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Experimental Study of Thermal Effect on Performance of PVC Pipes Using ANOVA Analysis

Dr. Muna Sabah Kassim [†], Dr. Sajeda Kareem Radhi[‡] and Ammar Fadhil Hussein Al-Maliki[†]

[†] College of engineering, Al- Mustansiriyah University, Iraq, Baghdad
[‡] College of Remote sensing and Geophysics, Al- Karkh University, Iraq, Baghdad
[†] College of engineering, Al- Mustansiriyah University, Iraq, Baghdad

Abstract

In this study thermal effect at high pressure on Chlorinated Polyvinyl Chloride (CPVC) pipes studied where a test rig is built and the pipe has a diameter (d=0.5 in). The temperatures of water are varied (40, 60 and 80 c^o) and the pressure is raised by using tester to reach (700 psi). The relationship between pressure and Reynolds number is discussed for the pipe used in this study with another pipe has a dimension (d= 0.75 in). ANOVA Analysis used to find the correlation of parameters effect the performance of CPVC pipes. The experimental results showed that the pressure drop increases with discharge increased at different values of temperature, when the pressure increased at constant temperature the friction losses is increased, where the values of friction losses were 4.8×10^{-4} , 8×10^{-4} and 2.4×10^{-3} mm at 100, 300 and 500 psi respectively. Thus the pipe is damage at pressure (500 psi) and temperature (80 C^o) when the thickness is (3.1 mm).

Keywords: CPVC pipe, design thickness, friction losses, regression analysis, ANOVA.

1. Introduction

Chlorinated polyvinyl chloride (CPVC) is a thermo plastic which made from chlorination of polyvinyl chloride (PVC) resin. Chlorinated polyvinyl chloride may help to made industrial liquid handling, cold and hot pipes of water. Genova Products where in Michigan in the beginning in the 1960, the first Chlorinated polyvinyl chloride fittings and tubing for cold and hot water distribution processes are produced. CPVC which is polyvinyl chloride (PVC) that had been chlorinated by a radical chlorination reaction, that type of reaction usually started by the thermal or UV energies using different ways. PVC is a resin produce a thermoplastic of type Chlorinated Polyvinyl Chloride (CPVC). The main molecular structures of the chlorinated polyvinyl chloride molecule are chlorine which obtain by ethylene and salt that derived by natural gas or oil. Piping systems of chlorinated polyvinyl chloride have been operated which installed at 1959 and the initial installations are performed without any errors. Also, presence of chlorine to the PVC molecule is leads to raising a glass transition temperature (Tg) for base resin from 95 ^{o}C to the 115-135 ^{o}C McGraw-Hill [1], Brann and Knight [2].

Polyvinyl chloride is a thermoplastic material which used to make many things that facing the consumers every day and some times more that are facing less considerably but are though very special in structure, healthcare electronics, also many applications. Different applications used PVC and vie with a different type of substitute materials. Such as pipe type PVC fixed a share commanding in huge pressure diameter water and healthy sewer pipe the cause the cost is low, insulation is simple, reliable and long life service and its repair is low and replacement cost also low [3].

A different quantity of chlorine is entered through the polymer to allow of method of measured to fine-tune the different properties. The structure of chlorine may varying from manufacturer to manufacturer the base consist of minimally PVC of 56.7% to maximally 74% of mass, also most of resins consist of chlorine with percentage 63% to 69%. When the chlorine content in the chlorinated polyvinyl chloride is increased, its glass transition temperature (Tg) also increases. In normal operating conditions the chlorinated polyvinyl chloride will be unsteady in 70% of chlorine mass. CPVC have many properties of the PVC, also it is readily handy, including welding, forming, and machining. CPVC is good for self-supporting constructions because of its very good corrosion resistance at high temperatures that a temperature over to 90 °C is illustrated. Mechanical difference between PVC and CPVC is the CPVC having greater flexure, more ductile, and resistance of crush. Also, mechanical strength makes the CPVC a viable candidate to replace different types of pipe metal in conditions which metal's may corroded when inter in use.

