STUDYING THE CONTROL OF ABSORPTION COLUMN

A Thesis

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Dalya Sameer Makki

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Muharrem 1431

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ABSTRACT

The absorption column is one of the essential separation processes in industrial operation, so the need arises to control absorption column by process simulation and also to analyze system by method called frequency response using $MATLAB_8$.

This work dealt with gas-liquid (air-water) absorption packed column which is analyzed by bode plot and frequency response to determine the stability of the system with or without Proportional Controller (P), Proportional Integral Controller (PI) or Proportional Integral Derivatives Controller (PID).The frequency response gives the transient response information, by defining such frequency response quantities as gain margin and phase margin. This work presents dynamic analysis of absorption column which is single input/single output (SISO) using feed back control (P, PI and PID) with the parameters of Cohen-Coon, Ziegler Nichols and Internal Model control and compares between them. Another method of analysis is using root locus method to check the stability of the system. The additional method is using bode plot in the methods: Cohen-Coon, Ziegler-Nichols and Internal Model Controllers to see the stability with or without controller. The goal of this work is to control the absorbed gas (as controlled variable) by changing the flow rate of liquid as a manipulated variable.

CONTENTS

Chapter Three: Modeling of Absorption Column

NOTATIONS

Symbol	Definition	Units
A	*Cross sectional area of the column*	m^2
a	*The packing area per volume*	m^{-1}
C	*State Space*	-
E	*Experimental error*	-
F	*Feed Rate*	*Kmol/s*
$\lvert G_{(jw)} \rvert$	*Magnitude of the open loop system*	-
$G_{(jw)}$	*The open loop transfer function*	-
G^*_C	*Theoretical transfer function*	-
G_C	*Transfer Function of Controller*	-
G_m	*The Molor Flow rates of The Gas and Liquid*	*Kmol/s*
$\tilde{G}_P$	*Approximate transfer function*	-
H	*Henry's law constant*	-
K_C	*Controller Gain*	-
K_G	*Mass transfer coefficient of gas phase*	-
K_s	*Steady State Gain*	-
L_m	*The Molor Flow rates of The Gas and Liquid*	*Kmol/s*
P	*Total pressure which is constant*	$N\ m^{-2}$
r	*Integer power*	-
s	*Laplace Form*	-
t	*Time*	*s*
T_C	*Time constant*	-
X_1	*The Outlet Concentration(mol-fraction) of The solute in liquid*	
X_2	*The Inlet Concentration(mol-fraction) of The solute in liquid*	
Y_1	*The Inlet Concentration(mol-fraction) of The solute in gas*	
Y_2	*The outlet Concentration (mol-fraction)of The solute in gas*	

Y	*Mole fraction in the bulk of gas*	
Y_0	*Mole fraction that the gas would has if it was in equilibrium with the liquid*	

Greek Letters

Symbol	***Definition***	***Units***
τ	*Time constant*	*s*
τ_D	*Derivative time*	*s*
τ_I	*Integral time*	*s*

Subscripts

Symbol	***Definition***
i	*Number of component*
j	*Number of component*

Abbreviations

Symbol	***Definition***
ADC	*Analog to digital converter*
DAC	*Digital to analog converter*
MIMO	*Multi-input/Multi-output*
ODE's	*Ordinary differential equation*
P	*Proportional controller*
PI	*Proportional integral controller*
PID	*Proportional integral derivatives controller*

SISO *Single-input/Single- output*

IMC *Internal model control*

List of Tables

List of Figures

CHAPTER ONE

INTRODUCTION

1.1 Absorption Operation

Absorption column is a unit operation where the solute of a gas are removed by being placed in contact with a nonvolatile liquid solvent that removes the components from the gas [(1)].

Absorbers are often employed to remove trace components from gas streams [(2)].

Absorption operation is carried out in vertical, cylindrical columns or towers containing plates or packing elements. The plates and packing elements provide a surface area for the liquid and gas to come into contact facilitating mass transfer between the two streams. The gas and liquid streams for both operations are commonly counter-current for a more effective mass transfer [(1)].

There are two types of absorption, first type is the chemical absorption, in which the liquid solvent reacts with the gas stream and remains in solution. Second type is the physical absorption, in which the solute in the gas is more soluble in the liquid solvent and, therefore, the solute is transferred to the liquid. Chemical is usually preferred over physical because the equilibrium for chemical absorption is much more favorable for the separation. However, physical absorption is important since it can be applied when chemical absorption is not possible [(3)].

Absorption column has been the subject of many dynamic and control studies because of its unique and challenging control problems. These systems have many troubles some features from control standpoint, slow dynamic response, significant dead time's, non-linearity and multi variable interaction, and energy and material integration with other parts of the process. The stable and reliable performance of one or more absorption columns are very important for safe and economic operation of many plants [(2)].

1.2 Process Operation

Changing the conditions of the absorption column can influence the effectiveness and efficiency of absorption. Some important controlled variables are as follows:

- Pressure of the column.
- Temperature of entering liquid and gas streams.
- Humidity of the gas stream.
- Ratio of the liquid and gas stream rates.

Raising the total pressure of the column may increase the efficiency of the separation because increasing the pressure decreases the liquid flowrate and increases the concentration of the gas. The temperature of entering liquid affects absorption in that it affects the flow rate of liquid required for the separation with a given number of stages.

Inlet gases of the absorber with high humidity at a high temperature affect the capability of the gas to consume latent heat hindering the absorption process. Therefore, dehumidification of the inlet gas should be considered for absorbers with large heat effects. The ratio of the liquid to gas stream rates has effect in that if the ratio is too low, the solute builds in the upper portion of the column causing a higher temperature profile in the top of the column. As a result, internal cooling maybe necessary for lower liquid to gas ratios [4].

Gas liquid absorption is a heterogeneous process, which involves the transfer of a soluble component of a gas phase into a relatively non-volatile liquid absorbent [5].

1.3 Assumptions of an Absorption Column

The following assumptions are taken into consideration in developed/developing model for gas absorption packed column and in the analysis of the predicted result of the model [6]:

1. Absorption process is carried out in a series of contacts, with the occurrence of unidirectional mass transfer and counter-currently using diluted absorbent.
2. The column operates under steady state conditions, hence there are negligible heat effects in the column and the absorption process is accompanied by (pseudo-first order reaction).
3. There exist constant molal flow rates due to the occurrence of perfect mixing.

1.4 Process Control

The conventional method of process control is to use the feedback control loop with a controller. The control actions depend upon the control models present and at what values of gain and time constants of the model are set. A feed back system gives satisfactory control for a wide range of processes, and design of feedback loop does not demand any knowledge of the dynamic behavior of the process.

The feedback gives poor performance in process, which involves considerable time lags between the measurement of the controlled variable and the effect of the control action. If the lag is large and the controlled variable fluctuates quite rapidly, by the time the control action takes effect, it may well augment the disturbance rather than reduce it. Even If the disturbance is reduced eventually, the controlled variable can be outside the specification limits for considerable time [(7)].

More advanced control techniques involve feedforward and combined feed forward and feedback control. If the magnitude of an input disturbance can be measured and the effect of such disturbance on process is known, then control action may be taken before the products deviates from the specified values. This is in direct contrast to feedback control in which no action can be taken until the controlled variable moves away from its desired values, This type is feed forward control, so the advantage to feed forward control is that disturbance variable is measured and manipulated variable is changed before output is affected and the disadvantage to this approach is sensitivity to uncertainly [(8)].

The basic requirement of such system is that the effect of both input disturbance and changes in controlling variable on the controlled products be known, so to predict this effect theoretically, it is necessary to form some mathematical model of the process. In combined feedforward and feedback control, the feed forward control is applied first and any remaining error in the controlled variable is fedback to the feedback controller, which further adjusts the manipulated variable to achieve final control. In practice, feedforward control combined with feedback control accounts for uncertainly so that feed forward control is always used along with feedback control because a feedback control system is required to track set point changes and to suppress unmeasured disturbances that are always present in any real process. In fact, the feedforward of control system does not affect the stability of the feedback system and that each system can be designed independently [8].

1.5 Computer Analysis of Control System

The computer plays an important role in the design of modern control systems. Fortunately there is computer and software that remove the hard work from the task. With desktop computer, performance analysis, design, and simulation can be made with one program, with the ability to simulate a design rapidly, easily make changes and immediately test a new design. A computer model of the system behavior may be utilized to investigate various designs of a planned system without actually building the system itself [9].

Assuming that the model and simulation are reliably accurate,computer simulation has the following advantages:

1- Reduced cost.
2- Flexibility in responses to design changes.
3- Noise immunity.
4- System performance can be observed under all conceivable conditions.
5- Trial of system under test can be accomplished in a much-reduced period.
6- Simulation results can be obtained at lower cost than real experimentation.
7- Computer modeling and simulation is often the only feasible safe technique to analyze and evaluate a system.

The advantage of using computer is that many loops can be controlled or compensated by the same computer through time-sharing. Furthermore, any adjustments of compensator parameters required to yield a desired response can be made by a change in software rather than hardware.

Mathematical modeling and simulation are important and useful areas of computer application. In the mid 1970, engineers in industry were skeptical of simulation as a valid way to solve manufacturing problems, few people then believed accurate predictions from mathematical model. However, the prevailing view in industry is that it is much less expensive and more reproducible to run simulation experiment then that it is to perform repeated experiments involving actual equipment.

The confidence level in what can do with simulation has risen considerably, and this is having a deep influence on the practice of process engineering, the process control modules (PCM) area set programs written in the Matlab Simulink environment ($Matlab_8$ and Simulink) ($Matlab_8$) is a software package which enables carrying out many calculation associated with control systems including matrix computation, there are many specialized built-in functions for such things as gain value computation and bode analysis, the model is based on fundamental process model of industrial unit operation [9].

1.6 Aim of This Work

The aim of the present work is:

1- To analyze the system via bode plot from which the process stability steady state can be limited.

2- Design the required controller (P, PI and PTD)to improve process response and using (P ,PI and PID) as a convential control methods with tuning methods (Cohen-Coon, Ziegler Nichols)

3- Using IMC and Fuzzy control as advanced methods of control.

CHAPTER TWO

LITERATURE SURVEY

2.1 Absorption Column

Lewis and Whitman, in 1924 [10] pointed out that the basis of all processes involving the absorption or the escape of gas lies in the fact that a liquid-gas system which is not in equilibrium tends to approach equilibrium conditions. Thus, if the liquid is not saturated with gas under the existing conditions, absorption occurs, whereas if it is supersaturated the reverse is true. The escape of gas, as applied in this case, is merely negative absorption, and for simplicity the discussion will be confined to absorption alone. Equilibrium or saturation represents the ultimate state which the system tends to assume, and is the first of the primary characteristics of absorption phenomena to be considered. The other fundamental is the rate at which the system approaches equilibrium, and in many cases the rate is more important than the equilibrium itself. These two factors are not independent of each other and, in general, the rate is greater the further the system is from the equilibrium.

Danckwerts, in 1951 and 1954 [11,12] considered the liquid surface to be composed of a large number of small elements each of which is exposed to the gas phase for an interval of time after which they are replaced by fresh elements arising from the bulk of the liquid.

Cullen and Davidson, in 1957 [13] studied the absorption of carbon dioxide into a laminar jet of water. When the water was issued with a uniform velocity over every cross-section the measured rate of absorption corresponded closely to the theoretical value. When the velocity profile in the water was parabolic, the measured rate was lower than the calculated value; this was attributed to a hydrodynamic entry effect.

In an attempt to test the surface renewal theory of gas absorption **Danckwerts and Kennedy, in 1958** [14] measured the transient rate of absorption of carbon dioxide into various solutions by means of a rotating drum which carried a film of liquid through the gas. Results so obtained are compared with those for absorption in a packed column and it was shown that exposure times of at least 1s are required to give a strict comparison; this was longer than could be obtained with the rotating drum.

Absorption experiment in columns packed with spheres were carried out by **Davidson, in 1959** [15] who absorbed pure carbon dioxide into water. When a small amount of surface active agent was present in the water no appreciable mixing was found between the layers of spheres. With pure water, however, the liquid was almost completely mixed in this region.

Davidson, in 1959 [16] built up theoretical models of the surfaces existing in a packed bed. He assumes that the liquid runs down each surface in laminar flow and is then fully mixed before it commences to run down the next surface. The angles of inclination of the surfaces are taken as random. In the first theory he assumes that all the surfaces were of equal length, and in the second that there was a random distribution of surface lengths up to a maximum.

