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Analysis of Pneumatic Systems Using the Laplace Equation Based on Python Programming

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ABSTRACT

Analysis for Pneumatic Systems using the Python programming language on Google Colab has been carried out. The steps taken before the simulation are to design a pneumatic system and then determine the Laplace equation based on Bernoulli's law equation. The Python programming language on Google Colab was chosen because it allows users to type Python code in a web browser and can be used for free. The simulation is carried out by varying the value of capacitance (C) from 50 kPa - 300 kPa with an increase of 50 kPa. This aims to determine the effect of changes in capacitance variations on the pressure exerted on the pneumatic system. Based on the simulation results, the greater the capacitance variation given, the resulting graph will be more sloping or closer to the x-axis. The C = 50 kPa variation has a steeper graph, while the C = 300 kPa variation has a more sloping graph and is closer to the x-axis.

Keyword: Pneumatic; Capacitance; Laplace Equation; Python Programming

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1. INTRODUCTION

The pneumatic system is a system that involves gas flow (Ren et al. 2019). Pneumatic pressure is one among the vital variables used in industries like power plants (Al-Dhaifallah et al. 2018), automotive and aircraft (Nehler 2018), chemical reaction control (Leszcynski et al. 2019), bioengineering (Ren et al. 2018), food (Makiyama et al. 2020), medical (Sénac et al. 2019), position servo systems (Mu et al. 2019), well drilling (Leiden et al. 2023), electronic (Walker et al. 2020), heating (Fang et al. 2018), ventilating (Krasteva et al. 2018), air conditioning systems (Merzvinskas et al. 2020), automobile [Sun et al. 2021), and so on. The use of pneumatic systems that have been widely applied in industry is not impossible to be applied to other fields where the control devices are combined with other systems. The advantage of using work controls with a pneumatic system such as high speed (Dong et al. 2021; Boland et al. 2019) and better efficiency (Fang et al. 2018; Zhou et al. 2020; de Fretas et al. 2022)

Mathematical modelling and control of pneumatic systems is an active research area attracting many researchers around the world for past few decades. (Al-Dhaifallah et al. 2018) Design an intelligent fuzzy-based fractional-order PID control scheme to ensure a robust performance with respect to load variation and external disturbances. A novel model of a pilot pressure regulating system is developed to validate the effectiveness of the proposed control scheme. Simulation studies are carried out in a delayed nonlinear pressure regulating system under different operating conditions using fractional-order PID (FOPID) controller with fuzzy online gain tuning mechanism. The results demonstrate the usefulness of the proposed strategy and confirm the performance improvement for the pneumatic pressure system. (Shin et al. 2019) Provides a method to analyze and measure the power of pneumatic system, lay a foundation for the optimization and energy-saving design of pneumatic system. (Xu et al. 2021) Presented the step response characteristics of the pneumatic motor and the relationship between rotation speed, torque, power output, and volume flow rate, as well as analyze the uncertainties of the power output and energy efficiency of the pneumatic motor. Experimental results show that the power output and energy efficiency of the pneumatic motor first increase and then decrease with the increase of torque. The energy efficiency of the pneumatic motor reaches the maximum value of approximately 62%.

Pneumatic system simulation can be done on Google Colab using the Python programming language. Python was chosen because it is one of the most popular programming languages (Sharma et al. 2020; Khoirom et al. 2020), open source (Vallat 2018; Smith et al. 2020), free to use (Harris et al. 2020; Holohan et al. 2019) and has many learning resources (Peirce et al. 2019; Sakai et al. 2018). As an application of the Python programming language, the author presents Pneumatic System Analysis Using Python Programming-Based Laplace Equations using Python Simulation on Google Colab. The simulation is carried out by varying the capacitance value from 50 kPa - 300 kPa with an increase range of 50 kPa. It aims to determine the effect of capacitance on changes in the value of the pressure exerted on the pneumatic system.

