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Effects of Hydraulic Orifice Area on Resistive Pressure Drop and Inertia Pressure Drop Using Simulation Method.

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ABSTRACT

The study, effects of hydraulic orifice area on resistive pressure drop and inertia pressure drop using simulation method was successfully achieved. Block models gotten from simscap- hydraulics were used to represent all the elements of orifice system hydraulic model. The general objective was achieved using 5 variable orifice areas, 0.1m², 0.04m², 0.15m², 1.5m² and 0.0002m² and their corresponding resistive pressure drop and inertia pressure drop were evaluated respectively. The modeled orifice(Fixed Orifice and Fixed Orifice with Fluid Inertia) retained orifice hydraulic diameter of 0.0113 m, initial orifice area 1e-1m² within orifice length of 0.01 m. Initial flow rate was set to 0.2 m³/s at differential pressure of 1.5 bar. Coefficient of discharge of the orifices was adjusted to 0.2. Also, critical Reynolds's Numbers for the two orifices were 12 and 10 respectively. The hydraulic reservoir was pressurized to 2bar at initial fluid volume of 0.08m³. ODE23 solver was used to run the Simulation for 10seconds. Results showed that at orifice area of 0.1m², differential pressure was found to be 150 bar, inertia pressure drop was 0.00002bar with resistive pressure drop being 149.99998bar. Furthermore, orifice area was reduced to 0.04m², differential pressure increased to 1000 bar, inertia pressure drop also increased to 0.00005 bar as well as resistive pressure drop, 999.99995 bar. These results indicated that narrowing or decreasing hydraulic orifice area, will increase resistive pressure drop as well as inertia pressure drop and vice-versa. It was also discovered that, when orifice coefficient of discharge was 0.2, at orifice area of 0.1m², differential pressure was found to be 150bar. At coefficient of discharge of 0.5, with the same orifice area, differential pressure decreased to 25bar. Hence, increasing orifice coefficient of discharge, will decrease differential pressure and increase discharge through the orifice. The researchers made the following recommendations: The influence of hydraulic orifice area and coefficient of discharge must be compromised if maximum flow rate is paramount, this research can also be done in future using different hydraulic design models and other advanced software for generalization.

Keywords *-----hydraulic orifice area, resistive pressure drop, inertia pressure drop, simulation, simscap-hydraulics, block models.*

INTRODUCTION

Hutagalung (2019) stated that fluid flow control is a very important process in the industry. In addition, the orifice plate flow has the greatest pressure difference across the meter while Venturi has the smallest pressure difference. Greater pressure variations are easier to determine and gives fewer errors than very small pressure differences.

The orifice plate is used to estimate the flow rate of a mass flowing through a pipe, vessel or channel by connecting the measured loss pressure and mass flow rate. Despite having minimum installation problems in pipes, the main disadvantage of this device is having greater energy losses due to friction, contraction, blockage, etc, than venturimeter tubes or flow nozzles. In principle, meter orifice occurs due to the narrowing of the flow in the pipe and produces a pressure difference between the plate upstream and downstream.

Fluid dynamics suggested that orifice geometry (area) is a determinant of discharge properties and therefore, should influence empirical constants governing orifice formulas (Frank, Flachskampf, Arthur, Weyman, Lius & James, 1990).

Rajput (2011) explained that a hydraulic orifice plate is an opening in the wall, base of a vessel or pipe through which the liquid flows. The top edge of the orifice is always below the free surface. He added that orifices are used to measure discharge and can be classified according to size, shape, upstream edge and discharge conditions.

Any restriction in the conduit or channel will cause a reduction in the flow rate of the entire line but the flow will be constant throughout the line. Resistive pressure drop occurs due to resistance to flow offered by orifices due to change in cross-sectional area of flow. Inertia pressure drop occurs when frictional forces caused by resistance to flow, act on a fluid as it flows through a conduit or channel.

This paper, adopted a simulink simulation method and according to Nkwor et al., (2023) is a MATLAB-based graphical programming environment for modeling, simulating and analyzing multi-domain dynamical systems. The primary interface consists of graphical block diagrams or tools and a customizable set of block libraries.

Obviously, hydraulic orifice area to a greater extent influences resistive pressure drop and inertia pressure drop through a conduit or channel and can lower flow rate along a control line. Hence, researchers aimed at studying effects of hydraulic orifice area on resistive pressure drop and inertia pressure drop using simulation method.