The possible existence of an interface resistance in mass transfer has been examined by **Raimondi and Toor, in 1959** [17] absorbed carbon dioxide into a laminar jet of water with a flat velocity profile, using contact times down to 1ms. They found that the rate of absorption was not more than 4 per cent less than that predicted on the assumption of instantaneous saturation of the surface layers of liquid. Thus, the effects of interfacial resistance could not have been significant.

When the jet was formed at the outlet of a long capillary tube so that a parabolic velocity profile was established, absorption rate was lower than predicted because of the reduced surface velocity. The presence of surface-active agents appeared to cause an interfacial resistance. But this effect is probably attributable to a modification of the hydrodynamic pattern.

Sternling and Scriven, in 1959 [18] examined interfacial phenomena in gas absorption and have explained the interfacial turbulence which has been noted by a number of workers in terms of the Marangoni effect which gives rise to movement at the interface due to local variations in interfacial tension. Some systems have been shown to give rise to stable interfaces when the solute is transferred in one direction, but instabilities develop during transfer in the reverse direction.

Garner, in 1959 [19,20] developed a vertical wind tunnel in which drops could be suspended for considerable periods of time in the rising gas stream. During the formation of each drop the rate of mass transfer was very high because of the high initial turbulence. After the initial turbulence died out, the mass transfer rate fell towards the rate for molecular diffusion provided that the circulation had stopped completely. In a drop with stable natural circulation the rate was found to approach 2-5 times the rate for molecular diffusion.

Roberts and Danckwerts, in 1962 [21] used a wetted-wall column to extend the times of contact up to 1.3 s. The column was carefully designed to eliminate entry and exit effects and the formation of ripples.

Danckwerts, Kennedy and Roberts, in 1963 [22] showed that experimental results and conclusions could be used, on the basis of the presentation theory model, to predict the performance of a packed column to within about 10 per cent. There have been many recent studies of the mechanism of mass transfer in a gas absorption system. Many of these have been directed towards investigation whether there is a significant resistance to mass transfer at the interface itself. In order to obtain results which can be readily interpreted it is essential to operate with a system of simple geometry.

Goodridge and Robb, in 1965 [23] used a laminar jet to study the rate of absorption of carbon dioxide into sodium carbonate solutions containing a number of additives including glycerol, sucrose, glucose and arsenates. For the short times of exposure used, absorption rates into sodium carbonate solution or aqueous glycerol corresponded to those predicted on the basis of pure physical absorption. In the presence of additives, however, the process was accelerated as the result of chemical reaction.

Levinspiel, in 1972 [24] noticed that chemical reactor design is based on the modeling of reactors and of the reactions that take place in them. Also, a mathematical model is a simplified image of the processes that take place in a reactor. It retains the most essential properties of the actual process and presents them in mathematical form. Depending on the objective sought, a mathematical model may involve a varying number of properties of the prototype, and so it may be wide or narrow. Mathematical modeling is so important that it is now being used in computer simulations. Also simulation represents the application of modeling techniques to real systems, thus enabling information on plant characteristics to be gained without either constructing or operating the full scale plant or the system under consideration. Simulation methods in chemical reactor designs are of two types, digital and analogue. Digital simulation involves the use of codes and program which are more in use since they can be implemented on modern computers at exceptional speed.

Coulson J.M. and Richardson J.E., in 1996 [25] considered that the removal of one or more selected components from a mixture of gases by absorption into a suitable liquid is based on interphase mass controlled largely by rates of diffusion. Absorption processes are therefore conveniently divided into two groups, those in which the process is solely physical and those where a chemical reaction is occurring. In considering the design of equipment to achieve gas absorption, the main requirement is that the gas be brought into intimate contact with the liquid, and the effectiveness of the equipment will largely be determined by the success with which it promotes contact between the two phases. In absorption, the feed is a gas and is introduced at the bottom of the column, and the solvent is fed to the top, as a liquid; the absorbed gas and solvent leave at the bottom, and the unabsorbed components leave as gas from the top.

Coulson, in 1996 [25] states that most reactions utilized in the chemical process industries involve substances, which exist in different phases. There may be two-phase (binary) and three-phase (tertiary) systems .For all the differences between them; they have one thing in common. Before a chemical reaction can take place, the reactants must be transported from the bulk of the stream and carry one phase to the inter-phase boundary or into bulk of the other phase.

2.2 Control Engineering

Control engineering is an engineering science that is used in many engineering disciplines-for example, chemical, electrical, and mechanical engineering-and it is applied to a wide range of physical systems from electrical circuits to guided missiles to robots. The field of *process control* encompasses the basic principles most useful when applied to the physicochemical systems often encountered by chemical engineers, such as chemical reactors, heat exchangers, and mass transfer equipment. The first significant work in automatic control was James Watt's centrifugal governor for the speed control of a steam engine in the eighteenth century. Other significant works in the early stages of development of control theory were due to Minorsky, Hazen, and Nyquist, among many others [(26)].

Minorsky, in 1922 worked on automatic controllers for steering ships and showed how stability could be determined from the differential equations describing the system.

Nyquist, in 1932 developed a relatively simple procedure for determining the stability of closed-loop systems on the bases of open-loop response to steady-state sinusoidal inputs.

Hazen, in 1934 introduced the term servomechanisms for position control systems, discussed the design of relay servomechanisms capable of closely following a changing input.During the decade of the 1940s, frequency-response methods (especially the Bode diagram methods due to Bode) made it possible for engineers to design linear closed-loop control systems that satisfied performance requirements.From the end of the 1940s to the early 1950s, the root-locus method due to Evans was fully developed. The frequency-response and root-locus methods, which are the core of classical control theory, lead to systems that are stable and satisfy a set of more or less arbitrary performance requirements. Such systems are, in general, acceptable but not optimal in any meaningful sense [26].

2.3 Control Strategies of Absorption Column

Steady state process models have long been used to assist the control engineer in designing control strategies for absorption columns. However, with the large number of industrial columns still operating in manual or with ineffectual controls. The control of absorption column has received a great interest because absorbing operations are found in almost every phase of the chemical industry.

They are also frequently used in the final step of purification of a product; thus, the accurate control of product composition and/or column performance may be very important.A control for the amount of a gaseous fluid absorbed in a liquid flowing through an absorption column comprises a gage in an outlet from the absorption column for the liquid having the gaseous fluid absorbed therein, an auxiliary absorption column of a substantially smaller capacity than that of the absorption column and receiving a comparatively small amount of the gaseous fluid in addition to the liquid is used, another gage in an outlet from the auxiliary absorption column for the liquid having the gaseous fluid absorbed there, the gages measuring respective parameters which are a function of the amount of the gaseous fluid absorbed in the liquid in the respective outlets and producing output signals corresponding to the respective parameters, a comparator is connected to the gages for receiving the output signals and comparing them to produce a control signal, and a flow control in the inlet for the gaseous fluid or the liquid of the absorption column, the flow is connected to the comparator and controlled by the control signal.[27]

Ebru K. and Soner G., in 2003 [28] describe the technical specifications of the "Computer Controlled Gas Absorption Column" to be procured for use in mass transfers in liquid-gas systems and they showed that control panel should provide the following:

1) There shall be a control panel between the gas absorption column and the computer, and control of process parameters shall also be possible over the control panel.
2) Indicators on the control panel shall be indicated schematically in conformity with the actual system
3) All sensors and the related signal powers shall be suitable for computer output.
4) The sensor connectors shall be of different form in order to prevent any connection errors (number of pins, shape, color etc.)
5) Calibration of all sensors in the process shall be possible.
6) The control panel shall have an enclosure for protection against any external interference and shall use filtered signals.
7) Real time on/off buttons shall be provided for pumps, compressors, heaters, control valves etc.

8) Real time parameter controls shall also be realized by PID control. There shall be proportional control, integral control (general, primary) and derivative controls (secondary) based on real time PID mathematic formula. Said controls shall be possible by changing proportional, integral and derivative constants.

Najim K., in 2007 [29] describes the model and solution of the constrained optimal control problem associated with a packed absorption column. The control problem is solved using a learning automaton operating in a random environment. On the basis of physical and chemical laws, a model has been developed. It consists of three hyperbolic partial non-linear differential equations. A solution of diethanolamine (the absorbent) is used to absorb the CO_2 contained in a gas mixture. The primary manipulated variables are the flow rate of the absorbent and the concentration of CO_2 in the gas mixture. The control objective is to maintain the concentration of CO_2 close to a desired value, subject to control limit restriction, in order to avoid the flooding of the column. It leads to a stochastic programming problem, the solution of which is closely associated with the behavior of an automaton in a random environment corresponding to the column. Detailed computer simulation results which demonstrate the performance of this automaton controller are presented.

2.3.1 Feedback Control

Feedback control is the achievement and maintenance of a desired condition using an actual value of this condition and comparing it with a reference (set point), then the difference between these two values (error signal (e)) is fed through a feedback controller transfer function *Gc(s)* and which sends out a signal (*COS)*. The controller output signal changes the position of control value, which changes the flow rate of manipulated variable *(M)* [30].

Moor, in 1970 [31] has worked with a scalar space model, using the analytic solution of the modeling equation to predict the value of the state one delay time ahead. This analytical predictor was developed primarily for sampled data systems and hence included in its structure corrections for effect of sampling and zero-order hold.

2.3.2 Feed Forward Control

Feed forward control mode is of a particular interest in absorption column control. The use of effective and economical feed forward control can result in increased profits over conventional feedback schemes, because the column can be operated with less specification product [32].

Luyben, in 1990 [33] found that a feed forward controller must calculate how to adjust the manipulated variable to precisely compensate for the effect of the disturbance. This can be done using a model of the process. A simple model might use steady state relationship among the variables or more complex dynamic model can be used.

Doyle, in 2000 [34] describes the feed forward control in absorption column as the control in which information concerning one or more conditions that can disturb the controlled variable is converted, outside of any feedback loop into corrective action to minimize deviation of the controlled variable. The basic idea of feed forward is measure the disturbance and sends this signal through a feed forward control algorithm that makes appropriate changes in the manipulated variable to keep the controlled variable near its desired value. Figure 2.1 represents the feed forward [34]

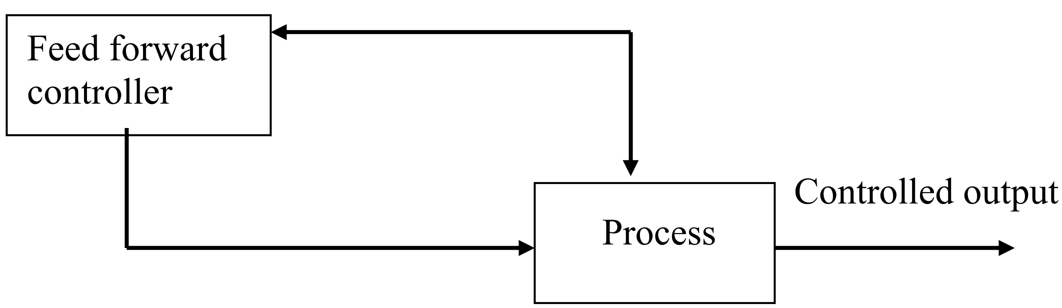

Figure 2-1 Feed forward control

2.3.3 Combined Feedback/Feed Forward Control

The feed forward control is the control in which information concerning one or more condition that can disturb the controlled variable converted, outside of any feedback loop, into corrective action to minimize deviation of the controlled variable.

Perry, in 1973 [35] found that the feed forward can rarely fulfill all the control requirements, so that the feedback control is normally used in combination with it. A rather specialized application for combined feed forward and feedback controllers illustrate some of the potential of such systems. In a two input, two-output process the output can be decoupled so that control action takes place as a result a measurement of one output variable will affect only that one output variable.

CHAPTER THREE

MODELING OF ABSORPTION COLUMN

3.1 Introduction

Absorption is usually carried out in packed columns. A column is essentially a pipe set on its end contains inert material or tower packing. The packing inside the column increases the area of contact between the gas and the liquid phase. The liquid is essentially fed from the top and trickles down through the packing. The gas, on the other hand, is pumped into the bottom and flows in the opposite direction. The two phases come in contact with each other inside the column, which facilitates the absorption of the gas into the liquid phase [36].