2. RESEARCH METHOD

A. Pneumatic System Diagram Design

The first stage is to design a pneumatic system diagram and look for the final equation of the pneumatic system. Figure (1) is a pneumatic system design that will be simulated.

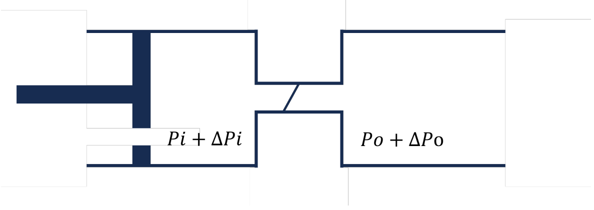


Figure 1. Pneumatic System Diagram Design

The equation in Figure (1) is obtained by Bernoulli's concept, then proceed to look for the Laplace equation so that a transfer function is found.

B. Bernoulli's Equations

Bernoulli's equation in fluid mechanics states that in a fluid flow, an increase in velocity will cause a decrease in pressure on the flow. The sum of the energy at one point in a closed flow is equal to the sum of the energy at any other point in the same flow path. Bernoulli's principle states that in a horizontal pipe, the highest fluid pressure has the lowest flow rate, while the lowest pressure has the highest flow rate, as shown in figure (2).

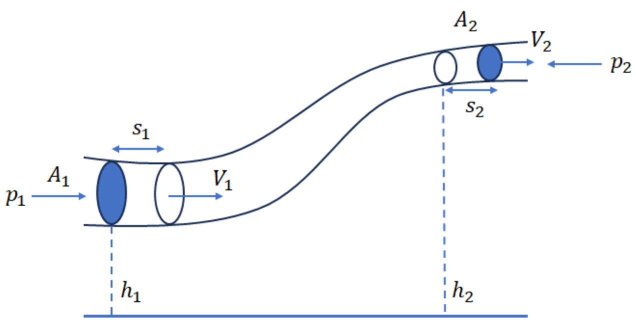


Figure 2. Bernoulli System

Based on the picture above, Bernoulli's equation can be written as follows

$$\frac{1}{2}\rho v_1^2 + \rho g h_1 + P_1 = \frac{1}{2}\rho v_2^2 + \rho g h_2 + P_0 \tag{1}$$

Since the pneumatic system has the same height from the same surface, equation (1) can be rewritten as:

$$\frac{1}{2}\rho v_1^2 + P_1 = \frac{1}{2}\rho v_2^2 + P_0 \quad (2)$$

The discharge is expressed as $Q = A . V$, the smaller the cross-sectional area the greater the speed.

$$Q \sim V \sim \Delta P$$

$$dQ = \Delta P \quad (3)$$

The greater the pressure, the greater the flow rate, so the equation becomes:

$$Q_{in} = \frac{dQ}{dP}\Delta P \quad (4)$$

However, the process of moving or transferring air from the left system to the right side of the system experiences an obstacle, namely the reduction in the cross-sectional area which is assumed to be.

$$\frac{dQ}{dP} = R \quad (5)$$

The value of R is influenced by the large cross-sectional area. The larger the cross-sectional area, the smaller the discharge, while the smaller the cross-sectional area, the greater the velocity and discharge. so that equation (4) can be rewritten as:

$$Q_{in} = \frac{1}{R}\Delta P \quad (6)$$

$$\Delta Q_{in} = \frac{\Delta Pi - \Delta Po}{R}$$

$$Q_{in} = C$$

$$Q_{in} = \frac{dQ}{dP}\Delta P$$

$$\Delta V = \Delta Q \; dt$$

$$C = \frac{\Delta Q}{\Delta Po}\left(\frac{m^3}{newton//m^2}\right)$$

$$\Delta Q = C \; \Delta Po$$

$$\frac{\Delta Pi - \Delta Po}{R} = C \; \Delta Po$$

$$\frac{\Delta Pi - \Delta Po}{R} = C \frac{d}{dt}\Delta Po$$

$$\Delta Pi - \Delta Po = RC \frac{d\Delta Po}{dt}$$

$$\Delta Pi = RC \frac{d\Delta Po}{dt} + \Delta Po \quad (7)$$

After entering the Laplace transform, the equation (7) becomes:

$$\Delta Pi = RC \frac{d\Delta Po}{dt} + \Delta Po$$

$$\frac{d\Delta Pi}{dt} = RC\frac{d^2\Delta Po}{dt^2} + \frac{d\Delta Po}{dt}$$

$$s\,\Delta Pi = s^2\,RC\Delta Po + s\,\Delta Po$$

$$\Delta Pi = s\,RC\Delta Po + \Delta Po$$

$$\Delta Pi = \Delta Po(s\,R\,C + 1)$$

$$\frac{\Delta Po}{\Delta Pi} = \frac{1}{s\,R\,C + 1} \tag{8}$$

Equation (8) is the transfer function obtained. The transfer function will then be used in the simulation stage using the Python programming language.

C. Bernoulli's Equations

The simulation carried out at this stage was carried out using Google Colaboratoty (Google Colab) with the Python programming language. Google Colab allows users to type Python code on a web browser (Kuroki 2021). Googe Colab provides serverless jupyter notebooks for interactive development, besides Google Colab is free to use (Bisong et al. 2019). Figure (3) below shows the initial view when visiting Google Colab.

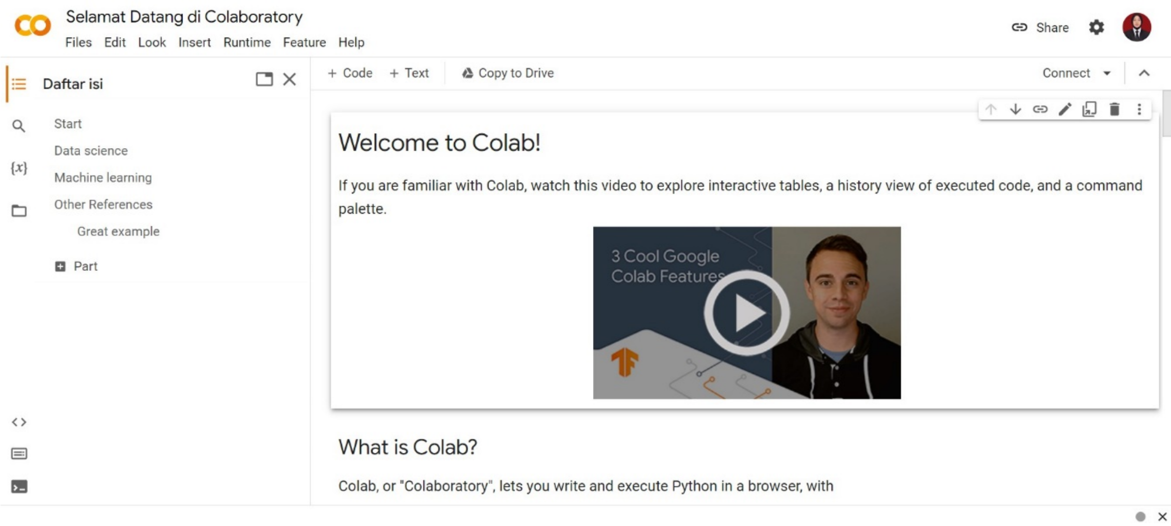


Figure 3. Welcome Google Colab

To create a program on Google Colab you need to open the file menu and select "New Notebooks". as shown in figure (4) below.