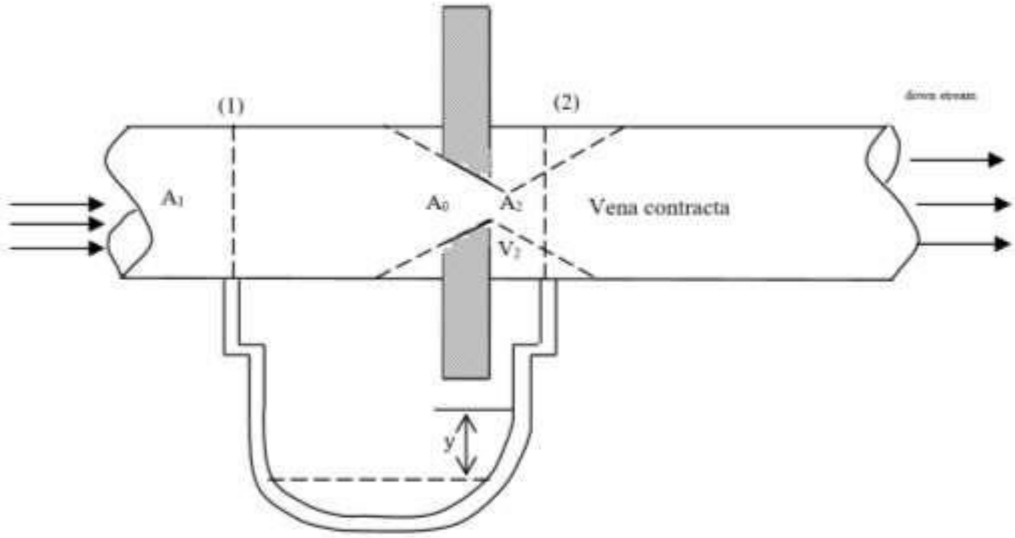

Fig 1.0 Orifice Plate in Pipe

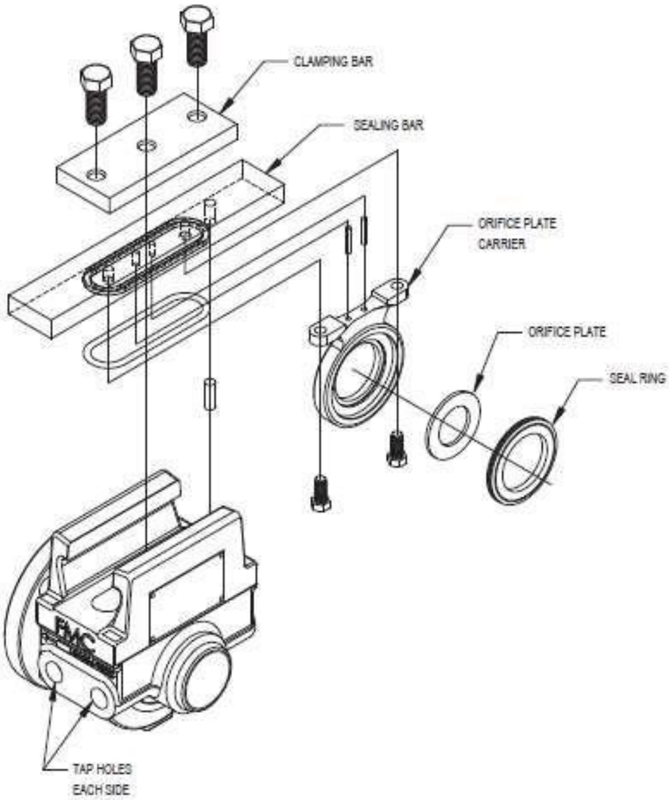

Fig 2.0 Industrial Orifice Plate fitting (Source: Carlson, 2000)

MATERIALS AND METHOD

Effects of hydraulic orifice area on resistive pressure drop and inertia pressure drop was carried out using simulink simulation in MATLAB. Simulink in the MATLAB command window contains block models that were used to represent the entire elements of hydraulic orifice flow model. The block models gotten from simscap- hydraulics, includes: Demux Block Properties, Fixed Orifice Block Properties, Fixed Orifice with Fluid Inertia Block Properties, Hydraulic Constant Pressure Source Block Properties, Hydraulic Flow Rate Sensor Block Properties, Hydraulic Flow Rate Source Block Properties, Hydraulic Pressure Sensor Block Properties, Mux Block Properties, PS-Simulink Converter Block Properties, Product Block Properties, Ramp Block Properties, Reservoir Block Properties, Simulink-PS Converter Block Properties, Solver Configuration Block Properties, Transfer Fcn Direct Form II Block Properties, Chirp Block Properties, Block Type Count.

Block ports were connected as shown in **Fig 3.0 and Fig 4.0** below. The hydraulic orifice elements (Fixed Orifice and Fixed Orifice with Fluid Inertia) as shown in **table 2.0** were modeled to retain orifice hydraulic diameter of 0.0113 m, initial orifice area 1e-1 m^2 within orifice length of 0.01 m. The initial flow rate was 0.2 m^3/s at differential pressure of 1.5 bar. Coefficient of discharge of the orifices was 0.2. Also, critical Reynolds's Numbers for the two orifices were 12 and 10 respectively. The hydraulic reservoir was pressurized to 2 bar at initial fluid volume of 0.08 m^3. ODE23 solver was chosen at maximum order of 5 to run the Simulation for 10seconds, see **table 1.0** below.

DESIGN ANALYSIS/CALCULATION

The pressure differential across the orifice is given as below

$$\boldsymbol{P = P_{in} - P_r} \text{ ...(1) (Rajput, 2011)}$$

Where

$$P_{in} = inertia\ pressure\ drop, P_r = resistive\ pressure\ drop.$$

$$\boldsymbol{P_{in} = \rho \frac{L}{A} \times \frac{dq}{dt}} \text{ ...(2)}$$

$$\boldsymbol{q} = discharge, L = length\ of\ orifice, A = orifice\ area, \rho = density\ of\ fluid$$

$$P_{in} = 1000 \frac{0.01}{0.1} \times \frac{0.2}{10}$$

$$\boldsymbol{P_{in} = 2\ N/m^2 = 0.00002\ bar}$$

$$P_{in} = 1000 \frac{0.01}{0.04} \times \frac{0.2}{10}$$

$$\boldsymbol{P_{in} = 5\ N/m^2 = 0.00005\ bar}$$

The discharge through the orifice is given as below

$$\boldsymbol{q = C_D \times A \sqrt{\frac{2}{\rho}} \times \frac{P_r}{(P_r^2 + P_{cr}^2)^{1/4}}} \text{ ....(3)}$$

$$C_D = orifice\ discharge\ coefficient, P_{cr} = minimum\ pressure\ for\ turblent\ flow$$

