Journal of University of Babylon for Engineering Sciences, Vol. (27), No. (3): 2019.

Investigation the Variation of Bulk Modulus of Elasticity on The Performance of Conventional Electrohydraulic System

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Submission date:- 18/6/2019 | **Acceptance date:- 22/7/2019** | **Publication date:- 8/8/2019**

Abstract

Basically, all hydraulic performance systems are extremely reliant on the rising of the oil temperature, due to an increase in the pressure, decrease lubricate moving parts, increases leakage and dissipate heat. This could lead to the variation in bulk modulus of elasticity for different working cnditions, which could be affected in the performance of the system. Accordingly, an attempt was made to examine the effect of the bulk modules of elasticity on the accurate position. Six pressure suppliers were critically used (20, 30, 40, 50, 60 and 70) bar at five oil temperatures (25, 40, 50, 60 and 70) °C. Experimental results showed that the maximum variation percentage in the actuator displacement at the same load occurred at 70 °C oil temperature and there were 4.252%, 7.25% , 9.154% , 9.253%, 8,727%, 15.476 and 19.23% in 20 , 30, 40, 50, 60 and 70 bar pressure supply, respectively.

Keywords: Bulk modulus of Elasticity, Performance, Conventional Hydraulic System.

Nomenclature

P: Pressure of Fluid,
σ_m: Mean stress,
$K_{\emptyset}$: Bulk modulus of elasticity of porous material,
K_m : Bulk modulus of elasticity of mineral grains,
K_a : Bulk modulus of elasticity of air,
K_d: Bulk modulus of elasticity of the frame,
K_e: Effective Bulk modulus of elasticity,
K_f: Bulk modulus of elasticity of resident fluid,
K_o: Bulk modulus of elasticity of oil,
$\overline{K_a}$: Secent Bulk modulus of elasticity of air,
$\overline{K_o}$: Secent Bulk modulus of elasticity of oil,
α_f: Thermal expansivity of fluid,
$\alpha_{\emptyset}$: Thermal expansivity of porous material,
V: Volume of the saturated porous material,
V_a: Air volume,
V_o; oil volume,

$\beta_\emptyset$: Thermal expansion of pore volume,
: Isothermal compressibility,$C_\emptyset$
$\emptyset_0$: Initial porosity,
$\mathrm{V}_{\mathrm{str}}$: Volume strain,
$\propto_{\mathrm{eff}}$: Effective thermal expansion coefficient,
m : Bulik modulus versus pressure curve slop,
n : plytropic constant,
t : Operating time,
T : Temperature (K),
x_p : Air fraction volume,
x_{po} : Air fraction volume at intial pressure,
x_d : Air volume change,
ΔL: Length,

1. Introduction

It is well known that the interaction between the spring effect of a liquid and the mass of mechanical parts provides a resonance in all hydraulic components. In fact, this resonance considered to be the main control in the dynamic performance. Fluid spring on the other hand is reliant to the value of the bulk modulus, since the bulk modulus of elasticity of a liquid can be significantly dropped by entrained air and/or mechanical compliance [1]. It should be noted that the variation of the bulk modulus of elasticity values must be taken into account at high pressure and temperature of hydraulic system, because of their effect on the performance and subsequently on the accurate position of the actuator.

J.Koralewski, [2], investigated the effects of the oil viscosity in the hydraulic system on the volumetric losses that occurred in the piston of the pump. The results showed that there was no impact by the pump capacity coefficient bP on the intensity QPv of pump losses.

On the other hand, the performance of the density and viscosity of vegetable oils over a wide range of temperatures was studied by B.Esteban et.al [3]. The examined vegetable oils were carefully preheated to 120°C. It was found that the optimal range of temperatures at which each vegetable oil was operated. Furthermore, an experiential relationship was established between the reliance of the viscosity and the density.

M. JANA et.al [4], examined the critical loading conditions for structural integrity of solid propellant grains. The results revealed that bulk modulus of elasticity extremely reliant on the hydrostatic pressure values. Numerical results on the other hand, showed that the displacements and strains that determined from the non-linear behaviour were significantly smaller than the linear behaviour at original bulk modulus of elasticity value.