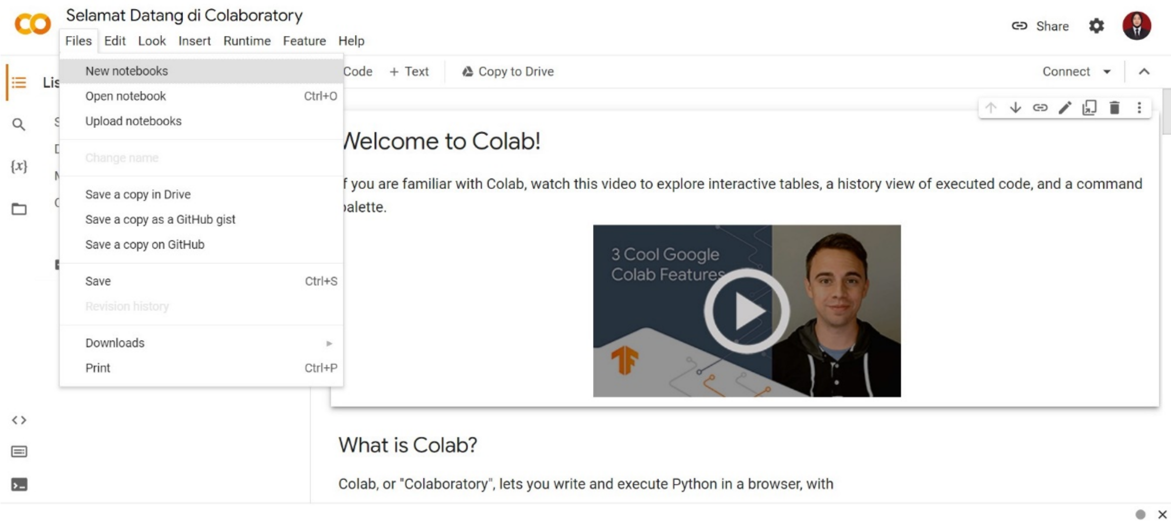


Figure 4. New Notebooks Google Colab

After selecting "New Notebooks", a display will appear as shown in figure (5) below.

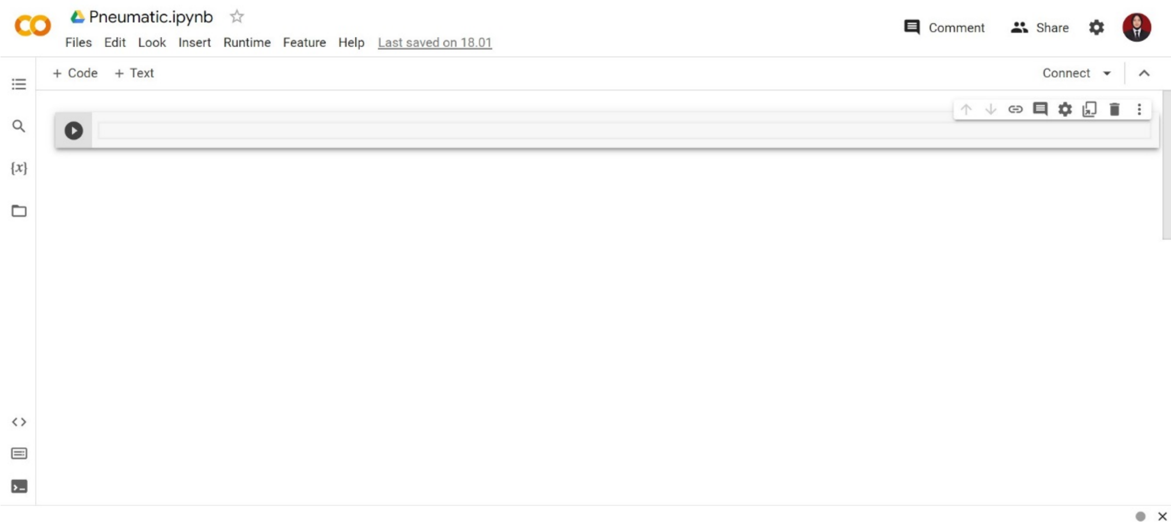


Figure 5. Google Colab to Generate Code

The purpose of this research is to find out how the pneumatic system works using the Python programming language. The parameters used in this simulation are capacitance and resistance factor. From these parameters it can be seen how the pneumatic system works by looking at the simulation results of the behavior of the inlet pressure to changes in the output pressure. The initial stage in making this pneumatic system program is to define variables and libraries in python, as shown in the following program:

```
import numpy as np
import scipy.signal as signal
import matplotlib.pyplot as plt
```