It is very difficult to measure the surface area of a liquid to or from which mass transfer takes place except in very few cases. Hence, in the case of a packed column, the mass transfer coefficient is expressed as $K_G a$ where (a) is the surface area per unit volume of packing.

The design of a packed absorption column mainly involves three steps [34].

(i) *Overall mole balance:* This indicates the overall size of the process to be designed.

(ii) *Diameter of the column:* For rapid mass transfer between the phases, intimate contact between the gas and the liquid is desirable. This is made possible if the gas and the liquid flow through a narrow range inside the tower.

(iii) *Height of the column:* The solute inside the column must be allowed sufficient time to diffuse from the gas into the liquid. This time depends on the height of the column.

3.1.1 Overall Mole Balance

In the case of dilute gas, if the liquid is non-volatile and the inert gas is practically insoluble in the liquid, we can take the gas and the liquid flow rates to be constant throughout the column. The overall mole balance at steady state becomes [36]

$$\begin{pmatrix}\text{solute entering}\\ \text{in gas stream}\end{pmatrix}-\begin{pmatrix}\text{solute leaving}\\ \text{in gas stream}\end{pmatrix}=\begin{pmatrix}\text{solute leaving}\\ \text{in liquid stream}\end{pmatrix}-\begin{pmatrix}\text{solute entering}\\ \text{in liquid stream}\end{pmatrix}$$

or,

$$\boldsymbol{G_M}(y_1-y_2)=\boldsymbol{L_M}(x_1-x_2) \qquad \ldots(3.1)$$

where $\boldsymbol{G_M}$ and $\boldsymbol{L_M}$ are the molar flow rates of the gas and liquid, respectively, kmoles/s

y_1,y_2 are the inlet and outlet concentrations of the solute in the gas, Mole-fraction

x_1,x_2 are the outlet and inlet concentrations of the solute in the liquid, Mole-fraction

3.1.2 Diameter of Absorption Column

The cross-sectional area of the tower essentially depends on two factors: the type of packing which provides a large contact area between the gas and the liquid and the nature of fluid flow [36].

Three main problems arise when a gas and liquid flow through a packed bed. ***Channeling*** occurs when the gas or liquid flow is much greater at some points than at others. This effect reduces the mass transfer and should naturally be avoided. This effect leads to the greatest problem in towers packed with stacked packing and is reduced to a minimum in randomly packed towers.

The other two problems are ***loading*** and ***flooding***. Let us consider a packed tower in which gas and liquid are flowing counter-current to each other. Initially there is no gas flow. At low rates of gas flow, the flow of the liquid is unaltered. But if the gas flow continues to increase, the liquid flow is disturbed and reduced until appoint is reached when the liquid starts accumulating in the bed. This condition is called loading. Under such a condition the pressure drop increases more rapidly with an increase in the gas flow rate. At very high rates of gas flow, the liquid stops flowing and the whole bed is occupied by it. This condition is called flooding. Flooding reduces the mass transfer dramatically. It can be avoided by reducing the liquid and the gas fluxes, i.e. flow rates per area. The fluxes are reduced by increasing the cross-sectional area of the tower. The optimum area is found from a plot of the gas flow at flooding as a function of the ratio of the liquid and gas flow rates, which is fixed for a given separation, usually 50-75% of this flux is taken as the actual flux. This empirical choice of 50-75% is desirable because a lower flux requires a large tower while a higher flux demands a large pump [36].

3.1.3 Height of Absorption Column

The height of a packed column for the absorption of a dilute gas mixture depends on the mole balance in the solute in the gas and liquid over the differential volume of the column as shown in Fig.(3.1). This differential volume is located at an arbitrary position Z in the column. In the case of dilute gas mixture, the amount of absorption is small and the gas flux $\boldsymbol{G_M}$ and liquid flux $\boldsymbol{L_M}$ are both taken as constant, independent of Z. the mass transfer coefficient can also be taken as constant throughout the tower [36].

Refer to Fig.(3.1) the material balance equation for the column is:

$$G_M (y_1 - y_2) = L_M (x_1 - x_2) \qquad \dots (3.2)$$

where y and x are the mole fractions of the solute in the gas and the liquid and subscripts 1 and 2 denote the bottom and top of the tower, respectively.

The mole balance on the solute in the gas and liquid over the differential volume gives

$$\boldsymbol{G_M}\, dy = \boldsymbol{L}_M\, dx \qquad \dots (3.3)$$

Or

$$\frac{G_M}{L_M} = \frac{dx}{dy} \qquad \dots (3.4)$$

Integrating

$$x = x_1 + \frac{G_M}{L_M}(y - y_1) \qquad \dots (3.5)$$

Considering the system as gas film controlling, the rate equation for the differential tower height dh may be expressed as

$$G_M \ \mathrm{d}y \times A = K_G a\mathrm{P}(y - y_e) \times A \times \mathrm{d}h \qquad \dots (3.6)$$

Where A is the cross sectional area of the column, a represents the packing area per volume and K_G is the overall gas phase mass transfer coefficient. y is the mole fraction in the bulk of gas and y_e is the mole fraction that the gas would have if it were in equilibrium with the liquid. P is the total pressure which is constant.

The height of the tower may be calculated by integrating Eq. (3.6)

$$h = \int_0^h \mathrm{d}h = -\frac{G_M}{K_G aP}\int_{y1}^{y2} \frac{\mathrm{d}y}{y - y_e} \qquad \dots (3.7)$$

The integral in Eq.(3.7)can be calculated if the equilibrium relationship is known. When the gas mixture is dilute**,**

$$y_e = Hx \qquad \dots (3.8)$$

Where H is the Henry's law constant. Putting this equilibrium relationship in Eq.(3.5) results in

$$y_e = H\left[x_1 + \frac{G_M}{L_M}(y - y_1)\right] \qquad \dots (3.9)$$

Substituting this equation in Eq. (3.7) yields

$$h = \frac{G_M}{K_G a P}\int_{y_2}^{y_1} \frac{dy}{(1 - HG_M / L_M)y + H\left[(G_M / L_M)y_1 - x_1\right]}$$

$$= \frac{G_M}{KGaP}\left(\frac{1}{1 - HGM / LM}\right)\ln\left(\frac{y_1 - Hx_1}{y_2 - H\left[x_1 + (G_M / L_M)(y_2 - y_1)\right]}\right)$$

$$= \frac{1}{K_G a P}\left(\frac{1}{1/G_M - H / L_M}\right)\ln\left(\frac{y_1 - Hx_1}{y_2 - Hx_2}\right) \qquad \dots (3.10)$$

This case involves the mass transfer of solute vapor from a gas into a liquid. Such a process is called *gas scrubbing*. The reverse process, i.e. the mass transfer of a vapor from a liquid into a gas is called *stripping*. The height of tower is calculated in terms of the gas phase mass transfer coefficient. It may also be obtained from an analogous equation in terms of the liquid phase mass transfer coefficient using liquid phase mole fractions [36].

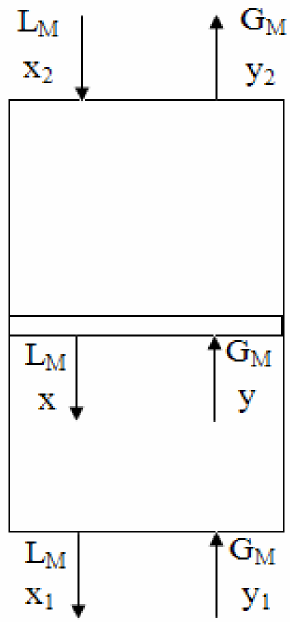

Figure (3-1) Material balance for packed column (36)

3.2 Description of Absorption Column Used in This Work

In this work, a gas-liquid absorption packed column operating under a continuous mode for the absorption of air-water system. Gas absorption is usually carried out in vertical counter current packed column. The packed column is arranged to operate individually. The liquid solvent is fed at the top of the column and is distributed over the surface of the packing either by nozzle or distribution plates. Pressure tapping is provided at the base, center and top of the column to determine pressure drops across the column. Sampling points are also provided for the gas at the same three points. The liquid outlet stream and feed solution are also equipped with sampling point. Suitable manometer measurement is included. Water/solvent is taken from a sump tank, and pumped to the column via a calibrated flow meter. Air/solute is supplied and monitored from a small compressor. The effluent gas leaves the top of the column and is intended to be exhausted to atmosphere outside the laboratory building. The apparatus is designed to absorb air into an aqueous solution flowing down the column. Gas analysis is provided for this system shown in Fig.(3.2) [37].

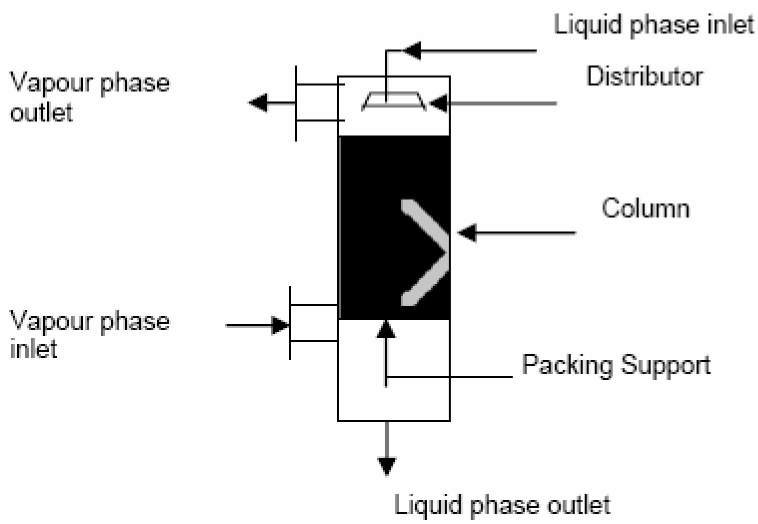

Figure (3-2) Gas absorption column(37)

The apparatus used in the experiments consists of a glass packed cylindrical tower filled with packing material. The packing material used was a 3/8" glass Raschig ring randomly packed into a three inch diameter by six foot high section. A Raschig ring is simply a hollow cylinder that has an outer diameter equal to its height. The liquid and gas streams are designed to flow counter-currently past each other to obtain the greatest absorption rate. The liquid (tap water) enters the column from the top and exits out the bottom, while the gas (air) enters the bottom of the column and exits through the top. Each inlet stream has two flow meters; one mechanical and the other an electrical transmitter. [38].

3.3 The Control Strategies

In this work different control strategies both conventional and advanced are used to show its effect on the system. Feed control in general is used to achieve and maintain the desired condition using an actual value of this condition it compares it to a reference value *(set point)*, using differences between those values to eliminate any difference between them. Most controllers use negative feedback, which measures process output (controlled variable), subtracted from a desired value *(set point)* to generate an error signal. The controller recognizes the error signal and manipulates a process input (control element), to reduce the error. The most important types of industrial feedback controllers; include *P, PI, and PID* controller. [39]

3.3.1 Proportional Control (*P*):

In this type of control the output of proportional controller changes only if the error signal changes. Since a load change requires a new control valve position, the controller must end up with a new error signal; this means that proportion controller usually gives a steady state error off set. The magnitude of the offset depends on the size of the load disturbance and on the controller gain, that means the bigger gain, the smaller the offset as the gain is made bigger, however, the process becomes under damped and eventually at still higher gain, the loop will go unstable, acting like an on/off.

$$P \, \alpha \, E(t) \qquad \ldots (3.11)$$

where p is proportional controller;

Moreover, E (t) is the error which depends on time:

$$P = G_c E(t) + P_S \qquad \text{... (3.12)}$$

$$G_C = K_c \qquad \text{... (3.13)}$$

$$P - P_S = K_c E(t) \qquad \text{... (3.14)}$$

$$P(S) = K_c E(s) \qquad \text{... (3.15)}$$

$$\frac{P(S)}{E(S)} = K_c = G_c(S) \qquad \text{... (3.16)}$$

Therefore, the transfer function of proportional controller is

$G_c = K_c$ … (3.17)

In the frequency response, proportional controller merely multiplies the magnitude of system at every frequency by constant *kc*. On bode plot, this means proportional controller raises the log magnitude curve by 20log*(kc)*dB but has no effect on the phase angle curve [40].