J. da Silva et.al [5], pointed out the additional exchange-entropy on an elastic ferromagnetic as a response effect of the dependence of its bulk modulus of elasticity and temperature. It was confirmed that the whole entropy that determined from the Maxwell’s relation, was relatively consistent with the conventional and additional contributions to entropy.

N.Cheng and L.Guan [6], inspected the position of the controller to solve three main problems in the control of an electro-hydraulic servo system. The first two problems were taken about the nonlinearities behavior and the uncertainties of the electro-hydraulic servo system. While, the third problem was adopting sliding mode control. It was concluded that the electro-hydraulic servo system was far away from the steady state, when the response performance was identical to that of the nonlinear controller.

Meanwhile, a model identification and validation of electro-hydraulic position servo system by using MATLAB environment were critically simulated by J.Shaoet.al [7] . A proportion-fuzzy adaptive fuzzy PID controller was successfully designed, based on the transfer function. The proportion - fuzzy PID control was utilized not only to change the system parameters, but also enhance the quickness and control accuracy in the steady-state of the system.

K.Rydberg [8] , examined the efficiency of a system which was extremely reliant on the viscosity of the hydraulic oil. It was found that the viscose index was very essential in the mobile systems. Further, the synthetic ester fluids exhibited the lower friction losses than standard mineral oil. The shear stability of saturated esters was extremely good compared to the mineral oil and unsaturated esters.

I. Alkammash [9], studied the variation of relative compression volumes for (NaF, NaCl, NaBr and NaI), in the range between (1 to 0.5) with isothermal bulk modulus of elasticity and high pressure at temperature 300 K. It was found that the bulk modulus of elasticity increased regularly with rising the pressure.

Further, H. Han et.al [10], investigated the position closed-loop control and established the corresponding relation between the pressure of hydraulic cylinder and load by collecting the pressure signal from rear cavity and rod cavity of hydraulic cylinder; meanwhile. It was found that the control method was effective and feasible. Also, the method can achieve online converts between position and pressure, which are different variables and improve the response speed and control precision of the system.

Further, surface tension, density and viscosity for five food oils were successfully inspected by M. Mearaa et.al [11], by using several methods such as Archimedean, Pendant drop, and Brookfield viscometer. It was observed a linear reduction in the density and surface tension as the temperature increased . While, the viscosity decreased as an exponential relationship.

M.Amadu and A.Miadonye [12], on the other hand, examined the effect of both pressure and temperature on the bulk modulus of elasticity for the saturated porous system. Constitutive equation was established to predict the experimental observations at various pressures and temperatures. It was found that the increasing temperature resulted in the reduction in the material density. The reason for that was attributed to the thermal expansion phenomenon. Consequently, it was concluded that the effective bulk modulus of elasticity of a poroelastic system increased with an increase in the pressure at a certain temperature.

L.Matlakhova et.al [13], studied the effects of the phase transformations, internal friction and elastic modulus for Ti–Nb alloys with 2 wt.% Al, and Nb . The internal friction peaks and the elastic modulus exhibited the minimum values which was due to an increase in the temperatures. These results were also attributed to the phase transformations that may occur as the temperature increased .

M. Persson et.al [14], studied several parameters that affected on the modulus of elasticity and also the fatigue properties of the flapper valve materials. It was observed that the modulus of elasticity of flapper valve material can vary with the orientation of the sample due to the presence of texture in the material.

It was concluded from the previous research, the temperature and pressure used in the hydraulic systems has a significant effect on the change in bulk modulus of elasticity due to the change in the density and viscosity of liquids and thus reflected negatively on the performance of the hydraulic system.

Current study pay more attention to examine the effect of changing the bulk modules of elasticity practically. The varation of the bulk modules of elasticity is due to an increase the pressure and temperature in the hydraulic systems which is extremely affected on the performance of the system.