The parameters used for the simulation in this study are the values of R = 0.0047 and C = 50 - 300 kPa with an increase range of 50 kPa. As shown in the following program:

```
R = 0.0047
C1 = 50
C2 = 100
C3 = 150
C4 = 200
C5 = 250
C6 = 300
L1 = R*C1
L2 = R*C2
L3 = R*C3
L4 = R*C4
L5 = R*C5
L6 = R*C6
```

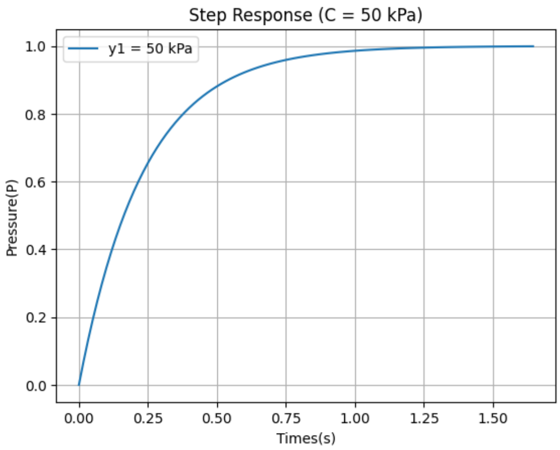
The next step is to enter the transfer function obtained in equation (8) in the Python programming language. Then make a graph of pressure changes with time. As shown in the following program:

```
num = np.array([1])
den1 = np.array([L1, 1])
den2 = np.array([L2, 1])
den3 = np.array([L3, 1])
den4 = np.array([L4, 1])
den5 = np.array([L5, 1])
den6 = np.array([L6, 1])

H1 = signal.TransferFunction(num, den1)
H2 = signal.TransferFunction(num, den2)
H3 = signal.TransferFunction(num, den3)
H4 = signal.TransferFunction(num, den4)
H5 = signal.TransferFunction(num, den5)
H6 = signal.TransferFunction(num, den6)

t1,y1 = signal.step(H1)
t2,y2 = signal.step(H2)
t3,y3 = signal.step(H3)
t4,y4 = signal.step(H4)
t5,y5 = signal.step(H5)
t6,y6 = signal.step(H6)

plt.plot(t1,y1)
plt.plot(t2,y2)
plt.plot(t3,y3)
plt.plot(t4,y4)
plt.plot(t5,y5)
plt.plot(t6,y6)
plt.legend(["y1 = 50 kPa","y2 = 100 kPa", "y3 = 150 kPa", "y4 = 200 kPa","y5 = 250 kPa", "y6 = 300 kPa"])
plt.title("Step Response")
plt.xlabel("Times(s)")
```

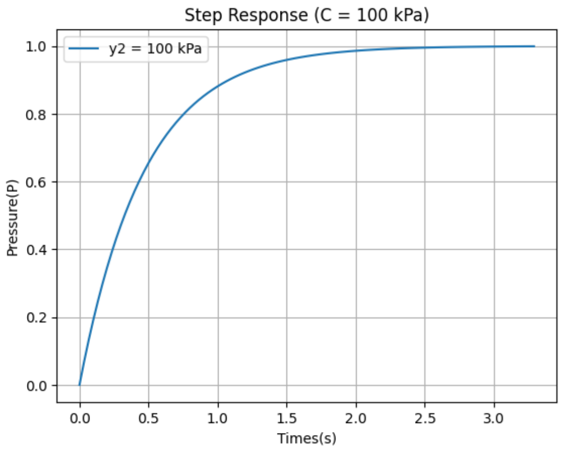
```
plt.ylabel("Pressure(P)")
plt.grid()
plt.show()
```

