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The performance analysis of Hydraulic Ram Pump: Influence of specific parameters and validation with Comsol-Multiphysics

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Abstract: Both energy and environmental conservation have been major issues in today's world. Conventional pumping devices use a huge amount of energy. This gave rise to interest in alternate pumping devices like hydraulic ram pumps. The hydraulic ram pump is capable of pumping water higher than its source with some inlet pressure and velocity head. It works on the principle of the water hammer effect which occurs due to sudden stoppage of flow resulting in the rise in pressure. Since it uses just two moving parts it is mechanically very simple, has very high reliability, minimal maintenance requirements, and long operational life. In rural areas where unconventional energy suffers from various limitations, emphasis is given mainly to the use of unconventional forms of energy. It is designed on the principle of conversion of the potential energy of water into kinetic energy and further conversion into pressure energy to lift water to some desired elevation without the use of electricity, motors, generators or batteries and that is the main advantage for opting this technology. It can operate autonomously, requiring minimal maintenance and having a long lifespan. Additionally, it is a green energy concept, environment-friendly, producing no emissions or pollutants. But, as it runs from the power of water itself in the form of waste water, efficiency is found to be minimal, rendering its limited scope. Hence, it is a need-based approach for maximizing its performance by providing a sustainable and efficient water pumping solution. The vital components of this technology have been detected which play a pivotal role in its performance. These are called influencing parameters. This paper investigates the effect of influencing parameters specifically–the horizontal distance between the pressure chamber and to waste valve (HD) on the performance and the overall efficiency of the Hydraulic ram pump (hydram). Both experimental and simulation studies were done in order to achieve the justification. Five sets of prototypes have been designed and tested individually for experimental and analytical studies. The maximum efficiency comes out to be 79 % with a flow rate of 140 L/hr for optimized HD of 17 cm. The results obtained from the experimental investigation are further simulated with comsol multiphysics for final validation. The experimental study and Comsol multiphysics simulation validate the proposed model and confirm its justification.

Introduction

Ram pump has been in use for the last 200 years (Young, l995, 2016). The first suggestion was given by John Whitehurts in 1772, but it was not feasible until Joseph Montgolfier, a French inventor, made ram pumps in 1796. Guo et al. (2018) have conducted a lot of experimental studies for optimum performance which

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Table1. Main components of Test rig

Sl. no.	Component	Material	Dimension(in mm)
1	Supply Pipe	UPVC	25.4 Diameter
2	Delivery Pipe	UPVC	25.4Diameter
3	Waste Valve	G.I.	25.4Diameter
4	Delivery Valve	G.I.	25.4Diameter
5	Check Valve	PVC	25.4Diameter
6	Supply Tank	Plastic	200L
7	PVC Chamber	Plastic	3L
8	Tee	PVC	25.4Diameter
9	Elbow	PVC	25.4Diameter
10	Nipple	G.I.	25.4Diameter
11	Reducer	PVC	12.7 Diameter
12	Intake water supply Tank	PVC	1000 L
13	Pressure Transmitter x 2	Instrument	1. Inlet (4-20) mA, 0-10 bar 2. Out let (4-20) mA,0-10 bar
14	Data Acquisition	Instrument	Keysight IO, Agilent Bench Link Data Logger.

performance of hydraulic ram pumps (hydram) has been performed by researchers Krol (1951), Schiller (1984), Browne (2005), Suarda (2018), Dhaiban (2019) in various countries by fabrication of hydram and feasibility analysis. Various studies were carried out to understand and simulate the functioning of a hydram (Sheikh et al., 2013; Deo et al., 2016; Hussin et al., 2017). They provided significant findings for maximizing the efficiencies. These research established that the length of the drive pipe causes an increase in efficiency and power to a maximum level. A larger air chamber also increased power and efficiency by almost 10% Inthachot et al. (2015). The velocity to initiate the waste valve closure is identified as the most important parameter controlling hydraulic ram operation. It is affected by waste valve design and adjustment, supply head elevation (Sutanto et al., 2022) and drive pipe length. The performance of hydraulic ram predicted by (Schiller, 1984) with parameters such as velocity in drive pipe, drag force coefficient and head loss factor under static flow conditions. An elastic seal is added for the waste and delivery valves to reduce noise and improve efficiency by Yang et al. (2014). Performance features of the head ratio and the flow rate ratio are dependent on cyclic frequency (Calvert, 1957). Experimental and theoretical investigations on hydrams were done for the first time by Gosline et al. (1933), who found that velocity in the drive pipe is an influencing factor. The experiments on hydrams were conducted by varying independently the following factors by Asvapoositkul et al. (2019) supply head, air chamber pressure, and waste valve beats per minute. Varying the weight and stroke of the waste valve a study on the effects of tuning of waste valve on hydram was was conducted Johanis et al. (2021) also. Performance plays a vital role in the relative position of Input-Pressure chamber (Compressor)-Waste (ICW) with variations in the pressure chamber height on the efficiency of Hydrams Mado et al. (2021) Hence, research works particularly for influence of the horizontal distance between the pressure chamber and waste valve (HD) of a Hydraulic Ram Pump for achieving Optimum Performance analysis are found very less. As already mentioned, a ram pump works with a water hammer effect which occurs due to sudden stoppage of flow, resulting in high surge of pressure which propagates through the piping system rapidly. This author's previous analysis of the ram pump with the Taguchi method yielded a conclusive result that a waste valve and a pressure chamber greatly influence its performance. In this experimental study, the proposed model has also been justified by the simulation results.

Materials and Methods

A set-up also called a Test rig (TR) has been constructed with the following assemblies and components shown in Table 1 and the complete test rig in Figure 1. The output flow rate of the ram pump and the outlet pressure has been measured experimentally to investigate the effect of the most influencing parameter - the height of the horizontal distance (HD) from the waste valve (WV) to the pressure chamber (PC).

Five sets of TRs were developed and tested individually both experimentally and analytically in Table 3. The ratio of supply pipe length to supply pipe diameter L/D referred to by (Calvert, 1957) is kept at 157, (the supply pipe length = 4 m, supply pipe diameter = 0.0254

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giving this ratio 157) and L should be $2.5 \times H$, where H= head. (Hussin et al., 2017). This value of L/D must lie between 150 and 1000 for proper functioning of the ram pump. (150 < L/D < 1000). Also, turbulence is neglected so laminar flow has been assumed throughout the study (Sheikh et al., 2013). The pipe fittings are done in the following orders mentioned below.

1) First, the PVC supply pipe is fitted with the supply tank through the tank nipple and the other end is connected with the body of the Ram pump.
2) A check valve is installed between them to regulate the fluid flow into the pump.
3) As shown in the figure below, a waste valve and delivery valve are fitted, so its flap is initially open due to its self-weight.
4) To prevent the backflow of water due to forces in the pressure chamber, a delivery valve is placed on
5) A Pressure chamber whose function is to absorb the water hammer pressure Asvapoositkul et al. (2021) that will occur in hydram is a PVC chamber fitted above the delivery valve with a nipple and a reducer, as shown in Figure 22.
6) The delivery pipe that connects the pump system is open to the atmosphere and is placed between the pressure chamber and the delivery valve with the help of the T joint. The setup is finally connected with a DAQ system comprising two pressure transducers to monitor the current signals for measuring inlet and outlet pressures in the figure below.

Table 2. Parameters of pipe fittings for Test rig

Sl. No.	Parameter	Dimension in m
1	Supply head (h)	1.7
3.	Supply pipe diameter	0.0254
4.	Delivery pipe diameter	0.0254
5.	Delivery head (H)	2.9

The (DAQ) has been used to monitor the data as an electrical current consisting of a Current Transducer (CT). The Software used for this experiment is Keysight IO, Agilent Bench Link Data Logger and Bench Vue. The Keysight 34972A Data Logger Switch Unit has a three-slot mainframe with a built-in digital multimeter. The Channel Multiplexer also can be configured as per the requirement for measuring different functions shown in Figure 2. Two ASPT series pressure transducers were used to measure the inlet and outlet pressure of the RAM pump with the help of the DAQ. For inlet and outlet pressure measurements the current transducer of range 4-20 mA with pressure range of 0-10 Bar has been used. (Figure 3)

Experimental setup design

The experimental setup has been built with the parameters chosen from the author's previous research works Sarma et al. (2016), where three one-factor-at-a-time (OFAT) experiments have been conducted to find the input parameter levels. An experiment was done using Taguchi's L9 Orthogonal Array with three repetitions and an Analysis of Variance (ANOVA) (Bagchi, 1992) was performed to verify the significance of the effect on output flow rate. Results showed that the distance between the pressure chamber and waste valve (HD), the height of the waste valve (WVH), and the height of the air chamber (PCH) have a significant effect on the outlet flow. Therefore, this study is comprised of five sets with three parameter alterations. These parameters are - a) waste valve height and b) pressure chamber height and c) horizontal distance between the pressure chamber and waste valve.

Let drive pipe length = L, W = water flowing per second into the chamber from the supply tank, w = weight of water lifted per second, h = height of water in the supply tank above the chamber and H = height of water raised from the chamber.

Let, the energy supplied to the ram pump is = Q_s

= weight of water supplied x height from which the water is supplied = $W \times h$………………………..(1)

Similarly, let energy delivered by the ram pump = Qd

= weight of water lifted × height through which water is raised, Qd = $w \times H$……………………………..(2)

Now, Work Output, W_o

The work output, W_o is the work done by the system to lift the fluid to height, H

$W_o = (w \times g) \times H = (w \times H) \times g$ where, g is the acceleration due to gravity…………………………(3)

The total work input, W_i

=The work required in lifting the fluid + the work required to overcome the weight of the fluid. So, total work input, $\mathbf{W_i = W_{lift} \times W_{weight}}$ = $(w \times g) \times h + (W \times g) \times h = (w + W) \times g \times h$…………………(4)

Now, efficiency = Work output, W_o ÷ Work input ,W_i

Figure 1. Complete test rig with Data Acquisition (DAQ)

Figure 2. Data Acquisition (DAQ) of test rig

Figure 3. Current sensor (CT) for DAQ of test rig

Substituting the values of work output and work input from (3) and (4) yields,

$\eta = w \times H \times g / (w + W) \times h \times g$

$\eta = (w \times H)/(w + W) \times h$……………………..(5)

This efficiency, η is known as D' Aubuisson's efficiency Phyoe et al. (2019) and Sheikh et al. (2013).