Orifice hydraulic diameter is given below

$$\boldsymbol{D_H = \sqrt{\frac{4A}{\pi}}} \text{ ....(4)}$$

The Reynolds Number is given as below

$$\boldsymbol{R_e = \frac{q \times D_H}{A \times \nu}} \text{ ....(5)}$$

Where $\nu = fluid\ kinematic\ viscosity$

By Bernoulli's equation from **Fig1.0,** we have

$$C_c = \frac{A_2}{A_0}$$

Coefficient of vena contraction, $C_c = \frac{A_2}{A_0}$

$$\frac{P_1}{W} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{W} + \frac{V_2^2}{2g} + Z_2 \text{...... (6)}$$

$$\left(\frac{P_1}{W} + Z_1\right) - \left(\frac{P_2}{W} + Z_2\right) = h = differential\ head$$

From continuity equation

$A_1V_1 = A_2V_2 \ldots \ldots (7)$

$$V_1 = \frac{A_2V_2}{A_1} = \frac{A_0C_cV_2}{A_1}$$

$\therefore Q = \frac{C_dA_0A_1\sqrt{2gh}}{\sqrt{(A_1^2 - A_0^2)}}$ …….(8)

C_d is smaller than that of venturimeter.

RESULTS AND PRESENTATIONS

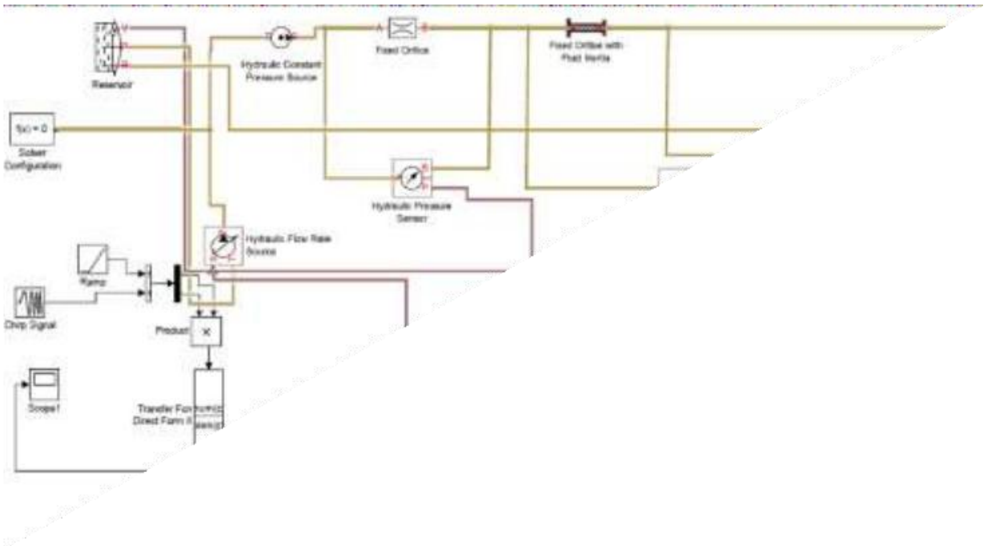

Fig 3.0 System Hydraulic Orifice Model 05-Mar-2023 03:50:20

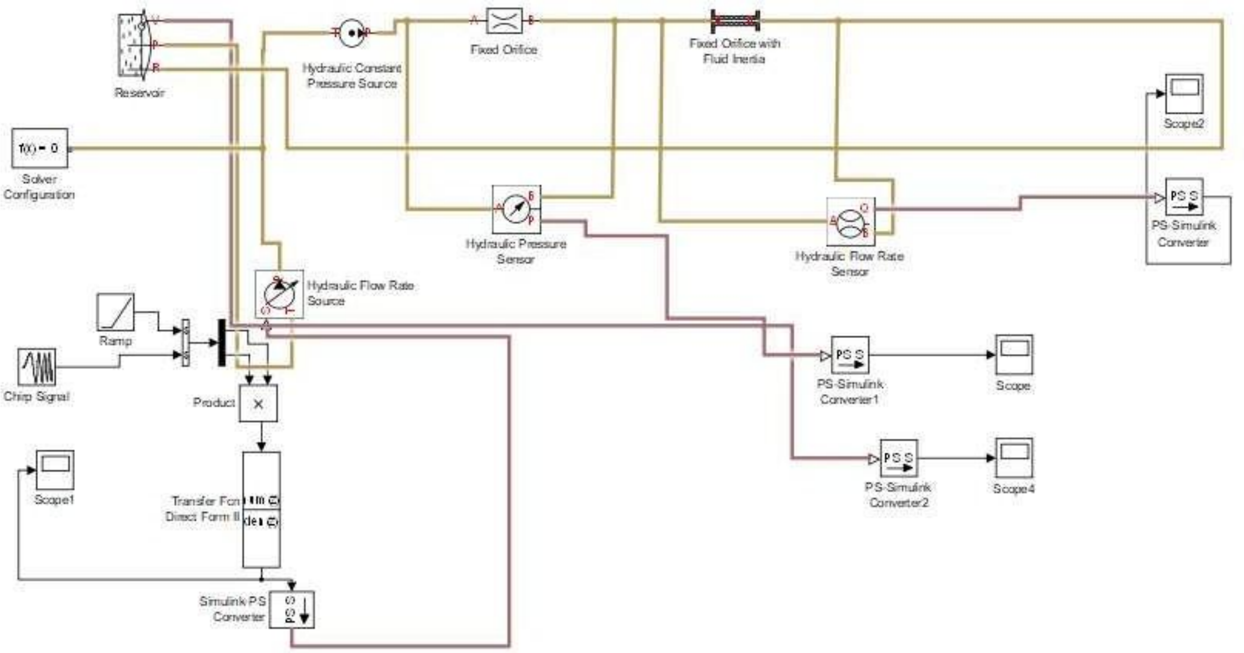

Fig 4.0 Hydraulic Orifice Model 05-Mar-2023 03:50:20

Table 1.0: Simulation Parameter

Simulation Parameter	Value
Solver	ODE23
RelTol	1e-3
Refine	1
MaxOrder	5
ZeroCross	on
Simulation time	10 seconds

