FLOWRATE PERFORMANCE OF MANUALLY FABRICATED PRESSURE CONTROL VALVES

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ABSTRACT

In this project work, a prototype of pressure control valve was fabricated with a 60liter tank and an experiment was conducted taking time intervals of 5s, 10s, 15s, 20s and 25s to find the corresponding pressure values with which on application of Bernoulli's principle was used to calculate final pressure and volumetric flow rate as 1.294kg/m^2 and 0.001697m^3/s respectively. The fluid utilized for the experiment is water. Also, determining the dimensionless Froude number as 6.982 which is greater than one (>1) meaning the flow within the pipe is laminar. Conclusively as the volume within the tank reduces, the pressure within the pipe reduces and flow rate also reduces as time increases consecutively.

Keywords: Pressure Control Valves, Volumetric Flow Rate, Pressure, Volume, Time, Froude Number

INTRODUCTION

A pressure control device protects process equipment from the hazards of high (or low) pressure in a process (Ken Ludvigsen, 2016). It operates by opening at a designated pressure and ejecting mass from the process. The ejected mass contains energy; the removal of the energy reduces the process pressure (Ken Ludvigsen, 2016). Pressure control valve play an integral role in oil and gas production. They modulate the heat necessary for separating the oil, gas and water mixture and to keep the gases in their vapor phase during transportation through pipelines (R. Wrighta, 2015). The pressure control valves perform different functions in the hydraulic systems, such as: establish maximum pressure, reduce pressure in some circuit lines, and establish sequence movements, among other functions (R. Wrighta, 2015).

The main operation of these valves consists of providing a balance between pressure and the force load on a spring. Most of these valves can be positioned in many different levels, between totally open and totally closed, depending on the flow and on the pressure differential. Pressure controls are mainly used to perform the following system functions: regulating/reducing pressure in certain portions of the circuit, unloading system pressure, assisting sequential operation of actuators in a circuit with pressure control, any other pressure-related function by virtue of pressure control, reducing or stepping down pressure levels from the main circuit to a lower Pressure in a sub-circuit, act as a safety control measure for pressure devices in the oil and gas industry (S. Meniconia, 2015).

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Types of pressure control valves include: Pressure relief valves, Pressure reducing valves, Sequence valves, and Counterbalance Valves (Choudhury et al. (2005)).

In the chemical process industries, problems that can result when control valves exhibit stiction include set-point tracking issues or oscillations in a control loop. Stiction is a nonlinear friction effect that negatively impacts control system performance and causes the dynamics between the linear controller input to a sticky valve and the flowrate out of the valve to be described by four major regions: deadband, stickband, slip-jump, and the moving phase (Li Tang, 2015).

METHODOLOGY

The conventional control valves are the inlet pressure to the valve is directly opposed by a spring force. Spring tension is set to keep the valve shut at the normal operating pressure. At the set pressure, the forces on the disc are balanced and the disc start to lift and it full lifted when the vessel pressure continues rise above set pressure (Helen Durand, 2016). Furthermore; the pressure relief is a spring-loaded pressure relief device which is designed to open to relieve excess pressure and to reclose and prevent the further flow of fluid after normal conditions have been restored. It is characterized by rapid opening pop action or by opening generally proportional to the increase in pressure over the opening pressure. It may be used for either compressible or incompressible fluids depending on design, adjustment or application (H.Chen X. J., 2015).

DESCRIPTION OF WORKING PRINCIPLE

A pipe is connected to tank of 60litre capacity of water when its open or relief it flows in the direction of the valve and then valve lift in the direction of the flow of the liquid then pressure gauge measure the maximum range flow of the liquid pass through the pipe respect to time interval between 5s, 10s,15s, 20s, 25s respectively, to find pressure in bar and flow rate in m^3/s.

MATERIAL USED FOR THE CONSTRUCTION OF 60-LITRE CAPACITY WATER TANK

i. 1 socket G.I (size 3cm): power point in which liquid flows.
ii. 1 Giger pipe (2.0cm – diameter, 5.8meter - length) = 1pipe: A tube path which liquid flows.
iii. 1 Bud Valve: opening tag in which liquid flows.
iv. 1 Adopter (size 4cm): It use to support a pipe’s connection.
v. Thread Tape: It use to tight a metal within the contact
vi. Tangit Gum: It use to rub a metal to hold a contact tight
vii. TCM Aradite: It use to tight a metal within the contact surface.
viii. Pressure Gauge (size 8cm): It is a manual pressure reading meter.
ix. Rubber Disc (size 2.5cm): Attached to light metal which give support to pressure gauge and lift in the direction of the liquid flow.
x. Light Spring (size 4cm): It give support to pressure gauge in the direction of liquid flow.
xi. Pan of 16gate: ion bundle support.
xii. Light Metal (size 3cm): Attach the light spring which supports the pressure gauge in the fluids direction of flow.