The inlet head was maintained at 170 cm and the outlet head was maintained at 2.969 m (taking approx. 3 m) compared to drive head = 1.86 m, outlet head = 3.81 m, waste valve height = 11.43 cm, pressure chamber height = 40.6 cm, supply pipe diameter = 25.4 mm, Supply pipe length = 4 m, Delivery pipe diameter = 25.4 mm., Waste valve height = 17cm = 0.17m, The Number of beats of the waste valve = 79 beats/min. Higher beating is desirable, but if the waste valve beating is too high, there will be no buildup of the powerful hammer. Earlier, the periods of waste valve operation were divided into four time zones but later it was considered to comprise six or seven periods, and few researchers simplified the hydraulic ram pump system into a drive pipe and two check valves that open and close instantaneously and performed a parameter variation study on the frictional head loss coefficient and wave speed. In this study, this beating of waste valve is not considered to avoid misleading results because this study is basically focussed on the relative distance of waste valve and pressure chamber only so it is completely excluded from the influential parameter.

First, the pump is run for 10 minutes then the displacement of liquid level in the supply tank is measured which is (Displacement of water level) (l) = 0.0508m, Diameter of supply tank (d1) = 75cm = 0.75m, Hence, the volume of the liquid supplied from the tank is calculated as- $\pi \div 4 \times d^2 \times l = 0.022428$ Where, d= Inner diameter of the supply tank, l =Level of water displaced in time t=600s, Supply flow rate, Qs = 0. 022428/600 = 3.738×10^{-5}m3/sec giving mass flow rate of 0.03738kg/s and Flow velocity, $Vs = \frac{Qs}{As} = 0.074$ m/s

………………………………………(6)

[Calculated Cross-sectional area, A_s for 25.4 mm inlet pipe = 0.0005064506 m²]……………………………(7)

Similarly for determining the amount of water lifted, (w), a calibrated burette has been used.

Design Parameters

All five test rigs (TR) were developed with the parameters shown below. Let, Waste valve height (WVH) = a, Pressure chamber height(PCH) = b and Horizontal distance between pressure chamber and waste valve (HD): = c, Now, taking parameters (all dimensions in cm)for TR-1: a = 11.43, b = 35, c = 10; Parameters for TR-2: a = 15, b= 37, c = 11; Parameters for TR-3: a = 20, b = 40.6, c = 13; Parameters for TR-4: a = 22, b = 47, c = 15.24; Parameters for TR-5: a = 25, b = 48, c = 20,the setup is run for 10 minutes as individually as explained earlier. Efficiency for Test rigs is calculated using D' Aubuisson's efficiency relationship from Eqn (5), $\eta = (w \times H)/(w + W) \times h$ gives η_1 = 16.44 % with flow rate = 0.029489 kg/s while TR-2 has achieved η_2 = 26.44 % efficiency and flow rate of 0.0374 kg/s. However, for TR-3, efficiency is found to be very less η_3 = 9.66% with a flow rate of 0.061211kg/s. For TR-4, the efficiency is found to be η_4 = 13.10% and the flow rate is 0.24896 kg/s. For TR-5, efficiency is found to be η_5 = 20.13% and the output flow rate is 0.5099 kg/s. So, it is found that TR-2 has the highest efficiency. Hence, TR-2 is the best model for further study amongst all five configurations with the three pre-assigned parametric values a, b, and c above as shown in Table 3.

Simulation Study

Investigation with variable parametric effect on hydram has not been found in detail with Comsol multiphysics except Fatihhiet al. (2018) for enhanced design of hydraulic pumps. Simulation analysis with Fluent and Computational fluid dynamics (CFD) was performed by (Shende et al., 2015; Harith et al., 2017).

Comsol multiphysics has the facility of importing geometry (readable format) from hardware-enforced in the system, where Comsol is installed. Moreover, it has also the facility of drawing geometry. However, in the present study, the model has been made in Solid Works software with proper dimensions and imported to Comsol Multiphysics.

The proposed method is simulated and tested by using Comsol Multiphysics 6.1 (Build: 282), Pipe Flow Module, in AMD64 Family 25 Model 80 Stepping 0, 6 cores, 5.9 GB RAM with Windows 10. For identification of real-time validation 13 nos of separate geometric configurations starting from 13 cm to 25 cm (Fig 17(a) and 17(b) have been constructed in the geometry section of Comsol and run the simulation. The whole flow is considered laminar while performing this Simulation study. Simulation analysis has been performed by observing the variation of pressure and velocity distribution to consider the different

Table 3. Design Parameters

Parameter	TR-1 (cm)	TR-2 (cm)	TR-3 (cm)	TR-4 (cm)	TR-5 (cm)
a) Waste valve height (WVH)	11.43	15	20	22	25
b) Pressure chamber height (PCH)	35	37	40.6	47	48
c) Distance between pressure chamber and waste valve (HD)	10	11	13	15.24	20
d) Pipe diameter (mm)	25.4	25.4	25.4	25.4	25.4
e) Efficiency %	16.44	26.44	9.66	13.10	20.13

parameters from experimental findings. In terms of magnitude, the outlet pressure was found much higher than the inlet pressure due to the water hammer effect. The pressure surge created by the sudden closure of the waste valve can result in a momentary increase in pressure that is higher than the initial supply head. However, this pressure surge is transient and lasts only for a short duration. The inlet pressure provides the initial energy to start the pump cycle, while the outlet pressure is the result of the water hammer effect and is responsible for delivering water to a higher elevation.

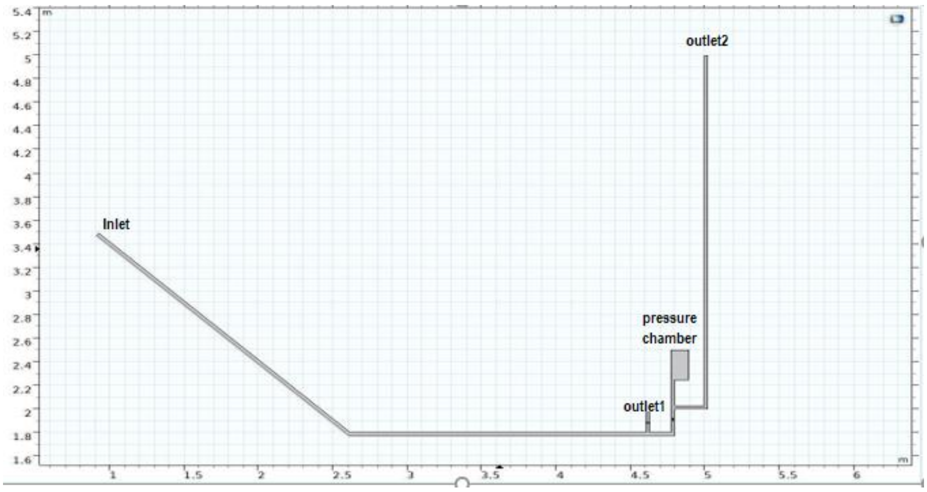

Figure 4. Model geometry of TR created in COMSOL

Simulation Material

The hydraulic ram pump used in this study is made up of PVC (polyvinyl chloride). Some properties of PVC are: Density: The density is 1380 kg /m^3, Ultimate tensile strength =48 MPa, Young's modulus of elasticity-3.4GPa, Brinell hardness-35BHN, Melting point -177^{o}C.

Meshing

Meshing is the process in which the continuous geometric space of an object is broken down into thousands or more shapes to properly define the physical shape of the object. In this study, the triangular mesh, physics controlled, normal element size and 2D model have been used. The features of the meshing are shown in Figure 5.

Laminar flow

The Laminar Flow interface is used to compute the velocity and pressure fields considering the flow as a single-phase fluid. As Reynolds number, (Re) plays a vital role while computing fluid analysis; it also depends on the model of the flow. In this example of pipe flow, where the critical Reynolds number is found to be approximately near 2000.

Re = $\rho \times V \times D/\mu$ = 1000× 0.074× 0.0254÷8.90 $\times 10^{-4}$ = 2111 (Rajput, 2019) (8)

It is assumed to be a laminar flow so that comsol simulation yields simplified results having minimal errors due to complexity.

Fluid properties

The density of wate, $\rho = 997\ kg/m^3$ and dynamic viscosity, $\mu = 0.001 Pa.s$ are taken (Figure 7).

