NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT]
ISSN: 2394-3696
VOLUME 2, ISSUE 12, DEC.-2015

MATHEMATICAL MODELLING FOR ANALYSIS OF CHANGE IN SHAPE OF SUCTION MANIFOLD TO IMPROVE PERFORMANCE OF THE CENTRIFUGAL PUMP

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ABSTRACT

Centrifugal pumps are used extensively for pumping water over short to medium distance through pipeline where the requirements of head and discharge are moderate. The design and optimization of turbo machine impellers such as those in pumps and turbines is a highly complicated task due to the complex three-dimensional shape of the impeller blades and surrounding devices. Small differences in geometry can lead to significant changes in the performance of these machines. The efficiency of the centrifugal pump can be increased by number of ways such as modifying the geometry of the sump, increasing the diameter of the suction pump, having multiple pumps working in series, etc. This paper is part of research work carried out to improve efficiency of a centrifugal pump through changing shapes of the manifolds.

INTRODUCTION

A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action. Pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps.
Pumps operate by some mechanism (typically reciprocating or rotary), and consume energy to perform mechanical work by moving the fluid. Pumps operate via many energy sources, including manual operation, electricity, engines, or wind power, come in many sizes, from microscopic for use in medical applications to large industrial pumps.
Mechanical pumps serve in a wide range of applications such as pumping water from wells, aquarium filtering, pond filtering and aeration, in the car industry for water-cooling and fuel injection, in the energy industry for pumping oil and natural gas or for operating cooling towers. In the medical industry, pumps are used for biochemical processes in developing and manufacturing medicine, and as artificial replacements for body parts, in particular the artificial heart and penile prosthesis.

Pump Efficiency

Pump efficiency is defined as the ratio of the power imparted on the fluid by the pump in relation to the power supplied to drive the pump. Its value is not fixed for a given pump; efficiency is a function of the discharge and therefore also operating head. For centrifugal pumps, the efficiency tends to increase with flow rate up to a point midway through the operating range (peak efficiency) and then declines as flow rates raise further. Pump performance data such as this is usually supplied by the manufacturer before pump selection. Pump efficiencies tend to decline over time due to wear (e.g. increasing clearances as impellers reduce in size).

When a system design includes a centrifugal pump, an important issue it its design is matching the head loss-flow characteristic with the pump so that it operates at or close to the point of its maximum efficiency. Pump efficiency is an important aspect and pumps should be regularly tested. Thermodynamic pump testing is one method. Depending on how the measurement is taken suction lift and head may also be referred to as static or dynamic. Static indicates the measurement does not take into account the friction caused by water moving through the hose or pipes. Dynamic indicates that losses due to friction are factored into the performance. The following terms are usually used when referring to lift or head.

MATHEMATICAL MODELLING

Jacobin matrix and Newton Raphson Method:-

The pipe network can be analyzed using the Newton-Raphson method. The Newton-raphson method is a powerful numerical method for solving system of non linear equations. Suppose that there are three non-linear equations $F_1(Q_1, Q_2, Q_3) = 0, F_2(Q_1, Q_2, Q_3) = 0\ and F_3(Q_1, Q_2, Q_3) = 0$ to be solved for $Q_1, Q_2\ and\ Q_3$. Adopt a starting solution(Q_1, Q_2, Q_3). Also consider that $(Q_1 + \Delta Q_1, Q_2 + \Delta Q_2\ and\ Q_3 + \Delta Q_3)$ is the solution of the set of equations. Tha is,

$$F_1(Q_1 + \Delta Q_1, Q_2 + \Delta Q_2, Q_3 + \Delta Q_3) = 0$$
$$F_2(Q_1 + \Delta Q_1, Q_2 + \Delta Q_2, Q_3 + \Delta Q_3) = 0$$
$$F_3(Q_1 + \Delta Q_1, Q_2 + \Delta Q_2, Q_3 + \Delta Q_3) = 0$$