3.3.2 Proportional Integral Controller (PI)

Most control loops use PI controller. The integral action eliminates steady state error. The smaller τ_I then the faster the error is reduced, but the system becomes more under damped as τ_I is reduced, if it is made too small, the loop becomes unstable.

$$P = K_c E(t) + \frac{K_c}{\tau_I} \int_0^t E(t)\, \partial t + P_S \qquad \text{... (3.18)}$$

τ_I is the integral time constant

$$P - P_S = K_c E(t) + \frac{K_c}{\tau_I} \int_0^t E(t)\,\partial t \qquad \text{... (3.19)}$$

$$P(s) = KcE(s) + \frac{Kc}{\tau I}\frac{E(t)}{s} \qquad \text{... (3.20)}$$

$$\frac{P(S)}{E(S)} = K_c E(S) + \frac{K_c}{\tau_I S} \qquad \text{... (3.21)}$$

Therefore, the transfer function of proportional integral controller is:

$$G(S) = K_c(1 + \frac{1}{\tau_I S}) \qquad \text{... (3.22)}$$

In bode plot, at low frequency a proportional integral controller amplifies magnitudes and contributes -90 of phase angle lag. This loss of phase angle is undesirable from a dynamic standpoint since it moves the *Gm Gc* polar plot closer to the (-1,0)point [40].

3.3.3 Proportional Integral Derivatives Controller (PID)

PID controller is used in loops where signals are not noisy and where tight dynamic response is important. The derivative action helps to compensate for lags in the loop.

$$P = K_c E(t) + \frac{K_c}{\tau_I} \int_0^t E(t)\,\partial t + K_c \tau_d \frac{\partial E(t)}{\partial t} + P(S) \qquad \text{... (3.23)}$$

$$P - P(S) = K_c E(t) + \frac{K_c}{\tau_I} \int_0^t E(t)\,\partial t + K_c \tau_d \frac{\partial E(t)}{\partial t} \qquad \text{... (3.24)}$$

$$P(S) = K_c E(S) + \frac{K_c}{\tau_I S} E(S) + K_c \tau_d SE(s) \qquad \text{... (3.25)}$$

$$\frac{P(S)}{E(S)} = K_c + \frac{K_c}{\tau_I S} + K_c + \tau_d S \qquad \text{... (3.26)}$$

$$G(S) = K_c\left(1 + \frac{1}{\tau_I S} + \tau_d S\right) \qquad \text{... (3.27)}$$

Two methods are used to find K_C, τ_I and τ_D (40)

3.4 Ziegler-Nichols Tuning

The Ziegler-Nichols controller setting is standards in the control field. The Ziegler-Nichols tuning consists of first finding the ultimate gain Ku, the value of gain at which the loop is at the limit of stability with (P) only feedback controller. The period of the resulting oscillation is called the ultimate period, Pu (minutes per cycle).The Ziegler-Nichols settings are then calculated below for the three types of controllers. Notice that a lower gain is used when integration is included in the controller (PI) and that the addition of derivatives permits a higher gain and faster rest [(41)].

3.5 Cohen-Coon Tuning

The Cohen-Coon tuning of controller tuning corrects the slow, steady-state response given by the Ziegler-Nichols tuning when there is a large dead time (process delay) relative to the open loop time constant; a large process delay is necessary to make this method practical because otherwise unreasonably large controller gains will be predicted. This method is only used for first-order models with time delay; due to the fact that the controller does not instantaneously respond to the disturbance (the step disturbance is progressive instead of instantaneous).The Cohen-Coon tuning is classified as an 'offline' method for tuning, meaning that a step change can be introduced to the input once it is at steady-state. Then the output can be measured based on the time constant and the time delay and this response can be used to evaluate the initial control parameters [42].

Advantages [43]

1. Used for systems with time delay.
2. Quicker closed loop response time.

Disadvantages and Limitations [43]

1. Can only be used for first order models including large process delays.
2. Offline method.
3. Approximations for the K_c, τ_i, and τ_d values might not be entirely accurate for different systems.

3.6 Internal Model Control (IMC)

One of the most popular control strategies in industrial process control is the Internal Model Control (IMC) strategy, because of its simple structure, fine disturbance rejection capabilities and robustness. This control strategy can be used for both linear and non-linear systems. The IMC design is lucid for the following reasons [(44)]:

1- It separates the tracking problem from the regulation problem.
2- The design of the controller is relatively straightforward.

The IMC strategy is especially suitable for the design and implementation of the open-loop stable systems and many industrial processes happen to be intrinsically open-loop stable. A more elegant approach is internal model control (IMC). The premise of IMC is that in reality, we only have an approximation of the actual process. Even if we have the correct model, we may not have accurate measurements of the process parameters. Thus the imperfect model should be factored as part of the controller design. In the block diagram implementing IMC (Fig. 3.3), our conventional controller G_c consists of the (theoretical) model controller G^*_c and the approximate function $\breve{G}_p$ [(44)].

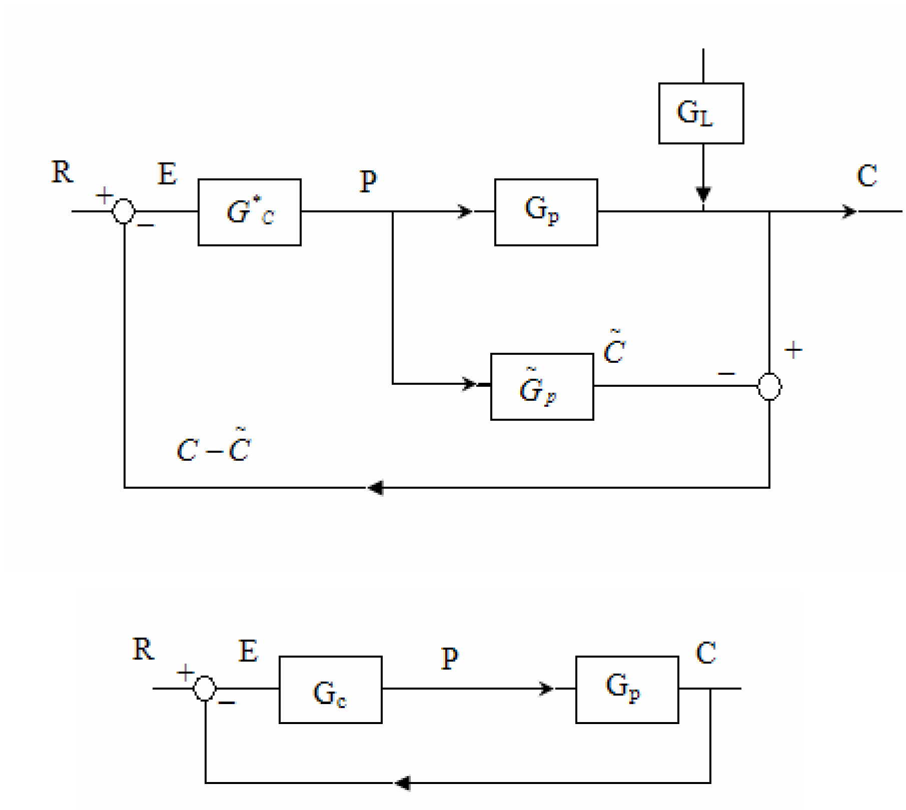

Figure (3-3) A system with IMC (upper panel) as compared with a conventional system in the lower panel.

We first need to derive the closed-loop functions for the system. Based on the block diagram, the error is

$$E = R - (C - \check{C}) \qquad \dots (3.28)$$

And the model controller output is

$$P = G^*_c\, E = G^*_C(R - C + \check{C}) \qquad \dots (3.29)$$

If we substitute $\check{C} = \breve{G}_p\, P$ we have

$$P=G^*_C(R - C + \breve{G}_p P) \qquad \dots (3.30)$$

from which we can rearrange to obtain

$$P = \frac{G^{*}{}_{C}}{1 - G^{*}{}_{C}\,\tilde{G}_{P}} \quad \ldots (3.31)$$

The gist of this step is to show the relationship between the conventional controller function G_c and the other functions:

$$G_{C} = \frac{G^{*}{}_{C}}{1 - G^{*}{}_{C}\,\tilde{G}_{P}} \quad \ldots (3.32)$$

This is an equation that will be used to retrieve the corresponding PID controller gains. For now, we substitute Eq.(3.31) in an equation around the process,

$$C = G_{L}L + G_{P}P = G_{L}L + \frac{G_{P}G^{*}{}_{C}}{1 - G^{*}{}_{C}\,\tilde{G}_{P}}(R - C) \quad \ldots (3.33)$$

From this step, we derive the closed-loop equation

$$C = \left[\frac{\left(1 - G^{*}{}_{C}\,\tilde{G}_{P}\right)G_{L}}{1 + G^{*}{}_{C}\left(G_{P} - \tilde{G}_{P}\right)}\right]L + \left[\frac{G_{P}G^{*}{}_{C}}{1 + G^{*}{}_{C}\left(G_{P} - \tilde{G}_{P}\right)}\right]R \quad \ldots (3.34)$$

The terms in the brackets are the two closed-loop transfer function. As always, they have the same denominator---the closed---loop characteristic polynomial.There is still one unfinished business. We do not know how to choose $G^{*}{}_{C}$ yet. Before we make this decision, we may recall that the poles of G_C are "inherited" from the zeros of G_P. If G_P has positive zeros, it will lead to a G_C function with positive poles. To avoid that, we "split" the approximate function as a product of two parts:

$$\tilde{G}_P = \tilde{G}_{P+} \tilde{G}_{p-} \qquad \text{… (3.35)}$$

With $\tilde{G}_{P+}$ containing all the positive zeros, if present. The controller will be designed on the basis of $\tilde{G}_{P-}$ only. Now define the model controller function is defined as

$$G^*_C = \frac{1}{\tilde{G}_{P-}}\left[\frac{1}{\tau_C\ s+1}\right]^r \quad \text{, where } r = 1,2, \text{etc.} \qquad \text{… (3.36)}$$

τ_C equal two-thirds the value of dead time

τ_c is the closed-loop time constant and our *only* tuning parameter. The first order function raised to an integer power of *r* is used to ensure that the controller is physically realizable.

Repeat the derivation of a controller function for a system with a first order process with dead time using IMC.

By modeling our process as a first order function with time delay, and expecting experimental errors or uncertainties, our measured or approximate model function $\tilde{G}_p$ is

$$\tilde{G}_p = \frac{K_p e^{-t_d s}}{\tau_p s+1} \qquad \text{… (3.37)}$$

The first order Padé approximation is used for the dead time and the positive zero term is isolated as in Eq.(3.35)

$$\tilde{G}_p = \frac{K_p}{(\tau_p s+1)(\frac{t_d}{2}s+1)}(-\frac{t_d}{2}s+1) = \tilde{G}_{p-}\tilde{G}_{p+} \qquad \ldots (3.38)$$

where

$$\tilde{G}_{p+} = (-\frac{t_d}{2}s+1) \qquad \ldots (3.39)$$

If we choose r = 1, Eq.(3.36) gives

$$G^*_C = \frac{(\tau_p s+1)(\frac{t_d}{2}+1)}{K_p}\frac{1}{(\tau_C s+1)} \qquad \ldots (3.40)$$

Substitution of Eq.(3.38) into Eq.(3.32), and after some algebraic work, will lead to the tuning parameters of an ideal PID controller :

$$K_C = \frac{1}{K_p}\frac{2\frac{\tau_p}{t_d}+1}{2\frac{\tau_C}{t_d}+1} \quad ; \quad \tau_1 = \tau_p + \frac{t_d}{2} \quad ; \quad \tau_D = \frac{\tau_p}{2\frac{\tau_p}{t_d}+1} \qquad \ldots (3.41)$$

3.7 Fuzzy Control Method

Fuzzy control is a control method based on fuzzy logic. Just as fuzzy logic can be described simply as ''computing with words rather than numbers''; fuzzy control can be described simply as ''control with sentences rather than equations'' [(45)].A fuzzy controller can include empirical rules, and that is especially useful in operator controlled plants.