2. Theoretical Analysis

Many researchers have studied and developed the effective bulk modulus of elasticity that depend on pressure and temperature with entrained air. Kim and Murrenhoff [15] investigated the variation of effective bulk modulus of elasticity of hydraulic oil in low-pressure conditions while Yang et.al [16] studed the effective bulk modulus of elasticity of oil, when the air content was known in which was expressed as a function of the working pressure only. Gholizadeh et.al [17] offered a summary of the literature that was depend on the bulk modulus of elasticity of fluids. However, their mathematical model did not take into account the change between the pressurized and unpressurized processes. Although Zhou et.al [18] suggested empirically a mathematical model expressive pressure differences as well as the amount of air bubbles.

A simple model can be developed by considering the compressibility of oil and entrained air within a series of oil springs. Therefore, the effective tangent bulk modulus of elasticity Ke is derived from Equation [19], [20].

$$k = -V\frac{dp}{dV} \qquad (1)$$

$$\frac{1}{k_e} = -\left[\frac{1-x_p}{V_o}\frac{dV_o}{dp} + \frac{x_p}{V_a}\frac{dV_a}{dp}\right] \qquad (2)$$

By rearranging Eq.(2)

$$k_e = \frac{k_o k_a}{k_a + x_p(k_o - k_a)} \qquad (3)$$

$$x_p = 1 - \frac{1}{1 + \dfrac{x_{p-dp} + x_d}{1 - \left(x_{p-dp} + x_d\right)} * \dfrac{1 - \dfrac{dp}{k_a}}{1 - \dfrac{dp}{k_o}}} \qquad (4)$$

$$k_H = \frac{\overline{k_o}(\overline{k_o} - P)}{k_{Ho}} \qquad (5)$$

$$k_B = np \qquad (6)$$

The secant bulk modulus of elasticity can be calculated from relation:

$$\overline{k_o} = k_{Ho} - m(p - p_o) \qquad (7)$$

By neglect the air dissolves in oil and x_d is assumed to be afunction of the operating pressure whene air releases from oil **[21]**:

$$x_d = -x_{po}\frac{dt}{t_d} \qquad (t \le t_c) \qquad (8)$$

$$x_d = \left(x_{po} - x_{pc}\right)\frac{d_p}{p_c - p_o} \qquad (t > t_c) \qquad (9)$$

$$x_{po} = \frac{\overline{k_a}(\overline{k_o} - \overline{k_e})}{\overline{k_e}(\overline{k_o} - \overline{k_a})} \qquad (10)$$

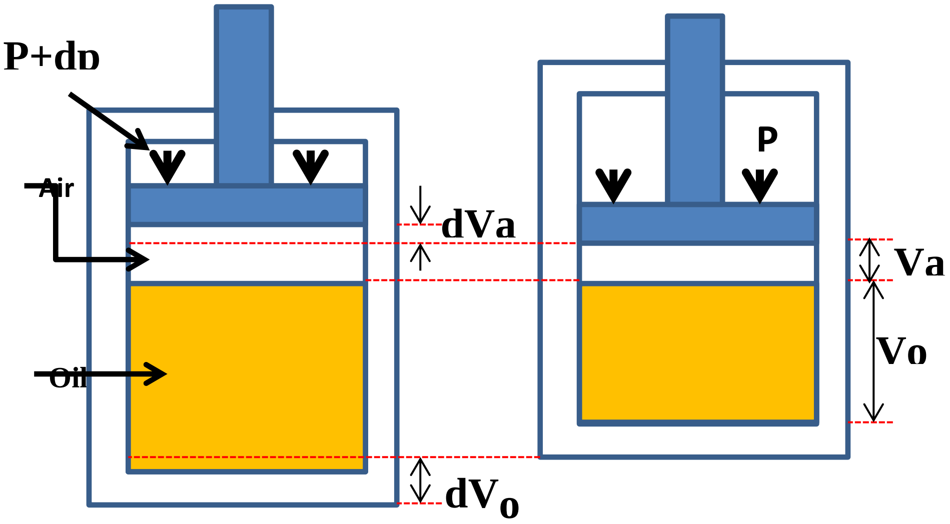


Figure (1): Oil and Air Compressibility

3. Methodology

The experimental side consists of two main parts, mechanical part involves the hydraulic system components and the electrical part which consists the control system and other accessories.

