EFFECT OF CUTOFF FLOW ON THE ENERGY CONSUMPTION AT DESIRED POINT OF PNEUMATIC ACTUATOR

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ABSTRACT

This paper presents a study the performance and to improve energy efficiency of the traditional pneumatic driver, three supply pressures used 4, 6 and 8 bar, by cutoff flow process occurs at stroke end of the actuator before execution position, in which pressure supply line cutoff and the exhaust line remains open in position specified previously. The piston stroke completes rest under the influence of air expansion , the inertia force of the piston exactly at execution position, that is saving in compressed air and energy, reduced in required air additional to reduce the cost. compared with the traditional control of motion of the asymmetric cylinder in which maximum energy saving obtained at 6 bar are 16.7%.

Keywords: Cutoff flow, Pneumatic Actuator, Desired Point

تاثير قطع الجريان للمشغلات الهوائية على معدل استهلاك الطاقة في نقطة محددة مسبقا

الخلاصة

في هذا البحث تم دراسة تحسين اداء كفاءة المنظومة الهوائية وذلك من خلال قطع جريان هواء الضغط المجهز قبل نهاية شوط المشغل بمسافة تحدد بالاعتماد على ضغط التجهيز والحمل الكلي مع بقاء خط العادم مفتوحا ولضغوط تجهيز 6 ، 8 و4 بار ولما لها من مردود في تقليل معدل صرف الطاقة وبالاستفادة من تمدد ضغط الهواء المحصور وقوة القصور الذاتي لوزن مكبس الاسطوانة في تكملة ماتبقى من الشوط ،كذلك توفير هواء مضغوط وطاقة بالاضافة الى تقليل الكلفه، مقارنة مع السيطرة التقليدية لحركة الاسطوانة غير المتماثلة للحصول على توفر طاقة قصوى 16.7٪ عند ضغط 6 بار.

NOMENCLATURE

A Piston area , m^2
C Constant (-)
C_f Discharge coefficient (-)
d diameter, m
F friction force,N
f Frictional factor(-)
K Specific heat ratio(-)
L Piston stroke(m)
M Piston mass (kg)
P Air pressure (Pa)
R Gas constant (kJ/kg.K)
T Temperature (K)
V Air cylinder volume (m^3)
X Air cylinder piston displacement (m)
α Coefficient (-)

INTRODUCTION

Pneumatic actuators can be offer better alternatives to the electrical and hydraulic actuators for wide many applications. Pneumatic actuator has the advantages of little cost, high power-to-weight ratio, Cleanliness, having a readily available; operating at high speed and cheap of source power. Owing to numerous advantage, pneumatic actuators and systems are widely applied in industrial automation for the so-called sequential control.

Generally saving of energy in pneumatic system divided, as the energy where is used, into: part of production, where energy of mechanical is converted into pneumatic energy i.e. in the compressor, part of transmission, where air under pressure is transported through the line, part of executions, where the potential air energy under pressure is converted to mechanical work.The cylinders and motors first reduced air consumption to minimum value as possible by reducing the losses of components or use some device or method, second can be reused exhaust air by recovery energy with some device or method, third in worker pneumatic system applied advanced control system to obtain the position in less time as possible , hence reduce in useful air consumption of delay time.

The researcher proved that pneumatic servo system can be using for the accurate robust position control, did not only for movement between two hard stops. Their experimental results shows that proposed sliding-mode controller gives very fast response , good transient performance. The controlled system was robust to variations of system parameters and external disturbance ,they do not be require accurate modeling..

Khalid A. et al., (2003) proposed variation on a sliding mode control approach that provides significant energy savings for the control of pneumatic servo systems , Due to nonlinear model of the pneumatic cylinder Jia. K. et al(2004) developing and energy-efficient control strategy to avoid the problem of solving the complicated nonlinear differential equations which transfer to linear system description which lead to poor air saving.

Ming.H .T et al., (2006) studied the hybrid fuzzy sliding mode controller with loading compensator applied to control the vertical position of the pneumatic rodless cylinder, Vladislav .B. et.al (2008) and Khalid .D et.al (2009) reduce pressure difference between pressure supply and active pressure line at the stroke start motion by adding bridging two ways valve with rodless cylinder and horizontal load.