Table 2.0: Fixed Orifice, Fixed Orifice with Fluid Inertia and Reservoir

S/N	NAME	VALUE	UNITY
	FIXED ORIFICE		
1	Area	1e-1, 4e-2, 1.5e-1, 15e-1& 0.2e-3	m^2
2	Coefficient of discharge	0.2	
3	Critical Reynolds's Number	12	
4	Orifice hydraulic diameter	0.0113	m
5	Minimum pressure for turbulent flow	1	Pa
6	Flow rate	0.2	m^3/s
7	Initial differential pressure	1.5	bar
	FIXED ORIFICE WITH FLUID INERTIA		
1	Area	1e-1, 4e-2, 1.5e-1, 15e-1& 0.2e-3	m^2
2	Orifice length	0.01	m
3	Coefficient of discharge	0.2	
4	Critical Reynolds's Number	10	
5	Flow rate	0.2	m^3/s
	RESERVIOR		
1	Pressurization level	2	bar
2	Initial fluid volume	0.08	m^3
3	Return line diameter	0.02	m

Fixed Orifice and Fixed Orifice with Fluid Inertia

Connections A and B are conserving hydraulic ports associated with the orifice inlet and outlet, respectively. The block positive direction is from port A to port B. This means that the flow rate is positive if fluid flows from A to B, and the pressure differential is determined as p = p_A - p_B.

Table 3.0: Demux Block Properties

Name	Outputs	Display Option	Bus Selection Mode
Demux	2	bar	off

Table 4.0: Mux Block Properties

Name	Inputs	Display Option
Mux	2	signals

Table 5.0: PS-Simulink Converter Block Properties

Name	Physical Domain	Sub Class Name	Left Port Type	Right Port Type	Pseudo Periodic	Unit	Affine Conversion
PS-Simulink Converter	network_engine_domain	ps_output	input	output	off	m^3/s	off
PS-Simulink Converter1	network_engine_domain	ps_output	input	output	off	bar	off

Name	Physical Domain	Sub Class Name	Left Port Type	Right Port Type	Pseudo Periodic	Unit	Affine Conversion
PS-Simulink Converter2	network_engine_domain	ps_output	input	output	off	m^3	off

Table 6.0: Ramp Block Properties

Name	Slope	Start	X0
Ramp	1	5	6

Table 7.0: Simulink-PS Converter Block Properties

Name	Physical Domain	Sub Class Name	Left Port Type	Right Port Type	Pseudo Periodic	Noise Distribution	Unit	Affine Conversion	Input Filtering	Simscape Filter Order	Input Filter Time Constant	Udot User Provided
Simulink-PS Converter	network_engine_domain	ps_input	input	output	off	none	m^3/s	off	on	1	0.001	1

Table 8.0: Transfer Fcn Direct Form II Block Properties

Name	Num Coef Vec	Den Coef Vec	Vinit	Rnd Meth	Do Satur
Transfer Fcn Direct Form II	[0.2 0.3 0.2]	[-0.9 0.6]	0.0	Floor	off

Table 9.0: Chirp Block Properties

Name	F1	T	F2
Chirp Signal	0.1	100	1

Table 10.0: Block Type Count

Block Type	Count	Block Names
Scope	4	Scope, Scope1, Scope2, Scope4
PS-Simulink Converter (m)	3	PS-Simulink Converter, PS-Simulink Converter1, PS-Simulink Converter2
chirp (m)	1	Chirp Signal
Transfer Fcn Direct Form II (m)	1	Transfer Fcn Direct Form II
Solver Configuration (m)	1	Solver Configuration
Simulink-PS Converter (m)	1	Simulink-PS Converter
Reservoir (m)	1	Reservoir
Ramp (m)	1	Ramp
Product	1	Product
Mux	1	Mux
Hydraulic Pressure Sensor (m)	1	Hydraulic Pressure Sensor
Hydraulic Flow Rate Source (m)	1	Hydraulic Flow Rate Source
Hydraulic Flow Rate Sensor (m)	1	Hydraulic Flow Rate Sensor
Hydraulic Constant	1	Hydraulic Constant Pressure Source

Block Type	Count	Block Names
Pressure Source (m)		
Fixed Orifice with Fluid Inertia (m)	1	Fixed Orifice with Fluid Inertia
Fixed Orifice (m)	1	Fixed Orifice
Demux	1	Demux