Campbell and Vogel [4] studied the differences in the factors of the thermal conductivity for the materials choose. In the collector used in test the tubing six materials done in a method that statistically there is no change. From the dispersion of heat and thermal conductivity to the fluid of the collector, each of these materials must be choose for used in the heater of the solar water. The materials selection on this factor does not conclusively give the material required for a particular use. This test provides that as the different piping materials are used they will produce similar method. The results of the work are to get data that will help in the process making a decision in the building be it by a manufacturer or an individual. The next process is to test the types of materials tubing to obtain their collector life cycle when comparing with the cost in manufacturing the panels and purchasing.

Signhild Gehlin [5] studied effect of the temperature due to fracture flow at thermal response, experiment has handle a case with one fracture reach the groundwater of an undisturbed ground temperature to the borehole, during the borehole water heated, its leaves to upper side of the borehole. That thermo siphon flow treating the convective transfer of heat from the groundwater has been heated loaded borehole in the rock which hard may found if specific conditions of fracture found at a heat exchanger of ground. If the conditions of such fracture found the thermal response experiment would due to a thermo siphon flow induced the difference of temperature between the borehole and the environments. The active thermal conductivity estimated from the thermal response experiment using standard method is sensitive to the interval of the measurement. A little measurement duration lead to lower the active thermal conductivity valuation. When comparing the data from thermal response experiments lead to the same borehole with injection of heat and extraction of heat respectively or with more than one level of power sometime takes data deals with the potential of thermos on the effects in a borehole. In addition, distinction thermo siphon action from the effect the flow of artesian borehole, while the last not affected by the modification in the injection of power. The temperature data over the borehole also give data about this approach. Xiao et.al [6] studied depending on the data of China Statistical Yearbooks, the present situation and development trend of the energy consumption of residential hot-water was discussed in this paper. Two hundred and sixty eight apartments were collected on the installation and operation situations of residential water heaters in five cities. Based on collected data, the proportion of pipeline heat loss was calculated in the energy consumption of a shower/bath. The effect factors of heat loss in residential hot-water pipeline network were discussed, and the measures were suggested for minimizing the transport heat loss. The pipeline heat loss is real because of some insulation measures and unreasonable network constriction. Measures for minimizing the transport heat loss were suggested as the following: optimizing the hydrodynamic design of the pipeline network, and selecting the good pipeline path and flow rate; optimizing the pipeline thermal design, and selecting the thermal insulation materials and insulation measures.

Wang and Shengfei [7] investigated the processing and formulation technology for chlorinated polyvinyl chloride thermal conductivity pipe get using single screw extruder. It was discovering that utilize of many stabilizers give excellent results. The processing and gelation characteristic of chlorinated polyvinyl chloride could be enhanced clearly by using the Refrigeration and Air Conditioning and thermal conductivity using powdered graphite filler with a minimum the decrease of the impact strength of the chlorinated polyvinyl chloride. So that it is necessary using the impact converter to increase the resistance of the impact, the mechanical properties and other properties very important to application. Merah et.al [8] investigated the effects of artificial and natural weather on the mechanical properties for (CPVC) pipe. The specimens from tensile type preparation from locally manufactured chlorinated polyvinyl chloride commercial pipes (4 in schedule 80) were exposure by a different period from 2 weeks to 18 months in the aggressive environment conditions on Saudi Arabia, Dhahran. The results of the tensile test showed that the accelerated artificial and natural environments have finite effects on the fracture strengths, tensile and modulus of the elasticity for materials. Anyway, the drop for the strain of fracture can be notice that the periods exposure as short as 15 days for natural environment and 100 hours for artificial Ultra-Violet (UV) environment. Visual analysis for the specimens which exposed detect that the both types of environments lead to the discoloration for specimens.

By using the artificial environment method, the effect of dry heat on the tensile properties of chlorinated polyvinyl chloride is studied by Bazoune [9]. The preparation of chlorinated polyvinyl chloride specimens were done according to ASTM (D 638) and exposed to hurried dry heat temperature to simulate the effect of natural environment of the long term outside exposure. The experiments were achieved at two values of temperatures at 40 oC and 70 oC for period more than 3000 hours. Then the stress-strain curves were determined for that material and the effect of environment on modulus of elasticity, tensile strength and strain at precense of the fracture. It can be notice that the fracture stress and the ultimate tensile stress show a little increase over the time of the exposure. The modulus of elasticity was not influnced by the exposure scince the strain of fracture has a small decrease at the start of the exposure and its constant for the rest time of the exposure.