Take for instance a typical fuzzy controller

1. If error is Neg and change in error is Neg then output is NB
2. If error is Neg and change in error is Zero then output is NM

The collection of rules is called a *rule base*. The rules are in the familiar if-then format, and formally the if-side is called the *condition* and the then-side is called the *conclusion* (more often, perhaps, the pair is called *antecedent-consequent or premise-conclusion*). The input value ’’Neg’’ is a *Linguistic term* short for the word *Negative* the output value ’’NB’’ stands for *Negative Big* and ’’NM’’ for *Negative Medium*. The computer is able to execute the rules and compute a control signal depending on the measured inputs *error* and *change in error*. There is no design procedure in fuzzy control such as root-locus design, frequency response design, or stability margins, because the rules are often nonlinear. The rules may use several variables both in the condition and the conclusion of the rules. The controllers can therefore be applied to both multi-input-multi-output (MIMO) problems and single-input-single-output (SISO) problems. The typical SISO problem is to regulate a control signal based on an error signal. The controller may actually need both the *error*, the *change in error*, and the *accumulated error* as inputs, but we will call it single-loop control, because in principle all three are formed from the error measurement.

Basically a linguistic controller contains rules in the format, but they can be presented in different formats. In many systems, the rules are presented to the end-user in a format similar to the one below [45],

1. If error is Neg and change in error is Neg then output is NB
2. If error is Neg and change in error is Zero then output is NM
3. If error is Neg and change in error is Pos then output is Zero
4. If error is Zero and change in error is Neg then output is NM
5. If error is Zero and change in error is Zero then output is Zero
6. If error is Zero and change in error is Pos then output is PM
7. If error is Pos and change in error is Neg then output is Zero

8. If error is Pos and change in error is Zero then output is PM
9. If error is Pos and change in error is Pos then output is PB

The names *Zero, Pos, Neg* are labels of fuzzy sets as well as *NB, NM, PB* and *PM* (negative big, negative medium, positive big, and positive medium respectively). The same set of rules could be presented in a *relational* format, a more compact representation [45].

Error	Change in error	Output
Neg	Pos	Zero
Neg	Zero	NM
Neg	Neg	NB
Zero	Pos	PM
Zero	Zero	Zero
Zero	Neg	NM
Pos	Pos	PB
Pos	Zero	PM
Pos	Neg	Zero

A third format is the tabular linguistic format.

		Change in error		
		Neg	Zero	Pos
Error	Neg	NB	NM	Zero
	Zero	NM	Zero	PM
	Pos	Zero	PM	PB

3.8 Description of Computer Control

The computer system requires personal computer, this unit is shown in Fig (3.4a) [(9)].

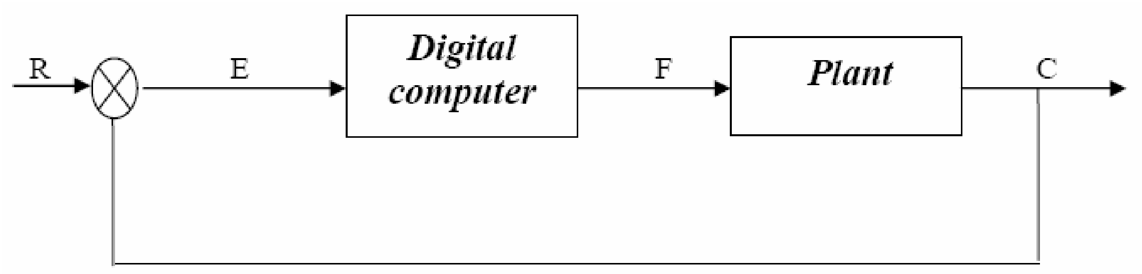

Figure (3-4a) Digital computer

We notice that the signal *R, E, F* and *C* can take on two forms digital or analog. Up to this point, analog signals are used exclusively. Digital signals, which consist of a sequence of binary numbers, are found in loops containing digital computers. This loop containing both analog and digital signal must provide a means for conversion from one form to the other as required by each subsystem. A device that converts analog single to digital single is called an analog to digital converter *(A/D),* and a device that convert digital signals to analog signals is called a digital-to-analog converter*(D/A)* The unit containing these two converters is called an interface unit, these unite are shown in Fig 3.4b [(9)].

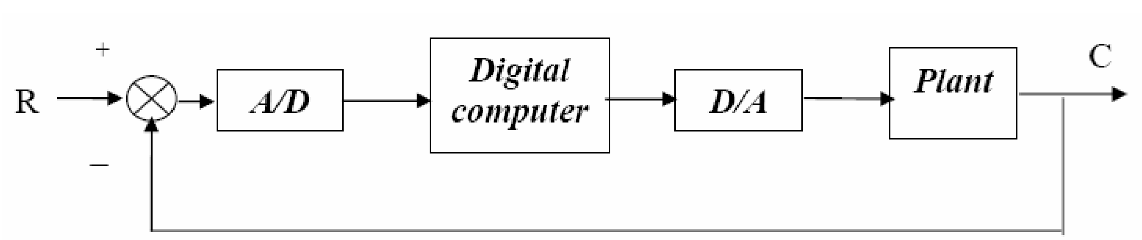

Figure (3-4b) Digital computer with converters

3.8.1 An Interface Unit

An interface unit receives on analog signal and converts it to digital signal through an ADC then sends it to the computer. The output signal from the computer is loaded to the *DAC*, which converts it to an analog signal. Then this signal is applied to the control element [9].

3.8.1.1 Input Interfacing

Most *ADC'S* are available in the form of integrated circuits(IC). It is connected to the measuring device via an amplifier to receive a suitable input signal. The overhead and bottom composition were measured using the measuring devices, which was connected to the *ADC* by means of an amplifier to make the signal larger before it was sent to the *ADC* [9].

3.8.1.2 Output Interfacing

Digital to analog converter (*DAC*) accepts digital information and transforms it to an analog voltage. The digital information is in the form of a binary number with some fixed number of digits. Especially when used in connection with a computer this binary number called a binary word or computer word. The *DAC* converts a digital word into an analog voltage [9].

3.8.2 Process Simulation

Process simulation technology has evolved dramatically over the past years with the increasing application of object-oriented programming. Many packages are available which allows intuitive visualization of process data coupled with user-friendly graphical interface, which allows rapid synthesis of process flow sheets using click and drag operations.

3.8.3 Process Control Modules

Process control modules are set of programs written in the Matlab/Simulink environment. The modules based on fundamental process models of absorption column, and incorporate a realistic graphical user interface to emulate an industrial control environment they were developed to allow educator to strike a proper balance between theory and practice using a computer-based control laboratory [(46)]. Such laboratory can address a variety of issues in process control, modeling, identification, simulation, analysis and design. The software tools that we have chosen for the instructional laboratory are Matlab (matrix laboratory) and Simulink (dynamic system simulation software). They represent an interactive program for scientific and engineering calculations [(46)]. The primary distinction of the PCM software package is the ability to incorporate complex dynamical process models with convenient graphical user interfaces (developed in the Matlab graphics language). In a way to achieve a realistic emulation of an industrial distributed control system operator's console. Furthermore, the entire packages are based on commercial software plate form (Matlab), which allows individual instructors customize or add to existing modules [(46)].

3.8.4 Simulink Response

Simulink Response Optimization can also improve the tuning of look up tables and aid in gain scheduling. Simulink has block libraries from which subsystems, sources (transfer function), and sink (scope). Sub system blocks are variable for responding linear, nonlinear, and discrete systems. Therefore, the responses of absorption column are obtained using Simulink. Simulink Response Optimization is a tool that helps to tune design parameters in Simulink models by optimizing time-based signals to meet user-defined constraints.

It optimizes scalar, vector, and matrix-type variables and constrains multiple signals at any level in the model. Simulink Response Optimization supports continuous, discrete, and militate models and enables you to account for model uncertainty by conducting Monte Carlo simulations [(47)].

3.8.5 Frequency Response Method

Frequency response of a system defined, as the steady state response of the system to sinusoidal resulting output signal for linear system, as well as signals throughout the system, is sinusoidal in the steady state, it differs from the input waveform only in amplitude and phase angle. There are three different kinds of plots commonly used to show how magnitude ratio (absolute magnitude) and phase angle (argument) vary with frequency *W*. They are called Nyquist, Bode, and Nichols plots [(40)].

There are some definitions for gain margin and phase margin:-

The phase margin is the amount of additional phase angle at the gain crossover frequency required to bring the system to instability. The gain crossover frequency is the frequency at which the magnitude of the open loop transfer function is unity. The phase margin is 180 plus the phase angle of the open loop transfer function at the gain crossover frequency. For minimum-phase system to be stable, the phase margin must be positive, while the gain margin is the reciprocal of the magnitude at the frequency at which the phase angle is -180. The phase crossover frequency is the frequency at which the phase angle of the open-loop transfer function equals -180 gives the gain margin [48].

3.9 Obtaining Transfer Function

The analytical determination for the system's transfer function is difficult. The individual component values have been known, or the internal configurations of the system may not be accessible. In such cases, the frequency response of the system, from input to output is obtained experimentally by using the frequency response plot experimentally, by using a sinusoidal force or signal generator at the input of the system and measures the output of steady state sinusoidal amplitude and phase angle. Repeating this process at a number of frequencies yields data for a frequency response plot. The transfer function can be presented as a block diagram, where the input is on the left and the output on the right and the system transfer function inside block [9,48].

3.10 The Transfer Function Models

The gas flow transmitter changes a gas flow rate reading into a voltage, which is sent to and interpreted as a numerical value by the computer. Transmitters have transfer functions that when multiplied by the input variables give an output variable. The output variable of the transfer function should be a representation of the actual dynamic response.

Transfer functions can be useful for analyzing dynamic behavior and designing control systems. A transfer function can be defined as the Laplace transform of the output divided by the Laplace transform of the input variable. The transfer function for the gas flow transmitter can be represented in the following form [38]:

$$\frac{Y(s)}{X(s)} = \frac{K e^{-t_o s}}{\tau s + 1} \qquad \ldots (3.42)$$

This transfer function is referred to as First Order Plus Dead Time (FOPDT), where K is the system Gain, τ is the first order time constant, and t_o is the dead time.The gas flow was subjected to step changes in input at various flow rates and the data collected .Each step change was graphed as a plot of air flow rate vs. time. The values for the gain, Tau, and dead time were determined for each step change using FIT 1 found in the Smith and Corripio controls. The values from FIT 1 where used as a starting point for the modeling. Three step changes in gas flow rates were modeled including a low, medium, and a high change in step of gas flow rate.

The results are as following:

Table (3.1) FOPDT Variables for Modeling

Water Flow Rate(g.p.h)	Delta Air Flow (s.c.f.p.m)	Gain	Tau	Deadtime
22	.53	1	5.9	1.5
22	1.6	1	7	.3
22	3.95	1	7.2	1.1
AVERAGE=		1	6.7	.755

The averages values in Table (3.1) are the values that were used to construct the transfer function of the Gas flow transmitter shown below:

$$G_s = \frac{e^{-0.755s}}{6.7s+1} \qquad \text{... (3.43)}$$

3.11 The Closed Loop Transfer Function In Frequency Domain Dynamic

Frequency response is based on converting system's differential equation to transfer function. Thus, generating mathematical model of the system that algebraically relates representation of the output to the input. Replacing differential equation with an algebraic equation not only simplifies the representation of individual sub-system but also simplifies, modeling interconnected sub-systems [9].

The closed loop transfer function for unity feedback system derived as- Typically, the first order transfer function is- [49]

$$G(S)=\frac{1}{\tau S+1} \qquad \text{... (3.44)}$$

The closed loop transfer function is:-

$$T(S)=\frac{G(S)}{1+G(S)} \qquad \text{... (3.45)}$$

$$T(S)=\frac{1/\tau S+1}{1+1/\tau S+1} \qquad \text{... (3.46)}$$

$$T(S)=\frac{1}{\tau S+2} \qquad \text{... (3.47)}$$

3.12 Time Delay

Time delay occurs in control system when there is a delay between the commanded response and the start of output response [(9)]. Time delay in feedback control loops often is a serous obstacle to good process operation, such delay prevents high controller gains from being used, leading to offset and sluggish system response [(50)].

Ray [(51)], suggested in absence of time delays, there are many multivariable control design procedure available for choosing the element *Gc* in order to achieve good control system performance.

Aleviskis and Seborg [(51)] suggested when the system has only one time delay, useful design method be also available.

Soliman and Ray [(51)] suggest a system contain multiple delay in the transfer function the choice of design algorithms is more limited.