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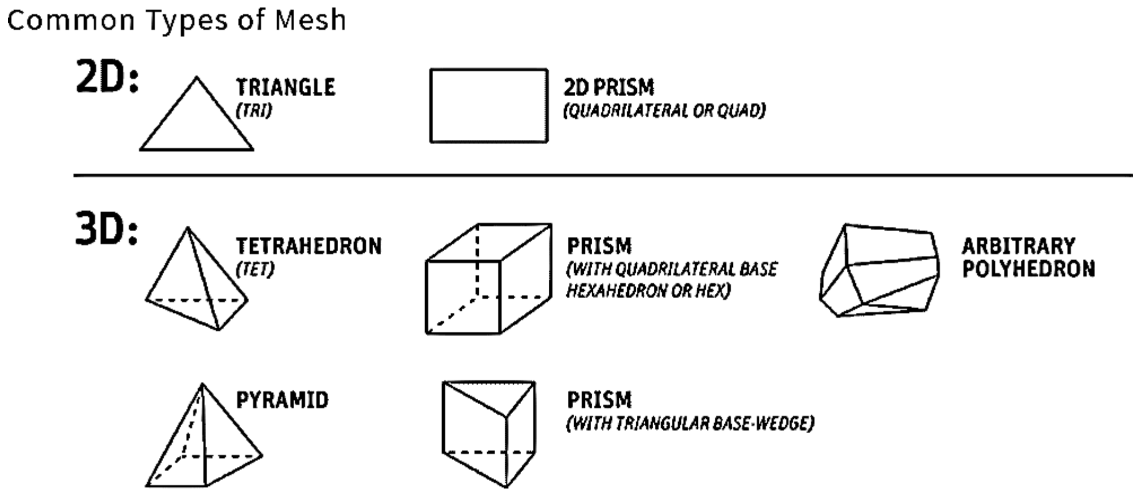

Figure 5. Types of Meshing

Initial values

Putting the initial value of inlet velocities in x, y direction from Eqn. (10) = 0.074 and pressure =16677 Pa from Eqn. (11) (Figure 8).

Wall condition

The wall is fixed with no slip condition (Figure 9).

Inlet condition

Putting the maximum velocity at the inlet from Eqn (6) is found 0.074 m/s the simulation has been carried out (Figure 10).

Outlet 1 condition

The inlet condition at outlet 1 (waste valve) is calculated from eqn. (6) & (11) which are found as 0.074 m/s and 16677 Pa respectively (Figure 11).

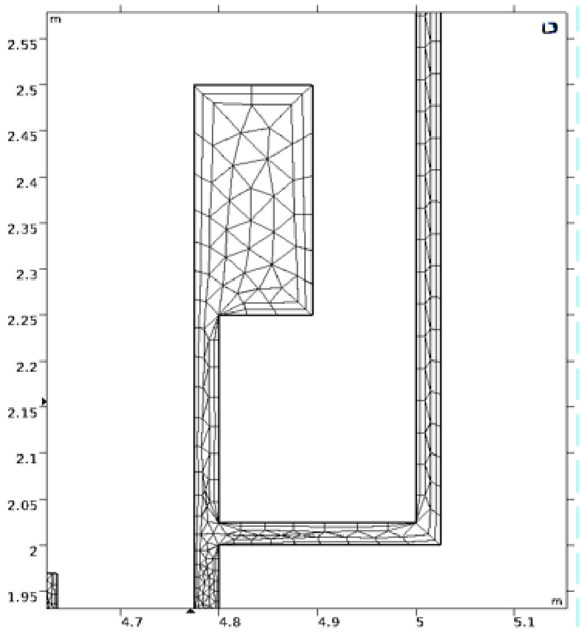

Figure 6. Enlarged view of meshing section

The outlet 2 (discharge) is open to atmosphere, P_o is atmospheric pressure = 101325Pa (Figure 12).

Outlet 2 condition

Water Hammer

The comsol simulation was done using inbuilt water hammer module. Water hammer plays a vital role in the working of hydram. It occurs when a valve closes very rapidly in a pipe network yielding a hydraulic transient and surge in pressure.

Fluid properties

Simulation has been carried out by taking the properties of density, dynamic viscosity and speed of sound from the material used in the simulation (default values) (Figure 13).

Pipe properties

PVC pipe has been used having a circular shape with 0.003 m thickness and diameter of 0.025 m and Young's modulus of 3275000000 Pa. (Figure 14).

Result and Discussion

Considering the efficiencies of the five TRs in Table 3, it is found that TR- 2 has shown the highest efficiency. Hence, TR 2 is assumed to be the best design among the four TRs. Now simulation has been done based on TR 2 parameters with the following variations a) for waste valve height varying from 0.13 m to 0.25m b) for pressure chamber height varying from 0.37 m to 0.5 m and c) for distance between pressure chamber and waste valve varying from 0.13 m to 0.25m. First, the a) velocities are calculated at waste valve outlet and at delivery outlet for variation of waste valve height from 0.13 m to 0.25m which are graphically represented in Figure 15(a) and Figure 15(b). Efficiency is calculated for all cases below using Eqn (5).

a. Efficiency calculation

For minimum flow of fluid through the waste valve, corresponding waste valve height (WVH) is calculated from graph. The minimum flow of fluid through the waste valve is always desirable to decrease the losses and

Fluid properties:

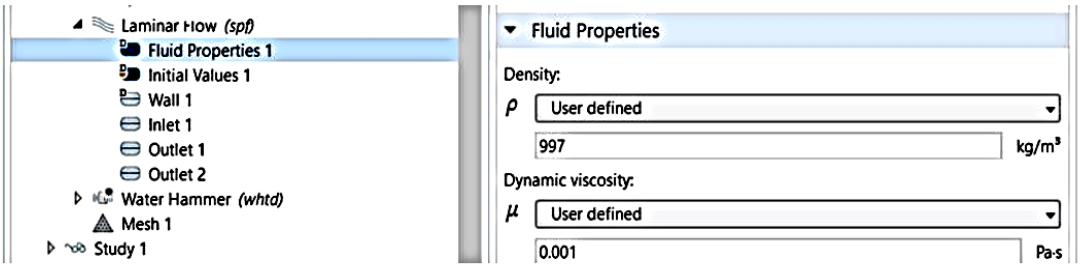

Figure 7. Fluid Properties of laminar flow

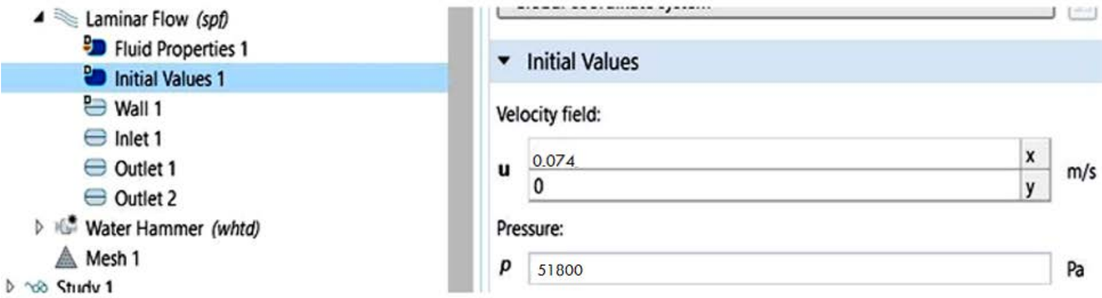

Figure 8. Initial values of laminar flow

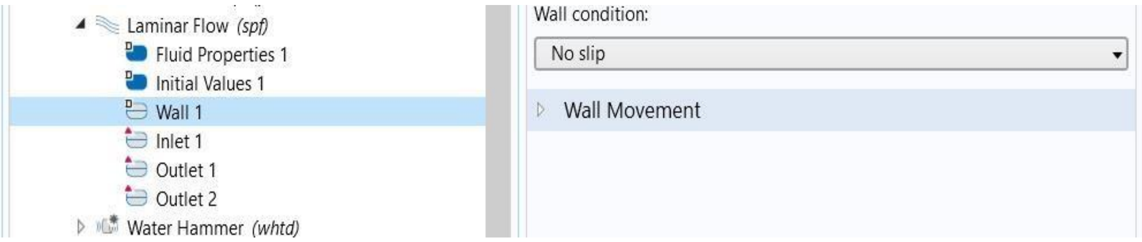

Figure 9. Wall condition of laminar flow

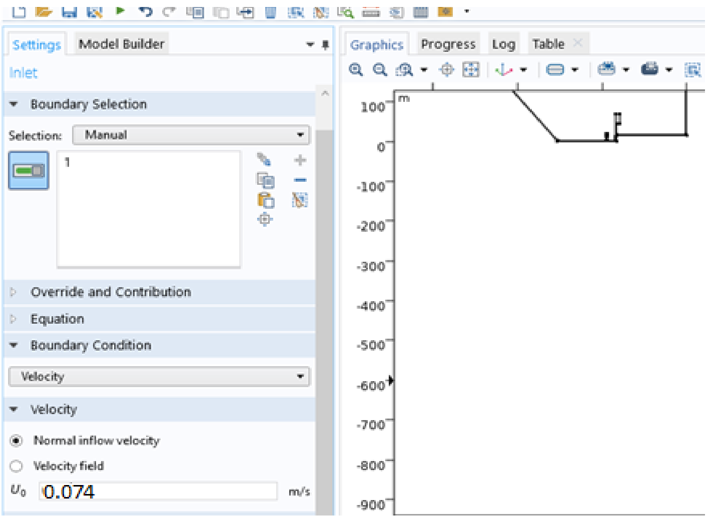

Figure 10. Inlet condition of laminar flow

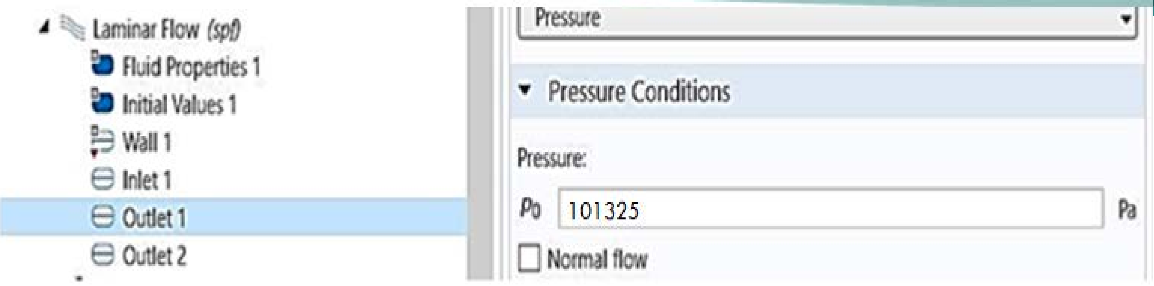

Figure 11. Waste valve outlet condition

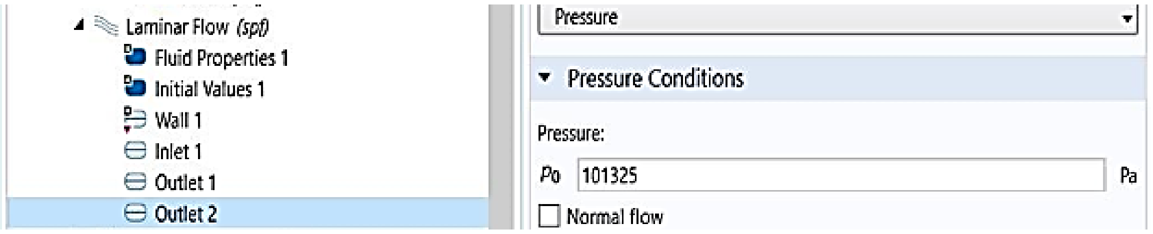

Figure 12. Delivery outlet condition

the minimum flow of fluid through the waste valve is obtained when the height of the waste valve (WVH) is found from simulation = 0.17 m (purple) in Fig 15(a).

