# Flow Control System Using Fuzzy Logic

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## Abstract

**In this work an experimental investigation has been applied to control the liquid flow of a flow system of three liters capacity, which fitted with all the hard-ware necessary for automatic control such as ADC,DAC, and DLI-DLO system , using three different feedback control modes(P,PI and PID) . Optimum control settings have been determined and implemented using Ziegler-Nicholls tuning method. The experimental results showed that proportional-integral-derivative (PID) control modes gave better results than proportional (P) and proportional-integral (PI) control modes .**

**Fuzzy logic control system (FLC) was used as another control strategy to compare the behavior of the control system with PID controller .FLC gave better performance with lower value of integral square of error (ISE) , and better control behavior .**

**Key words :Flow control, Conventional control, Fuzzy logic control**

# السيطرة على تدفق السائل باستخدام المنطق الغامض

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## الخلاصة

في هذه الدراسة تم السيطرة على مستوى تدفق السائل باستخدام منظومة جريان السوائل حيث تم مقارنة ثلاثة انماط مختلفة للسيطرة العكسية

تم ايجاد القيم المثلى لمعاملات السيطرة باستخدام طريقة ( زيكلر-نيكولاس) وقد اظهرت النتائج العملية تفوق طريقة السيطرة باستخدام تقنية السيطرة التناسبية-التكاملية-التفاضلية عن التقنيتين التناسبية والتناسبية- التكاملية

وقد استخدمت طريقة المنطق الغامض حيث اعطت قيم افضل لمقياس الخطا وكذلك اظهرت سلوكا افضل للسيطرة الديناميكية عند مقارنتها مع السيطرة التناسبية-التكاملية-التفاضلية

الكلمات الدالة : ليسطرة على تدفق السائل ، السيطرة التقليدية، السيطرة باستخدام المنطق الغامض

## Introduction

Control of liquid flow system is a routine requirement in many industrial processes. The control action of chemical and petroleum industries include maintaining the controled variables. Fuzzy logic control (FLC) can be applied for control of liquid flow and level in such processes.This technique is particularly attractive when the process is nonlinear [1]

The electric and electro-pneumatic control systems are widely applied in the industrial technology, especially , when action is controlled by using programmable logic controllers .Conventionally , when a process must be optimised,a mathematical model has to be built up [2-4].

The flow control system has nonlinear and time varying behaviours ; thus it is difficult to derive and identify an appropriate dynamic model for traditional controllers[5-7].Then a control system should be analysed and a controller should be designed.It is very difficult to get an accurate and linearised mathematical model[8] ; therefore the fuzzy control technology is applied.

Applying fuzzy control to a flow and level control system is particularly advantageous in terms of simplicity of design and implimentaton, and thus significantly reduce the time required to develop the entire system[9,10] .Experience shows that the success of a fuzzy control depends on the level of knowledge concerning the positioner's physical behaviour.

A flow control of a moving system is studied by [11,12], where a modeling , and control using six degree of freedom motion were implemented.Computational fluid dynamic (CFD)theoratical analysis and experimental results were used in their work.A fuzzy logic proportional- integral-derivative (PID) based control system has been developed in order to create a stable and highly maneuverable system. Advantages and disadvantages of both methods were discussed.

Initial computational studies to optimize the performance of the moving system [13,14] provided a basis for determining the system parameters to analyse as potential control variabled. To evaluate the system controller performance in simulation , a full range of system process need to be known.Therefore, curve fitting equations were derived to map system kinematics to stroke average forces.

Validating the experimental force measurement accuracy[15] , a library relating force data to specific system has been built [16,17].These experimental results provided a more accurate representation of the force generated by the system because the parameters used in CFD simulation do not take into account fluid structure interaction.

**Flow Control Unit**

The unit has been used to study the fundimentals of flow control and to observe the effect of the control parameters of a proportional , integral, and derivative controller.The computer was connected on-line with the system were it can be used as a simulation control using a fuzzy-logic control.