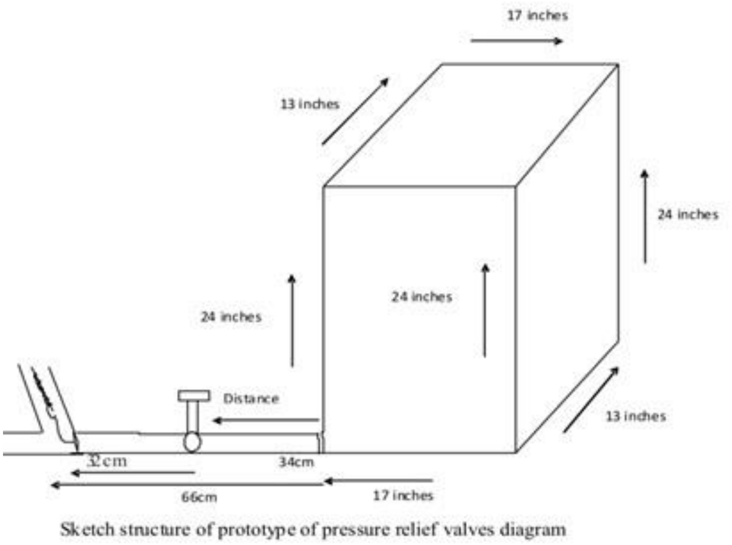

Figure 1. Sketch of a Prototype of Pressure Relief Valve System

The dimensions of the tank are: height 24 inches, breadth 13 inches, length 17 inches. Distance from the bud valve to the tank is 34cm, distance from the bud valve to the pressure relief valve/pressure gauge 32cm, total distance from the tank to the pressure relief valve/pressure gauge 66cm. Fluid used for the carrying out the experiment is water with a density of 1000kg/m^3.

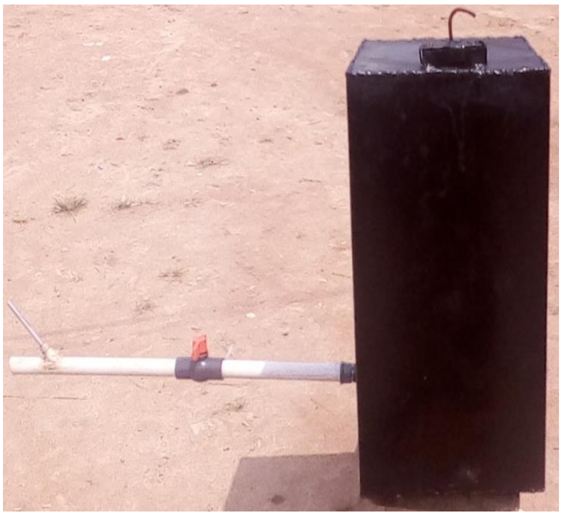

Figure 1. Pictorial Representation of prototype of pressure relief valves system

RESULTS AND DISCUSSIONS

Below are the following results from carrying out the experiment testing a pressure relief valve system.

Table 1. Conversion of pressure values from lb/in^2 to bar

S/N	Time (s)	First reading Pressure gauge (lb/in^2)	Second reading Pressure gauge (lb/in^2)
1.	5	85	60
2.	10	84	50
3.	15	80	45
4.	20	70	40
5.	25	60	35

CONVERSION

Table 2. One conversion of pressure values in 1lb/in^2 = 0.0689Bar

S/N	Time (s)	p_1 (bar)	p_2 (bar)	Average pressure $p_t A = \frac{p_1+p_2}{2}$
1.	5	5.856	4.134	4.995
2.	10	5.787	3.445	4.616
3.	15	5.512	3.100	4.306
4.	20	4.823	4.134	4.478
5.	25	4.134	3.445	3.789

Table 3. Calculated Flowrate (l/s) values against time (s)

Q (m^3/s)	t (s)
4.89x10-9	5
2.44x10-9	10
1.63x10-9	15
1.22x10^{-9}	20
9.786x10^{-10}	25

By plotting a graph of pressure (p_1) (bar) against time (s)