Expanding the above equations as Taylor's series,

$$F_1 + \left[\frac{\partial F_1}{\partial Q_1}\right]\Delta Q_1 + \left[\frac{\partial F_1}{\partial Q_2}\right]\Delta Q_2 + \left[\frac{\partial F_1}{\partial Q_3}\right]\Delta Q_3 = 0$$
$$F_2 + \left[\frac{\partial F_2}{\partial Q_1}\right]\Delta Q_1 + \left[\frac{\partial F_2}{\partial Q_2}\right]\Delta Q_2 + \left[\frac{\partial F_2}{\partial Q_3}\right]\Delta Q_3 = 0$$
$$F_3 + \left[\frac{\partial F_3}{\partial Q_1}\right]\Delta Q_1 + \left[\frac{\partial F_3}{\partial Q_2}\right]\Delta Q_2 + \left[\frac{\partial F_3}{\partial Q_3}\right]\Delta Q_3 = 0$$

Arranging above equations in matrix form,

$$\begin{bmatrix} \partial F_1/\partial Q_1 & \partial F_1/\partial Q_2 & \partial F_1/\partial Q_3 \\ \partial F_2/\partial Q_1 & \partial F_2/\partial Q_2 & \partial F_2/\partial Q_3 \\ \partial F_3/\partial Q_1 & \partial F_3/\partial Q_2 & \partial F_3/\partial Q_3 \end{bmatrix} \begin{bmatrix} \Delta Q_1 \\ \Delta Q_2 \\ \Delta Q_3 \end{bmatrix} = - \begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix}$$

Where,

$$\begin{bmatrix} \partial F_1/\partial Q_1 & \partial F_1/\partial Q_2 & \partial F_1/\partial Q_3 \\ \partial F_2/\partial Q_1 & \partial F_2/\partial Q_2 & \partial F_2/\partial Q_3 \\ \partial F_3/\partial Q_1 & \partial F_3/\partial Q_2 & \partial F_3/\partial Q_3 \end{bmatrix} \text{is called as jacobian matrix.}$$

$$\therefore \begin{bmatrix} \Delta Q_1 \\ \Delta Q_2 \\ \Delta Q_3 \end{bmatrix} = - \begin{bmatrix} \partial F_1/\partial Q_1 & \partial F_1/\partial Q_2 & \partial F_1/\partial Q_3 \\ \partial F_2/\partial Q_1 & \partial F_2/\partial Q_2 & \partial F_2/\partial Q_3 \\ \partial F_3/\partial Q_1 & \partial F_3/\partial Q_2 & \partial F_3/\partial Q_3 \end{bmatrix}^{-1} \begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix}$$

Knowing the corrections, the discharges are improved as

$$\begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \end{bmatrix}_{new} = \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \end{bmatrix}_{old} + \begin{bmatrix} \Delta Q_1 \\ \Delta Q_2 \\ \Delta Q_3 \end{bmatrix}$$

It can be seen that for a large network, it is time consuming to invert matrix again and again. Thus, the inverted matrix is preserved and is used for at least three times to obtain the corrections.

The overall procedure for looped network analysis by Newton- Raphson method can be summarized in the following steps:

Step 1: Number the entire entire pipe links.
Step 2: Write nodal discharge equation as

$$F_j = \sum_{n=1}^{j_n} Q_{j_n} - Q_j = 0 \dots\ for\ all\ nodes\ 1,2,3 \dots \dots n$$

Where Q_{j_n} the discharge in is n[th] pipe at node j, Q_j is nodal withdrawal and j_n is the total number of pipes at node j.
Step 3: Write pressure head loss equations.
Step 4: Assume initial pipe discharges $Q_1, Q_2, Q_3, \dots$ satisfying continuity equations.
Step 5: Find the values of partial derivatives $\partial F_n / \partial Q_i$ and the functions F_n, using the initial pipe discharges $Q_1, Q_2, Q_3, \dots$
Step 6: Find ΔQ_i. The equations generated are in the form $Ax = b$, which can be solved for ΔQ_i.
Step 7: Using the obtained ΔQ_i values, the pipe discharges are modified.