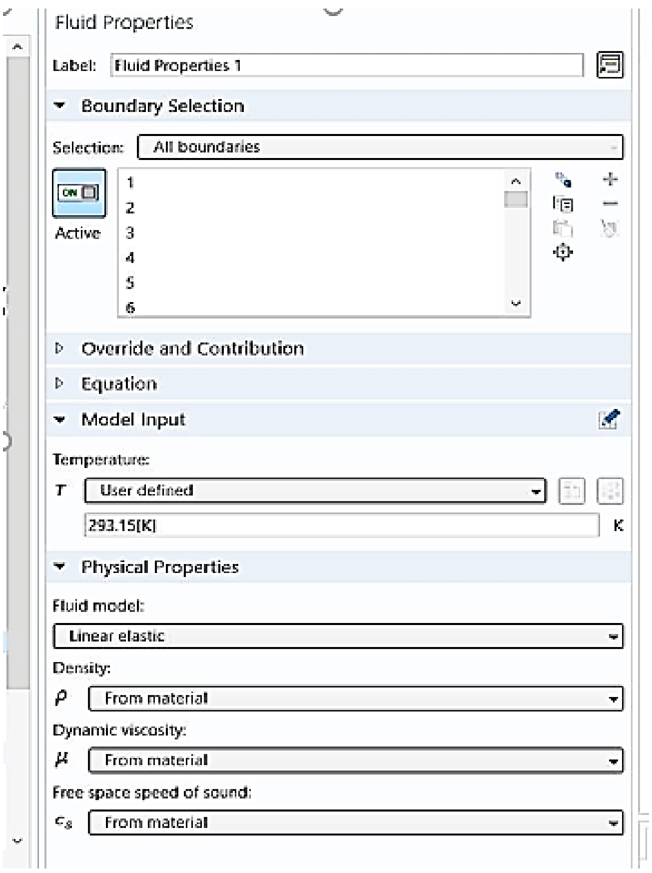

Figure 13. Fluid Properties of water hammer

Corresponding to this height the velocity of the flow obtained from comsol graph is V = 0.12035 m/s, Figure (15a,15b), now mass flow rate through the waste valve, $Q_w = \rho \times A \times V$ (Rajput,2002), whereρ is the density and A, V is the cross-sectional area of the pipe and velocity of flow respectively. So, $Q_w = \rho \times A \times V, Q_w =$ 0.0588994 kg/s

For WVH = 0.17m, the velocity obtained from comsol graph in the outlet pipe is 0.07635m/s, So, the delivery flow rate will be Q_d = 0.0373657 kg/s and efficiency, using Eqn. (5) is found as 68.49%

Similarly b) velocities are calculated at waste valve outlet and delivery outlet due to variation of pressure chamber height from 0.37 m to 0.5 m, which are graphically represented in Figure 16(a) and Figure 16(b). Efficiency is calculated for this criterion as follows.

b. Efficiency calculation

For the minimum flow of fluid through the waste valve, corresponding pressure chamber height (PCH) is calculated from graph. When the height of the pressure chamber = 0.47m (Green colour), Fig 16(a) &16 (b), it is minimum. Observing at this point, the corresponding velocity found from the graph, V = 0.11195m/s, Mass flow rate is attained has been calculated as Q_W = 0.05478846 kg/s, For PCH = 0.47, the velocity at the delivery outlet obtained, V = 0.0756m/s, the delivery flow rate Qd = 0.0369 kg/s, Efficiency found to be 71.02%.

Finally,Velocities are calculated at waste valve outlet and at delivery outlet for variation of distance between waste valve and pressure chamber (HD) which are graphically represented in Figure 17(a) and Figure 17(b). Efficiency is calculated for this criterion as follows.

c. Efficiency calculation

Efficiencies are calculated for minimum flow of fluid through the waste valve, corresponding distance between waste valve and the pressure chamber (HD) is calculated from graph. The minimum flow of fluid through the waste valve is obtained when the distance between the waste valve and pressure chamber is 0.17m shown by a curve with lowest peak (purple color) in Figure, and the velocity at the waste valve outlet corresponding to this value is

0.095 m/s, Flow rate Q_w = 0.0479 kg/s, for the distance of 0.17 m, The velocity obtained at the delivery outlet (purple color with highest peak in Figure 17(b),V = 0.077 m/s, delivery flow rate,Q_d= 0.038899 kg/s, So, efficiency is 79%.The velocity and pressure profiles for this criterion from comsol interface is shown in Figure Figure 18(a) and Figure 18.(b)

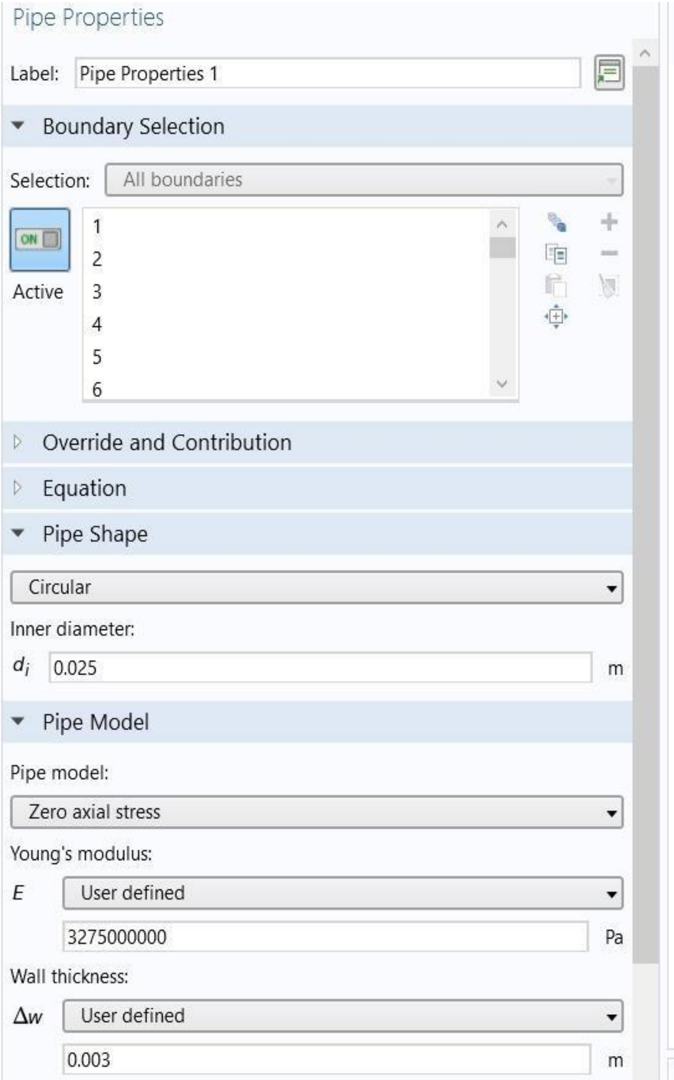

Figure 14. Pipe properties of water hammer

Results from Experimental Studies

Observing the Figures 20(a) and 20(b) above, current I is measured where maximum output is attained with DAQ using pressure transducer as shown below with selective range of I= 4-20 mA, and Pressure = 0-10 Bar and it is measured 4.82936 mA for inlet and 9.96 mA for outlet. (Highest peak). Using conversion formula for inlet, it is converted as follows: $(I-4)/(20-4) = (P-0)/(10-0)$,

$$P = (4.82936 - 4)/16 \times 10$$

P = 0.518 Bar (9) from Figure 20(a)

Similarly, conversion formula for Outlet Pressure $=(I-4)/(20-4) = (P-0)/(10-0)$, giving

$$P = (9.96 - 4)/16 \times 10$$

P = 3.725 Bar (10)

from Figure 20(b)

Maximum peaks from CT readings are tabulated as follows. In Fig 20(a), 21(a) for inlet and 20(b), 21(b) for outlet. Similarly, one confirmatory simulation is conducted again in Comsol Software to find out the optimized and validated parameters shown in table 4. Waste valve height (WVH) = 0.17m, Pressure chamber height (PCH) = 0.47 distance between waste valve and pressure chamber (HD) = 0.17, The designs were tested in the experimental study, the best design yielded an efficiency of 79 % with a flow rate of 140 L/hr. and comparable with (Phyoe 2019) with efficiency of 70 %, 70.45 % Johanis et al. (2021) and efficiency of also this author's earlier own design of 93.14 L/hr.; The final proposed model obtained are as follows (Figure 22)

Table 4. Final parameter of proposed model

Parameter	Final Model dimensions (cm)
a) Waste valve height (WVH)	**17**
b) Pressure chamber height(PCH)	**47**
c) Distance between pressure chamber and waste valve(HD)	**17**
d) Pipe diameter (mm)	**25.4**
e) Efficiency %	**79 %**

Confirmatory Experiment

The Confirmatory experimental investigation was done by choosing altering the values from Table 3, to following optimized values of a) Waste valve height (WVH) = 17 cm and b) Pressure chamber height (PCH) = 47 and c) the horizontal distance between the pressure chamber(PC) and Waste Valve(WV), HD = 17 cm from Table 4 using DAQ system whose CT values are plotted in the following graphs Fig 20(a) and 20(b) respectively. The VUE graphics interfaces are also shown in Figure 21(a) and 21(b). Finally, these readings are compared with the simulation results.