J. Gyeviki et.al (2010), Vladislav et.al (2010) using sliding mode control and hybrid fuzzy sliding mode control with and without rod double acting cylinder They proved that pneumatic servo systems can be used for the accurate robust position control, not only for the movement between two hard stops. The experimental results showed that proposed sliding-mode controller gives fast response and good transient performance. Furthermore, the controlled system was robust to the variations of the system parameters and external disturbances and they do not require accurate modeling, Jihong. W. et.al (2011) presented recent work in developing an energy-efficient tracking control strategy for pneumatic rod less cylinders.

Previous research studied energy conservation in actuations represented a double acing cylinder without rod where this type has poor practical applications, therefore in present study a novel method for energy saving in a point-to-point actuation of double acting cylinder with single rod of a pneumatic system in which have wide applications. The method predicts the system's actuation using the gas law and the actuator model, and commits air supply cut-off at the time when the energy in the actuator is sufficient to complete the actuation task. Experimental implementation is compared with simulation. The effect of the method is compared with conventional no cut-off actuations.

EXPERIMENTAL SYSTEM APPARATUS

Figure.1 shows a pneumatic system rig present the experimental work. It consists of two important parts, electric and pneumatic part. Electric part consists of PC, data acquisition and control module, amplifier and safety module, position sensor; flow sensor and pneumatic part consists of the necessary components for conventional pneumatic system, such as double acting cylinder with single rod, 5/3 way directional control valve, , A Festo variable non return throttle valve type, Non return valve type KAM-08, Pressure regulator type Expflex AR-200, A Festo flow sensor type SFAB-200U-WQ8-25A-M12, , data acquisition type NI USB-6212, Power supply type MCH-505D, proximity switch and tubes, the schematic diagram of the circuits in which be used shown in figure 1 and 2.

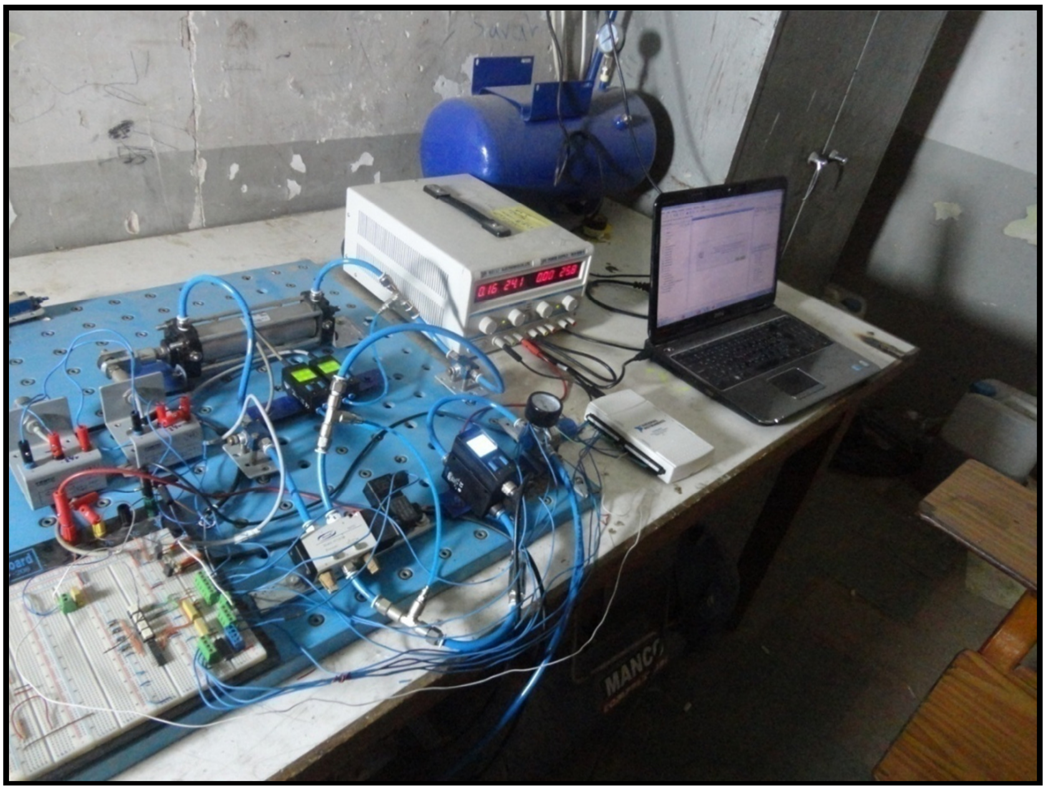
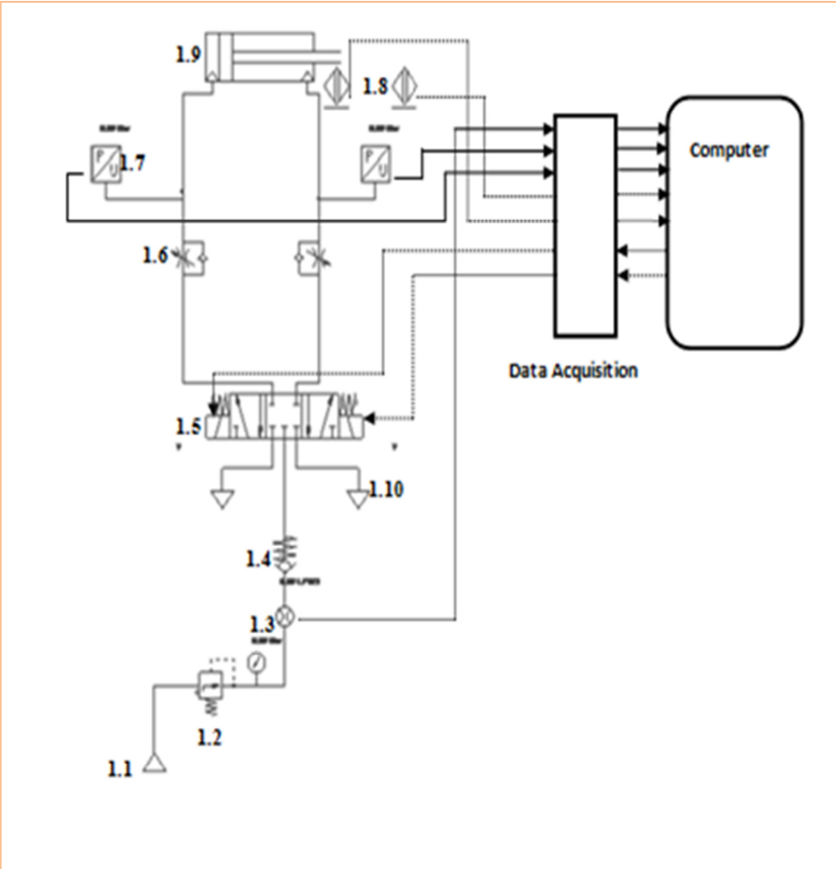