Smith [52] developed a time delay commentator for single delay in single control loop which elemental the delay from the feed back loop, allowing higher controller gain, in our system the effect of multiple delays in control and out put variables.

3.13 Bode Diagrams

A Bode diagram consists of two graphs: One is a plot of the logarithm of the magnitude of a sinusoidal transfer function; the other is a plot of the phase angle; both are plotted against the frequency on a logarithmic scale. The standard representation of the logarithmic magnitude of $G(jw)$ is $20 \log \left| G(jw) \right|$, where the base of the logarithm is 10. The unit used in this representation magnitude is the decibel, usually abbreviated dB [41].In the logarithmic representation, the curves are drawn on semilog paper, using the log scale for frequency and the linear scale for either magnitude (but in decibels) or phase angle (in degrees).The main advantage of using the Bode diagram is that multiplication of magnitudes can be converted into addition. Furthermore, a simple method for sketching an approximate log-magnitude curve is available. It is based on asymptotic approximation. Such approximation by straight-line asymptotes is sufficient if only rough information on the frequency-response characteristics is needed. Should the exact curve be desired, corrections can be made easily to these basic asymptotic plots. Expanding the low-frequency range by use of a logarithmic scale for the frequency is highly advantageous since characteristics at low frequencies are most important in practical systems. Although it is not possible to plot the curves right down to zero frequency because of the logarithmic frequency (log0= $-\infty$), this does not create a serious problem. Note that the experimental determination of a transfer function can be made simple if frequency-response data are presented in the form of Bode diagram.(41)

CHAPTER FOUR

SIMULATION RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the result of system using simulation response, Simulink and $Matlab_8$ programs are used to show the composition response, in using different methods of control.Take a single input-single output (SISO) absorption column as a system, which is analyzed by frequency response method and find the stability of the column. Also, it discusses the root locus and Bode diagram to observe the values of gain margin, phase margin and their frequencies in the P, PI and PID controllers for each of the used methods to find out which one of these methods is the more stable.

4.2 Process Simulation

The process simulation is represented and explain in these figures. Before running the process simulation controllers we must test it without controllers.

First Figure (4.1) and (4.2) represent the block and step respons respectively of absorption column without any controller.

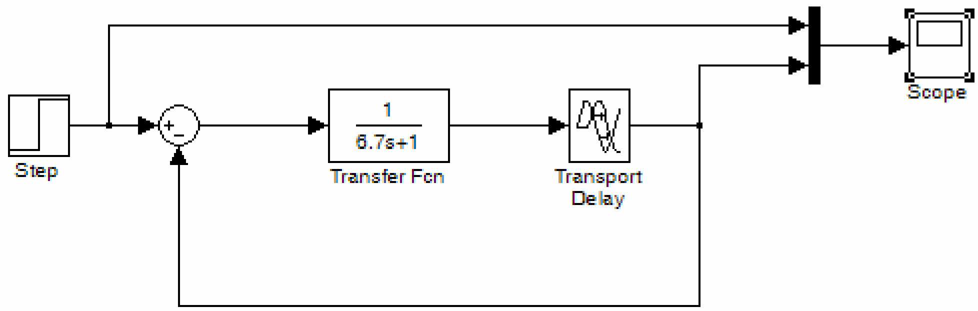

Figure (4-1) Block diagram of absorption column without controller

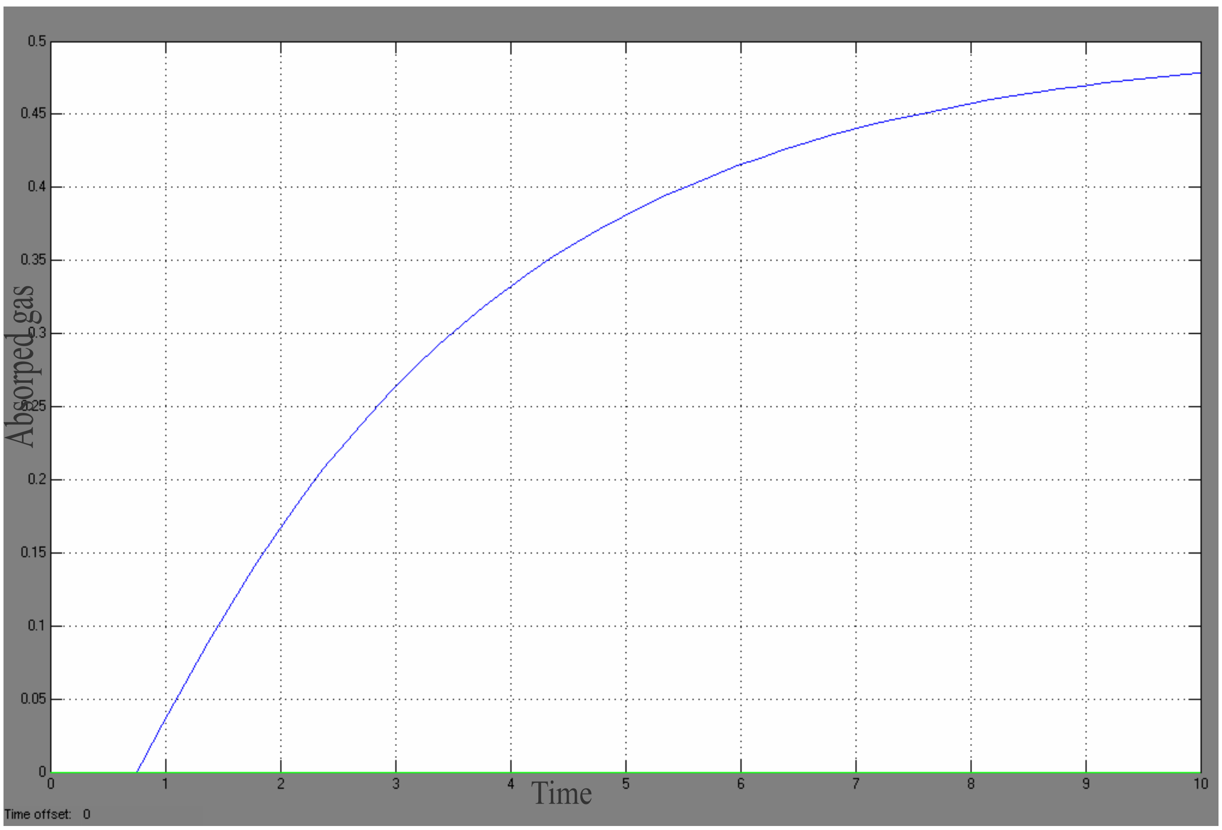

Figure (4-2) Response of absorption column without controller

Figure (4.2) The step change of system without controller .

In Figure (4.3) we can see the system with controller.

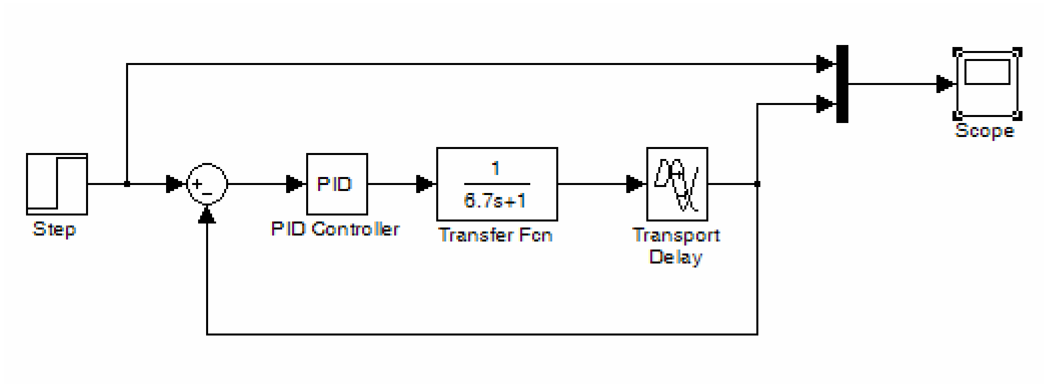

Figure (4-3) Block diagram with controller

Now, comparison is made between P, PI and PID for each method used in this work via response to see which is the best value of controller setting that gives the best steady state value of control variable.When the P controller is applied to the Cohen-Coon tuning and Ziegler-Nichols tuning we get the following diagrams:

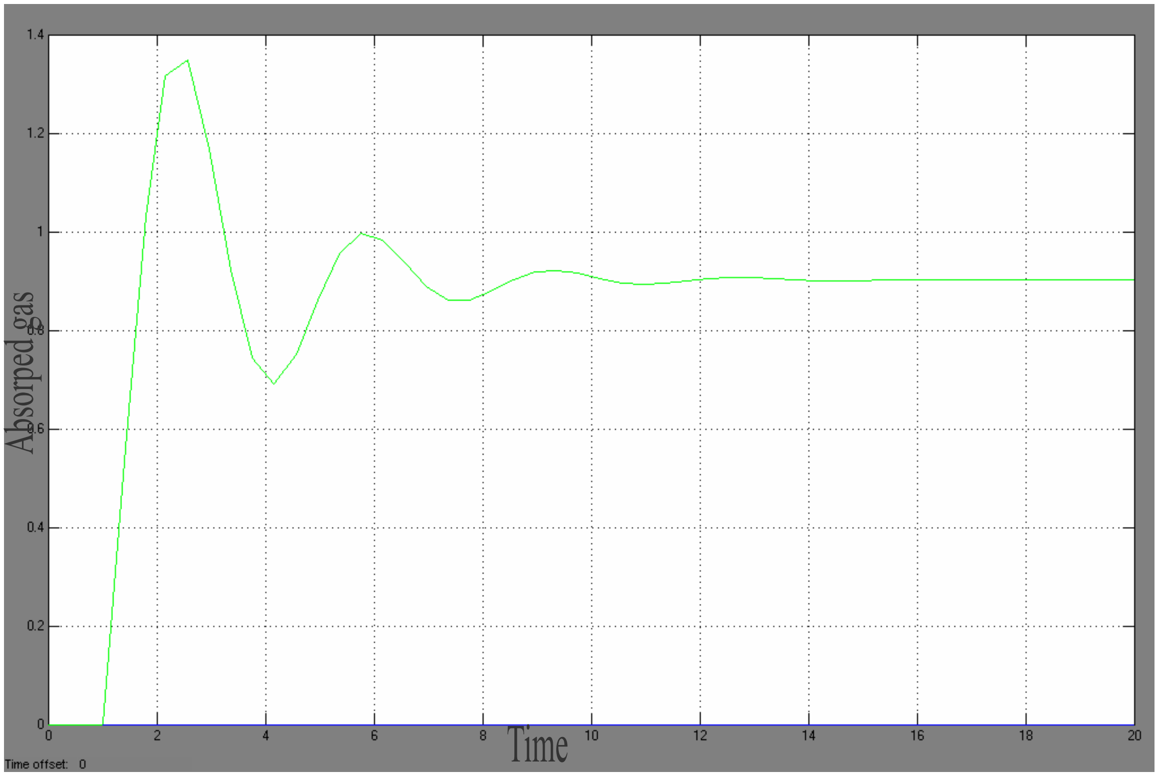

Figure (4-4) Response of control variable using P controller with Cohen-Coon tuning

