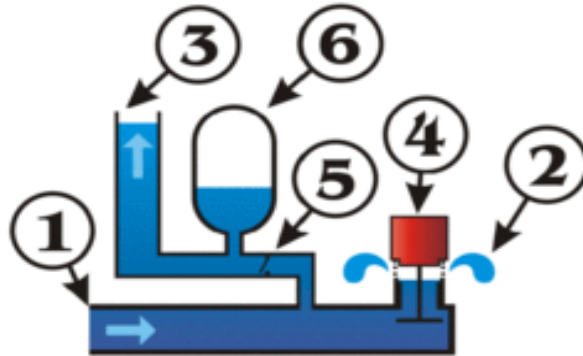
The present study is centred towards the development of a hydraulic ram pump that would conveniently alleviate the problem of water supply to the mass population. Ideally, different combinations of the supply and delivery heads and flows, stroke length and weight of the impulse valve, length to diameter ratio of the drive pipe, volume of the air chamber and size of the snifter valve, etc. we're tried to come up with an optimum size of a hydram pump presented in this study. The pump works successfully but the valve timing should be proper in order to get the pump working.

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Schematic diagram of hydram:



1. Inlet – drive pipe
2. Free flow at waste valve
3. Outlet – delivery pipe
4. Waste valve
5. Delivery check valve
6. Pressure vessel

V. CONCLUSION

We have designed the hydraulic ram pump using these dimensions and we are getting the efficiency up to 60 %. There are various types of losses and leakage problems that we have gone through but the problem is solved by using the PVC solvent which we have used. The size of air vessel plays vital role in the design of the hydram. The design of waste valve is also very much importance in that aspect too.

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