3.1 Hydraulic System

A hydraulic system apparatus is shown in Figs (2) and (3) which involve atmosphere reservoir type ELF3 have a capacity 80 liters of hydraulic oil used type HL32. Two oil heaters were placed in the tank in order to heat the hydraulic oil rapidly to the desired temperature. The length and diameter of the heater were used as 180 cm and 1cm, respectively. The heating power for each heater was set at 1000 W. The temperature of the controller was ranged from (0 to 400˚) C. The pump was used in the system is a gear type G2 (Rexroth Company Production). It was rotated by an electrical motor to provide 3 kW to the pump with a speed of 1500 rpm. The flow rate of this pump is 14 L/min and can provide a hydraulic pressure of 120 bar. In order to control the flow direction in the system 4/3 directional control valve (Rexroth Company Production) was successfully used with size 10 solenoid 24v and spring return to a neutral position in which closed. Fluid pressure was adjustable at required pressure by a relief type DBD size 6. Mnual flow control valve size 10 type (DV(10−i)/OP350) was used, This valve works on the oil that has a viscosity limit between (2.8→380) cSt and oil temperatures ranging between (-20→100)˚C with the maximum pressure of 350 bar.

To protect the pump from reverse pressure, check valve type (S10A1) size 10 was used. Double acting with single rod was used as an actuator. The stroke length of this cylinder is 250 mm, piston and rod diameter 50mm and 25mm, respectively. Further, a flow control valve was also used in the current system (DV(10−i) /OP350) which was a direct mounting on the pressure line, valve's size 10. This valve works on the oil that has a viscosity limit between (2.8→380) Pa.s, oil temperatures ranging between (-20→100)°C and the maximum pressure that can be supported by this valve was 350 bar. A position sensor was used to control the accurate position of hydraulic cylinder with maximum stroke 300 mm, for measuring the change in the volume of liquid due to the variation in bulk modulus of elasticity of working oil at multi temperature was used, a degreased glass tube was used.

Figure (2): Experimental Apparatus

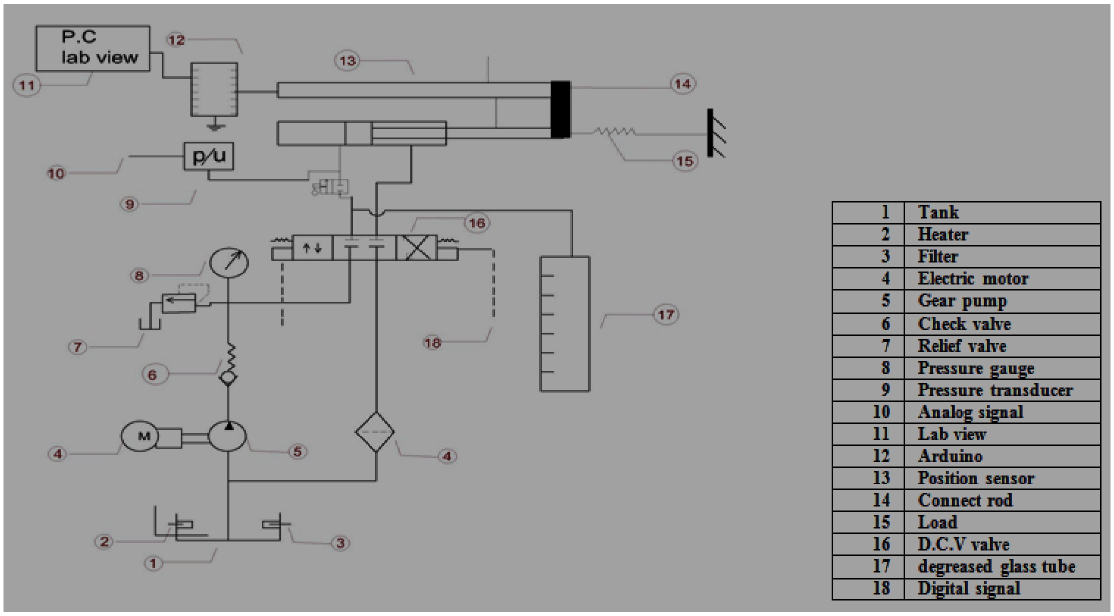
3.2 Electrical and Control Parts

In order to control and transfer a signal from the system to a personal computer. A micro-controller on the board is programmed by Arduino Programming language and by Arduino's integrated development environment was used.