Table 4. Pressure values P1 (bar) against time (s)

(p_1) (bar)	t (s)
85	5
84	10
80	15
70	20
60	25

Table 5. Pressure values P2 (bar) against Flowrate (l/s)

P_2 (Bar)	Q (m^3/s)
60	4.89x10^{-9}
50	2.44x10^{-9}
45	1.63x10^{-9}
60	1.22x10^{-9}
50	9.786x10^{-10}

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ANALYSIS

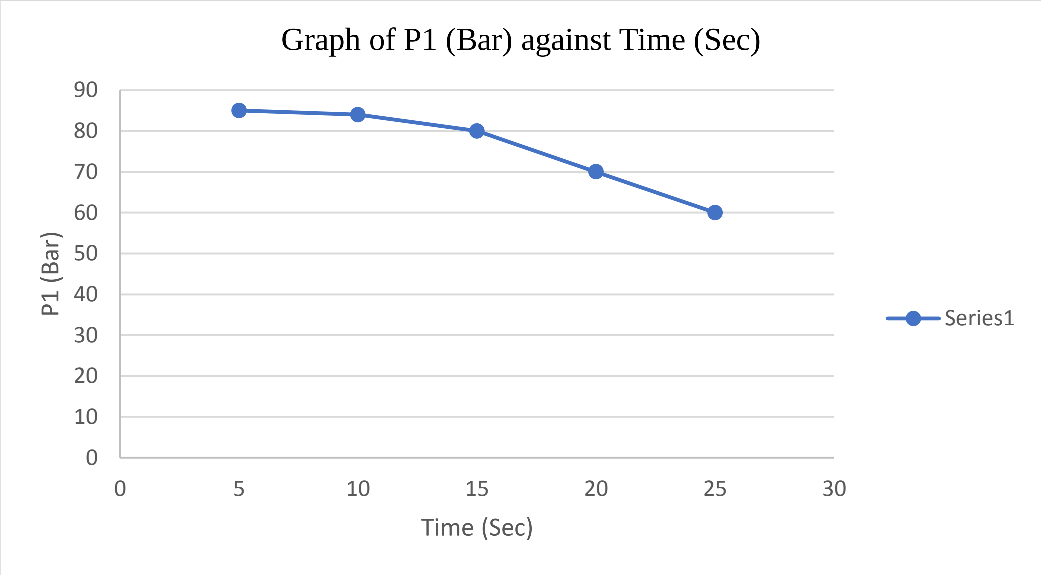

Chart 1. Graph of P1 (Bar) against Time (Sec)

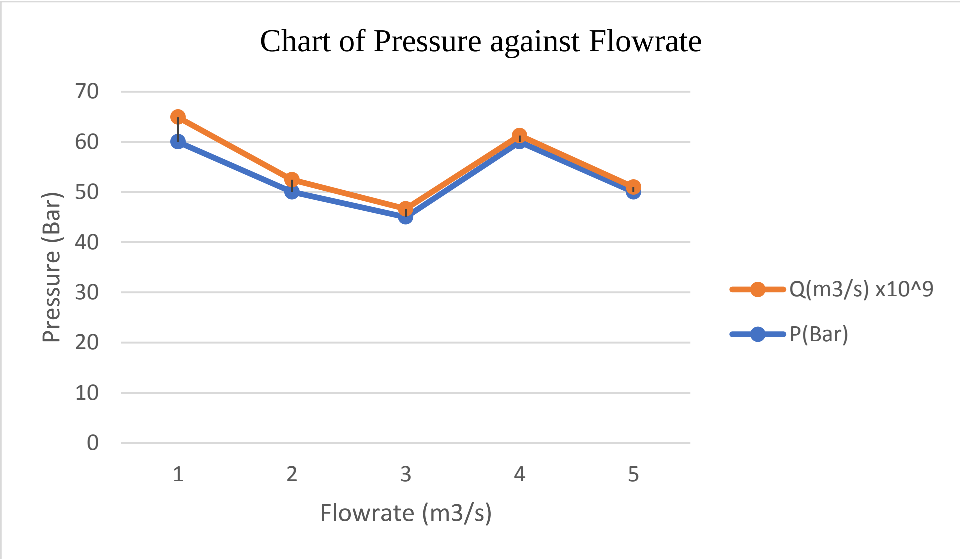

Chart 2. P2 (Bar) against flow rate **(m^3/s)**

PRESSURE AND VELOCITY, BERNOULLI'S PRINCIPLE

In 1740, Bernoulli Daniel obtained a relation between the pressure and velocity at different parts of a moving in compressible fluid (Ken Ludvigsen, 2016). If the viscosity of the fluid is negligible small, there are no frictional forces to overcome. In this case, the work done by the pressure difference, per unit volume of the fluid flowing along a pipe steadily is equal to the gain in kinetic energy per unit volume plus the gain in potential energy per unit volume. At the beginning of the pipe, where the pressure p_1 is the work done per unit volume in the fluids is thus p_1 at the other end the work done per unit volume = $p_1 - p_2$