Kaizhou Zhang et.al [10] used long glass fiber (LGF) and thermoplastic polyurethane elastomer (TPU) to provide LGF/TPU master batch for providing heat resistance and mechanical properties of PVC. By scanning electron microscopy and vicar test, the heat resistance and morphology were noticed respectively. Scanning electron microscopy (SEM) confirms that the combination of LGF/TPU into PVC varied the morphology of the composites and renovated well with mechanical properties. By dynamic mechanical analysis (DMA), the both of the storage modulus of PVC and glass transition temperature increased with the insert of LGF/TPU master batch. The existence of a single glass transition temperature (Tg) showed that every part of composites was miscible. In this study, the series properties of the composites at 24% weight LGF were the better ratio in the range of 0 to 30 phr of LGF thus because of it gain better heat resistance and mechanical properties.

2. Experimental Work

The experimental investigation is carried out with the test models consisting of pipe has diameter (0.5 in).

The aims of this research are to study the effect of pressure and temperature on pipes and the effect of friction on the discharge of water. The whole investigations aims to build up a test rig and provide the compatible circumstances about thickness of pipes and friction factor for perform the tests about the research. Results of pressure and Reynolds number is discussed and compared with another diameter pipe (0.75 in).

2.1 Test Rig Requirement

Schematic diagram and a photograph of the experimental rig are shown fig (1) The main utilities of test rig unite are: (1) centrifugal pump (2) water tank, (3) hydraulic valve, (4) hydraulic pipes, (5) temperature and pressure gages (6) safety (7) Water Heater.

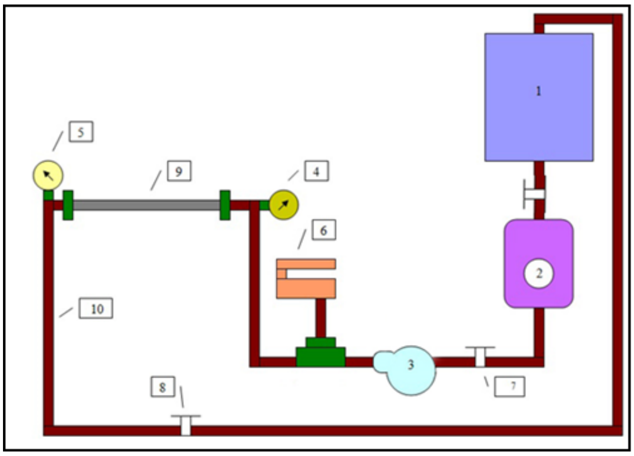

Fig. 1 Graphical diagram of the test rig.

1.Tank	2.Heater	3.Water Pump
4.Temp. gauge	5.Pressure gauge	6.Tester
7. Inlet valve	8. Outlet valve	9.Testing pipe
10. Iron pipe		

1. Water pump:

High pressure pump of (370w) with a maximum volumetric flow rate (34 L/min.) and given pressure (30bar) and a maximum head (16 m) used for pumping the water in pipes.

2. Water Tank:

An insulated water tank of (1 m^3) capacity manufactured from a galvanized steel sheet. By fixing a pipe out of the tank to connected it with source of water. A pontoon was fixed inside the tank to regulate the amount of water.

3. Hydraulic valve:

Two valves of ball type are used for controlling the direction of water flow and flow rate.

4. Pipes:

Chlorinated polyvinyl chloride (CPVC) pipe is produce from Chlorinated vinyl and plastic composite material. The pipes are long lasting, durable and hard to damage. A CPVC pipe does not wear, rot and rust. So that, CPVC pipes is the most commonly used in such systems (water, sewer lines and underground wiring) shows in fig (2).

Fig. 2 CPVC pipe

5. Gages.

Two gages have been used for measuring pressure and Temperature. Temperature gage is used for measuring temperature of water until (0-120°C). Pressure gage is used for measuring pressure of water, maximum (1000 psi).