Arduino was used (table.1) can be integrated, arduino was connected to its sensors and electronic parts only or arduino was connected to communicates with programs on the computer, such as processing and max MSP and lab program. Three digital signal was used two from solenoid of the direction control valve and one from thermostat, while two analog signals from pressure transducer and position sensor.

Table.1 Arduino specifications

Working voltage	5 volts
Input voltage limits	6-20 volts
Preferably voltage	7-12 volts
I / O outlet	40 mA
Memory Size	32 KB
Speed	16 MHzP



1	Tank
2	Heater
3	Filter
4	Electric motor
5	Gear pump
6	Check valve
7	Relief valve
8	Pressure gauge
9	Pressure transducer
10	Analog signal
11	Lab view
12	Arduino
13	Position sensor
14	Connect rod
15	Load
16	D.C.V valve
17	degreased glass tube
18	Digital signal

Figure (3) : Schematic Diagram of Experimental Apparatus

4.Results and Discussion

Present work examined the effect of oil temperature rises in conventional electro hydraulic system on bulk modules of elasticity and subsequently their effect on supply pressure and actuator displacement introduced. It was utilized five oil temperatures (25, 40, 50, 60, and 70) Co for seven pressure supply (20, 30, 40, 50, 60 and 70) bar. Oil heated by using heaters placed in the main reservoir of the system. To evaluate the variation in oil volume due to temperature and pressure changes a degreased glass tube was used. Data (digital and analog) logged through the PC by using the Arduino with Lab View program.

Figure (4) indicates to a complex impact of the bulk modules of elasticity on the working hydraulic oil properties under the influence of pressure and temperature. The bulk modulus of elasticity (Ɓ) decreases with the increase of temperature at costant pressure. From this figure one can see that the relative compression volume decreases continuously with the increase in pressure at constant temperature. Maximum (Ɓ) value is1.5477 MPa at pressure and temperature 80 bar 25 Co respectively, while minimum value 0.8423 MPa at pressure 20 bar and temperature (60,70) Co respectively . This means that avoid work in this type of oil in low temperature and high pressure and low pressure with high temperature and preferred the system operated at moderate pressure and temperature.

Figure (5) displays the change of the oil temperature with pressure supply. It was observed that there was a quasi linear decrease in the pressure supply with temperature for oils, because at low temperatures the air bubbles do not form as they begin to grow and form after 40 °C and increase their numbers and sizes by increasing the temperature which leads to increased compressibility and reduce supply pressure . Further, the pressure was slightly decreased at temperatures ranged from 20 °C to 40 °C. Whereas, there was an increase in the pressure which clearly observed at temperatures ranged from 40 °C to 70 °C. The minimum value of pressure was reached (65.2, 55.2, 43.7, 35.3, 25.7 and 16.5) bar at temperature increment (25, 40, 50, 60 and 70) °C, respectively.

It was found that as the pressure increases at a specified temperature, the exponent which was presented by porosity decreases. This also occurs in the denominator which lead to an increase in the bulk modulus. That means the elastic wave velocity could be increased as the pressure increases at a certain temperature. Meanwhile, as the temperature increases at a constant pressure, the exponent increases and leads to an increase in the denominator and decrease in the bulk modulus of elasticity decreases. This corresponds lead the reduction in the elastic wave velocity at a constant pressure as explained in the relationship below [12, eq. (27)].

$$\frac{\Delta\sigma_m}{\frac{V\Delta L}{V}} = \frac{\sigma_m}{V_{str}} = \frac{[\frac{1}{1+K_\emptyset\left(\frac{1}{K_d}-\frac{1}{K_m}\right)}-B]^{-1}(\alpha_f-\alpha_\emptyset)\emptyset_0 e^{[\beta_\emptyset T-C_\emptyset P]}}{\left(\frac{1}{K_d}-\frac{1}{K_\emptyset}\right)+\emptyset_0 e^{[\beta_\emptyset T-C_\emptyset P]}\left(\frac{1}{K_f}-\frac{1}{K_\emptyset}\right)}\frac{1}{\propto_{eff}} \qquad (11)$$

The increase in the pressure supply and temperature for working oils leads change in the bulk modules of elasticity. This result exhibits a sharp impact on the hydraulic system performance in which represented by acuurate position of actuator displacement.