The kinetic energy per unit volume = $\frac{1}{2}$ mass per unit volume (ρ) x $velocity^2$ where ρ is the density of the fluid. Thus if v_2 and v_1 are the final and the initial velocity respectively at the

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end and the beginning of the pipe, the kinetic energy gained per unit volume = $\frac{1}{2}$ ρ $(v_2 - v_1)^2$. Further, if h_2 and h_1 are the respective heights measured from a fixed level at the end and beginning of the pipe, the potential energy gained per unit volume = mass per unit volume $(h_2 - h_1)$ = ρ g $(h_2 - h_1)$.

From the conversation of energy.

$p_1 - p_2 = \frac{1}{2}\rho\,(v_2^2 - v_1^2) + \rho\, g\,(h_2 - h_1)$ --eqn. (1)

$p_1 - p_2 = \frac{1}{2}\rho\,(v_2^2 - 0) + \rho\, g\,(h_2 - 0)$ ---eqn. (2)

$p_1 - p_2 = \frac{1}{2}\rho\,(v_2^2) + \rho\, g\,(h_2)$---eqn. (3)

$p_1 - p_2 = \frac{1}{2}\rho\, v_2^2 + \rho\, g\, h_2$--eqn. (4)

$p_1 = p_2 + \frac{1}{2}\rho\, v_2^2 + \rho\, g\, h_2$---eqn. (5)

When $p_2 = 0$, then $p_1 = p$

therefore

$p = \frac{1}{2}\rho\, v_2^2 + \rho\, g\, h_2$--eqn. (6)

$p = \frac{1}{2}\rho\,(v_2^2 + gh_2)$

where

p = pressure

ρ = density of water 1000kg/m^3

g = acceleration due to gravity 9.81m/s^2

z1 = height 24 inches = 0.6096 m

V = velocity (m/s)

Final Velocity

$U_2 = \sqrt{}$ (2g x (z1 – z2)

$U_2 = \sqrt{}$ (2 x 9.81m/s^2 x (0.6096m))

U_2 = 3.458 m/s

Volumetric flowrate Q = Au

Area of pipe = πd^2/4

Area of pipe = 3.142 x (0.025)^2/ 4 = 0.00049 m^2

Volumetric flowrate Q = 0.00049m^2 x 3.458m/s = 0.001697 m^3/s

Using Bernoulli's equation

$P1/\rho g + u1^2/2g + z1 = P2/\rho g + u2^2/2g + z2$

Where

u1 = 0

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p1 = 0

g = 9.81m/s^2

ρ = 1000 kg/m^3

u_2 = 3.458m/s

z1 = 0.6096m

z2 = 0

inserting values into Bernoulli's equation to obtain the pressure p2

p2 = ρg (z1- $(u_2)^2$/2g)

p2 = 1000kg/m^3 x 9.81m/s^2 (0.6096m – 3.458^2/2x9.81)

p2 = 1.294 kg/m^2

Froude Number = $\frac{Velocity}{\sqrt(Diameter\ x\ gravity)}$

Froude Number = $\frac{3.458m/s}{\sqrt(0.025m\ x\ 9.81m/s2)}$ = 6.982

Since the Froude number is greater than 1 and it is dimensionless quantity used to indicate the influence of gravity on fluid motion. Therefore, small surface waves within the pipe will be carried downstream. Hence, the flow within this pipe is laminar.