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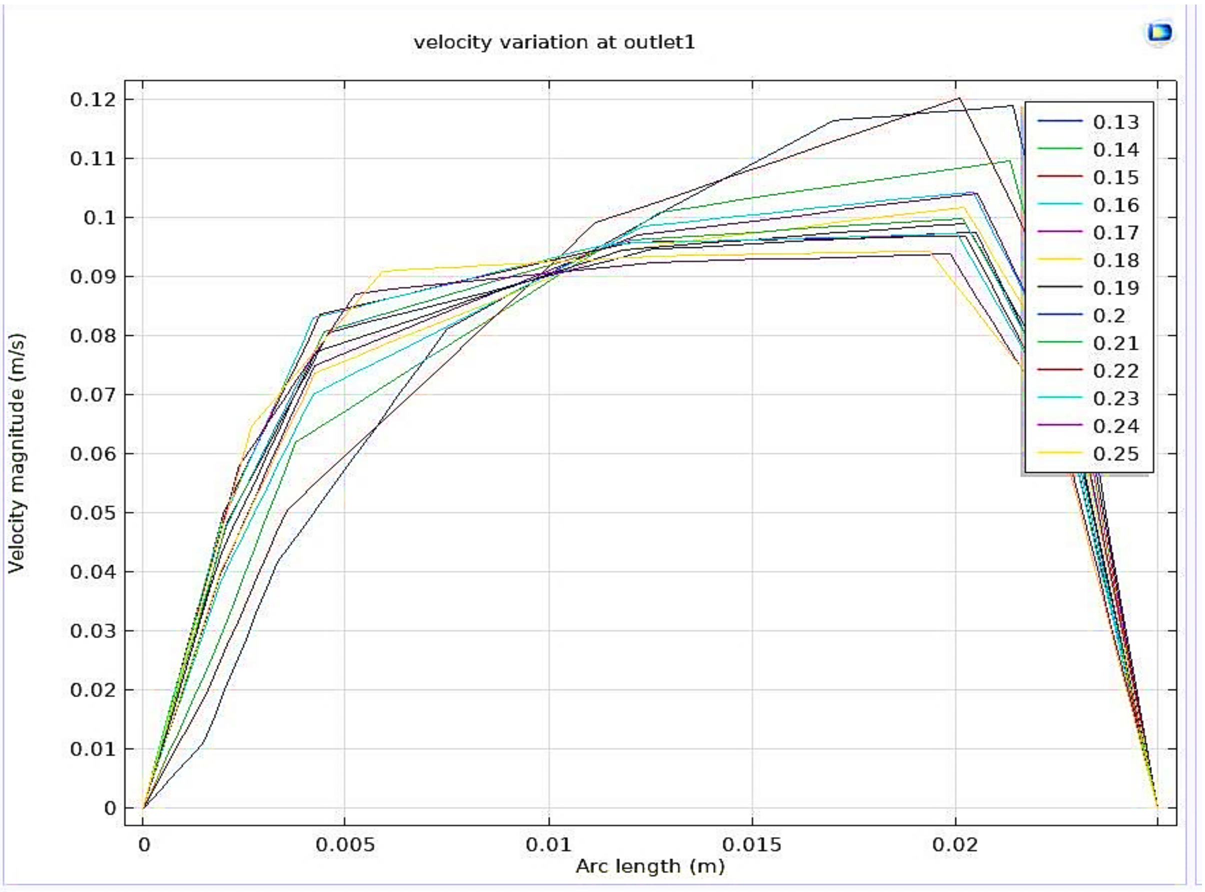