Figure (6) illustrates the effect of this result in the accurate position in the specific load . Obviously, the actuator displacement decreased as temperature increase for all pressure supplies. It seems to be that all the maximum drop values accrued at 70°C in which equal to (3.7, 5.8, 6.5, 6, 4.8 and 5) mm at supply pressure (20, 30, 40, 50, 60 and 70) bar.

Figure (7) also demonstrates the increment percentage in position error due to variation in bulk modules of elasticity. Maximum value accrued at 20 bar pressure supply and 70 °C in which equal to 19.23% , while the minimum value equal to 2.2% at 70 bar and 40 °C.

5. Conclusions

The most important conclusions to be drawn from the current study :

1- It was preferable to use the hydraulic oil type HL32 at pressure supply 70 bar and oil temperature 40 °C to reduce the error position as less as possible.
2- Avoid work with this type of oil at low pressure (20 bar) and the temperature exceed 30 °C, due to the high losses in displacement position. However, it was preferred utilizing this type of oil at a pressure 70 bar at all working oil temperatures, because the lowest values of the error position that obtained.
3- It was observed that there was a quasi linear decrease in the pressure supply with temperature for oils, because at low temperatures the air bubbles do not form as they begin to grow and form after 40 °C and increase their numbers and sizes by increasing the temperature which leads to increased compressibility and reduce supply pressure.
4- Hydraulic system performance dependence mainly on the oil temperature in which increases with working period.
5- It is preferable to use close loop control hydraulic system (servo-hydraulic system) an alternative to loop control hydraulic system (conventional-hydraulic system) for precise applications.

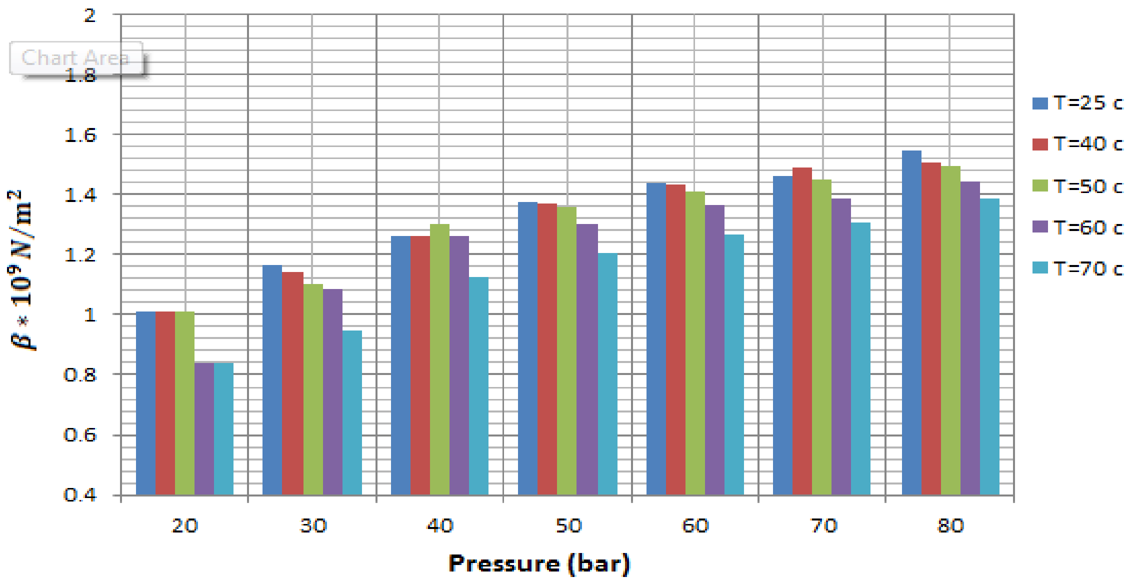


Figure (4): Variation of bulk modules of elasticity with pressure and temperature