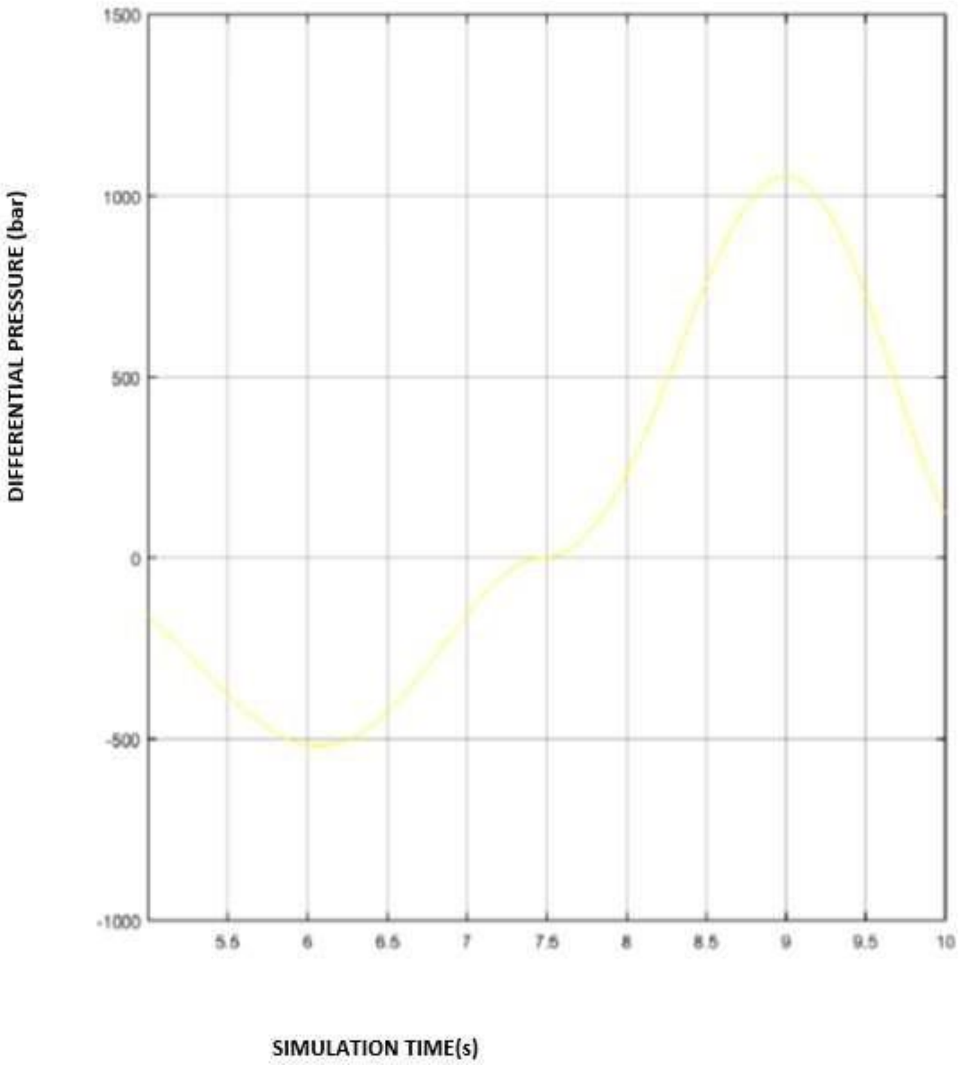

Fig 5.0: Differential Pressure at Orifice Area of 1e-1 m^2 at Cd of 0.2

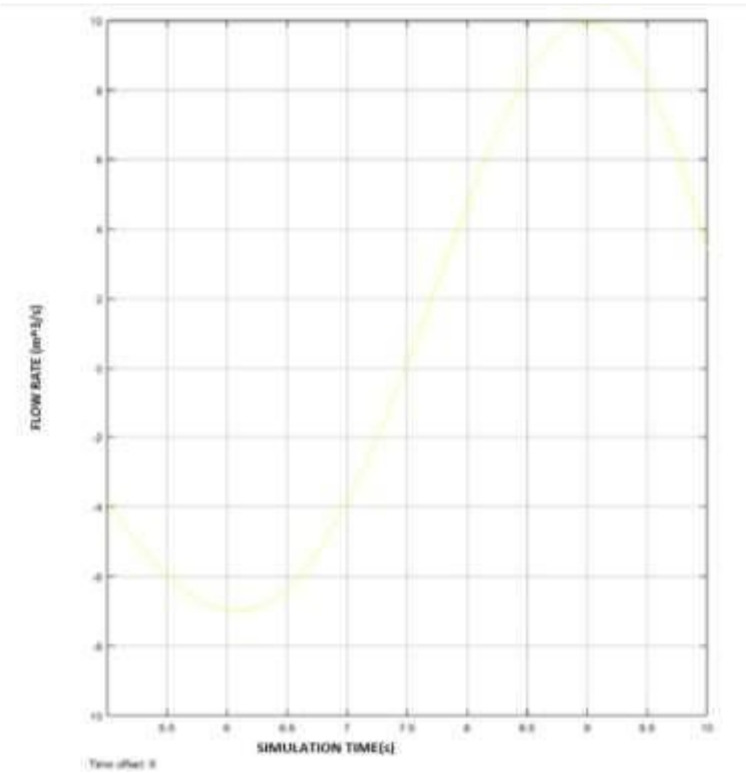

Fig 6.0: Flow Rate at Orifice Area of 1e-1 m^2 at Cd of 0.2

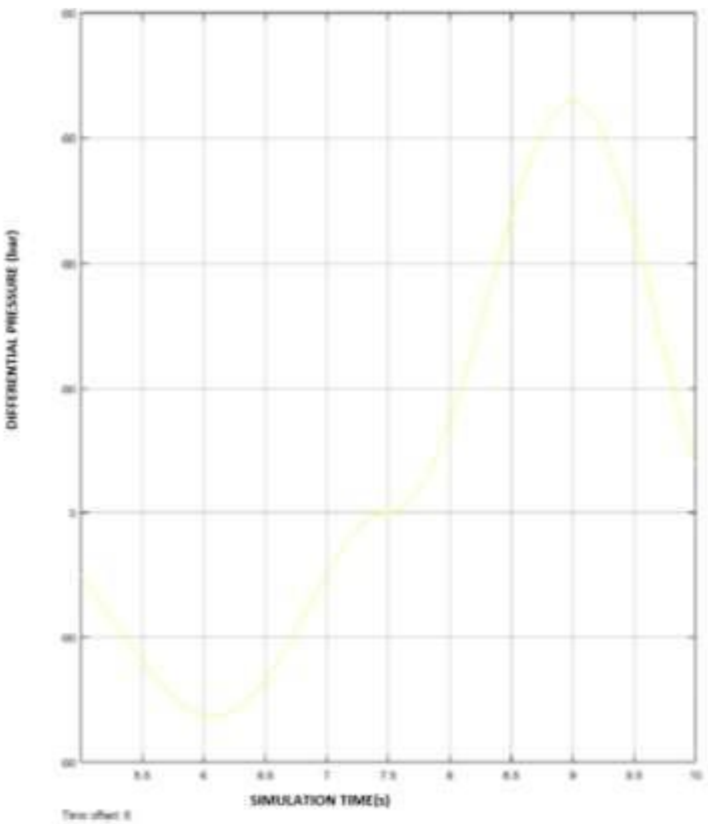

Fig 7.0: Differential Pressure at Orifice Area of 4e-2 m^2 (2000bar per scale at vertical) at Cd of 0.2