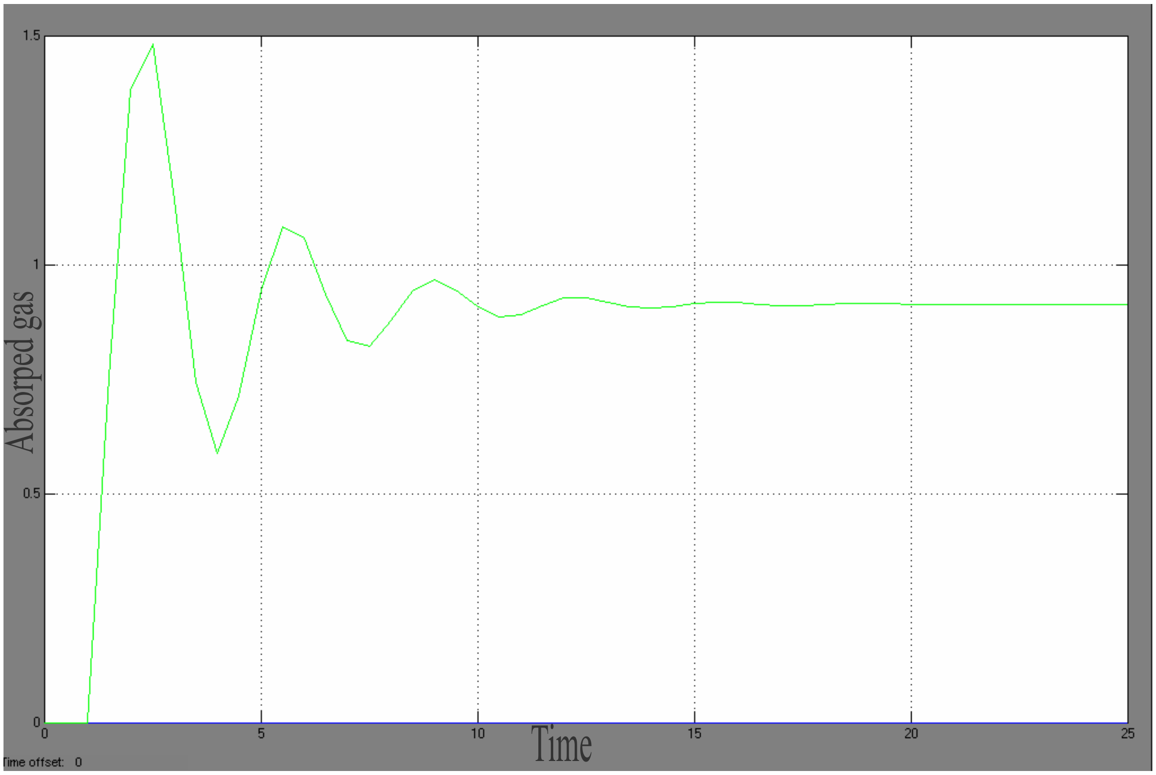

Figure (4-5) Response of control variable using P controller with Ziegler-Nichols tuning

Figures (4.4) and (4.5) show that when we apply the proportional action only, the control system is able to arrest the rise of the controlled variable and ultimately bring it to rest at a new steady-state value. The difference between this new steady-state value and the original value is called ***offset***. The offset value of these figures is 2.2%.

In the PI controller when it is applied to the Cohen-Coon tuning, Ziegler-Nichols tuning and Internal model control we get the following diagrams:

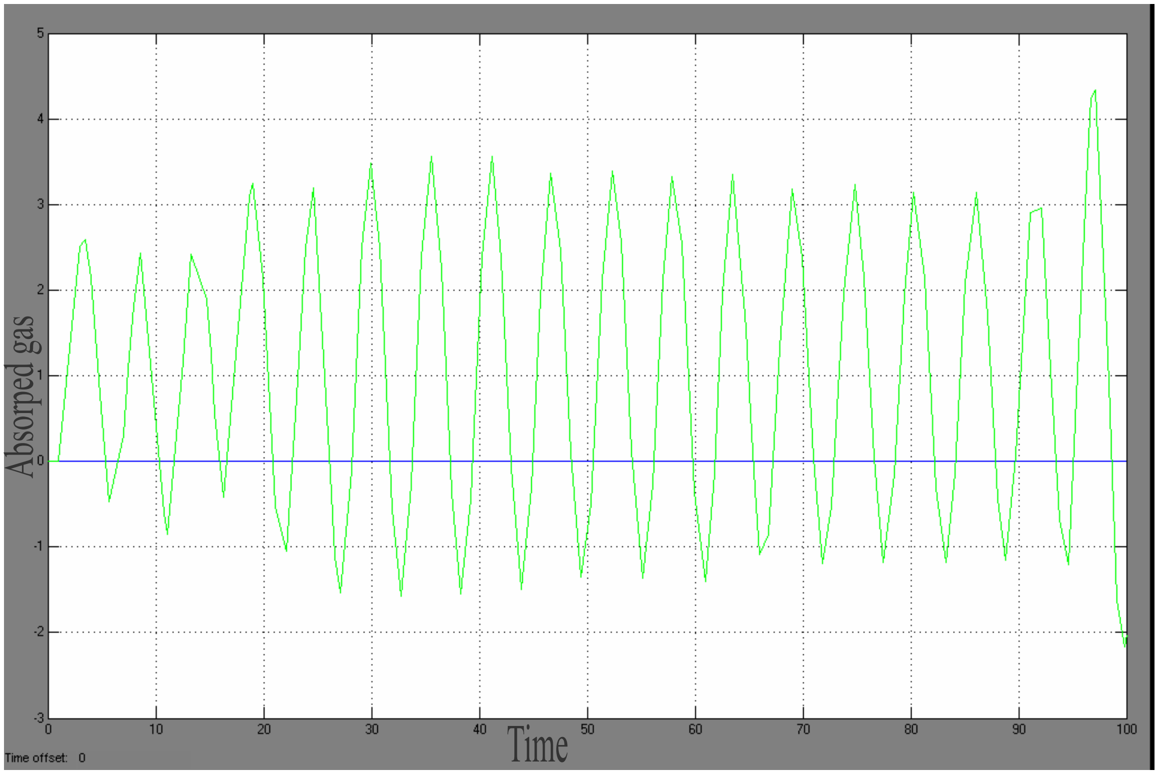

Figure (4-6) Response of control variable using PI controller with Internal Model Control tuning

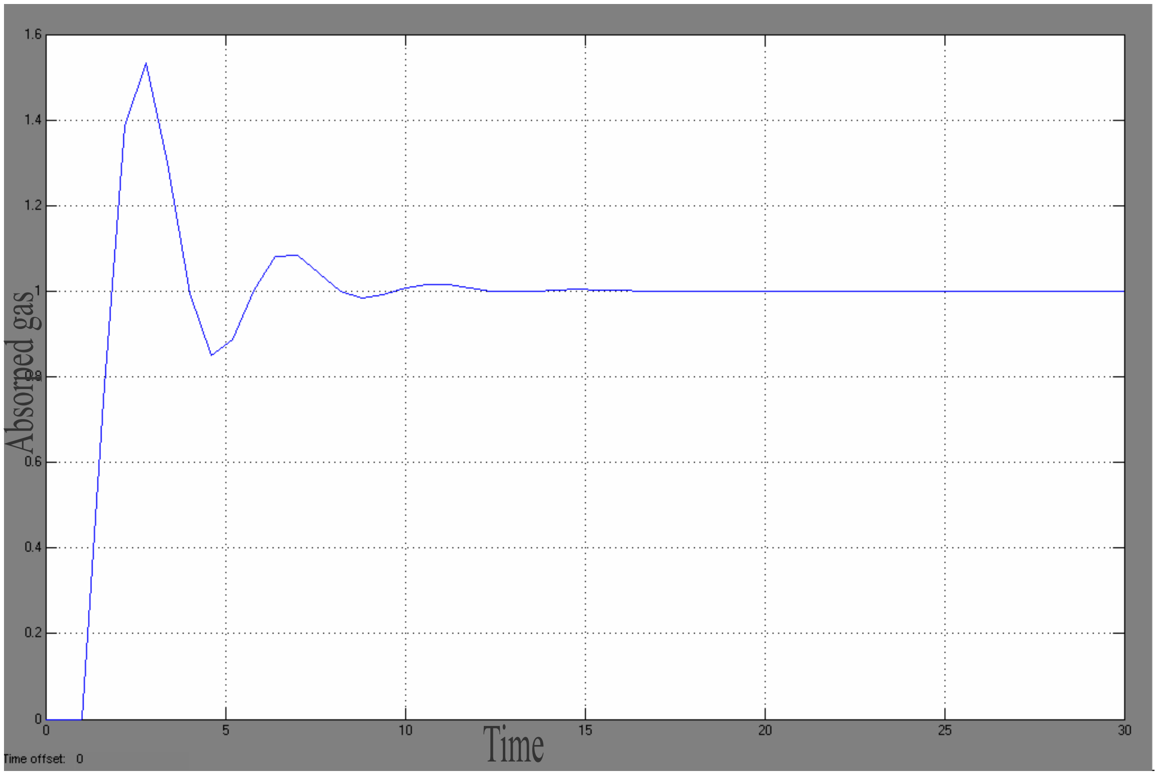

Figure (4-7) Response of control variable using PI controller with Cohen-Coon tuning

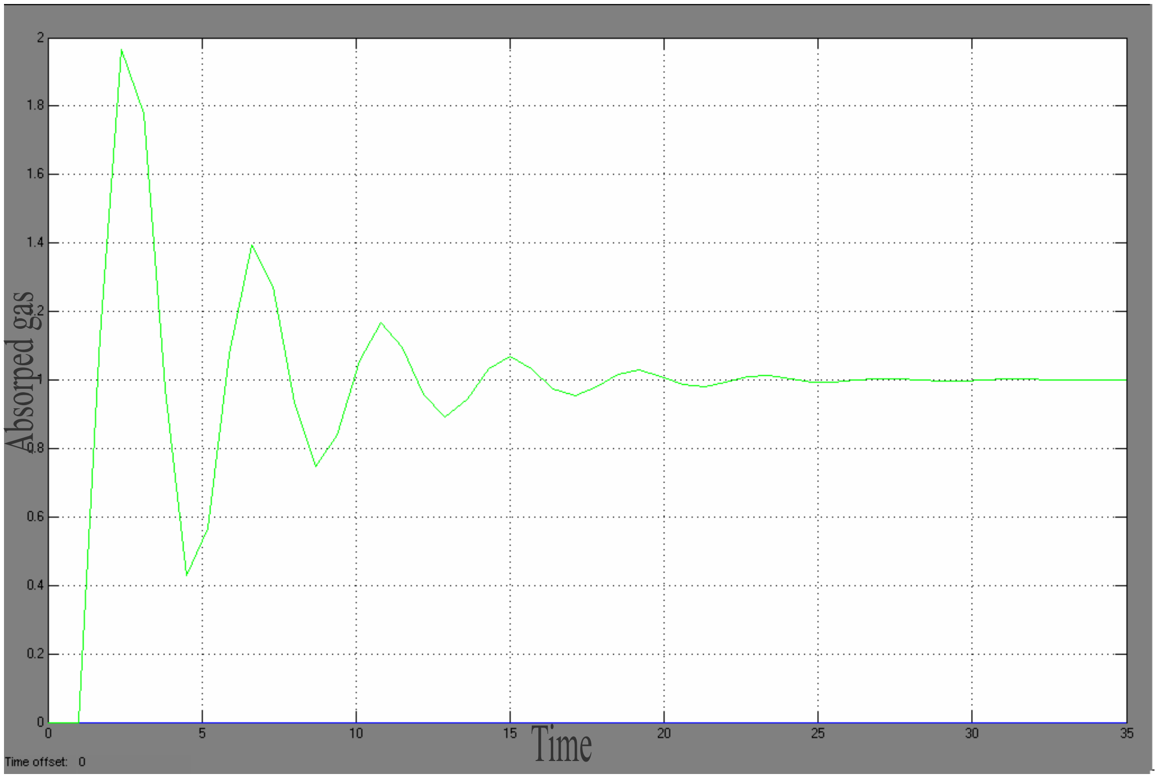

Figure (4-8) Response of control variable using PI controller with Ziegler-Nichols tuning

Figure (4.6) shows the too much oscillation so the system in Internal Model Control with PI controller is unstable. On the other hand in Figures (4.7) and (4.8) applying the proportional-integral will eliminate the offset and the controlled variable ultimately returns to the original value.

