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AN EXPERIMENTAL STUDY OF THREE PHASE FLOW THROUGH HELICAL COIL AND CONTROL VALVE IN SERIES

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ABSTRACT

Experimental investigations have been carried out to evaluate the three phase pressure drop and the hold-up for Oil + Water + Gas flow through horizontal helical coils and control valve. Three phase flow occurs in petroleum industries especially in oil rigs where crude oil is explored in bulk quantity. While pumping crude oil in the oil rig not only the crude oil is coming alone, it is mixed with water and natural gas and air. So we have to pump these three components together. These three components (oil + water + gas) forms three phase flow. That is three immiscible fluids, such a complex mixture is pumped in the oil rig pump and it is transported in pipes to the on shore refinery. The design of such pump, control valve and pipelines is very difficult. In this work, we have designed an experimental set up of such kind of three phase flow through pipes and helical coil and control valve in the laboratory. Various three phase flow data for kerosene + water + air, diesel + water + air, groundnutoil + water + gas etc. have been collected. Various pressure drop data across the helical coil and the control valve have been collected. By using these data, the flow versus pressure drop chart has been drawn. By linearising the curve by the second order equation the PID controller has been designed, which is controlling the control valve. By adjusting the control valve, we can change the flow patterns, oil flow rate and maximize the extraction of crude oil exploration from the rig by using minimum of pump energy.

Key words: Flow pattern, Pressure drop, Hold up, PID controller, Pneumatic control valve.

INTRODUCTION

Three phase flow (Gas-oil-water) mostly occurs in the petroleum exploration industries, oil rigs and chemical reactors and it occurs in transporting the gas oil water mixtures from Off–shore production. This happens because when we dig inside the earth for

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crude oil water is frequently coming out from the crude oil wells in addition to the product crude oil and natural gas streams, the water is coming out both naturally within the oil reservoir (i. e. connate water) and from water injected into the crude oil reservoir at the latest stage in the production (i. e. injected water). Thus, it is important to have some knowledge on the flow characteristics of the three components, such as flow patterns, pressure drop and holdup, especially at high pressure, for the proper design and operation of pumps and control valves used in the pipelines of oilrig and one more problem is sand is also coming out in many cases, so we have to design a rig cope with up to four phase. This type four phase flow of oil-water-gas-sand is called by a name of AOWS (Air-Oil-Water-Sand), so designing the pipe lines and controllers used for the control of such a three phase flow is very difficult. Here, we have to consider that the oil plus water and air are three immiscible fluids. Two immiscible fluids flows such as oil and water are also occur frequently in the design of variety of industrial processes and equipment.

Though there were number of publications on two-phase flow (two immiscible liquids) in the 2000's and 2010's. Compare to the number of publications of two phase flow in the literature there are only limited publications on three-phase flow of liquid-gas-liquid mixtures. Xu and Li.[1] construct a oil gas water three phase flow apparatus and studied various flow pattern. They did not study the flow through helical coil and control valve. Wang et al.[2], did experiments in three phase flow through only on horizontal and vertical pipes alone, Keskin et al.[3] and Adriane et al.[4] studied about three phase flow and identified various flow pattern.

Hemamalini et al.[5] studied two phase flow through helical coil and control valve in series by using water plus palm oil mixture they measure the pressure drop across the helical coil and control valve and by using locart martini equation they studied the installed characteristics of control valve Oddie et al.[6] conducted study of two and three phase flow through inclined pipes alone not using helical coil and control valve. Wambsganss et al.[7] conducted an experiment on oil-air-water flow in a 66.53 mm horizontal pipe at 4 bar pressure. They observed six different flow patterns of three phase flow and created a flow pattern map. They found that maximum pressure gradient versus the water fraction of the (fixed) total liquid flow which is happening because of phase inversion and he introduced new parameter, called mixing degree coefficient, which is quantitatively describe the mixing between the two immiscible liquids.

Chen and Guo[8] studied air, water, oil three phase flow pressure drop across helical coil alone. Lee[9] experimentally found new flow patterns in oil-air-water flow through helical tubes and Acikgoz et al.[10] conduct a study of three phase flow regimes alone. They did not study and design PID controllers. Skogestad[11] and Padula and Visioli[12] proposed simple analytical rule for PID controller, which is used in this study. The above research works are only on straight pipes oriented vertically or horizontally; there is limited work done on oil-water two-phase flow and oil-air-water three phase flows in helical coil and curved tubes. Since coils and helical tubes are used wildly in chemical reactor, agitated vessels, storage tanks, and in some nuclear steam generators and nowadays coiled tubes are usually employed as intermediate heater elements in oil transporting system.