The unit is composed (figure 1) of a transparent storage tank, 3 litres capacity, and a submersible water pump with a flow rate of 8 l/min. and a maximum head of 6 m.The proportional valve with $k_v$ of 0.9 $m^3/h$ is used. A potentiometer pump speed regulation is used to regulate the motor speed then to adjust the input flow rate.The system is supplied with all the hard-ware necessary for automatic flow control

***Experimental Procedure***

The procedure steps of the experimental work can be expressed as follows:

1-The tank was filled with 2 liters of water by a submersible water pump.

2-The computer system was operated which is supplied with all the hard-ware devices necessary for automatic control (analogue to digital converter (ADC),digital to analogue converter(DAC),and digital logic in and out(DLI/DLO)).

3-Set the water flow rate at a certain input value (input variable).

4-The system was set automatically to record the steady-state values of water flow rate (as a set point) after the steady-state conditions were reached.

5- a step change in the set point was carried .

6- The control systems were operated to eleminate the error values in water flow rate(output variable) using different control strategies (P,PI,PID, and Fuzzy-logic control).

7- The values of the errors in the flow of water versus time were recorded and plotted by means of a plotter for different control strategies.

***Fuzzy Logic Controller:***

The purpose of any plant controller is to relate the state variables to action variables. The controller of a physical system need not itself be physical but may be purely logic. Furthermore, where known relationships are vague and qualitative. A Fuzzy logic controller may be constructed to implement the known heuristic. Thus in such a controller the variables are equated to non-Fuzzy universe given the possible range of measurement or action magnitudes. These variables, however, take on linguistic values which are expressed as Fuzzy subset of the universe. The complete procedure of the fuzzy controller design was described [18] :

The derivation of the Fuzzy rules can be obtained directly from the phase-plane of error and its rate of change. Table (1) shows the Fuzzy rules conclusions. The five Fuzzy sets definition generates (25) rules Fuzzy controller.

The algorithm design steps of a Fuzzy logic controller system shown in figure (2), were the error ($E_i$) and rate of change of error ($CE_i$) defines the Fuzzy subsets with their discrete membership functions.

## Control Strategies :

In this work two different control strategies were used , feedback and fuzzy logic control , P,PI and PID controller modes were used as feedback control modes to control the liquid flow experimentally.

The problem with designing the feedback controller will essentially lie with making the optimum choice of the most appropriate values to be assigned to the parameters corresponding to the three contributions "P , I , and ,D " .This choice will not always be simple as it requires a detailed knowledge of the process to be controlled .

There exist several methods aimed at this purpose Ziegler – Nicholls [19] among them .Depending on the configuration of the variable controller , the parameter shown in table(2)

The final results will strictly depend on the dynamic behavior of the process being controlled.

The above optimisation technique was used to determine the optimum values of the controller parameters ( $K_c$,$\tau_I$,and,$\tau_D$ ) to give the minimum value of the integral square of error , which is defined as :

$$ISE=\int E^2 (t)\, dt \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The upper limit is t which is a finite time chosen some what arbitrarily so the integral approaches a steady-state value. It is usually convinient to choose t as the setlling time.

## Results and Discussion

In this work a control system was designed and applied to control the liquid flow of a flow system.

Feedback controllers (P, PI, PID) and fuzzy logic control system(FLC) were implemented , the optimum control with minimum integral square of error (ISE) was used as a criteria to compare between fuzzy logic control and PID control.

The optimum values of the P, PI, and , PID control parameters using Ziegler-Nicholls optimum method are given in table (3).

Figures(3-5) show the experimental dynamic response of different feedback control strategies .Figure(3) shows the control response using P control which shows the steady-state error of a rate of 0.1257 (offset) as a great disadvantage of this type of control .This disadvantage was eliminated using PI and PID controls.Figure(4) shows the oscillation response of PI control which represent one of the disadvantages of this type. It is clear that PID control mode(figure(5)) gives better response than P, and PI control with better rise time and settling time.In this work the PID control was used as a comparison mode with a Fuzzy –logic mode.