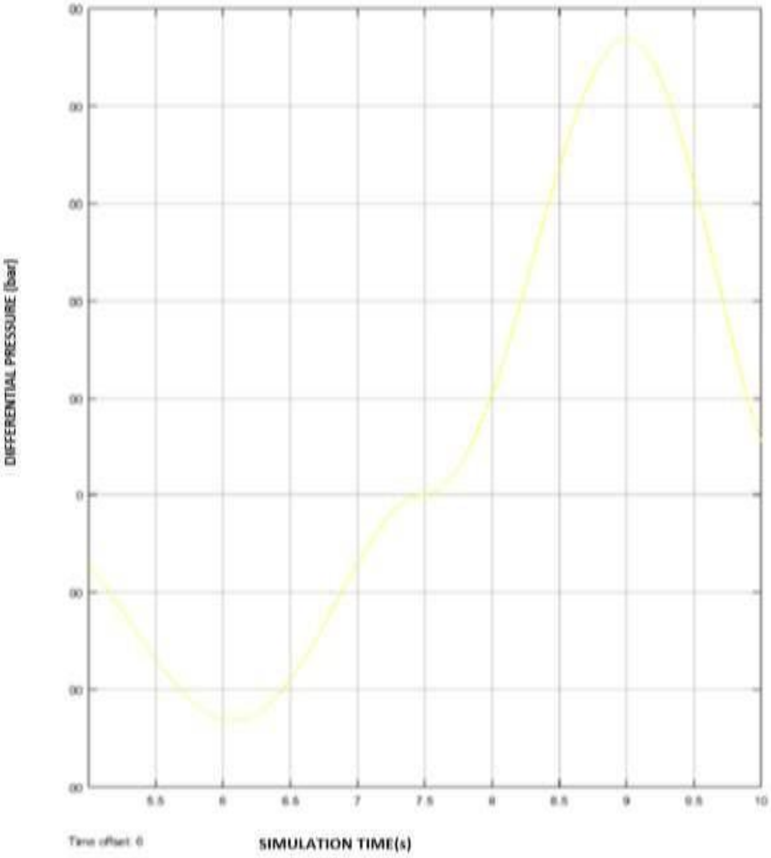

Fig 8.0: Differential Pressure at Orifice Area of 1.5e-1m^2, (100bar per scale at vertical)