3. RESULTS AND DISCUSSION

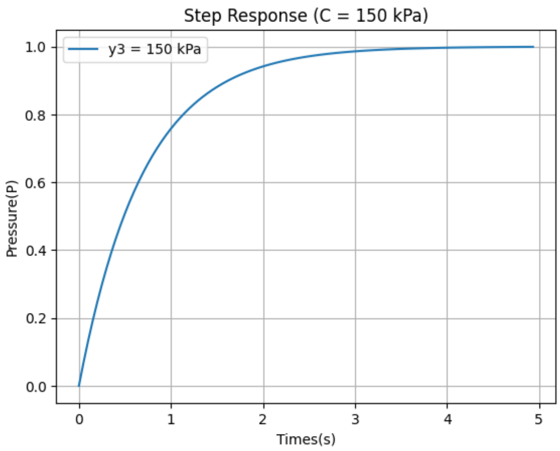
Research has been carried out to determine the work of pneumatic systems using python programming. The parameters used in this simulation are capacitance and resistance factor. From these parameters it can be seen how the pneumatic system works by looking at the simulation results of the behavior of the inlet pressure to changes in the output pressure. By using the parameter value R = 0.0047 and varying the C value from 50 - 300 kPa with an increase range of 50 kPa. the simulation graph obtained using Google Colab is as shown in Figure (6) below:



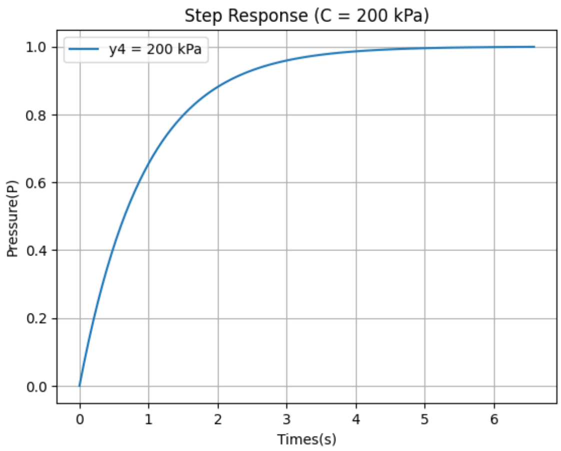
(a)



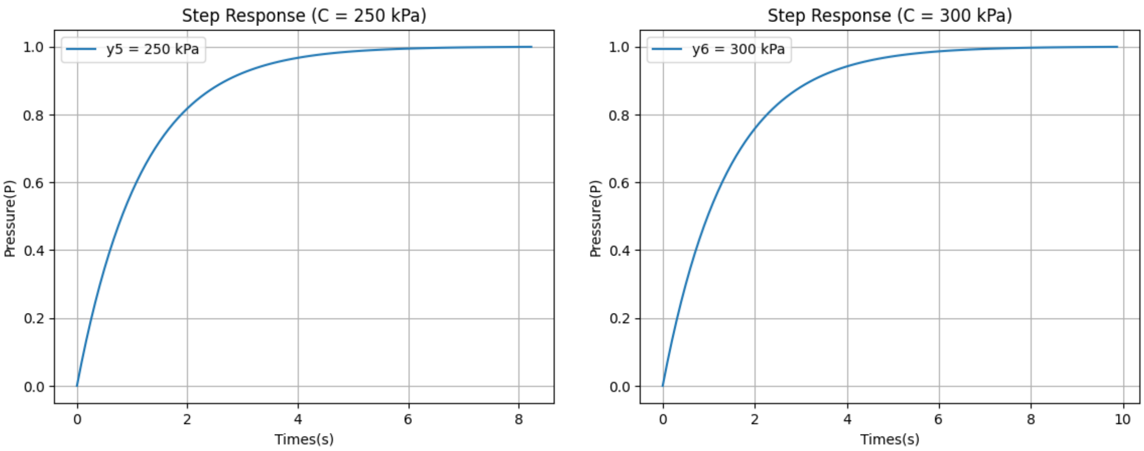
(b)