a) Regular suction side. (Single Pipe) :-
Given Data:-Inner diameter of pipe (d_i) = 76.2mm
Thickness of pipe (t) = 3.66mm

$$\therefore InternalDiameter d_i = d_0 - 2t$$
$$\therefore d_o = 76.2 + 2 \times 3.66$$
$$\therefore d_o = 83.52\ mm$$

Length of pipe (l) = 3m
Mass of flowing water per second (m) = 2.5 kg/sec
Density of flowing water (ρ_w) = 1000 kg/m^3
Weight Density of carbon steel (ρ_{cs}) = 7850 kg/m^3
Coefficient of friction for pipe (μ) = 0.005
Efficiency of motor (η) = 80%

a) Cross-sectional area of pipe:

$$a = \frac{\pi}{4} \times {d_i}^2$$
$$\therefore a = \frac{\pi}{4} \times (76.2 \times 10^{-3})^2$$
$$\therefore a = 0.00456\ m^2$$

b) Velocity of flowing liquid in pipe per second:

$$mass = densityofwater \times area \times velocity$$
$$\therefore velocity, v = \frac{mass}{area \times densityofwater}$$
$$\therefore v = \frac{2.5}{0.00456 \times 1000}$$
$$\therefore v = 0.548\ m/sec$$

c) Major losses in pipe :

$$h_f = \frac{4flv^2}{2gd_o}$$
$$\therefore h_f = \frac{4 \times 0.005 \times 3 \times 0.548^2}{2 \times 9.81 \times 76.2 \times 10^{-3}}$$
$$\therefore h_f = 0.01206\ m$$

d) Pressure developed in a pipe

$$p_d = \rho_w g h_f$$
$$\therefore p_d = 1000 \times 9.81 \times 0.01206$$
$$\therefore p_d = 123.606\ N/m^2$$

e) Weight of single pipe:

$$w = specificweight \times volume$$
$$\therefore w = specific\ weight \times area \times length$$
$$\therefore w = \rho_{cs} \times \frac{\pi}{4}\left({d_0}^2 - {d_i}^2\right) \times l$$
$$\therefore w = 7850 \times \frac{\pi}{4}[(83.52 \times 10^{-3})^2 - (76.2 \times 10^{-3})^2] \times 3$$
$$\therefore w = 21.614\ kg$$

f) Power required to pump water:

$$p = \frac{\rho_w Q g h_f}{\eta}$$

$$\therefore p = \frac{1000 \times (2.5/1000) \times 9.81 \times 0.01206}{0.8}$$

$$p = 0.3697kW$$

b) First Modification. (Two Pipe) :-

Given Data:-Inner diameter of pipe (d_i) = 76.2mm

Thickness of pipe (*t*) = 3.66mm

$$\therefore InternalDiameter d_i = d_0 - 2t$$

$$\therefore d_o = 76.2 + 2 \times 3.66$$

$$\therefore d_o = 83.52\ mm$$

Length of pipe (*l*) = 1m

Mass of flowing water per second (*m*) = 2.5 kg/sec

Density of flowing water (ρ_w) = 1000 kg/m^3

Weight Density of carbon steel (ρ_{cs}) = 7850 kg/m^3

Coefficient of friction for pipe (μ) = 0.005

Efficiency of motor (η) = 80%

a) Cross-sectional area of pipe:

$$a = \frac{\pi}{4} \times {d_i}^2$$

$$\therefore a = \frac{\pi}{4} \times (76.2 \times 10^{-3})^2$$

$$\therefore a = 0.00456\ m^2$$

b) Velocity of flowing liquid in pipe per second:

c)

$$mass = densityofwater \times area \times velocity$$

$$\therefore velocity, v = \frac{mass}{area \times densityofwater}$$

$$\therefore v = \frac{2.5}{0.00456 \times 1000}$$

$$\therefore v = 0.548\ m/sec$$

d) Major losses in pipe :

$$h_f = \frac{4flv^2}{2gd_o}$$

$$\therefore h_f = \frac{4 \times 0.005 \times 1 \times 0.548^2}{2 \times 9.81 \times 76.2 \times 10^{-3}}$$