The comparison of fuzzy logic control and PID control is shown in figure(6),and figure(7), respectively.Fuzzy logic control showed better dynamic control performance with better rise time, overshoot and response time ,also fuzzy logic control gives better value of ISE as shown in table (4).The advantage of fuzzy logic control is that it does not need a model to build the control settings as in the case of PID controller.

## Conclusions

In this work it can be concluded that the experimental results of the control system show that PID controller gave better results than P, and PI controllers .That was clear from the better rise time and response time.

For the comparison between fuzzy logic control and PID controller ,FLC gave a marked improvement over PID controller.However the fuzzy controller is preferable since it does not require an accurate mathematical model for the process to be controlled, while feedback controllers requires very wide knowledge about the dynamic behavior and accurate system parameters.

## Nomenclatures

| | | |
|---|---|---|
| **E** | : Error in the controlled variable | $m^3/s$ |
| **$K_0$** | : Limit value of kp | $m^3/s$ |
| **$K_p$** | : Steady-state gain | $m^3/s$ |
| **$K_v$** | : Steady-state gain of a control valve | $m^3/s$ |
| **$T_0$** | : Period of oscillation | s |

## Abbreviations

| | |
|---|---|
| **FLC** | Fuzzy-logic control |
| **ISE** | Integral square of error |
| **P** | Proportional mode |
| **PI** | Proportional-integral mode |
| **PID** | Proportional-integral-derivative mode |

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**Table (1): 25-Rule Fuzzy Logic Controller**

| | *NCB* | *NCS* | *ZC* | *PCS* | *PCB* |
|---|---|---|---|---|---|
| *NEB* | *PUB* | *PUB* | *PUB* | *PUS* | *ZU* |
| *NES* | *PUB* | *PUS* | *PUS* | *ZU* | *NUS* |
| *ZE* | *PUB* | *PUS* | *ZU* | *NUS* | *NUB* |
| *PES* | *PUS* | *ZU* | *NUS* | *NUS* | *NUB* |
| *PEB* | *ZU* | *NUS* | *NUB* | *NUB* | *NUB* |

**Table (2) : The control parameters using Ziegler –Nicholls method**

| Control Mode | P | PI | PID |
|---|---|---|---|
| Proportional Contribution | 0.5 $K_0$ | 0.45 $K_0$ | 0.6 $K_0$ |
| Integral Contribution | | 0.5 $T_0$ | 0.8 $T_0$ |
| Derivative Contribution | | | 0.125 $T_0$ |

**Table (3) : The values of the control parameters using Ziegler – Nicholls method**

| Control Mode | P | PI | PID |
|---|---|---|---|
| Proportional Mode | 3.8 | 1.8 | 2.5 |
| Integral Mode | | 0.5 | 0.3 |
| Derivative Mode | | | 0.076 |

**Table(4) :The comparison between the performance of PID and Fuzzy-logic control**

| Control strategy | Value of ISE | Rise time, s | Settling time,s | Overshoot |
|---|---|---|---|---|
| PID control | 0.435 | 0.812 | 2.658 | 0.151 |
| Fuzzy logic control | 0.231 | 0.601 | 0.820 | 0.053 |