(c)



(d)



(e) (f)

Figure 6. Variation of capacitance: (a) 50 kPa, (b) 100 kPa, (c) 150 kPa, (d) 200 kPa, (e) 250 kPa, and (f) 300 kPa.

The graphs in Figure (6) are then combined, so that the graph of pressure changes with time is obtained as shown in Figure (7) below:

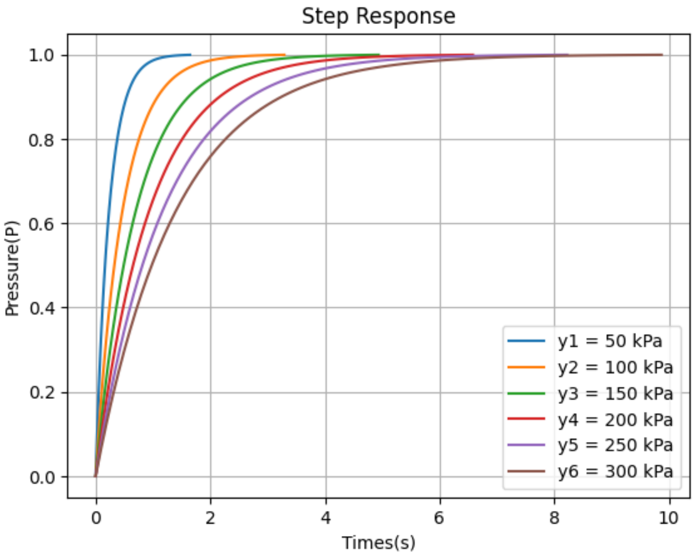


Figure 7. Combined graph of capacitance variations

Based on Figure (1) if there is a change in pressure in the system that enters the left system, the piston will push the air in the left system so that it switches to the right system. When air enters through the valve on the left side of the system, the piston will move forward and the valve on the right will open so that the Pi accent will be greater than Pi and cause air to flow towards the right side of the system resulting in a change in Po. Meanwhile, if Po is greater than Pi, there will be no change in pressure.

When there is a change in the inlet pressure there will be a change in the outgoing pressure. If there is no change in inlet pressure, then no pressure transfer occurs. Because the incoming pressure has reached the maximum pressure from the output tube, there will be no more pressure changes and the pressure will be constant. So that the graph changes from initially 0 to then forms an exponential curve.

Based on the graph in Figure (7), it can be seen that the more variations in capacitance (C) are given, the resulting exponential graph will be sloping closer to the x-axis. This is as shown in the graph, that the variation C = 50 kPa which is represented by the blue line has the greatest level of pressure change because the graph is the steepest, followed by the variation C = 100 kPa which is represented by the orange line, variation C = 150 kPa which is represented by the green line, variation of C = 200 kPa which is represented by the red line, variation of C = 250 kPa which is represented by the purple line, and variation of C = 300 kPa which is represented by the brown line which has the most graphic sloping or approaching the x-axis.

4. CONCLUSION

A pneumatic system simulation has been carried out using the python programming language. The simulation is carried out by varying the value of the capacitance (C) from 50 kPa - 300 kPa with an increase of 50 kPa to determine the effect of the change in variation. The results show that the C = 50 kPa variation has a steeper graph, while the C = 300 kPa variation has a more sloping graph and is closer to the x-axis. This shows that if the pressure at the input is greater than the output pressure then the air will flow in the compressor tube and if the pressure in the output tube is equal to the pressure in the tube, then the pressure will be constant so there is no change in pressure.

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