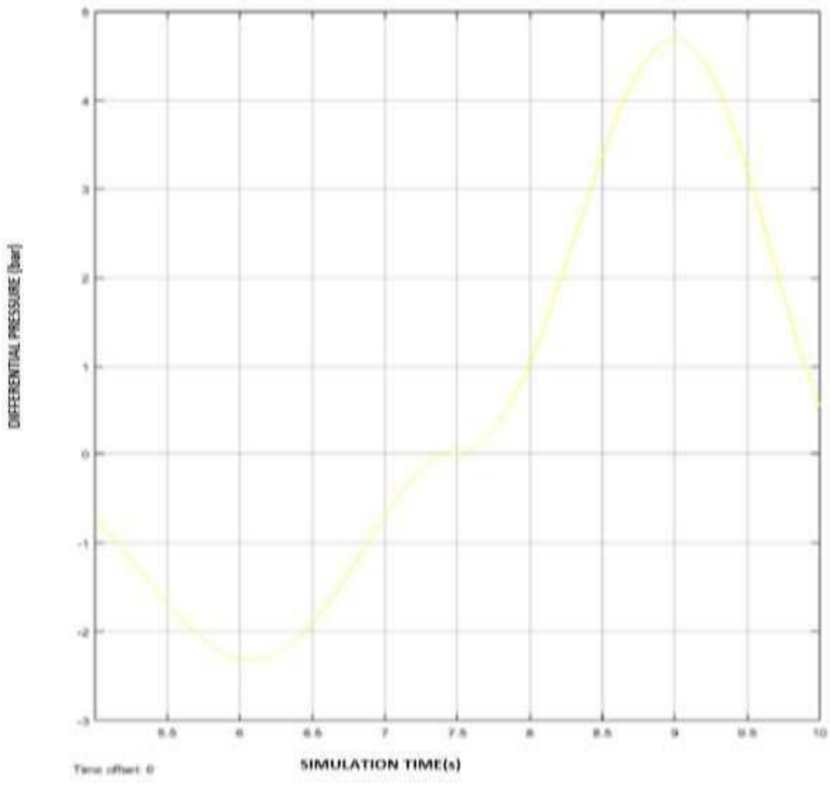

Fig 9.0: Differential Pressure at Orifice Area of 15e-1m^2

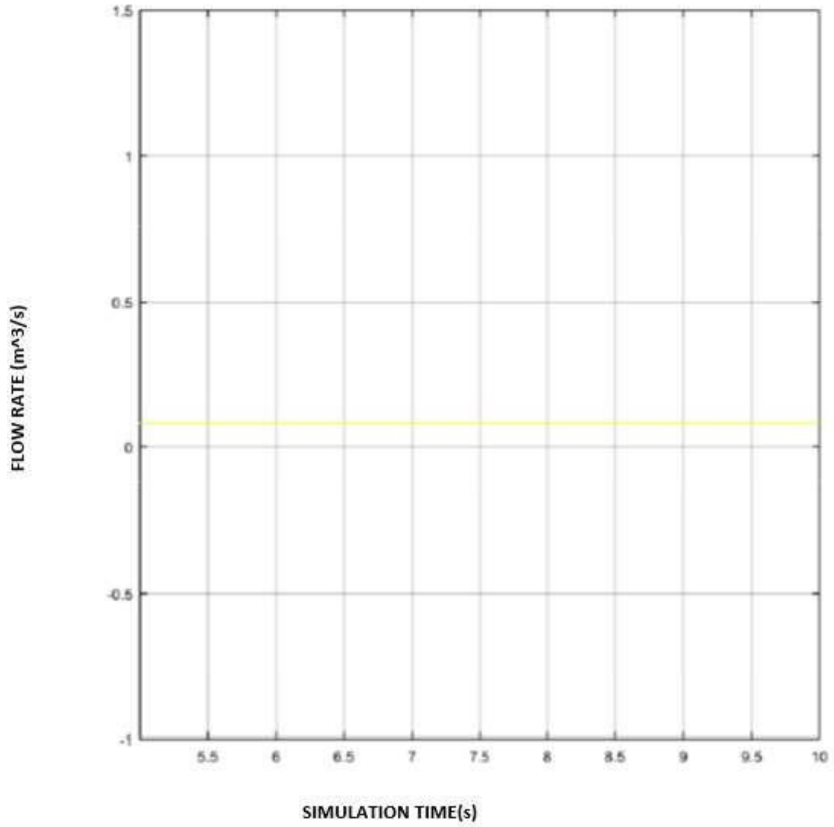

Fig 10.0: Initial Flow Rate

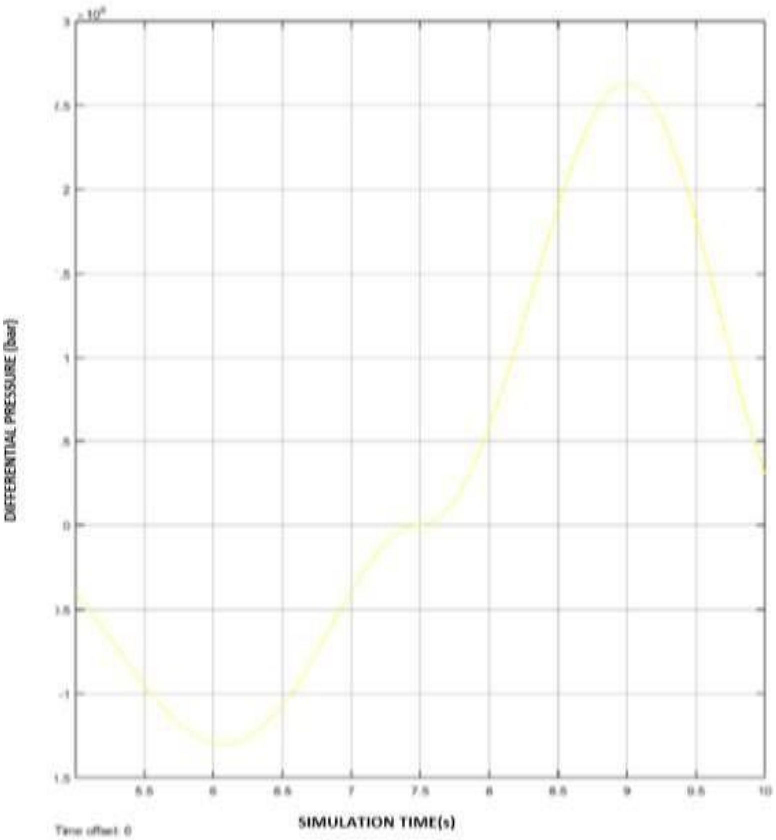

Fig 11.0: Differential Pressure at Orifice Area of 0.2e-3m^2

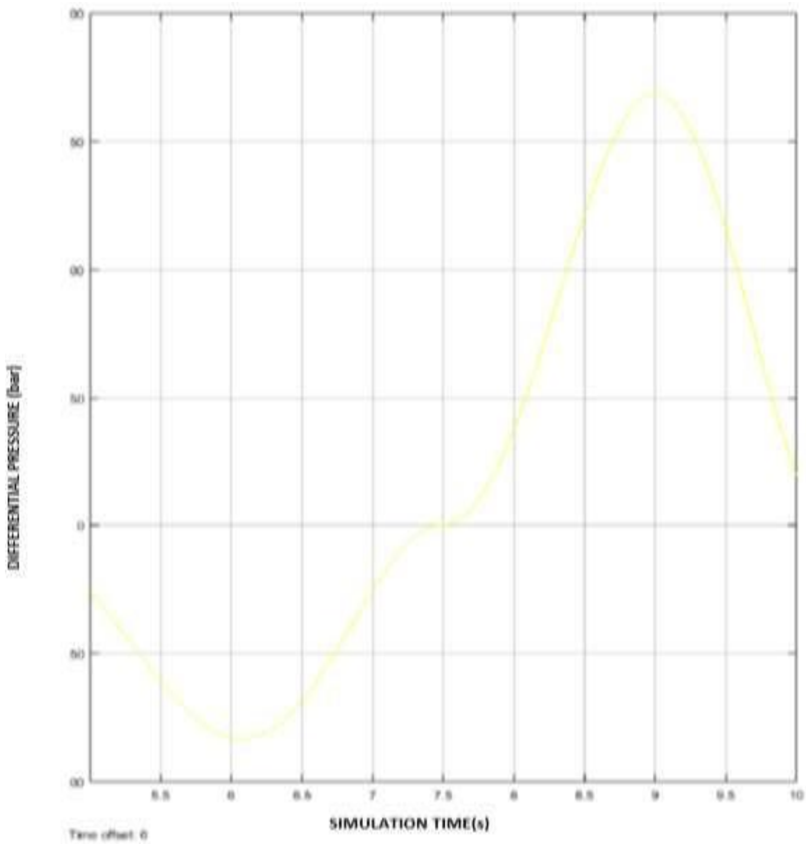

Fig 12.0: Differential Pressure at Orifice Area of 1e-1m^2 and Cd of 0.5

Table 11.0: Shows Values of Differential Pressure, Inertia Pressure Drop and Resistive Pressure Drop at Various Orifice Areas.