Figure 15 (a). Velocity Variation at waste valve

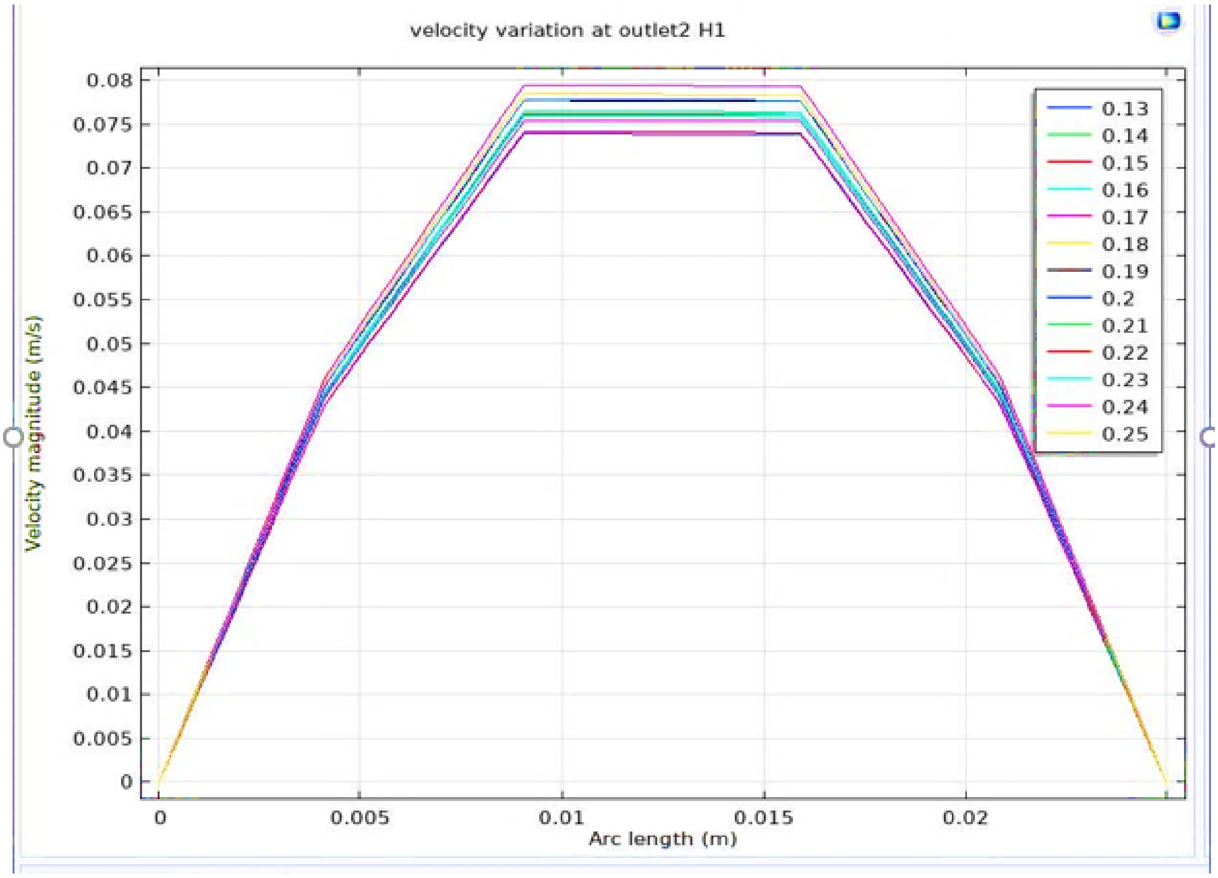

Figure 15 (b). Velocity Variation at waste valve

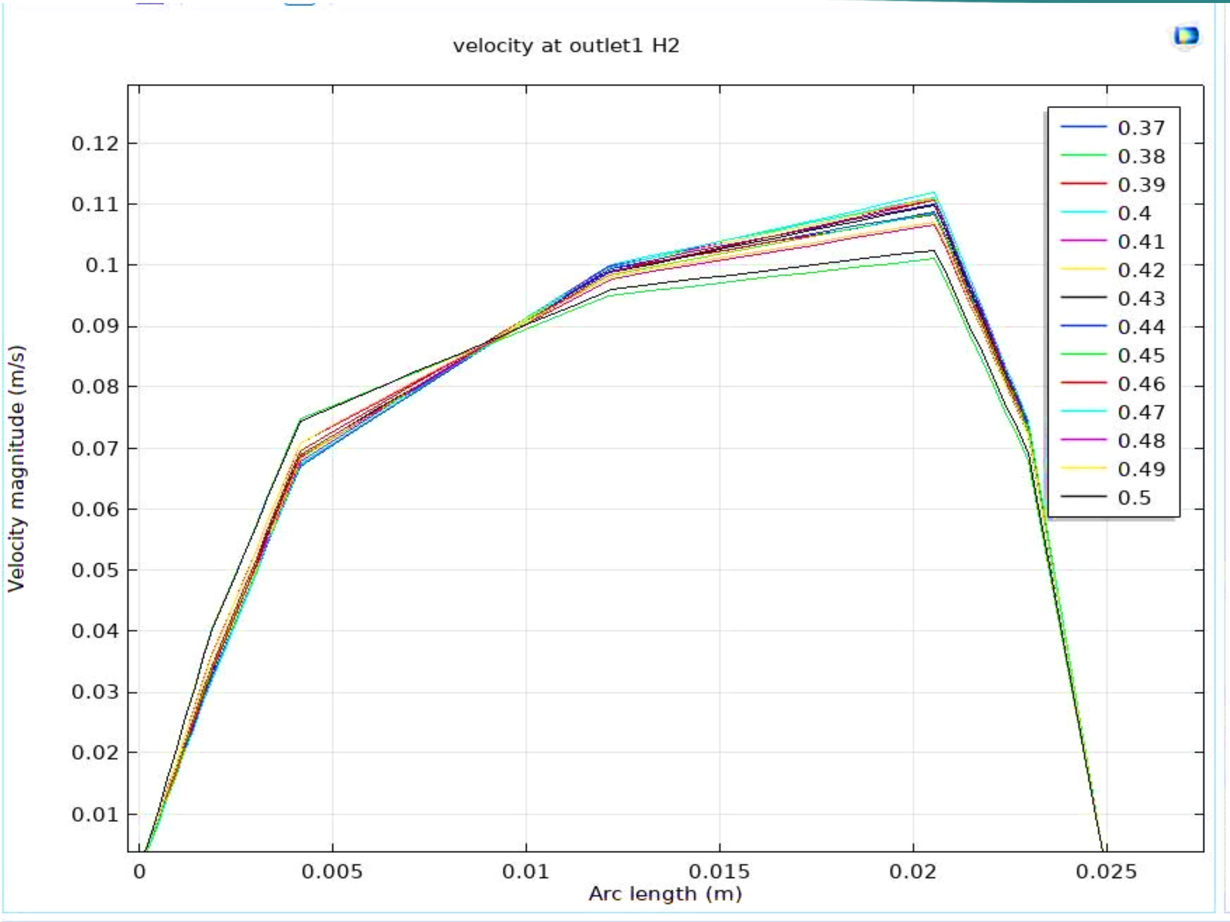

Figure 16 (a). Velocity Variation at waste valve outlet for pressure chamber height

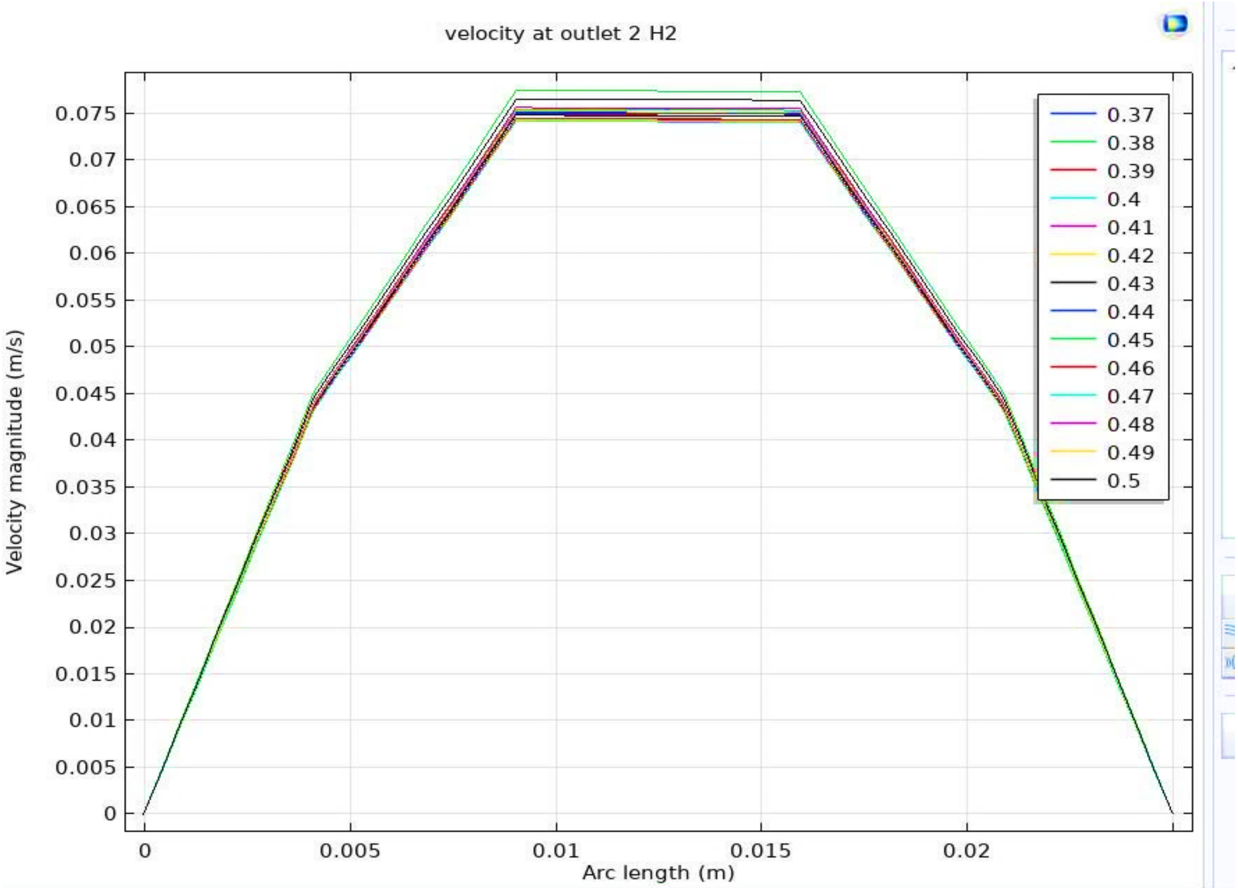

Figure 16 (b). Velocity Variation at delivery outlet for pressure chamber height

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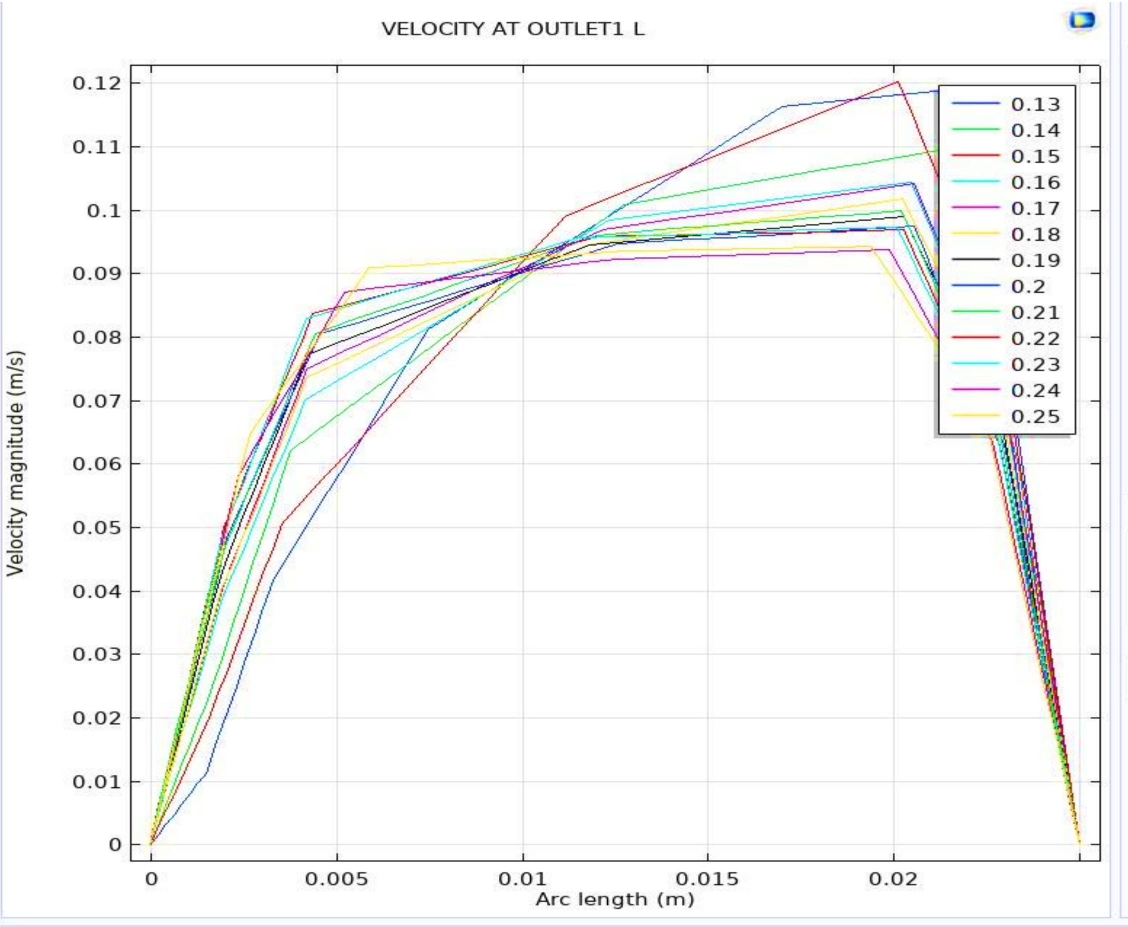