6. Water Heater:

Water heaters are familiar fixtures in most homes, we have one with (50 letter) and have thermostat to control water temperature with (40°C , 60°C , 80°C) shown in fig (3).

Fig. 3 Water Heater

7. Hydraulic Pressure Tester:

Is a device that use to maximize the presser in hydraulic system and in our research we use one shown in fig (4) with max pressure (700psi).

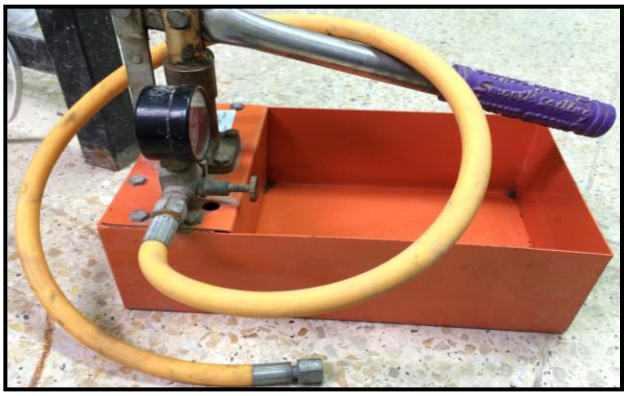

Fig. 4 Hydraulic tester

2.2 Instrument Calibration

The temperature gauge is calibrated by measured the temperature of flow at certain value by using calibrated thermometer which give a good results of reading. The gauges of pressure are calibrated by using Borden gauge which is found in the fluid laboratory of mechanical engineering department.

2.3 Work Steps

1-Connect one of the tested pipes to the test rig. Measure the ambient temperature of the lab.
2- Open electrical circuit so the pumps is wok
3- Raise the pressure of flow through the tester to certain value
4- Open the gauge valve at certain value.
5- after 5 minute so as to reach the steady state case, the difference of pressure is measured.
6- The steps from 3-5 are repeated for different gauge valve opening.
7- Open electrical circuits so the water heater work and repeat the step (3-5) and the flow temperature are measured.
8- The same steps are used for each type of pipes.

3. Theoretical Analysis

3.1. The discharge is calculated from

$$Q = A \times V \qquad \text{…… (1)}$$

Where:
Q : discharge (m^3/s)
V : velocity (m / s)
A : cross section area (m^2)

3.2. Reynolds number

$$Re = \frac{\rho\, v\, d}{\mu} \qquad \text{……. (2)}$$

Where:
v : velocity (m / s)
ρ = density (kg/m^3)
μ : viscosity (Kg/ m.s)
d : diameter (m)

3.3. The friction factor calculated by

$$f = \frac{64}{Re} \qquad \text{……. (3)}$$

Where:
f: friction factor (Laminar)

3.4. Losses of the friction in pipe

$$h_f = f\,\frac{L}{D}\frac{v^2}{2g} \qquad \text{………. (4)}$$

Where:
f= friction factor
L= pipe length (mm)
D= diameter of pipe (mm)
v= velocity (m/sec)

3.5. Calculated the hydrostatic pressure and thickness[11]:

$$P = \frac{2\,\sigma}{\frac{D_o}{t} - 1} \qquad \text{…….. (5)}$$

Where:
σ = Design stress (MPa)
Do = Outside diameter (mm)
t = Thickness (mm)

4. Results and Discussion

When the temperature seated to 40 C° and 60 C° respectively with changes inlet valve to test the pipes with different values of pressure. The pipe was not affected during the test because the temperature was relatively low as shown in fig (5) and fig (6).