It is found that there were not any work related to the design of PID controllers and AI controllers for the control of three phase flow through the control valve and helical coil. Therefore, it is of great interest to conduct research on the flow characteristics in oil-air-water three-phase flow through these kinds of tubes, helical coil and control valve.

The purpose of the present study was about understanding and obtaining the knowledge of oil-air-water three-phase flow in helically coiled tubes and control value in order to design the PID or other AI controllers. The flow patterns and pressure drop characteristics of various three phase mixtures such as diesel + air + water + petrol, air + water + ricebran, oil + air + water, groundnutoil + air + water (like nine different mixtures were tested in the experimental setup). The above various three phase mixtures are having different combined density starting from 0.65 Kg/Liter to 0.98 Kg/Liter and they are having different viscosity were investigated, while doing the experiment the pressure drop across the control valve and helically coiled tubes are measured by manometers and digital pressure gauge, readings are tabulated and correlation of flow versus pressure drop is predicted. By using this pressure-drop data the pneumatic control valve is designed and PID and other AI controller is also designed by using the experimental data. By using this controllers and the system, we can’t maximize the crude oil exploration from the oilrig. In this work various non-linear pressure drop data have been collected across the helical coil and control valve the flow versus pressure drop charts are drawn for various data. The nonlinear pressure drop curves were linearised by a second order equations and by using those linear equations the proper PID controller is designed to control the air flow rate and the valve opening of the pneumatic valve in order to maximize the crude oil extraction from the oil rig.

EXPERIMENTAL

An experimental setup was fabricated to obtain three phase flow pressure drop data for vertically helical coiled tube and control valve section. Tube has 23.5 mm ID, 15 cm coil diameter and 3.2 m length of coil. The experimental setup shown in Fig. 1. Consists of

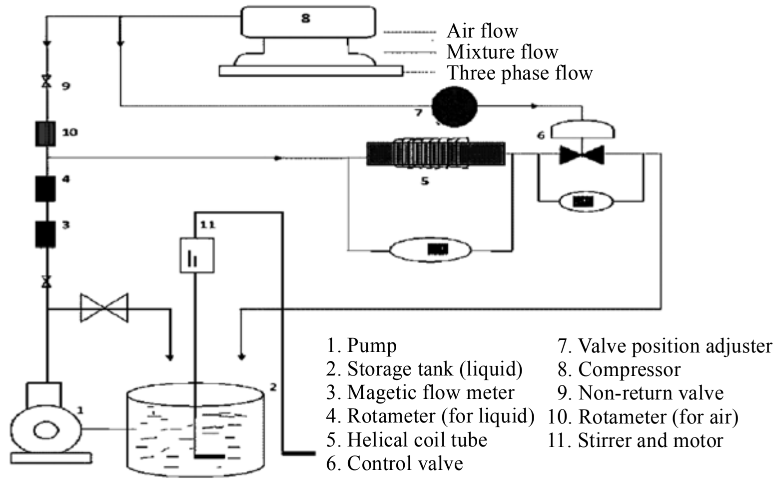


Fig. 1: Experimental setup for three phase flow through helical coil and control valve

The following related accessories:

- Air compressor
- Centrifugal pump
- Rota meter
- Magnetic flow meter
- Control valve
- U-Tube manometer
- Stirrer

Air compressor

Compression of gases and vapours is an important operation in chemical and petrochemical plants. The type of air compressor used in experiment is a two stage reciprocating compressor. This specification of the compressor are given in Table 1.

Table 1: Specification of compressor

Physical quantity	Unit	Value
Power	HP/Kw	3/22.2
Speed	Rpm	650
Maximum pressure	Psi	1750

Centrifugal pump

A 0.25 HP centrifugal pump is used to pump the water from the tank through the pipeline and valve. Table 2 shows the specification of the centrifugal pump used in the experimental setup.