Fig. 1. Pneumatic experimental Rig

Control circuit

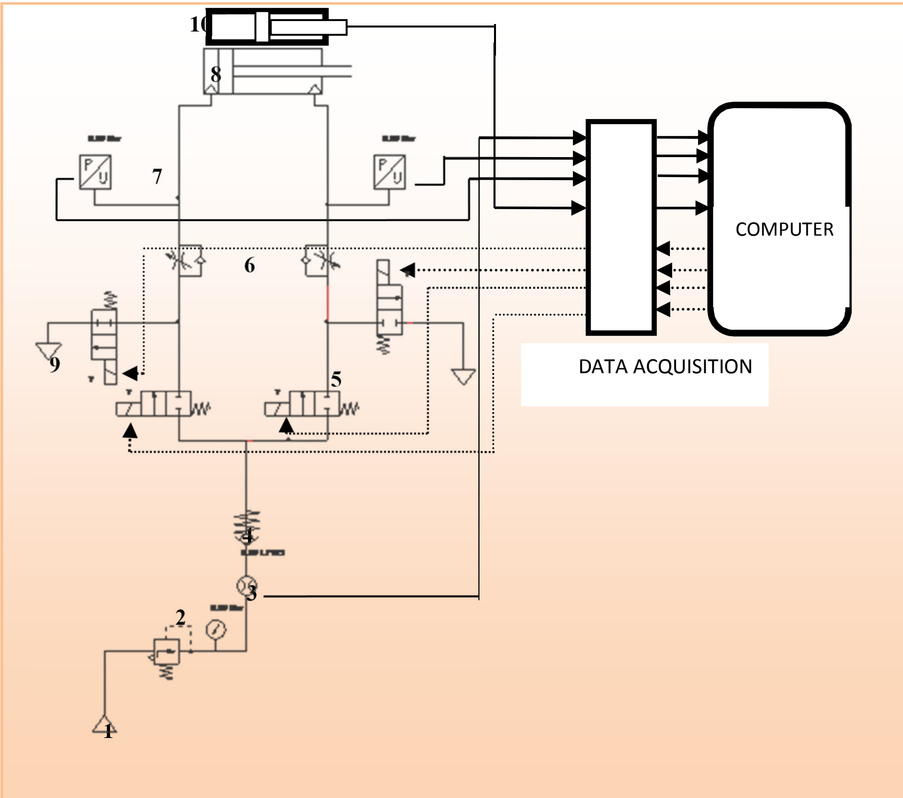
MATLAB SIMULIK program used to control work circuits in Fig.2 with 2 digital outputs and 4 analog inputs, in which included,