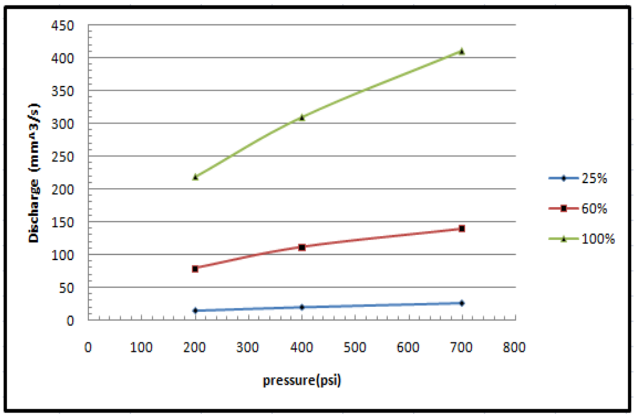

Fig. 5 The effect of temperature on the pressure and discharge at 40 C°

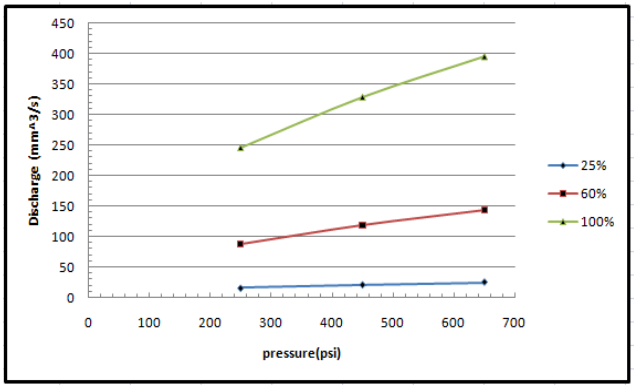

Fig. 6 The effect of temperature on the pressure and discharge at 60C°

The variation discharge with pressure illustrate in fig (7). at 80 C°.

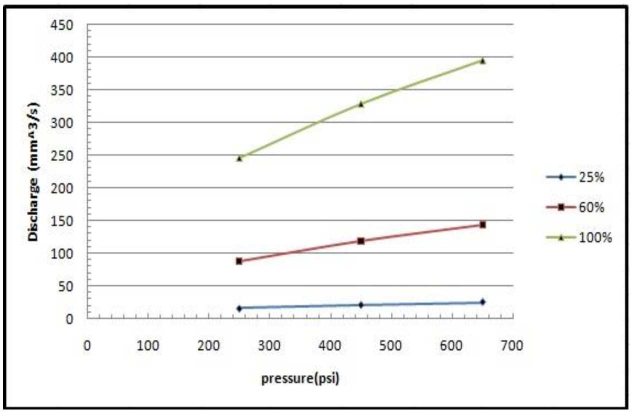

Fig. 7 Temperature effect on the pressure and discharge at 80 C°

It can be notice that the temperature seated to 80C° with changes inlet valve to test the pipes with different values of pressure. So that at pressure (500 psi) shows that a fracture happened on the tube at thickness 3.1 mm.

Fig (8) shows temperature effect on relationship between pressure and Reynolds number on different diameter in hydraulic system water. When increasing the pressure and Reynolds number (Re) is increase the friction factor is decrease and the pipe with greater diameter are effecting more than the smaller due to the velocity increases.

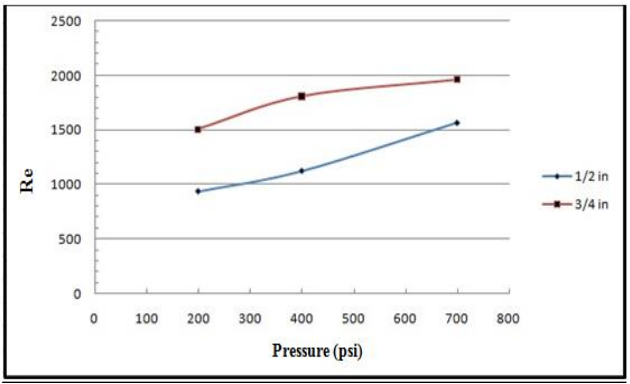

Fig. 8 Temperature effect on relationship between pressure and Reynolds number.

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Thickness and Reynolds number (Re) can be seen in fig (9), in this chart explain critical thickness with (Re). It can be observed that the fracture occur on the pipes at Re=1547.25.