$$\therefore h_f = \quad m$$

e) Pressure developed in a pipe

$$p_d = \rho_w g h_f$$

$$\therefore p_d = 1000 \times 9.81 \times$$

$$\therefore p_d = \quad N/m^2$$

f) Weight of single pipe:

$$w = specificweight \times volume$$

$$\therefore w = specific\ weight \times area \times length$$

$$\therefore w = \rho_{cs} \times \frac{\pi}{4}\left({d_0}^2 - {d_i}^2\right) \times l$$

$$\therefore w = 7850 \times \frac{\pi}{4}[(83.52 \times 10^{-3})^2 - (76.2 \times 10^{-3})^2] \times 1$$

$$\therefore w = \quad kg$$

g) Power required to pump water:

$$p = \frac{\rho_w Q g h_f}{\eta}$$

$$\therefore p = \frac{1000 \times (2.5/1000) \times 9.81 \times}{0.8}$$

$$p = \quad kW$$

Given Data:-Inner diameter of pipe (d_i) = 76.2mm
Thickness of pipe (t) = 3.66mm

$$\therefore InternalDiameter d_i = d_0 - 2t$$
$$\therefore d_o = 76.2 + 2 \times 3.66$$
$$\therefore d_o = 83.52\ mm$$

Length of pipe (l) = 1m
Mass of flowing water per second (m) = 2.5 kg/sec
Density of flowing water (ρ_w) = 1000 kg/m^3
Weight Density of carbon steel (ρ_{cs}) = 7850 kg/m^3
Coefficient of friction for pipe (μ) = 0.005
Efficiency of motor (η) = 80%

a) Cross-sectional area of pipe:

$$a = \frac{\pi}{4} \times {d_i}^2$$
$$\therefore a = \frac{\pi}{4} \times (76.2 \times 10^{-3})^2$$
$$\therefore a = 0.00456\ m^2$$

b) Velocity of flowing liquid in pipe per second:

$$mass = density of water \times area \times velocity$$
$$\therefore velocity, v = \frac{mass}{area \times density of water}$$
$$\therefore v = \frac{2.5}{0.00456 \times 1000}$$
$$\therefore v = 0.548\ m/sec$$

c) Major losses in pipe :

$$h_f = \frac{4flv^2}{2gd_o}$$
$$\therefore h_f = \frac{4 \times 0.005 \times 1 \times 0.548^2}{2 \times 9.81 \times 76.2 \times 10^{-3}}$$
$$\therefore h_f = \quad m$$

d) Pressure developed in a pipe

$$p_d = \rho_w g h_f$$
$$\therefore p_d = 1000 \times 9.81 \times$$
$$\therefore p_d = \quad N/m^2$$

e) Weight of single pipe:

$$w = specific weight \times volume$$
$$\therefore w = specific\ weight \times area \times length$$
$$\therefore w = \rho_{cs} \times \frac{\pi}{4}\left({d_0}^2 - {d_i}^2\right) \times l$$
$$\therefore w = 7850 \times \frac{\pi}{4}[(83.52 \times 10^{-3})^2 - (76.2 \times 10^{-3})^2] \times 1$$
$$\therefore w = \quad kg$$

f) Power required to pump water:

$$p = \frac{\rho_w Q g h_f}{\eta}$$
$$\therefore p = \frac{1000 \times (2.5/1000) \times 9.81 \times}{0.8}$$
$$p = \quad kW$$

Given Data:-Inner diameter of pipe (d_i) = 76.2mm
Thickness of pipe (t) = 3.66mm

$$\therefore InternalDiameter d_i = d_0 - 2t$$
$$\therefore d_o = 76.2 + 2 \times 3.66$$
$$\therefore d_o = 83.52\ mm$$