Table 2: Specification of centrifugal pump

Physical quantity	Unit	Value
Power	Kw/HP	0.18/0.25
Speed	Rpm	2800
Head	M	18
Volts	V	230
Frequencies	Hz	50
Current	Amps	65

Magnetic flow meter

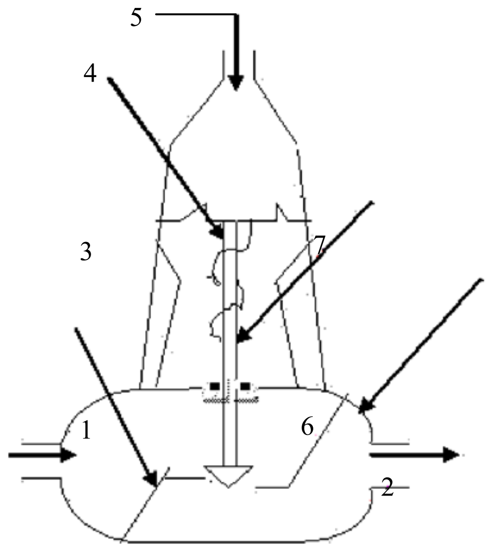
Operation of a magnetic flow meter is based on Faraday's law that is as a conductive material or fluid moves at right angles through a magnetic field. It induces a voltage, which is proportionate to the intensity of magnetic field and the velocity of the fluid. In a magnetic flow meter, field intensity is kept constant so that voltage induced is proportional to the fluid velocity alone. It does not restrict flow and is a zero pressure drop device. However, the fluid measured must be at least slightly conductive; a minimum conductivity of about 10 mW/cm^2 is required. The magnetic flow meter, show in flow diagram has a digital indicator for the liquid flow rate.

Rota meter

Rota meter comes under the type of area flow meters. It consists of devices in which the pressure drop is constant, or nearly so, and the area through which the fluid flows various with flow rate. The area is related through proper calibration, to the flow rate.

Control value (Pneumatic)

Pneumatic control valve is essentially a variable resistance to the flow of fluid, in which the resistance and therefore, the flow can be changed by a signal from a process controller. The control value consists of an actuator and a valve as shown in Fig. 2. The valve itself is divided into the body and the trim. The body consists of housing for mounting for the actuator and connections for attachment of the valve to a supply line and delivery line. The trim, which is enclosed within the body, consists of a plug, a valve seat and valve stem. The actuator moves the valve stem as the pressure on spring-loaded diaphragm changes. The stem moves a plug in a valve seat in order to change the resistance to flow through the valve.



1. Supply
2. Delivery
3. Seat
4. Diaphragham
5. Supply
6. Valve
7. Stem

Fig. 2: Parts of pneumatic control valve

In order to specify the size of a valve in terms of its capacity to provide flow when fully open, the following equation is used.

$$Q = C_V\text{: } \Delta P_v/G$$

Where, Q = Flow rate lpm,

ΔP = Pressure drop across the wide open valve (Psi)

G = Specific gravity at steam temperature relative to water; for water G=1

Cv = Factors associated with capacity of valve

C_v is defined as the flow (gpm) of a fluid of unit specific a gravity through a fully open valve, across which a pressure drop of 0.1 N/cm^2 exists. Manufacturers rare the size of a valve in terms of this factor C_s.

Manometer

Manometer is an important device for measuring pressure differences. Two manometers have been connected to the helical coil and the control valve, respectively. Carbon tetra chloride and mercury have been used as manometric fluid as shown in Fig. 1.

The densities of the manometric fluids are:

Density of carbon tetra chloride: 1.589 g/cc

Density of mercury = 13.6 g/cc

Stirrer

The metallic stirrer length 0.6 meter is connected in the tank by a metallic stand and the stirrer is rotated by a small motor, which is fitted in the stand. The speed of the stirrer is kept constant at 1200 rpm by a speed regular, which is connected to the motor.

Connections

The connections are made as shown in Fig. 1, Water is collected in the tank from water main line. It is pumped to the test rig through the magnetic flow meter. The valve is used to change the water flow rate. The flow indicator has been indicated to the magnetic flow meter. Air is fed to the rig through tank to suppress air surges. A pressure regulator is used to reduce the oscillatory rot meter. A non- return valve is connected to avoid the liquid flow in the airline. The pressure drop across the helical coil is calculated from manometer reading. A pneumatic control valve is connected with series of coil. To adjust the valve position, air in the range of 3 to 15 psi is used. The valve is air failure to open.