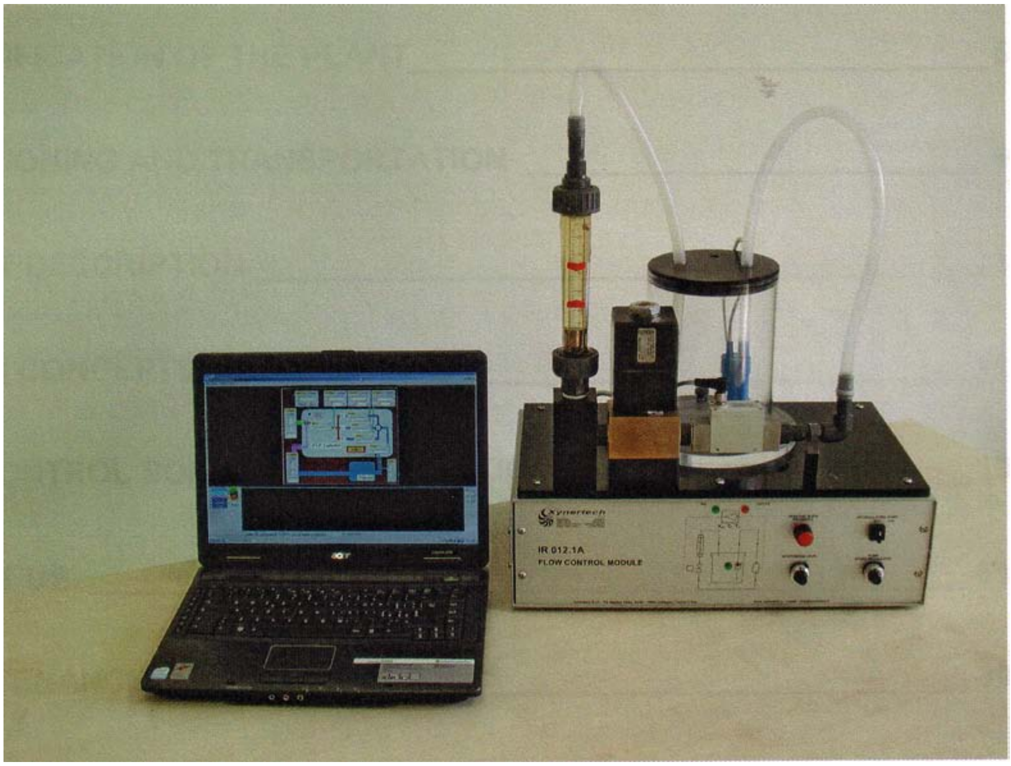


**Figure (1) On-line control of a flow system**

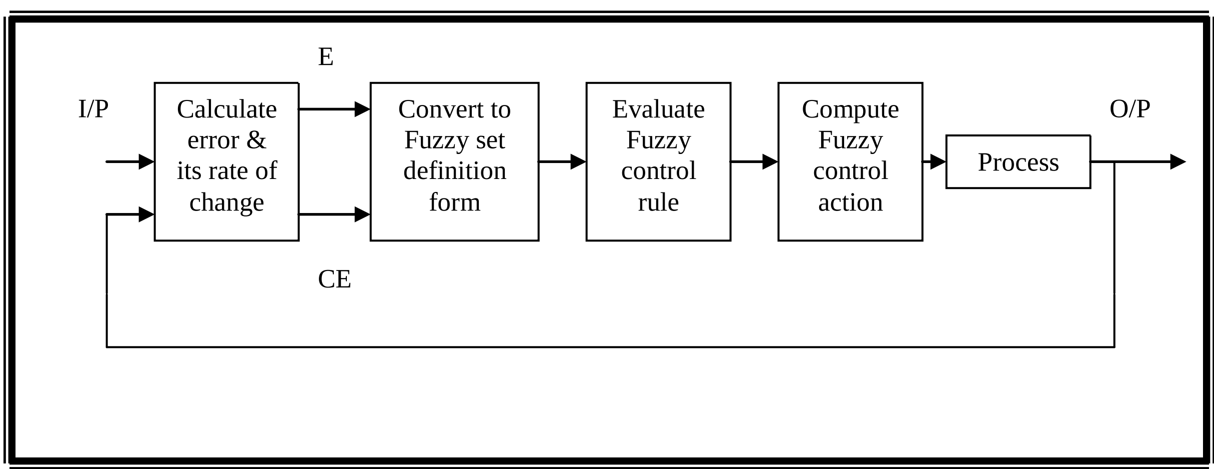