The volume of the tank is represented as V

V = b x l x h

Where

b = breath 13inches = 0.3302m

l = length 17 inches = 0.4318m

h = height 24 inches = 0.6096m

V = 0.3302 x 0.4318m x 0.6096m

V = 0.0869m^3

Flow rate = $\frac{V}{t}$

V= Volume of the pipe (m^3)

t= time in(s)

V= π r^{2}h

where

r^2=is the radius of the pipe

h= is the length of the pipe

r = $\frac{d}{2}$ = $\frac{d^2}{4}$

r = $\frac{d^2}{4}$

where

d= internal diameter of the pipe 2.5cm = $\frac{25}{100}$= 0.025

r= $\frac{(0.025)^2}{4} = \frac{0.00065}{4}$ = 0.00015625

r= 1.56 x 10^{-4}m

Therefore

V = πr^2h where h = l = 32cm = $\frac{32}{100}$ = 0.32m

V = 3.142x $(1.56x10^{-4})^2$ x 0.32

V= 2.446 x 10^{-8} m^3

Flow rate = $\frac{V}{t}$

Flow rate (Q) can be defined as a volume per time.

Q1 = $\frac{V}{t_1} = \frac{2.446 \text{ x } 10-8}{5}$ = 4.89x10^{-9}**m^3/s**

Q2 = $\frac{V}{t_2} = \frac{2.446 \text{ x } 10-8}{10}$ = 2.44x10^{-9} **m^3/s**

Q3 = $\frac{V}{t_3} = \frac{2.446 \text{ x } 10-8}{15}$ = 1.63x10^{-9} **m^3/s**

Q4 =$\frac{V}{t_4} = \frac{2.446 \text{ x } 10-8}{20}$ = 1.22x10^{-9} **m^3/s**

Q5 =$\frac{V}{t_5} = \frac{2.446 \text{ x } 10-8}{25}$ = 9.786x10^{-10} **m^3/s**

Bernoulli's principles show that at points a moving fluid where the potential energy change ρgh is very small, or zero as in flow through a horizontal pipe, the pressure is low where the velocity is high conversely, the pressure is high where the velocity is low. The principle has wide applications.

Fig 4 showing a graph of P1(bar) against time (sec) represents a reduction of the measured pressure which sequentially with respect to an increase in time. Fig 4showing a graph of P2 (bar) against flowrate (l/s) indicates that there is a decrease in pressure and also a decrease in the flowrate of the fluid (water) flowing through the pressure relief valve.

Comparing the value of velocity and pressure gotten from using Bernoulli's equation to the actual values gotten from this experiment shows a high degree of similarity.

CONCLUSIONS

From the experiment carried out shows that the final pressure, volumetric flowrate and Froude number to be 1.294kg/m^2, 0.001697m^3/s and 6,982 respectively. In refineries and tank farms which are mainly in downstream oil industry and are the places that mostly require these pressure relief valves. From this research conducted, we can equally determine flowrates, and pressure within a pipe line using the prototypes of the pressure relief valve that was constructed. From the experiment results and tables and graph, I was able to come to a conclusion through analysis that as the volume of the liquid in the tank reduces, the pressure reduces and volumetric flowrate also reduces all with respect to time which increases subsequently. Hence, flow through the pipe can be said to be laminar. The performance of this pressure relief valve prototype constructed is working at its optimum best capacity.

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REFERENCES

[1] Choon-Tae Lee, B.-Y. M. (2000). *Dynamic design of hydraulic pressure control valve of active suspension system using experimental method*. Korea: Department of Automotive Mechanical Engineering Silla, University Pusan.

[2] Dmitry, M., & Stadnik, A. A. (2017). The Muffler Performance Effect on Pressure Reducing Valve Dynamics. *Science Direct*, 706-717.

[3] Garcia, C. (2007). Friction model parameter estimation for control valves. *8th International IFAC Symposium on Dynamics and Control of Process Systems*, *2*.

[4] George, G. J. W. (2001). Analysis of load frequency control performance assessment criteria. *IEEE Transaction Power Systems*, 520-525.

[5] Chen, X. J. (2015). The effect of disc flexibility on the sealing perofmance of spring-loaded main steam pressure relief valves. *Science Direct*, 104-112.

[6] Durand, P. D. H. (2016). Empirical modeling of control valve layer with application to model predictive control-based stiction compensation. *Science Direct*, 041–046.

[7] Ludvigsen, K. (2016). *Fundamentals of pressure relief valves.* Texas, USA: Regulator Technologies Inc.

[8] Meniconia, B. B. (2015). Transient effects of self-adjustment of pressure reducing valves. *Science Direct*, 1030-1038.

[9] Tang, L. F. (2015). Modeling and identification for pneumatic control valves with stiction. *Science Direct*, 1244-1249.

[10] Wrighta, E. A. (2015). Optimized control of pressure reducing valves in water distribution dynamic topology. *Science Direct*, 1003-1011.

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