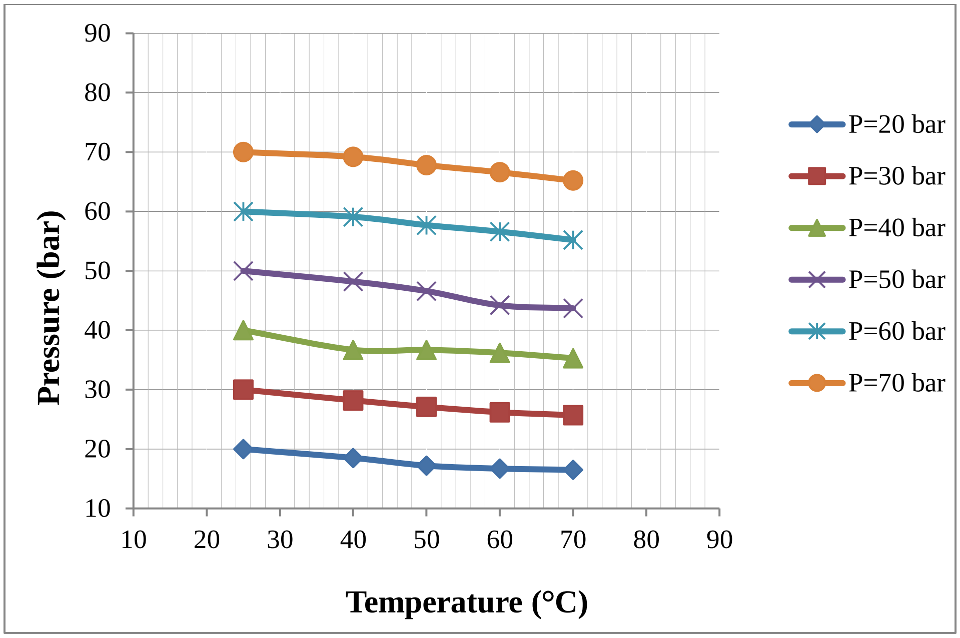


Figure (5) : Variation of pressure supply with temperature

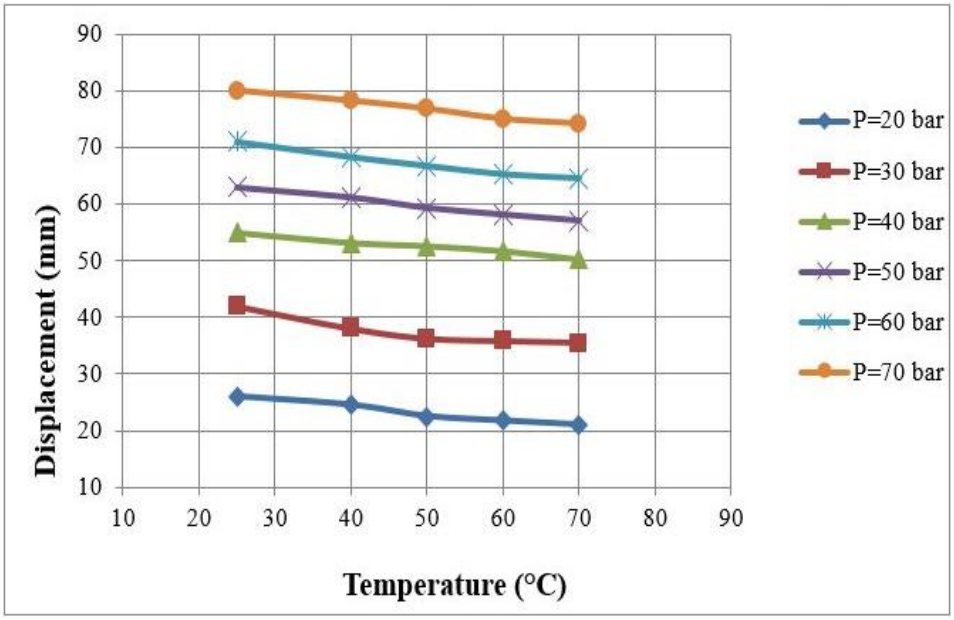


Figure (6): Variation of actuator position with temperature and pressure supply

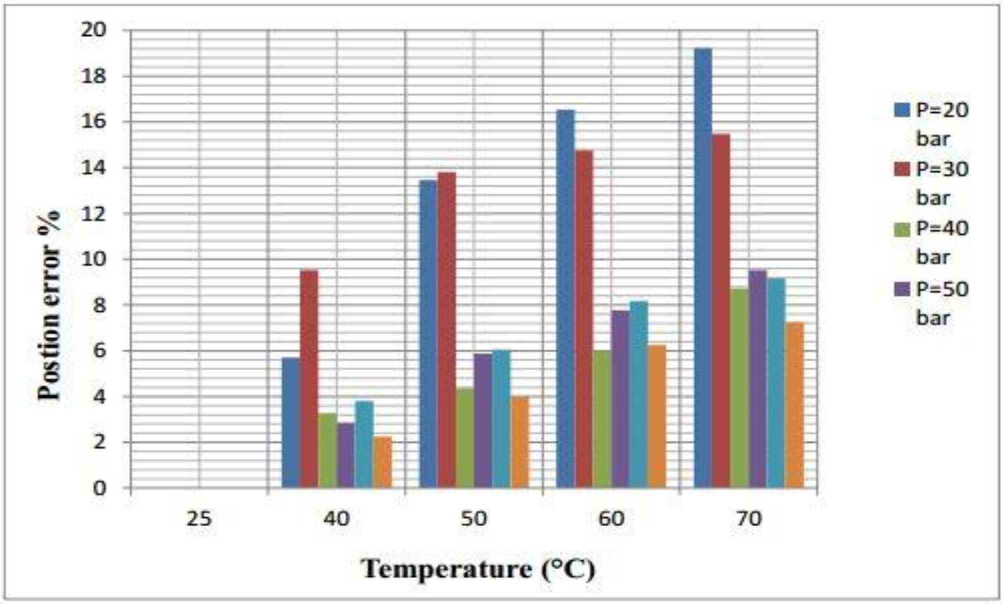


Figure (7) :Position error percentage

Conflicts of Interest

The author declares that they have no conflicts of interest.

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التحقق من تغيير قيمة معامل المرونة الحجمي على اداء المنظومة الكهروهيدروليكية التقليدية

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الخلاصة

بصورة عامة ان جميع أنظمة الأداء الهيدروليكية تتاثر بشكل كبير من ارتفاع درجة حرارة الزيت المستخدم وذلك بسبب زيادة الضغط وتزداد قيمتها مع ازدياد الضغوط المستخدمة، أن هذا الارتفاع يؤدي إلى التغيير في قيمة