***Figure (2): Block diagram of a control system using Fuzzy Logic Control***

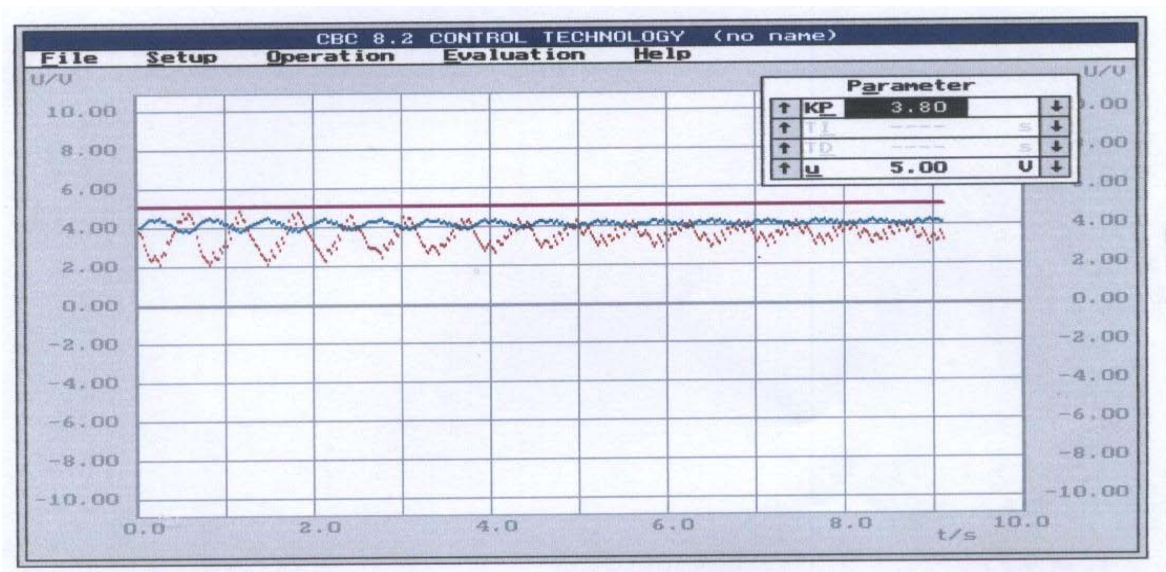