Two pressure aping have been connected across the control valve. In the manometer carbon tetrachloride and mercury has been used as manometric fluid. The outlet of the valve has left in the atmosphere. Galvanized iron pipe has been used in the experimental setup. At suitable places, the flexible hoses have been used. Electrical connections have been given to pump compressor and magnetic flow meter.

Experimental procedure

Liquid mixture was supplied to the section using a centrifugal pump, which is connected with a rotameter. Air was supplied to the test section from a compressor and air rotameter is used to measure the flow rate of air. A manometer was used to determine the pressure drop across control valve and coil section.

The 12.5 mm control valve was an equal percentage valve with a valve co-efficient of 4. The pressure taps are spaced at entrance and exit of coil and control valve. A dry type gas meter was used to calibrate the gas rotameter. The air lock in the manometer line was removed. By adjusting air lock in the manometer and by adjusting the valve, the water flow was regulated to the desired valve. The valve position and manometer readings were noted. First, the experiment was done only for water.

Airflow rate was taken as a parameter and for various mixtures flow rates the manometer readings were noted calculate the pressure drop across coil and valve. To reduce fluctuations in rotameter and manometer, the air from the compressor was passed through a surge tank and it was regulated the pressure regulator. Two atmosphere pressurized air was used in the experiment. For constant valve position and air flow rate, the mixture flow rate was varied from 30 Iph to 180 Lph and the corresponding manometer redings were noted. The same procedure was followed for various airflow rate and valve position, the readings were noted.

Design of PID and AI controller

Nine different mixtures were used during experiment, such as palm oil, diesel, petrol, crude oil, rice bran oil groundnut oil etc. The above different oils were used in order to obtain different viscosity and different density, more than hundred numbers of tables were prepared for the above nine different mixture and corresponding graphs were also drawn. Few number of tables such as Table 3 and 4 (Air + wate + transformer oil system) and Table 5 (air + water + ground nut oil system) are shown below.

Table 3: Readings taken from air-water-transformer oil system when percentage of valve opening is 100% and air flow rate-90 LPH

Air flow rate Iph	Mixture flow rate lph	Δh Coil cm	Δh Valve cm	Experimental			Best fit			% Error	
				(ΔP) Coil N/m^2	(ΔP) Valve N/m^2	(ΔP) Total N/m^2	(ΔP) Coil N/m^2	(ΔP) Valve N/m^2	(ΔP) Total N/m^2	Coil	Valve
90	60	5.2	0.1	6342.54	124.53	6467.07	6356.7	126.3	6483	1.96	1.58
	90	5.4	0.13	6743.9	157.9	6901.8	6748.9	158.3	6907.2	0.07	0.25
	120	6.3	0.17	7865.3	187.6	8052.9	7901.9	189.5	8091.4	1.72	1.05
	150	6.8	0.2	8632.6	248.9	8881.5	8731.6	252	8983.6	1.13	1.19
	180	6.74	0.21	8532.7	252.1	8784.8	8563.9	253.1	8817	0.36	0.39

Table 4: Readings taken from for air-water-transformer oil system when percentage of valve opening is 75% and air flow rate-120 LPH

Air flow rate Iph	Mixture flow rate lph	Δh Coil cm	Δh Valve cm	Experimental			Best fit			% Error	
				ΔP) Coil N/m^2	ΔP) Valve N/m^2	ΔP) Total N/m^2	ΔP) Coil N/m^2	ΔP) Valve N/m^2	ΔP) Total N/m^2	Coil	Valve
120	60	5.5	0.1	6817.9	128.8	6946.7	6854.6	129.1	6983.7	0.52	0.23
	90	5	0.2	6524.1	249.4	6773.5	6572.2	249.5	6821.7	0.76	0.04
	120	5.5	0.21	5542.6	251.2	5793.8	5601.2	252.2	5853.4	1.07	0.4
	150	4.8	0.25	5325.5	270.32	5595.82	5392.2	269.1	5661.3	1.29	0.38
	180	4	0.27	4980.1	278.5	5258.6	5010.1	279.1	5289.2	0.59	0.21

For each table two graphs were drawn, one for pressure drop across helical coil Vs flow rate and other for pressure drop across control valve Vs flow rate. More than two hundred number of graph were drawn, Few graphs Fig. 4 and 5 (for diesel oil system) Fig. 6 and 7 (for transformer oil system) Fig. 8 and 9 (for crude oil system) are shown below.