معامل المرونة الحجمي للزيت المستخدم وبالتالي تقليل فاعلية الزيت في تزييت الأجزاء المتحركة للمنظومة وزيادة معدل نضوح الزيت وتبديد الحرارة من المنظومة والذي ينعكس سلبا على أداء النظام. وفقاً لذلك ، في هذا البحث دراسة عملية لتأثير تغير قيمة معامل المرونة الحجمي على الموقع الدقيق للمشغلات الهيدروليكية. تم استخدام ستة قيم للضغوط المجهزة للمنظومة (٢٠ ، ٣٠ ، ٤٠ ، ٥٠ ، ٦٠ و ٧٠) بار وعند خمس درجات حرارة للزيت (٢٥ ، ٤٠ ، ٥٠ ، ٦٠ و ٧٠) درجة مئوية. أظهرت النتائج التجريبية أن الحد الأقصى لنسبة التغير في إزاحة المشغل الهيدروليكي مابين الموقع المطلوب الحقيقي والعملي ولنفس الحمل عند درجة حرارة ٧٠ درجة مئوية وهي٤,٢٥٢٪ ، ٧,٢٥٪ ، ٩,١٥٤٪ ، ٩,٢٥٣٪ ، ٨،٧٢٧٪ ، ١٥,٤٧٦ و ١٩,٢٣٪ وللضغط المجهز ٢٠ ، ٣٠، ، ٤٠ ، ٥٠ ، ٦٠ و ٧٠ بار على التوالي.

الكلمات الدالة: معامل المرونة الحجمي، اداء، المنظمة الهيدروليكية التقليدية.