Length of pipe (l) = 1m
Mass of flowing water per second (m) = 2.5 kg/sec
Density of flowing water (ρ_w) = 1000 kg/m^3
Weight Density of carbon steel (ρ_{cs}) = 7850 kg/m^3
Coefficient of friction for pipe (μ) = 0.005
Efficiency of motor (η) = 80%

a) Cross-sectional area of pipe:

$$a = \frac{\pi}{4} \times {d_i}^2$$
$$\therefore a = \frac{\pi}{4} \times (76.2 \ \times 10^{-3})^2$$
$$\therefore a = 0.00456 \, m^2$$

b) Velocity of flowing liquid in pipe per second:

$$mass = densityofwater \times area \times \ velocity$$
$$\therefore velocity, v = \frac{mass}{area \times densityofwater}$$

$$\therefore v = \frac{2.5}{0.00456 \ \times 1000}$$
$$\therefore v = 0.548 \, m/sec$$

c) Major losses in pipe :

$$h_f = \frac{4flv^2}{2gd_o}$$
$$\therefore h_f = \frac{4 \times 0.005 \times 1 \times 0.548^2}{2 \times 9.81 \times 76.2 \times 10^{-3}}$$
$$\therefore \ h_f = \quad m$$

d) Pressure developed in a pipe

$$p_d = \ \rho_w g h_f$$
$$\therefore p_d = 1000 \times 9.81 \times$$
$$\therefore \ p_d = \qquad N/m^2$$

e) Weight of single pipe:

$$w = specificweight \times volume$$
$$\therefore w = specific\ weight \times area \times length$$
$$\therefore w = \rho_{cs} \times \frac{\pi}{4}\left({d_0}^2 - {d_i}^2\right) \times l$$
$$\therefore w = 7850 \times \frac{\pi}{4}[(83.52 \ \times 10^{-3})^2 - (76.2 \times 10^{-3})^2] \times 1$$
$$\therefore w = \qquad kg$$

f) Power required to pump water:

$$p = \frac{\rho_w Q g h_f}{\eta}$$
$$\therefore p = \frac{1000 \times (2.5/1000) \times 9.81 \times}{0.8}$$
$$p = \qquad kW$$

b) Second Modification. (Three Pipe) :-

Given Data:-Inner diameter of pipe (d_i) = 76.2mm

Thickness of pipe (t) = 3.66mm

$$\therefore InternalDiameter d_i = \ d_0 - \ 2t$$
$$\therefore d_o = 76.2 + 2 \times 3.66$$
$$\therefore d_o = 83.52 \, mm$$

Length of pipe (l) = 1m

Mass of flowing water per second (m) = 2.5 kg/sec

Density of flowing water (ρ_w) = 1000 kg/m^3

Weight Density of carbon steel (ρ_{cs}) = 7850 kg/m^3

Coefficient of friction for pipe (μ) = 0.005

Efficiency of motor (η) = 80%

h) Cross-sectional area of pipe:

$$a = \frac{\pi}{4} \times {d_i}^2$$
$$\therefore a = \frac{\pi}{4} \times (76.2 \ \times 10^{-3})^2$$
$$\therefore a = 0.00456 \, m^2$$

i) Velocity of flowing liquid in pipe per second:

$$mass = densityofwater \times area \times \ velocity$$
$$\therefore velocity, v = \frac{mass}{area \times densityofwater}$$

$$\therefore v = \frac{2.5}{0.00456 \times 1000}$$
$$\therefore v = 0.548\ m/sec$$

j) Major losses in pipe :

$$h_f = \frac{4flv^2}{2gd_o}$$
$$\therefore h_f = \frac{4 \times 0.005 \times 1 \times 0.548^2}{2 \times 9.81 \times 76.2 \times 10^{-3}}$$
$$\therefore\ h_f = \quad m$$

k) Pressure developed in a pipe

$$p_d = \rho_w g h_f$$
$$\therefore p_d = 1000 \times 9.81 \times$$
$$\therefore\ p_d = \quad N/m^2$$

l) Weight of single pipe:

$$w = specificweight \times volume$$
$$\therefore w = specific\ weight \times area \times length$$
$$\therefore w = \rho_{cs} \times \frac{\pi}{4}\left({d_0}^2 - {d_i}^2\right) \times l$$
$$\therefore w = 7850 \times \frac{\pi}{4}[(83.52\ \times 10^{-3})^2 - (76.2 \times 10^{-3})^2] \times 1$$
$$\therefore w = \quad kg$$

m) Power required to pump water:

$$p = \frac{\rho_w Q g h_f}{\eta}$$
$$\therefore p = \frac{1000 \times (2.5/1000) \times 9.81 \times}{0.8}$$
$$p = \quad kW$$