Table 5: Readings taken from air-water-ground nut oil system when percentage of valve opening-50% and air flow rate-60 LPH

Air flow rate Iph	Mixture flow rate lph	Δh Coil cm	Δh Valve cm	Experimental			Best fit			% Error	
				(ΔP) Coil N/m^2	(ΔP) Valve N/m^2	(ΔP) Total N/m^2	(ΔP) Coil N/m^2	(ΔP) Valve N/m^2	(ΔP) Total N/m^2	Coil	Valve
60	60	2	0.1	2345.7	126.2	2471.9	2365.7	126.9	2492.6	0.31	0.47
	90	2.4	0.15	3324.9	167.3	3492.2	3329.7	168.2	3497.9	0.12	0.77
	120	2.8	0.2	3652.5	248.3	3900.8	3672.7	248.9	3921.6	0.62	0.25
	150	3.4	0.23	4230	264.6	4494.6	4250	267.5	4517.5	0.43	0.45
	180	4.5	0.25	5467.9	272.5	5740.4	5487.9	272.9	5760.8	0.36	0.15

By using the second order curve fitting corresponding linear equation is obtained (shown inside the graph). By using these linear equation from graphs proper PID controller is designed (4-20 mA). The output of PID controller is used to control the pneumatic control valve and the air flow rate to maximize the output oil mass flow rate. By using the huge data obtained from various tables and by using linear equation obtained from graphs AI controller can also be designed (Look up table method).

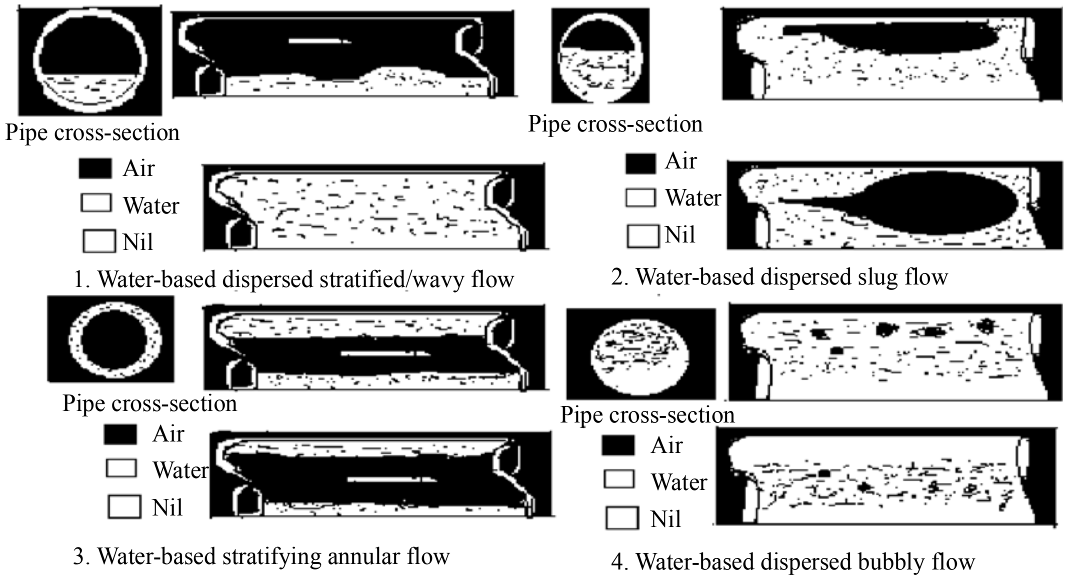


Fig. 3: Various types of three phase flow occurring during experiment

The Following flow patterns were observed during the three phase flow experiment they are given below (Fig. 3).

1. Water-based stratified/Wavy flow
2. Water-based dispersed slug flow
3. Water-based dispersed annular flow
4. Water-based dispersed bubbly flow

Drop across helical coil when valve opening is 75% control valve when valve opening and air flow rate is 120 LPH (transformer oil system) is 75% and air flow rate is 120l ph (transformer oil system).

RESULTS AND DISCUSSION

In this experiment pressure drop across the helical coli and control valve for various air flow rate and various level of opening of control valve is calculated using combined density of water plus oil Flow rate verses pressure drop curves are drawn by using second order curve fitting the curve fitting equations are obtained (which are shown in the figures). By using this linear equation a proper PID and AI controller can be designed to control the opening percentage of valve and the controller will increase or decrease the air flow rate in order to obtain the maximum oil mixture come out of the system. In previous studies research on oil-gas-water Three-phase flow Experimental Apparatus was not design by these kind of PID controller to maximize the oil flow rate[1].