Figure 17 (a). Velocity Variation at waste valve for HDIST

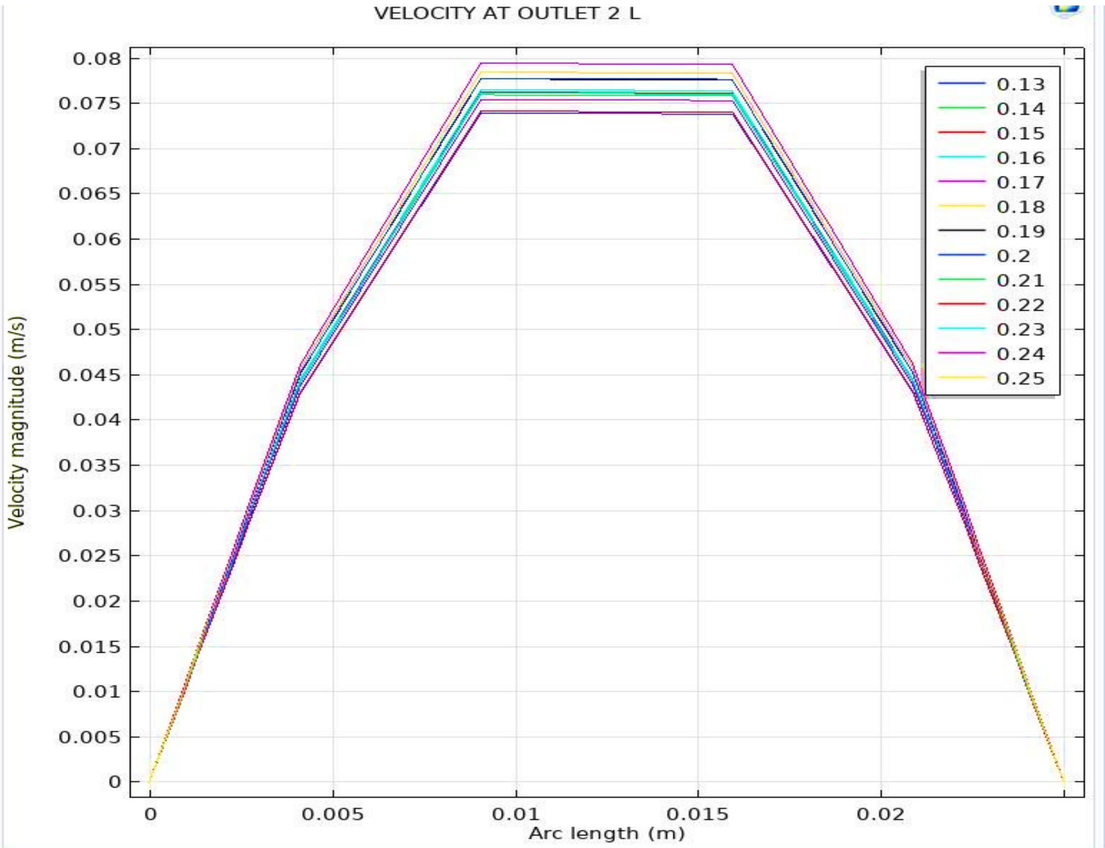

Figure 17(b). Velocity variation at delivery outlet for HDIST

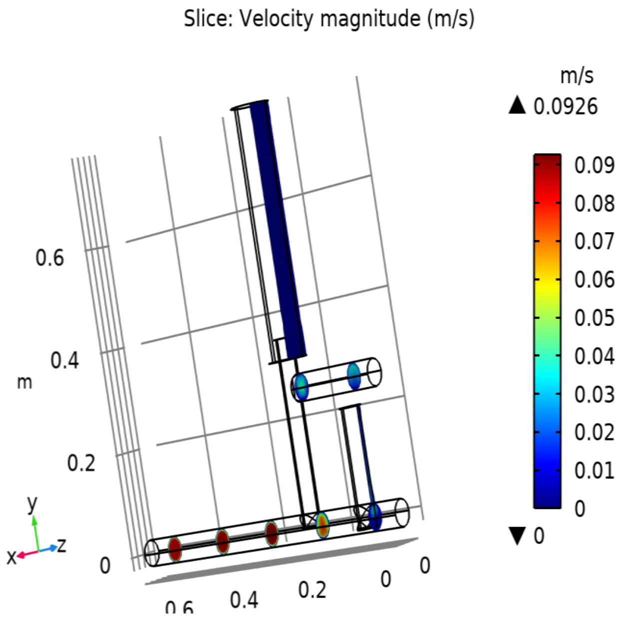

Figure 18 (a). Velocity Profile @HD17 cm

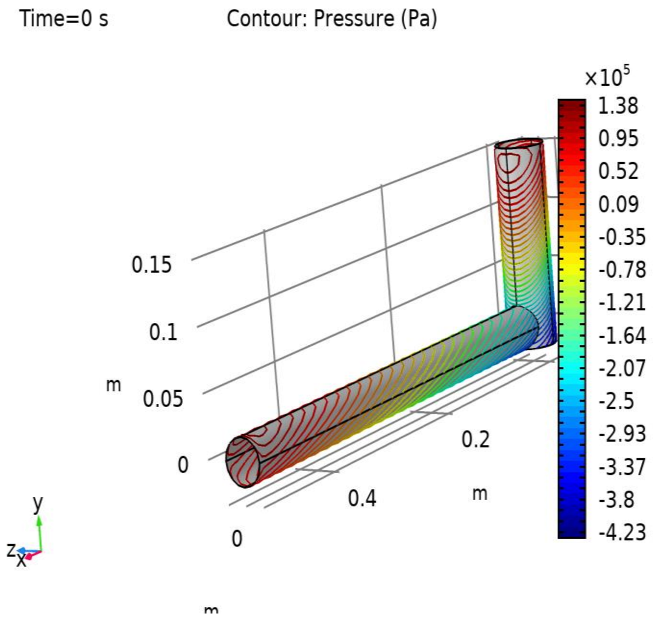

Figure 18 (b). Pressure Profile @HD17 cm

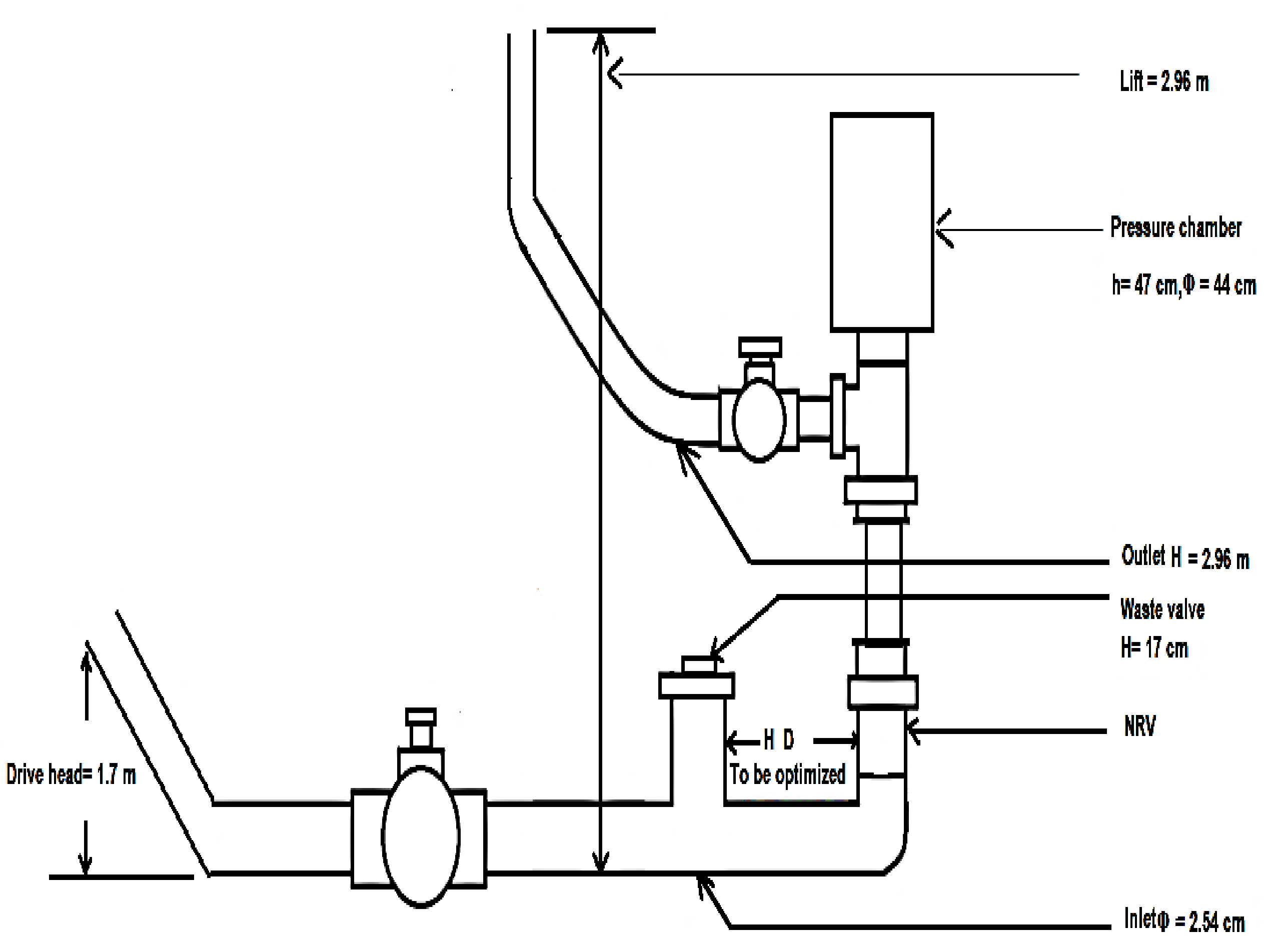

Figure 19. Parameters to be Optimized (HD)

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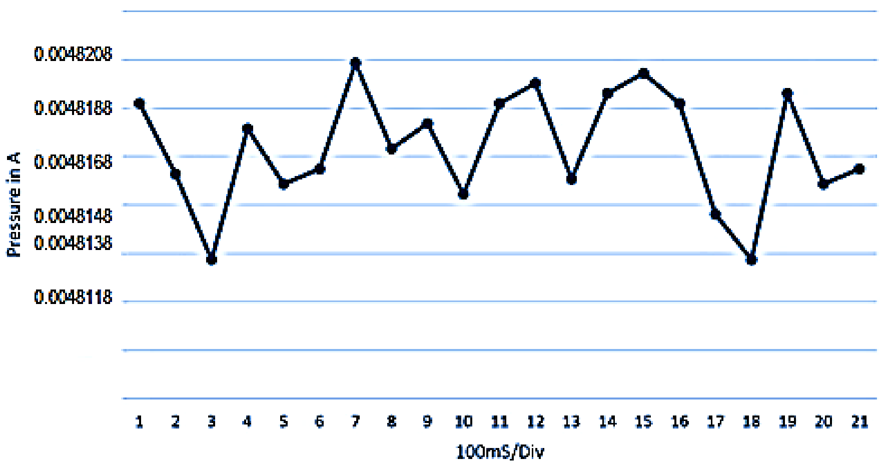