1- Sequence operation of digital and analog signals.
1- On-off switch.
2- Number of strokes.
3- Strokes reset.
3- Length of stroke.



1.1Pressure Source 1.2Pressure Regulator
1.3Flow Sensor 1.4Check Valve
1.5 5/3D.C.V 1.6Throttling non return
Valve
1.71Pressure Source 1.8Proximity Switch
1.9Single rod double acting Cylinder 1.10Exhaust Lin

Fig.2.a CPS Circuit



1. Pressure source . 2. Pressure regulator.
3. Flow sensor. 4. Check valve
5. One way valve . 6 .Throttling non- return valve
7. Pressure sensor. 8. Single rod double acting cylinder
9. Exhaust line 10. Position sensor

Fig.2.b CPS circuit

OPERATING SEQUENCES

A scematic diagram of the circuit is shown in Figure (2) a & b. The circuit used proximity switch, without load, supply pressure 4, 6, and 8 bar for ten strokes. The sequence operation of the circuit can be simplified as follow:

For circuit (a)

Operate the circuit from on-off switch in working program. Adjustable throttling non-return valve with required air flow, and the pressure regulator keep at required pressure.

The digital signal of proximity switch now operate hence the working program send digital signal to the solenoid of right side D.C.V 5/3 . Piston of the cylinder begins to move from left to right.

At the end of the stroke the digital signal of another proximity switch now operate hence the working program send digital signal to the solenoid of left side D.C.V 5/3 . Piston of the cylinder begins to move from right to left. The procedure is repeated the strokes then the system stopping automatically.

For circuit (b)

The operated of the circuit (b) was as the same of operated circuit (a)[Operate the circuit from on-off switch in working program. Adjustable throttling non- return valve with required air flow, and the pressure regulator keep at required pressure.].The length of required stroke from the equivalent output position sensor recorded from the program.

The program send digital signal to the valves to open, piston of the cylinder begins to move from left to right. After the piston reach specified position digital signal of the valve closed and the piston reaches final position freely then digital signal of the valve closed and for another valves opened.

After the piston reach specified position digital signal of the valve closed and the piston reaches final position freely then digital signal of the valve closed and for valves open. Finally The procedure is repeated to require stroke hence the system stopping automatically.

MATHEMATICAL MODEL

Mass flow rate(SHI H. et al 2012)

$$\dot{m}_{v}=\begin{cases} C_f * A_v * C_1 * \frac{P_u}{\sqrt{T}} & if \ \frac{Pd}{Pu} \le P_{cr} \\ C_f * A_v * C_2 * \frac{P_u}{\sqrt{T}} (\frac{P_d}{P_u})^{\frac{1}{k}} \sqrt{1-(\frac{P_d}{P_u})^{(k-1)/k}} & if \ \frac{Pd}{Pu} > P_{cr} \end{cases} \quad (1)$$

$$C_1=\sqrt{\frac{K}{R}(\frac{2}{K+1})^{\frac{K+1}{K-1}}} \quad ; \quad C_2=\sqrt{\frac{2K}{R(K-1)}} \quad ; \quad P_{cr}=(\frac{2}{K+1})^{\frac{K}{K-1}}$$

For air (k = 1.4) we have C_1 = 0.040418, C_2 = 0.156174, and P_{cr} = 0.528, T=300 k, $C_f = 0.25$

cylinder chambers:

For cylinder chamber 1 the pressure inlet (P_{in}) (Edmood R. et al 2001) :

$$\dot{P}_{in} = \frac{RT}{V_{01}+A_1 x}(\dot{m}_{in}\alpha_{in} - \dot{m}_{out}\alpha_{out}) - \alpha\frac{\pm A_1 P_1}{V_{01}+A_1 x}\dot{x}$$ (2)

gas constant R=287 J/kg.k, α_{in}=1.4, $\alpha_{out} = 2$, $\alpha = 1.2$, the model is simplified to follow form:

And for cylinder chamber 2 the pressure outlet(P_{out}):

$$\dot{P}_{out} = \frac{RT}{V_{02}+A_2(L-x)}(\dot{m}_{in}\alpha_{in} - \dot{m}_{out}\alpha_{out}) - \alpha\frac{\pm A_2 P_2}{V_{02}+A_2(L-x)}\dot{x}$$ (3)

ambient temperature T=300 k, Gas constant R=287 J/kg.k , α_{in}=1.4, $\alpha_{out} = 2$, $\alpha = 1.2$

piston-load dynamics

The force on the piston(Fleischer H.et al 1995):

$$M\ddot{x} + F_f = P_{in}.A_{in} - P_{out}.A_{out} - P_a.A_r \quad (4)$$

$$\ddot{x} = \frac{1}{M}\left(P_{in}.A_{in} - P_{out}.A_{out} - P_a.A_r - F_f\right) \quad (5)$$

$$F_{static}=0.67\frac{N}{mm}.d_{bore} \quad , \quad F_{dynamic}=0.4\frac{N}{mm}.d_{bore} \quad (6)$$

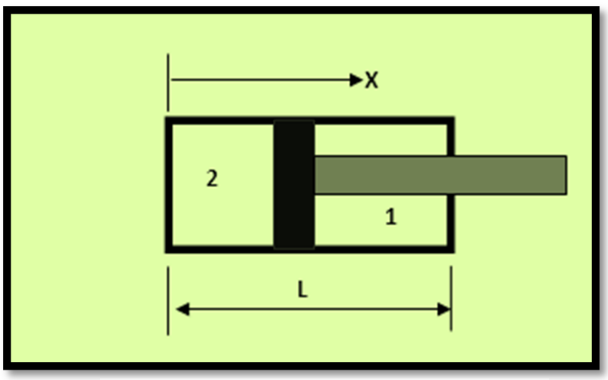


Fig.3. air cylinder coordinate

From Fig. 3 B.C: extend (1) $L \geq x \geq 0$

retract (2) $L \geq 0.2\text{-}x \geq 0$

RESULT AND DISCUSSION

Fig.4 show subsystem models of nonlinear mathematical model of the conventional pneumatic actuator using MATLAB/SIMULINK and plotted by axcell program with and without cutoff flow . Fig 5, 6, 7 shows air saving using cutoff method by simulation of circuit in figure 2 with and without cutoff flow at variable pressure supply (4, 6, and 8) bar. It is clear that air consumption value dropped in both extending and retracting strokes which lead to reduce mean value of ten strokes from ((1.5) to (1.11), (1.96) to (1.59), and (2.79) to (2,028)) L/min for above pressure supply respectively. The air saving at pressure supply (4, 6, and 8) bar were (22.8%), (17.6%), and (21.7%), respectively.

EXPERIMENTAL RESULTS

Figure.8 illustrates the difference in flow rate consumption with and without cutoff flow for 4 bar pressure supply. It's noted that the maximum extending overshoot drops from (26.63 to 20.82) L/min with saving of 21.8%. While retracting overshoot drops from (23.42 to 18.02) L/min with saving 18.8%.Overall flow rate along extending stroke drops from (14.45 to 13.2) and from (14.4 to 11.4) for retracting stroke. This lead to drop mean flow rate from (7.297 to 7.006) L/min and hence saving in air consumption from above results for ten strokes is 4%.
\Figure.9 show pressure supply effect on the flow rate consumption in cutoff method; two pressure supply values were used (6 and 8) bar, at 6 bar cutoff method saving 14.4% by increased period of time and 15% with increase in time 0.32 s for 3bar. It is noted that efficiency saving increases proportionally to the pressure.

CONCLUSION

The paper presents an experimental model for energy efficient examination of conventional pneumatic system. Architecture of experimental model for energy efficiency examination is a modular with the possibility of flexible adjustment for measurement of compressed air consumption (flow) at various linear and rotary or swivel pneumatic actuators.

The difference between the theoretical and experimental results due to high air compressibility and neglecting friction effects and some assumptions and approximation used to simplify the solution. When used pressure supply in the theoretical part as(4 , 6 , 8)bar the saving were (6.75, 19 , 7) percent respectively ,but when used experimental part at the same value of the pressure supply ,the saving are (6, 16.7 , 2)percent respectively . It is noted that efficiency saving increases proportionally to the pressure. One of the main purposes of experimental model is to provide energy efficiency using cutoff flow at desired Point depend on pressure supply, saving in compressed air and energy, reduced in the required air and cost.