S/N	Orifice Area (m^2)	Differential Pressure(bar)	Inertia Pressure Drop(bar)	Resistive Pressure Drop(bar)
1	0.1	150	0.00002	149.99998
2	0.04	1000	0.00005	999.99995
3	0.15	70	0.0000133	69.9999867
4	1.5	0.8	0.00000133	0.79999867
5	0.0002	30000000	0.01	29,999,999.99

MATLAB Codes for Component _Flow Rate_Source

```
% Hydraulic Flow Rate Source

% The block represents an ideal source of hydraulic energy that is

% powerful enough to maintain specified flow rate at its outlet regardless

% of the pressure differential across the source. Block connections T and P

% correspond to the hydraulic inlet and outlet ports, respectively, and

% connection S represents a physical signal port. The flow rate through

% the source is directly proportional to the control signal.

%

% The block positive direction is from port T to port P.

 inputs
```

```
    S = { 0, 'm^3/s' }; % S:bottom
  end
  nodes
    T = foundation.hydraulic.hydraulic; % T:bottom
    P = foundation.hydraulic.hydraulic; % P:top
  end
  variables (Access = protected)
    q = {1e-3, 'm^3/s' };      % Flow  rate
    p = {0,     'Pa'    };      % Pressure drop
  end
  branches
    q : T.q -> P.q;
  end
  equations
    p == T.p - P.p;
    q == S;
  end
end
```

MATLAB Codes for Component Hydraulic Pressure Sensor

```
% Hydraulic Pressure Sensor
% The block represents an ideal hydraulic pressure sensor, that is,
% a device that converts hydraulic pressure differential measured between
% two points into a physical control signal proportional to the pressure.
% Connections A and B are conserving hydraulic ports and connection P
% is a physical signal port. The sensor is oriented from A to B and
% measured pressure is P = p_A - p_B.
nodes
    A = foundation.hydraulic.hydraulic; % A:left
    B = foundation.hydraulic.hydraulic; % B:right
end
outputs
    P = { 0, 'Pa' }; % P:right
end
variables(Access = protected)
    q = { 1e-3 , 'm^3/s'  };       % Flow rate
    p = { 0 ,     'Pa'    };       % Pressure differential
end
branches
```

```
   q : A.q -> B.q;
end
equations
   p == A.p - B.p;
   q == 0;
   P == p;
end
end
```

DISCUSSION

Effects of hydraulic orifice area on resistive pressure drop and inertia pressure drop was investigated using simulink simulation method and discussed here. According to **Fig 3.0 and Fig 4.0**, block models gotten from simscap- hydraulics were used to represent all the elements of orifice flow hydraulic model. To achieve the general objective, 5 variable orifice areas, 0.1m^2, 0.04m^2, 0.15m^2, 1.5m^2 and 0.0002m^2 were considered by the researchers.

The hydraulic orifice elements (Fixed Orifice and Fixed Orifice with Fluid Inertia) as shown in **Table 2.0** were modeled to retain orifice hydraulic diameter of 0.0113 m, initial orifice area 1e-1 m^2within orifice length of 0.01 m. The initial flow rate was 0.2m^3/s at differential pressure of 1.5bar. Coefficient of discharge of the orifices was 0.2. Also, critical Reynolds's Numbers for the two orifices were 12 and 10 respectively. The hydraulic reservoir was pressurized to 2bar at initial fluid volume of 0.08m^3 . ODE23 solver was used to run the Simulation for 10seconds, according to **Table 1.0**.

According to **Table 11.0**, at orifice area of 0.1m^2 , differential pressure was found to be 150 bar, inertia pressure drop was 0.00002bar with resistive pressure drop being 149.99998bar. Furthermore, orifice area was reduced to 0.04m^2 , differential pressure increased to 1000 bar, inertia pressure drop also increased to 0.00005bar as well as resistive pressure drop, 999.99995bar. These results indicated that narrowing or decreasing hydraulic orifice area, will increase resistive pressure drop as well as inertia pressure drop and vice-versa.

According to **Fig 5.0 and Fig 12.0**, when orifice coefficient of discharge was 0.2, at orifice area of 0.1m^2, differential pressure was found to be 150bar. At coefficient of discharge of 0.5, with the same orifice area, differential pressure decreased to 25bar. Therefore, orifice coefficient of discharge influences differential pressure as well as discharge through the orifice.

CONCLUSION

According to the findings, we can conclude that narrowing or decreasing hydraulic orifice area, will increase resistive pressure drop as well as inertia pressure drop and vice-versa. In addition, increasing orifice coefficient of discharge, will decrease differential pressure and increase discharge through the orifice. These results are in line with Frank et al. (1990) which suggested that orifice geometry (area) is a determinant of discharge properties and therefore, should influence empirical constants governing orifice formulas.

RECOMMENDATIONS

The following recommendations are suggested based on the study:

1) The influence of hydraulic orifice area and coefficient of discharge must be compromised if maximum flow rate is paramount.
2) This research can also be done in future using different hydraulic design models and other advanced software for generalization.

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Disclosure of conflict of interest

The corresponding author declares that all of the authors have all participated in the design, execution, and analysis of this paper, and that they have approved the final version. More so, there are no conflicts of interest in connection with this paper, and the material described is original.

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