Experimental study of high-viscosity oil/water/gas three-phase flow in horizontal and upward vertical pipes were studied three phase flow only on horizontal pipes. They did consider the helical coil and flow through control valve in contradiction this study considering control valve and helical coil and maximize the oil flow rate[2]. “Three phase liquid-liquid-gas flows in 5.6 mm and 7 mm inner diameter pipes” studied three phase flow in horizontal pipes and various flow pattern elaborately. They did not consider the control valve and design the controller currently[13]. Most oil fields have a gas-liquid separator on the output of each well to separate the gas from the oil and water in order to transport to on shore. However, a gas-liquid separator is a very expensive piece of hardware. By properly design, this system we can pump the three phase mixture together and we maximize the oil extracting from the rig. oil & gas companies have billions of dollars tied up in their reservoirs even one percent improvement in crude oil exploration would save many millions of dollars.

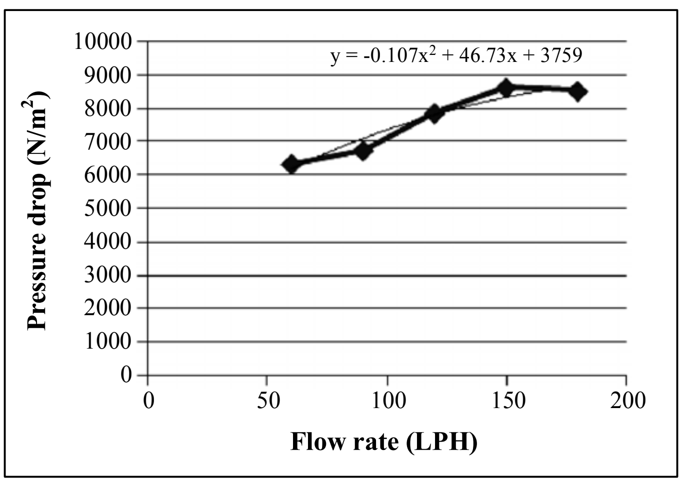


Fig. 4: Graph between pressure drop across helical coil when valve opening is 100% and air flow rate is 90 LPH for diesel oil system

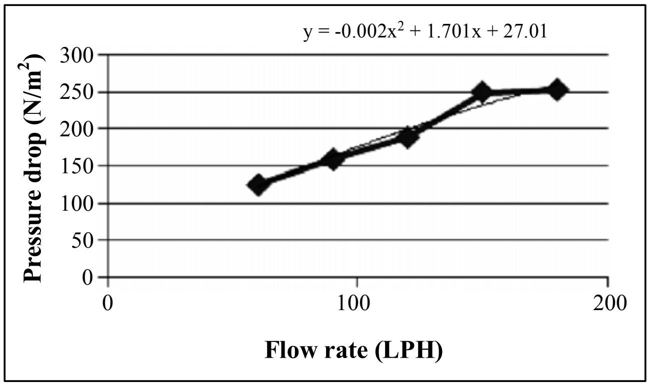


Fig. 5: Graph between pressure drop across control valve when valve opening is 100% and air flow rate is 90LPH for diesel oil system

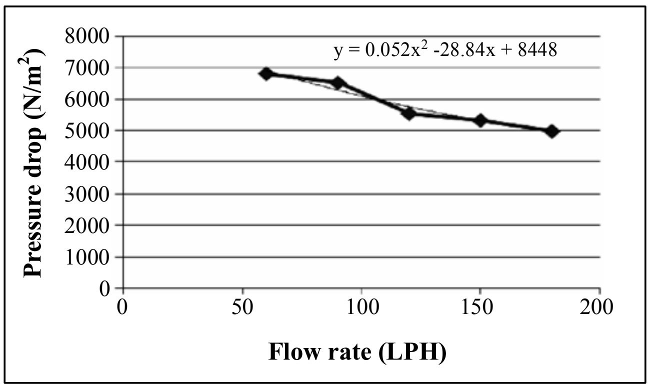


Fig. 6: Graph between pressure drop across Helical coil when valve opening is 75% rate is 120LPH (transformer oil system)