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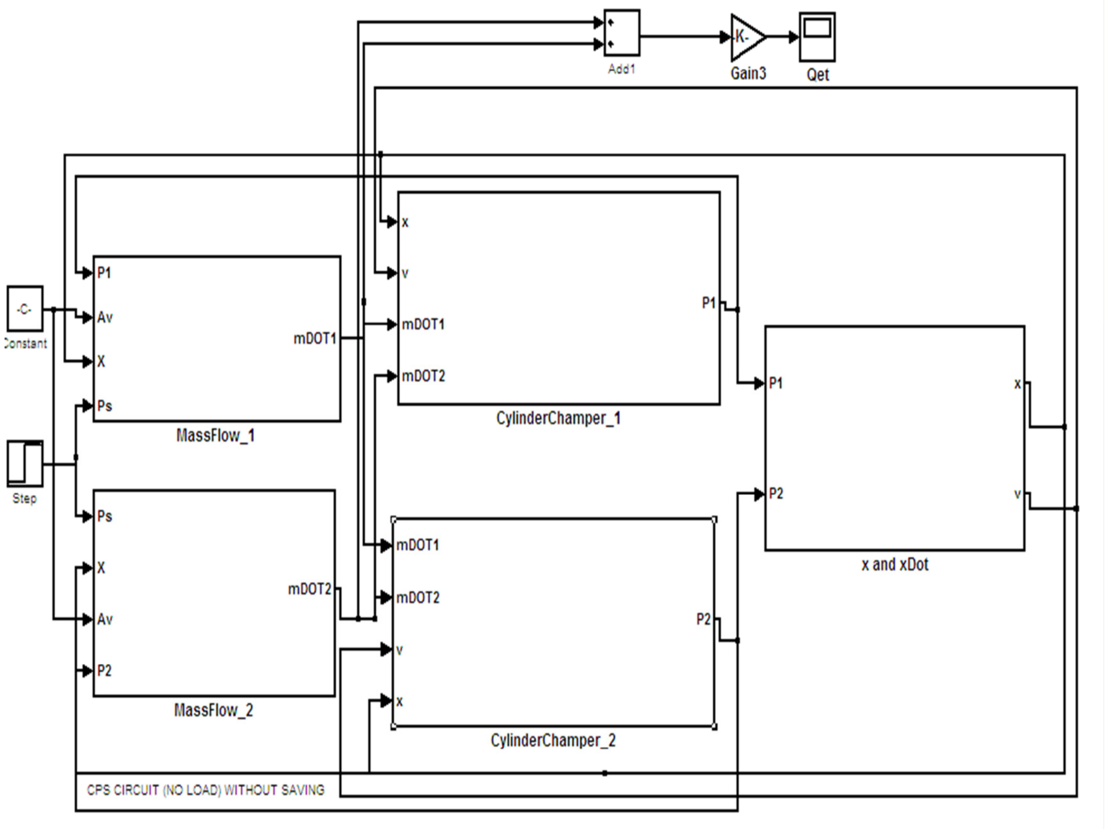


Fig.4. Simulation model of nonlinear mathematical model of the conventional Pneumatic actuator

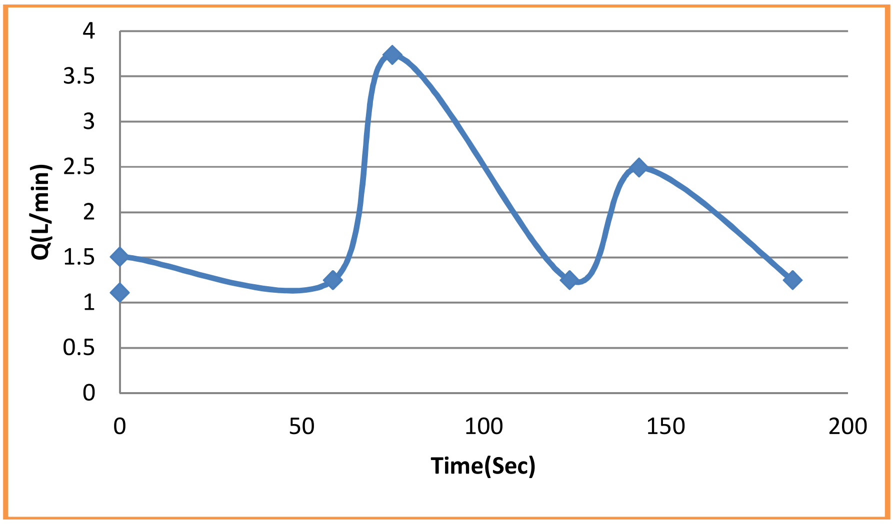


Fig.5. air consumption with and without cutoff flow (4bar)