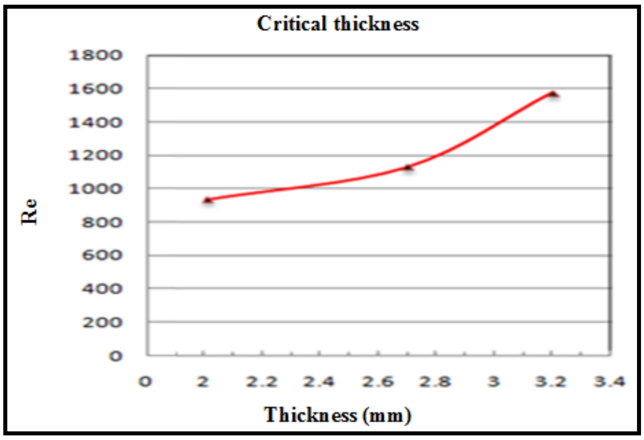

Fig. 9 Temperature effect on the relationship between the thickness and Reynolds number (Re)

Fig (10) and fig (11) illustrate the relation between Reynolds number (Re) and friction factor (*f*) for many types of pipes for ½ in and ¾ in respectively. It can be notice from these figures that the friction factor is decreased when Reynolds number is increased.

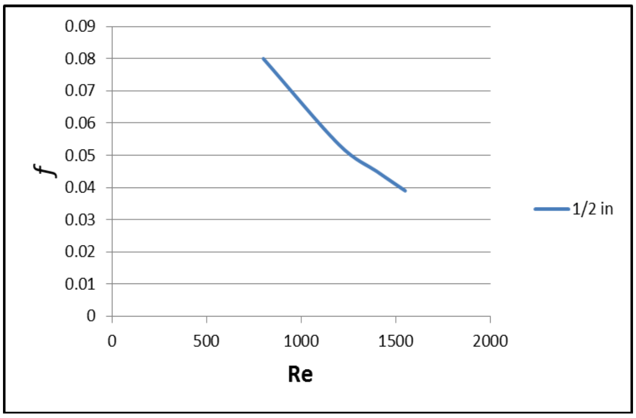

Fig. 10 The relation between friction factor (*f*) and Reynolds number (Re) for ½ in

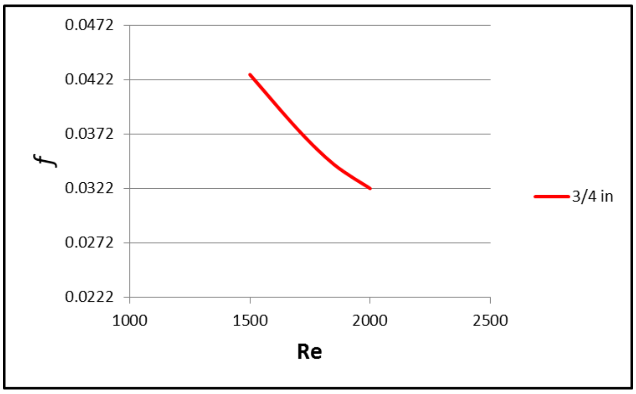

Fig. 11 The relation between friction factor (*f*) and Reynolds number (Re) for ¾ in

Friction losses in pipe were calculated by using equation (4) and the results listed in table (1).

Table 1 The values of friction losses

From the above values in the table, it can be seen that the friction losses increase with increasing the pressure and discharge.

The results were assessed using analysis of variance (ANOVA). ANOVA is approach of apportioning of an output of various inputs. The multiple linear regression models were obtained by using (Minitab16) software, the regression equations formulated are:

1- Regression Analysis: Discharge (mm^3/s) versus Pressure(psi) at 40 C°

- Valve 25% opened, Area = 9.6 mm^2

The regression equation is

Discharge = 9.20 + 0.0237 Pressure .... (6)

- Valve 60% opened, Area= 55.4 mm^2

The regression equation is

Discharge = 53.9 + 0.137 Pressure .... (7)

- Valve 100% opened, Area= 153.9 mm2

The regression equation is

Discharge = 150 + 0.379 Pressure .... (8)

2- Regression Analysis: Discharge (mm^3/s) versus Pressure(psi) at 60 C°

- Valve 25% opened, Area = 9.6 mm^2

The regression equation is

Discharge = 9.59 + 0.0235 Pressure .... (9)

- Valve 60% opened, Area= 55.4 mm^2

The regression equation is

Discharge = 55.7 + 0.135 Pressure .... (10)

- Valve 100% opened, Area= 153.9 mm2

The regression equation is

Discharge = 417 - 0.074 Pressure .... (11)