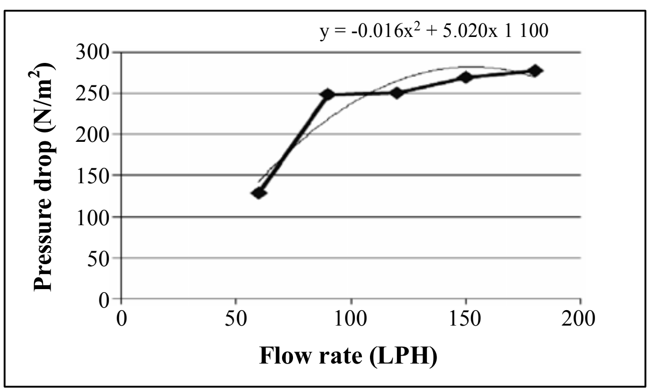


Fig. 7: Graph between pressure drop across control valve when valve opening and air flow is 75% and Air flow rate is 120l ph (transformer Oil system)

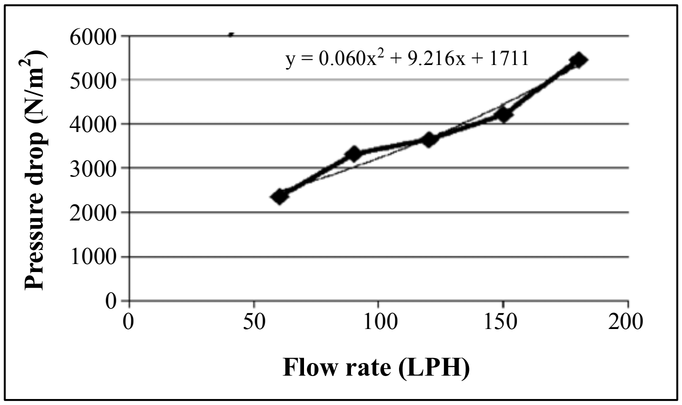


Fig. 8: Graph between pressure drop across Helical coil when valve opening is 50% and Air flow rate is 60 LPH (for crude oil system)

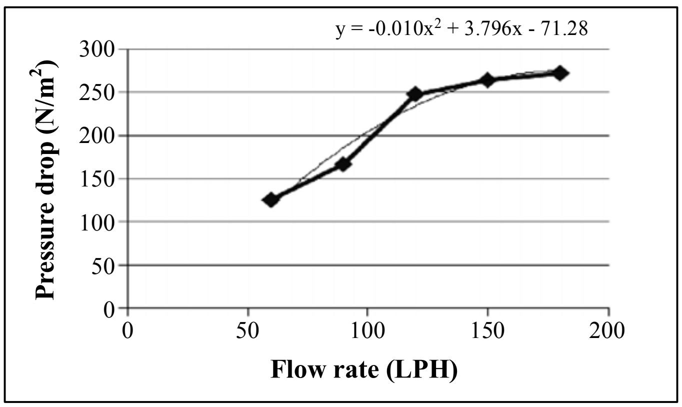


Fig. 9: Graph between pressure drop across control valve when valve opening is 50% and air flow rate is 60 LPH (for crude oil system)

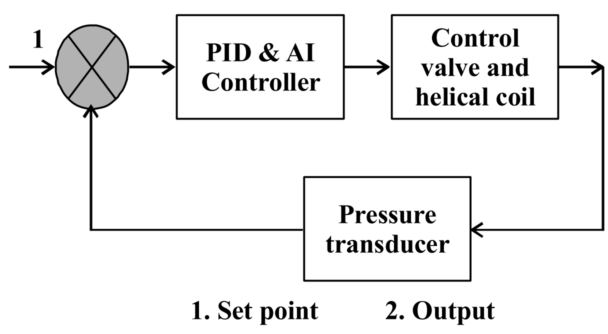


Fig. 10: Shows the proposed design of PID and AI controller for controlling the three phase flow through helical coil and control valve

CONCLUSION

The pressure drop across the control valve and helical coil for various three phase flow such as kerosene + water + air, diesel + water + watrer, etc. was studied. The flow pattern changes according to the pressure drop, by adjusting the air flow rate in a proper manner, we can control the flow rate of oil, flow pattern and maximize the oil flow rate that is extraction of crude oil. By using the experimental pressure drop data and linear equation from graphs for various density fluids such as kerosene, diesel, ground nut oil, transformer oil, rice bran oil a PID and other AI controller are designed and shown in Fig. 10, which is controlling the valve opening and air flow rate and maximize the crude oil extraction

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