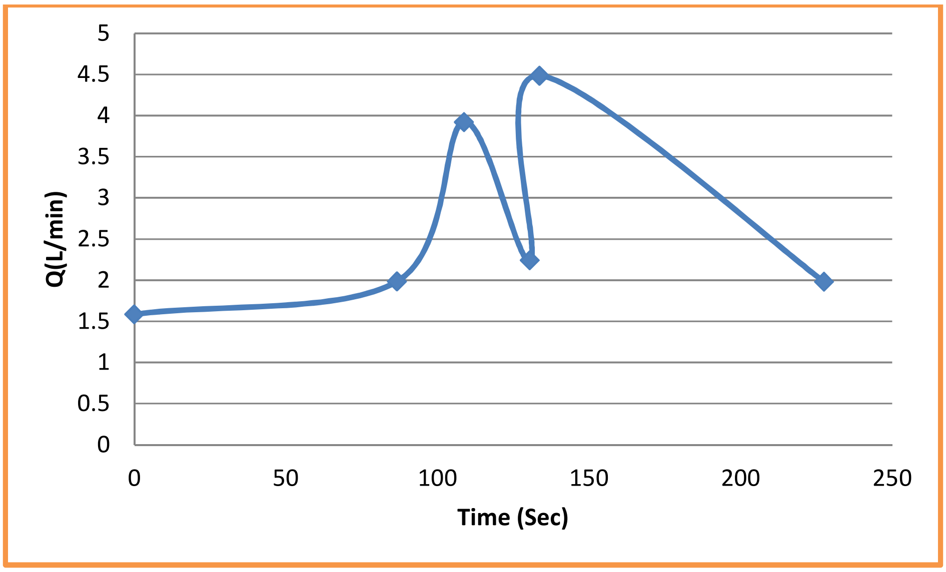


Fig.6. air consumption with and without cutoff flow (6bar)

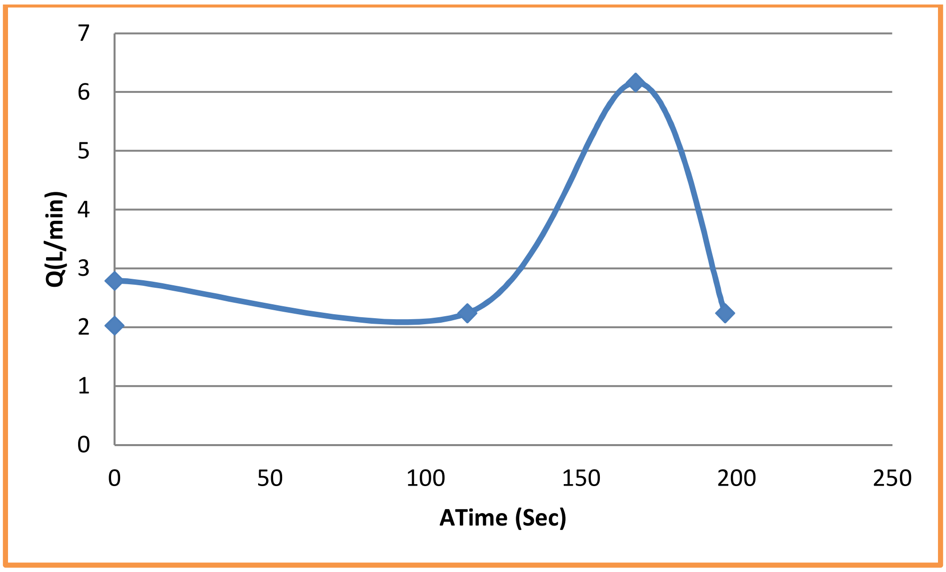
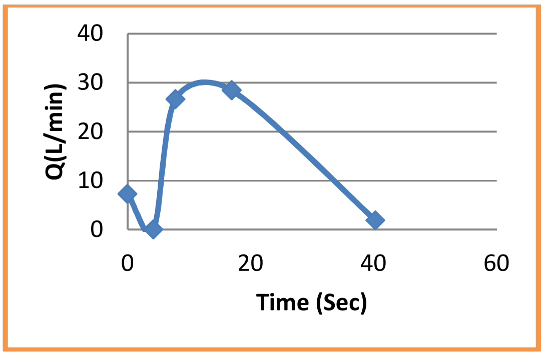
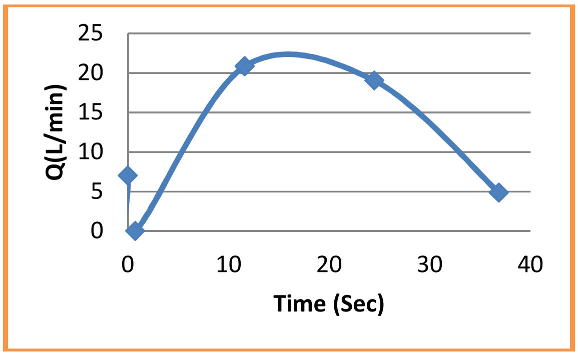