**Figure (3): Proportional Control (P) of a Flow System**

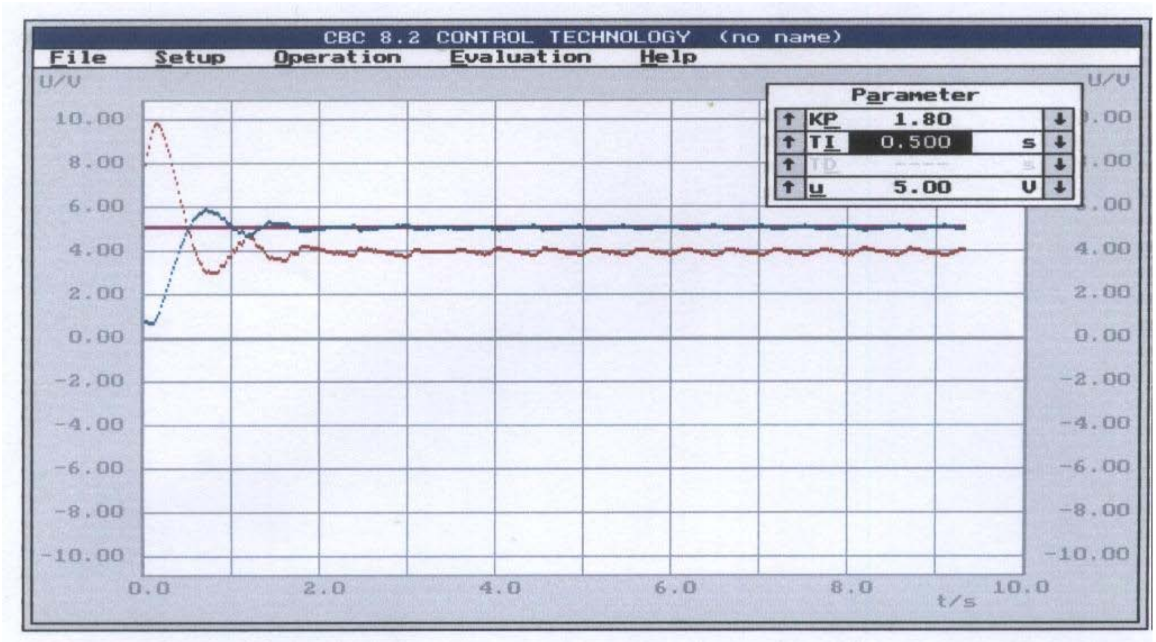
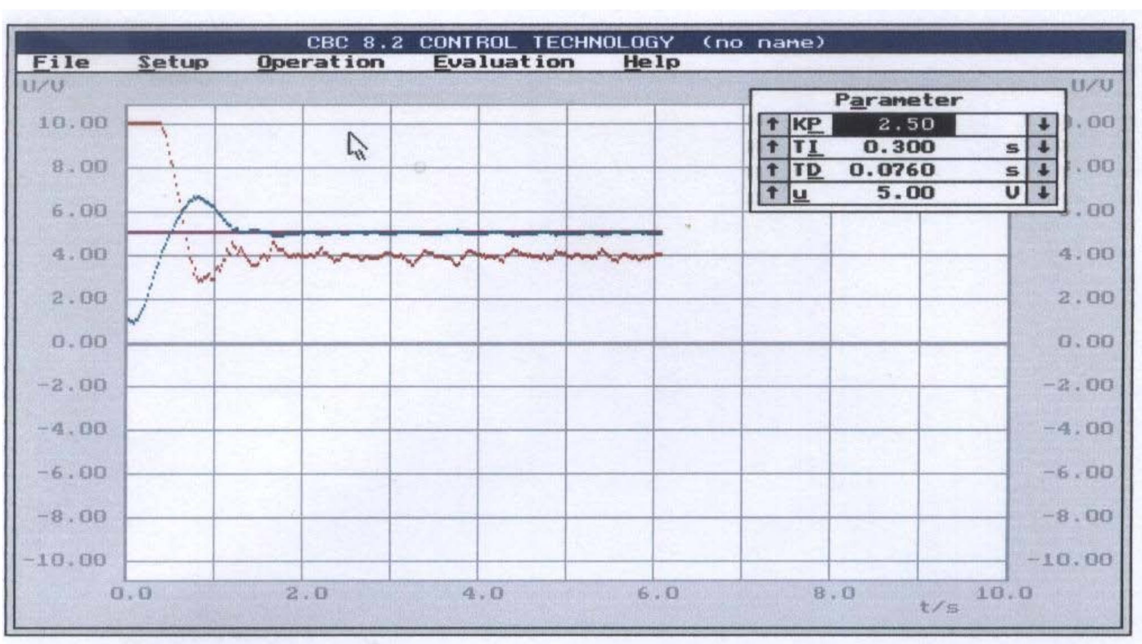