Given Data:-Inner diameter of pipe (d_i) = 76.2mm
Thickness of pipe (t) = 3.66mm

$$\therefore InternalDiameter d_i = d_0 - 2t$$
$$\therefore d_o = 76.2 + 2 \times 3.66$$
$$\therefore d_o = 83.52\ mm$$

Length of pipe (l) = 1m
Mass of flowing water per second (m) = 2.5 kg/sec
Density of flowing water (ρ_w) = 1000 kg/m^3
Weight Density of carbon steel (ρ_{cs}) = 7850 kg/m^3
Coefficient of friction for pipe (μ) = 0.005
Efficiency of motor (η) = 80%

g) Cross-sectional area of pipe:

$$a = \frac{\pi}{4} \times {d_i}^2$$
$$\therefore a = \frac{\pi}{4} \times (76.2\ \times 10^{-3})^2$$
$$\therefore a = 0.00456\ m^2$$

h) Velocity of flowing liquid in pipe per second:

$$mass = densityofwater \times area \times\ velocity$$
$$\therefore velocity, v = \frac{mass}{area \times densityofwater}$$

$$\therefore v = \frac{2.5}{0.00456 \times 1000}$$
$$\therefore v = 0.548\ m/sec$$

i) Major losses in pipe :

$$h_f = \frac{4flv^2}{2gd_o}$$
$$\therefore h_f = \frac{4 \times 0.005 \times 1 \times 0.548^2}{2 \times 9.81 \times 76.2 \times 10^{-3}}$$
$$\therefore\ h_f = \quad m$$

j) Pressure developed in a pipe

$$p_d = \rho_w g h_f$$
$$\therefore p_d = 1000 \times 9.81 \times$$
$$\therefore p_d = \quad N/m^2$$

k) Weight of single pipe:

$$w = specificweight \times volume$$
$$\therefore w = specific\ weight \times area \times length$$
$$\therefore w = \rho_{cs} \times \frac{\pi}{4}\left({d_0}^2 - {d_i}^2\right) \times l$$
$$\therefore w = 7850 \times \frac{\pi}{4}[(83.52 \times 10^{-3})^2 - (76.2 \times 10^{-3})^2] \times 1$$
$$\therefore w = \quad kg$$

l) Power required to pump water:

$$p = \frac{\rho_w Q g h_f}{\eta}$$
$$\therefore p = \frac{1000 \times (2.5/1000) \times 9.81 \times}{0.8}$$
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g) Cross-sectional area of pipe:

$$a = \frac{\pi}{4} \times {d_i}^2$$
$$\therefore a = \frac{\pi}{4} \times (76.2 \times 10^{-3})^2$$
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h) Velocity of flowing liquid in pipe per second:

$$mass = densityofwater \times area \times velocity$$
$$\therefore velocity, v = \frac{mass}{area \times densityofwater}$$
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i) Major losses in pipe :

$$h_f = \frac{4flv^2}{2gd_o}$$
$$\therefore h_f = \frac{4 \times 0.005 \times 1 \times 0.548^2}{2 \times 9.81 \times 76.2 \times 10^{-3}}$$
$$\therefore h_f = \quad m$$

j) Pressure developed in a pipe

$$p_d = \rho_w g h_f$$
$$\therefore p_d = 1000 \times 9.81 \times$$
$$\therefore p_d = \quad N/m^2$$

k) Weight of single pipe:

$$w = specificweight \times volume$$
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$$\therefore w = \rho_{cs} \times \frac{\pi}{4}\left({d_0}^2 - {d_i}^2\right) \times l$$
$$\therefore w = 7850 \times \frac{\pi}{4}[(83.52 \times 10^{-3})^2 - (76.2 \times 10^{-3})^2] \times 1$$
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l) Power required to pump water:

$$p = \frac{\rho_w Q g h_f}{\eta}$$
$$\therefore p = \frac{1000 \times (2.5/1000) \times 9.81 \times}{0.8}$$
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Given Data:-Inner diameter of pipe (d_i) = 76.2mm
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Coefficient of friction for pipe (μ) = 0.005
Efficiency of motor (η) = 80%

a) Cross-sectional area of pipe:

$$a = \frac{\pi}{4} \times {d_i}^2$$
$$\therefore a = \frac{\pi}{4} \times (76.2\ \times 10^{-3})^2$$
$$\therefore a = 0.00456\ m^2$$

b) Velocity of flowing liquid in pipe per second:

$$mass = density of water \times area \times\ velocity$$
$$\therefore velocity, v = \frac{mass}{area \times density of water}$$
$$\therefore v = \frac{2.5}{0.00456\ \times 1000}$$
$$\therefore v = 0.548\ m/sec$$

c) Major losses in pipe :

$$h_f = \frac{4flv^2}{2gd_o}$$
$$\therefore h_f = \frac{4 \times 0.005 \times 1 \times 0.548^2}{2 \times 9.81 \times 76.2 \times 10^{-3}}$$
$$\therefore\ h_f = \quad m$$

d) Pressure developed in a pipe

$$p_d = \rho_w g h_f$$
$$\therefore p_d = 1000 \times 9.81 \times$$
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e) Weight of single pipe:

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$$\therefore w = \rho_{cs} \times \frac{\pi}{4}\left({d_0}^2 - {d_i}^2\right) \times l$$
$$\therefore w = 7850 \times \frac{\pi}{4}[(83.52\ \times 10^{-3})^2 - (76.2 \times 10^{-3})^2] \times 1$$
$$\therefore w = \quad kg$$

f) Power required to pump water:

$$p = \frac{\rho_w Q g h_f}{\eta}$$
$$\therefore p = \frac{1000 \times (2.5/1000) \times 9.81 \times}{0.8}$$
$$p = \quad kW$$

CALCULATION SUMMARY

MASS FLOW RATE 2.5

di	Thickness	Length	Csarea	Velocity	mass	Density	Cp	K	viscosity	ff	Dcoeff	D Pr. Drop (Bend)	Delp
mm	Mm	m	m2	m/s	kg/s	kg/m3	J/kgK	W/mK	Pa.s				Pa
76.2	3.66	1	0.00456	0.5482	2.5	1000	4180	0.0242	0.01	0.005			39.439
44	3.25	1	0.00152	0.54805	0.833	1000	4180	0.0242	0.01	0.005	0.2	30.0363	98.301
44	3.25	1	0.00152	0.54805	0.833	1000	4180	0.0242	0.01	0.005	0.2	30.0363	98.301
44	3.25	1	0.00152	0.54805	0.833	1000	4180	0.0242	0.01	0.005	0.2	30.0363	98.301
													137.74

di	Thickness	Length	Csarea	Velocity	mass	Density	Cp	K	viscosity	ff	Dcoeff	D Pr. Drop (Bend)	Delp
mm	Mm	m	m2	m/s	kg/s	kg/m3	J/kgK	W/mK	Pa.s				Pa
76.2	3.66	1	0.00456	0.5482	2.5	1000	4180	0.0242	0.01	0.005			39.439
63.5	3.4	1	0.00317	0.39471	1.25	1000	4180	0.0242	0.01	0.005	0.2	15.57920	40.113
63.5	3.4	1	0.00317	0.39471	1.25	1000	4180	0.0242	0.01	0.005	0.2	15.57920	40.113
													79.552

1

di	Thickness	Length	Csarea	Velocity	mass	Density	Cp	K	viscosity	ff	Dcoeff	D Pr. Drop (Bend)	Delp
mm	Mm	m	m2	m/s	kg/s	kg/m3	J/kgK	W/Mk	Pa.s				Pa
76.2	3.66	3	0.00456	0.5482	2.5	1000	4180	0.0242	0.01	0.005	0	0	118.32

CONCLUSION

In this paper, we have done mathematical modeling, to optimize the geometry of the suction manifolds of test model of a centrifugal pump under preselected boundary conditions. This can be used for the analysis of the same.

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