Fig.7. air consumption with and without cutoff flow (8bar)



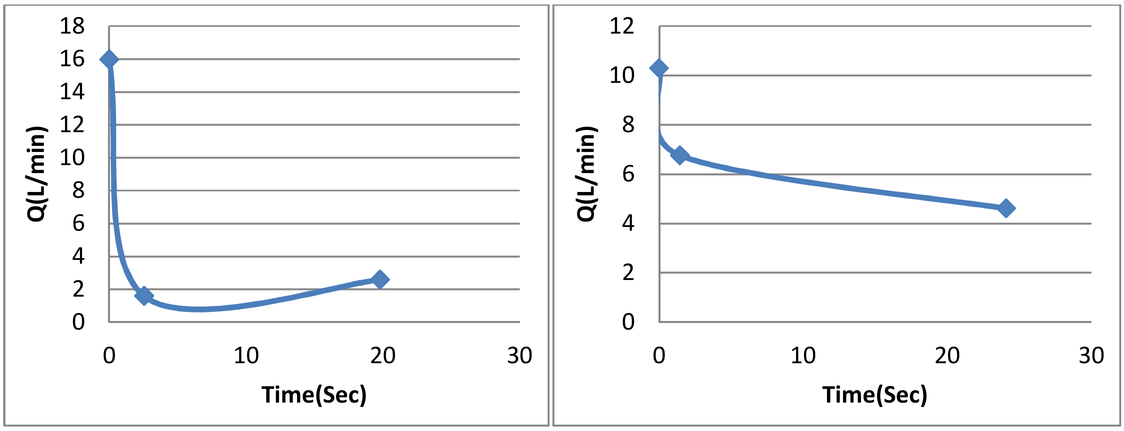


4 bar

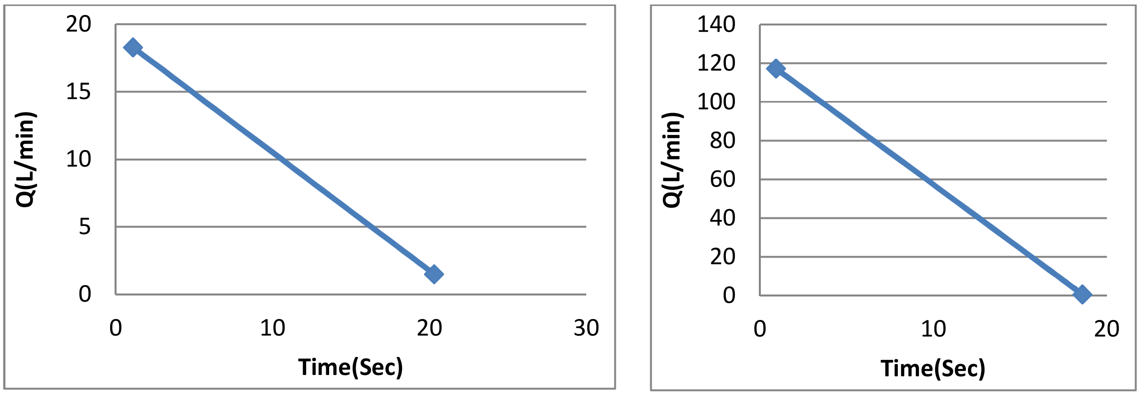
Without saving

With saving

Fig.8. Flow rate change with time



(6 bar)



(8 bar)

Figure. 9 cutoff saving at variable pressure