**Figure (4): Proportional-Integral Control (PI) of a Flow System**




**Figure(5): Proportional-Integral-Derivative Control(PID) of a Flow System**

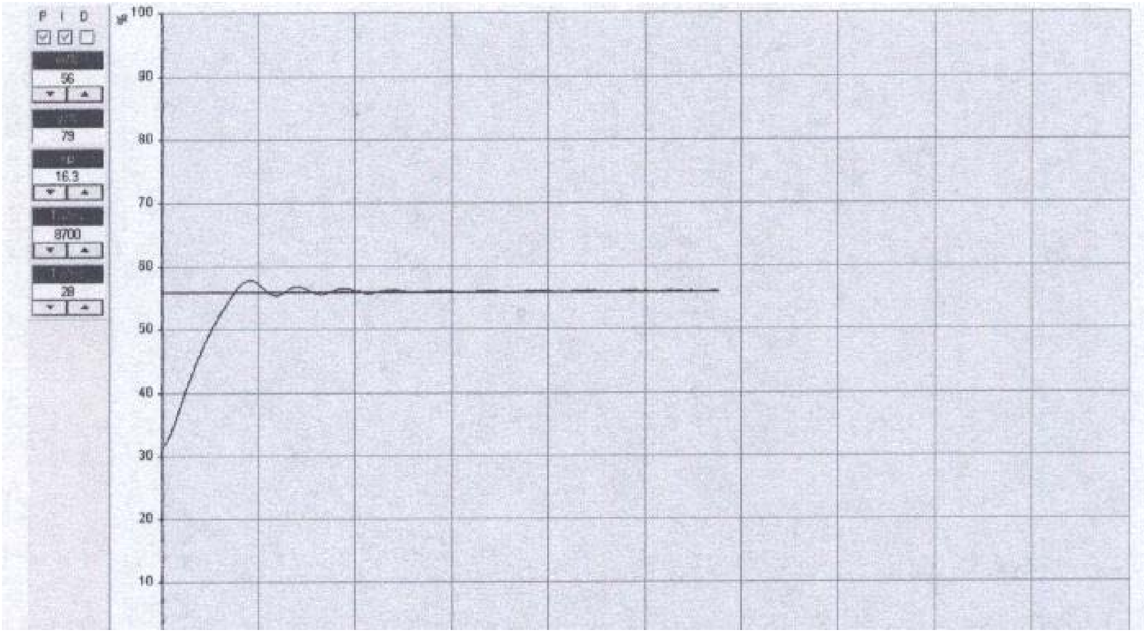



**Figure (6): PID Control for Comparison**

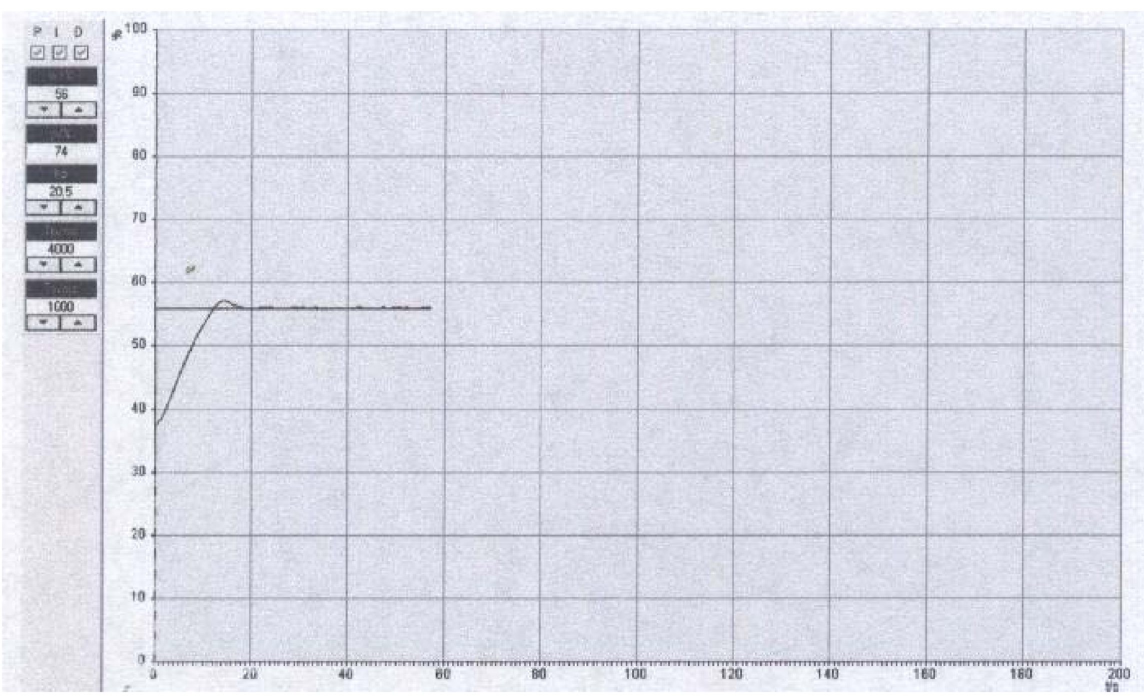



**Figure (7): Fuzzy-Logic Control (FLC) of a Flow System**