3- Regression Analysis: Discharge (mm^3/s) versus Pressure(psi) at 80 C°

- Valve 25% opened, Area = 9.6 mm^2

The regression equation is

Discharge = 7.32 + 0.0287 Pressure .... (12)

- Valve 60% opened, Area= 55.4 mm^2

The regression equation is

Discharge = 42.2 + 0.166 Pressure .... (13)

- Valve 100% opened, Area= 153.9 mm^2

The regression equation is

Discharge = 123 + 0.421 Pressure .... (14)

From the above equations it can be obtained to the theoretical results matching to the experimental results was obtained in this work.

Tables 2, 3 and 4 illustrate the analysis of variance (ANOVA) for the temperatures (40, 60 and 80 Cº) respectively. The ANOVA computes the summation of squares (SS), degree of freedom (DOF), variance (MS), F-test (F) and percentage contribution (P).

Table 2 Analysis of variance (ANOVA) at (40 Cº)

Inlet valve 25% opened / the area became 9.6 mm²					
Source	DOF	SS	MS	F	P
Regression	1	71.369	71.369	282.21	0.038
Residual Error	1	0.253	0.253		

Total	2	71.622			
Inlet valve 60% opened / the area became 55.4 mm²					
Source	DOF	SS	MS	F	P

Pressure (psi)	Discharge (mm³/s)	Friction losses (mm)
100	154.9	4.8×10^{-4}
300	268	8×10^{-4}
500	346.5	2.4×10^{-3}

Regression	1	2362.1	2362.1	134.01	0.055
Residual Error	1	17.6	17.6		
Total	2	2379.7			
Inlet valve 100% opened / the area became 153.9 mm²					
Source	DOF	SS	MS	F	P
Regression	1	18212	18212	131.67	0.055
Residual Error	1	138	138		
Total	2	18351			

Table 3 Analysis of variance (ANOVA) at (60 Cº)

Inlet valve 25% opened / the area became 9.6 mm²					
Source	DOF	SS	MS	F	P
Regression	1	44.180	44.180	265.08	0.039
Residual Error	1	0.167	0.167		
Total	2	44.347			
Inlet valve 60% opened / the area became 55.4 mm²					
Source	DOF	SS	MS	F	P
Regression	1	1468.3	1468.3	224.09	0.042
Residual Error	1	6.6	6.6		
Total	2	1474.8			
Inlet valve 100% opened / the area became 153.9 mm²					
Source	DOF	SS	MS	F	P
Regression	1	444	444	0.10	0.804
Residual Error	1	4396	4396		
Total	2	4840			

Table 4 Analysis of variance (ANOVA) at (80 Cº)

Inlet valve 25% opened / the area became 9.6 mm²					
Source	DOF	SS	MS	F	P
Regression	1	83.579	83.579	72.01	0.075
Residual Error	1	1.161	1.161		
Total	2	84.740			
Inlet valve 60% opened / the area became 55.4 mm²					
Source	DOF	SS	MS	F	P
Regression	1	2797.1	2797.1	73.37	0.074
Residual Error	1	38.1	38.1		
Total	2	2835.2			
Inlet valve 100% opened / the area became 153.9 mm²					
Source	DOF	SS	MS	F	P
Regression	1	18036	18036	34.79	0.107
Residual Error	1	518	518		
Total	2	18555			

5. Conclusion

From this research the following conclusion has been achieved:

1- The friction factor decrease with discharge increasing for temperature effect.

2- Pressure drop increase with discharge increase at different values of temperature.

3- Temperature effect on relationship between pressure and Re. no. on different diameter in hydraulic system water. When increasing the pressure, Re no. is increase because the friction factor is decrease and the pipe with greater diameter are affecting more than the smaller due to the velocity increases.

4. From the results, it can be seen that the friction losses increase with increasing the pressure and discharge, where the values of friction losses were 4.8×10^{-4}, 8×10^{-4} and 2.4×10^{-3} mm at 100, 300 and 500 psi respectively.

5. Depending on the results that have been obtained from the analytical method (ANOVA/ Minitab16), there is a reasonable match between the experimental and theoretical results.

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