Figure 20 (a). Confirmatory HD 17 Highest peak = 4.82936 mA inlet

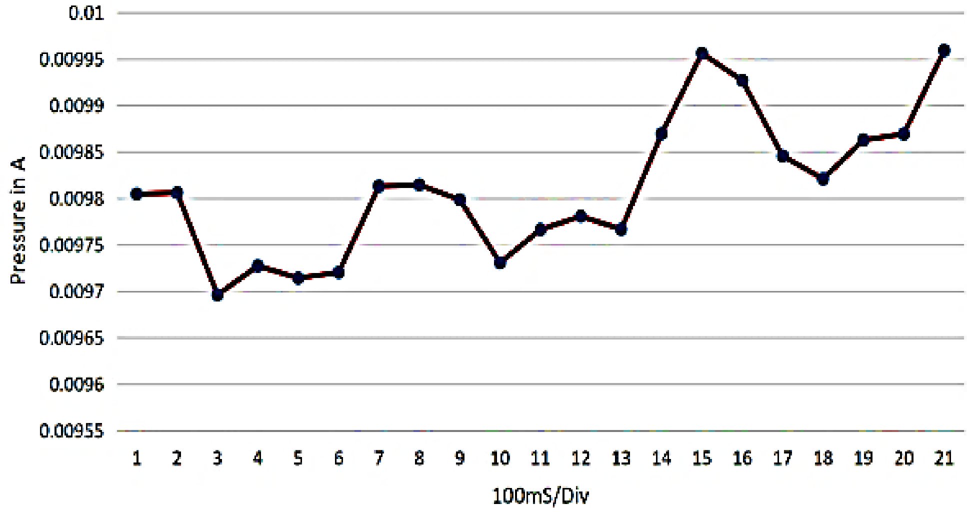

Figure 20 (b). Confirmatory HD 17 Highest peak = 9.96mA outlet

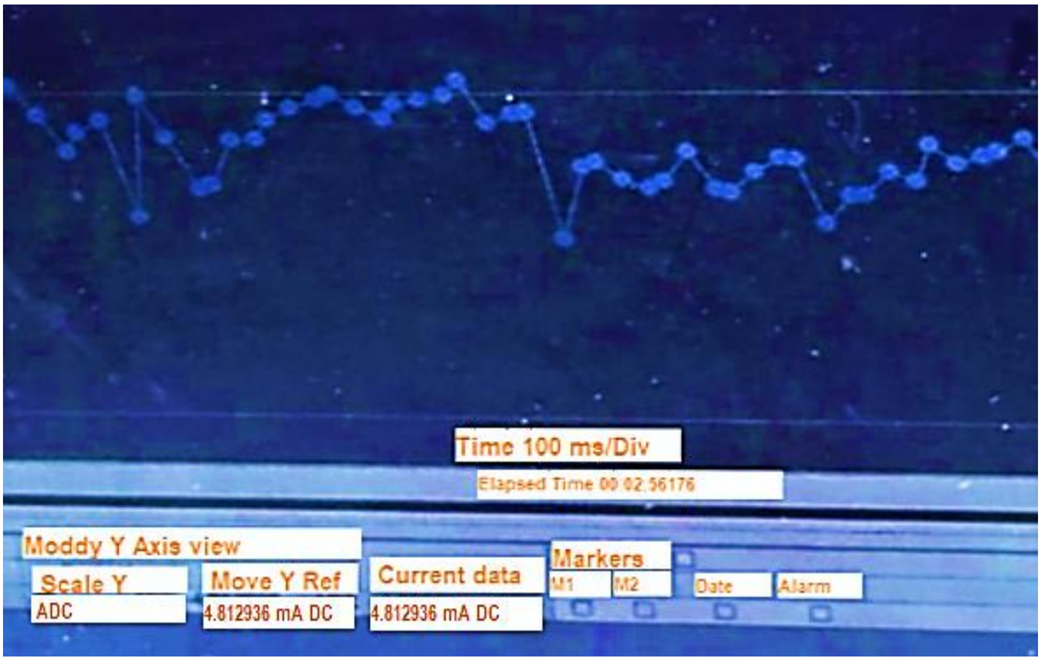

Figure 21 (a). The VUE graphics of 121 channel (inlet)@HD 17 Highest peak = 4.81mA

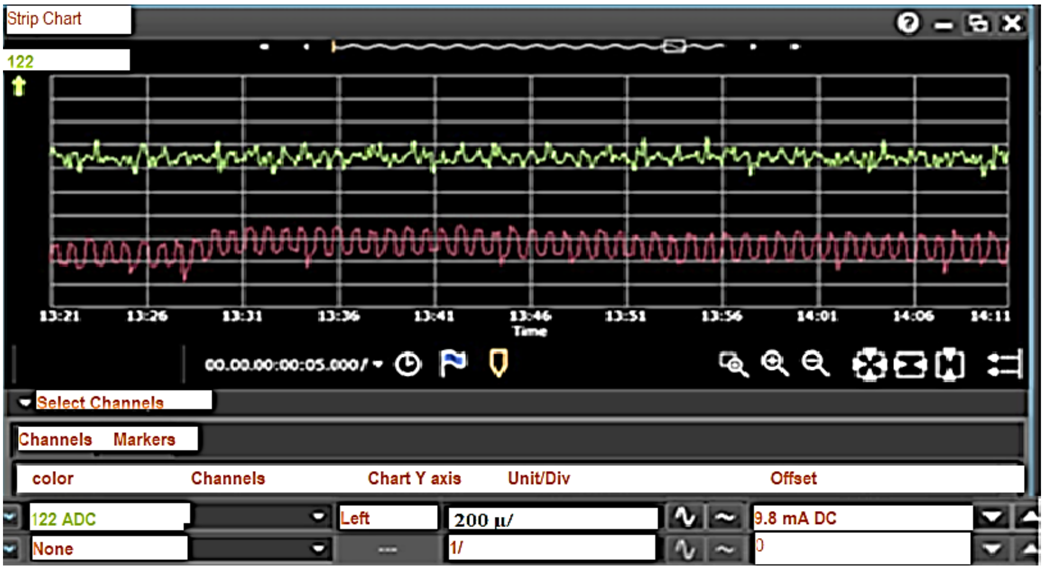

Figure 21 (b). The VUE graphics of 122 channels (Outlet) @HD 17Highest peak = 9.80 mA

Figure 22. Proposed model

Table 5. Optimum parameters with efficiencies

Parameters	Optimum Values	Flow Rate Through the Waste Valve (Qw) (Maximized)	Flow Rate Through the Delivery Outlet (Qd) (Maximized)	Max. Efficiency
Waste valve height	0.17m	0.0589 Kg/s	0.0374 Kg/s	68.49 %
Pressure chamber height	0.47 m	0.0548 Kg/s	0.0369Kg/s	71.02 %
Distance between waste valve and pressure chamber	0.17 m	0.0480 Kg/s	0.0389 Kg/s	79 %

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Conclusion

The new design has successfully shown higher output as compared to the old model of hydrams. The simulation result from the (Fig.18 (a), 18(b), for the velocity and pressure profile at HD17 cm, i.e., v = 0.05 m/s and P = $1.38x10^5$ Pa is fairly comparable to experimental results to 0.074 m/s and $3.72x10^5$ Pa respectively from the eqn. no (6) and (10) as in Comsol multiphysics simulation, the scope was limited because of the frictional loss, head loss, pressure drop, entry and exit loss were not considered. These would create the solution very complex and also for the assumption stated in eqn. (8). It resembles fully with the CFD analysis by (Shende et al., 2015; Harith et al., 2017) with their pressure distribution of $0.95x10^5$ Pa and the pressure distribution obtained in this study is, P = $1.38x10^5$ Pa also comparable to the volume flow rate of 4.5238×10-5m3/s (162 l/hr.) in the derived pipe with a power output of 1.273 KW and efficiency of 57.3% (Mohammed, 2007; Sutanto et al., 2022) obtained the best efficiency of 57.3% on the length of the 8 meter input pipe, Hence, using newly designed parameters in Table (4) in the proposed model is well justified. It must be worth mentioning that since more than 75% of the supply water is wasted at the waste valve to discharge water (Asvapoositkul, 2021) and hence ideal performance is rarely achieved (Young, 1995). The present proposal for proposed design allows further relevant investigations focusing on sophisticated assessment methods for hydrams for improvised performance and minimal waste valve losses as well. Investigation on hydram with flow visualization technique suggested by Suarda et al. (2019) such as Laser Doppler Anemometry (LDA), Particle Tracking Velocimetry (PTV) and Particle Image Velocimetry (PIV) may be suggested for further enhancement of the study.

The applications of hydram are diverse and widespread. Emphasis should be given by Govt. authorities for these valuable assets in agricultural land Handa et al. (2023), water for livestock, soil irrigation and hydroponic systems as well. In rural communities, it may play a major role in accessing clean drinking water, alleviating the burden of manual water lifting and reducing reliance on hand pumps. Moreover, they have found utility in renewable energy systems by integrating with micro-hydro power generation. In conclusion, hydrams offer a sustainable and viable solution for pumping water using the inherent of fluid power. Their ability to operate without the need for external energy sources, coupled with their reliability and versatility, can make them an alternative green energy (Shamsudeen, 2022) approach in near future. As the world continues to explore eco-friendly alternatives, these pumps hold the promise of addressing water pumping needs in a cost-effective and environmentally conscious manner.

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