When the PID controller is applied to the Cohen-Coon tuning, Ziegler-Nichols tuning and Internal model control we get the following diagrams:

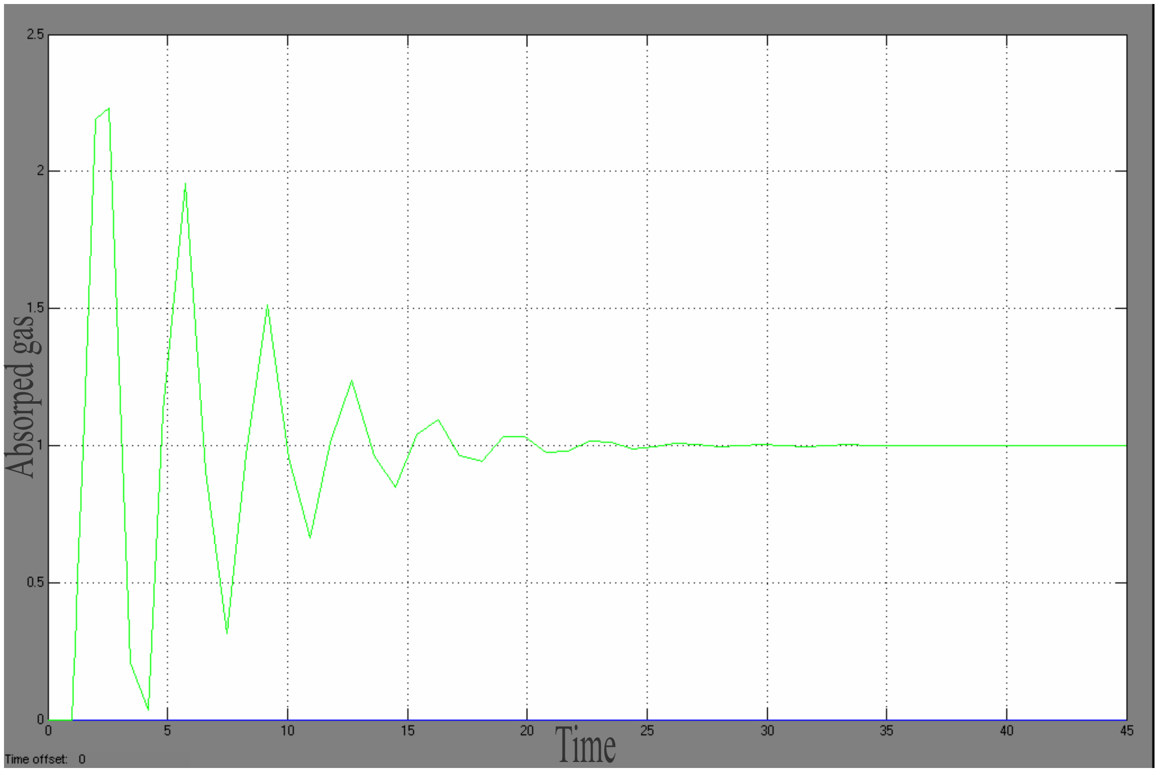

Figure (4-9) Response of control variable using PID controller with Internal Model Control tuning

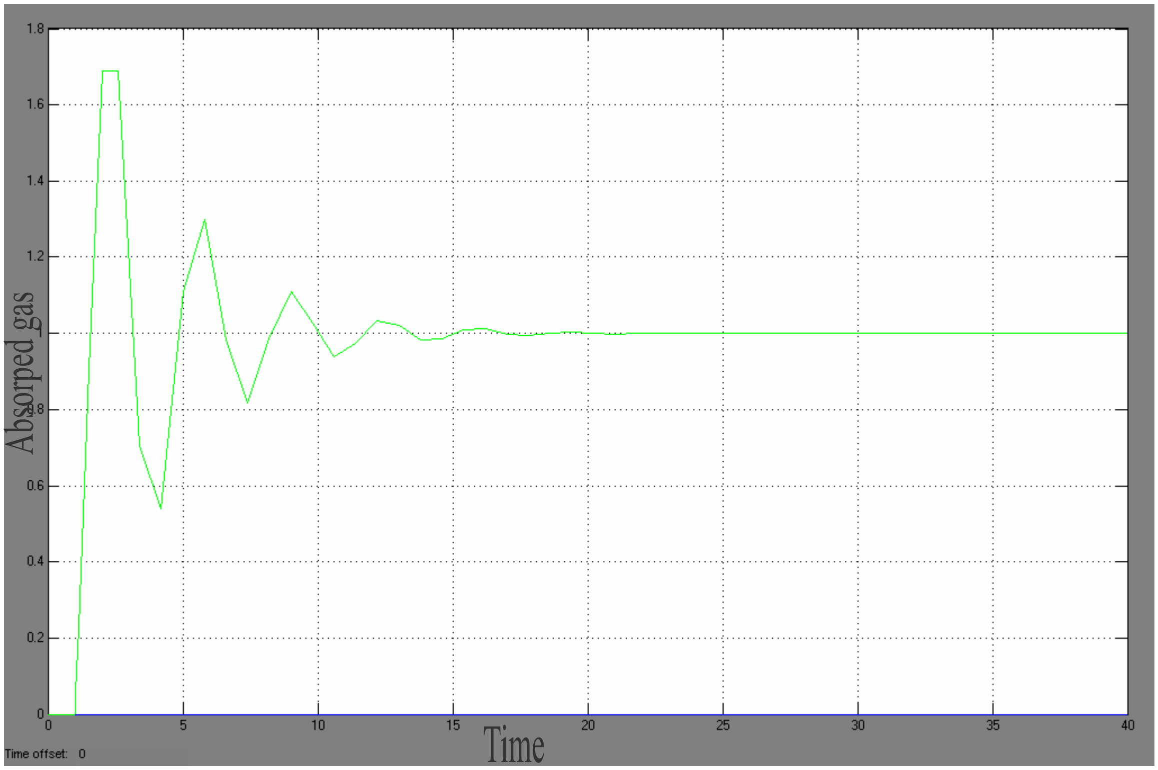

Figure (4-10) Response of control variable using PID controller with Cohen-Coon tuning

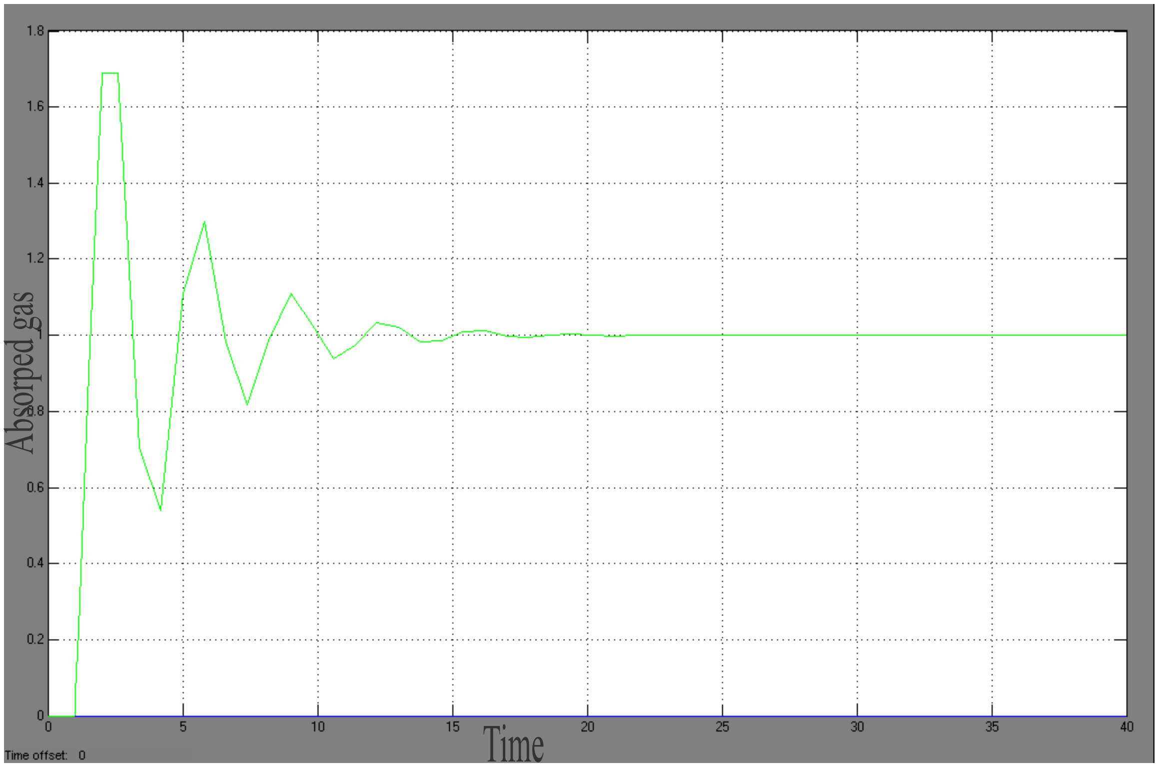

Figure (4-11) Response of control variable using PID controller with Ziegler-Nichols tuning

Figure (4.9) shows that the oscillation in Internal Model Control with PID controller is more than that of Cohen-Coon tuning and Ziegler-Nichols tuning.On the other hand Figures (4.10) and (4.11) show that when the proportional-integral is applied, it will eliminate the offset and the controlled variable ultimately returns to the original value, so they are stable.

The all times responses for all figures from (4.4) to (4.11) are presented in Table (4-1):

Table (4-1) Times responses

Method	Controller	Settling time(sec.)	Rise time (sec.)	Steady state
Cohen-Coon	P	5.72	0.559	0.902
	PI	9.17	0.5881	1
	PID	2.32	0.264	1
Ziegler-Nichols	P	6.67	0.975	0.913
	PI	6.32	0.541	1
	PID	—	N/A	Inf.
Internal Model Control	—			
	PI	21.5	3.39	0.333
	PID	—	N/A	Inf.

In Table 4.1 it can be noticed that the Cohen-Coon tuning with PID controller is the best method for reaching stability in the open loop system compared with other methods using other kinds of controllers, this is because the Cohen-Coon tuning with PID controller has the lowest settling time and rise time of all the others.

4.3 Analyzing Absorption Column by Using Frequency Response (Closed Loop System)

Analysis of the system by Bode plot diagram depends on the gain margin and phase margin and from this we can see the stability of the system.

Before the frequency response of closed loop system is shown with controllers it first must be shown without controller.

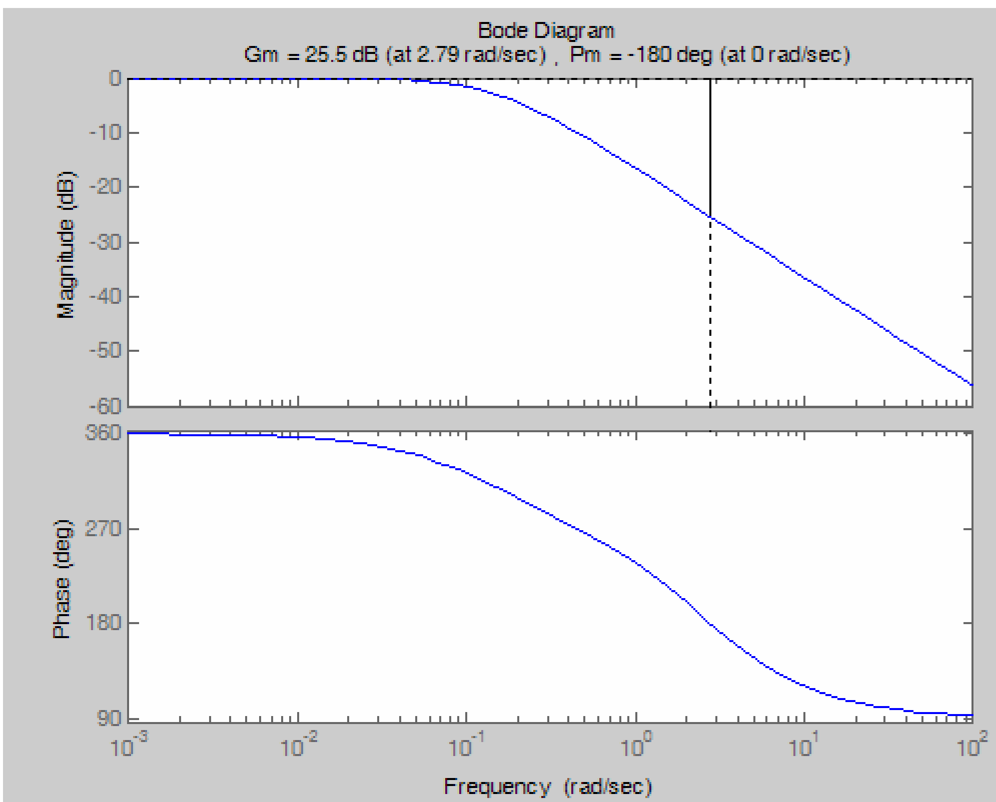

Figure (4-12) The frequency response of closed loop system without controller

Figure (4.12) shows that this case is an unstable system because the gain margin is positive and phase margin is negative, so a controller must be used to get a stable system.

First the P controller is shown for each of the used methods.

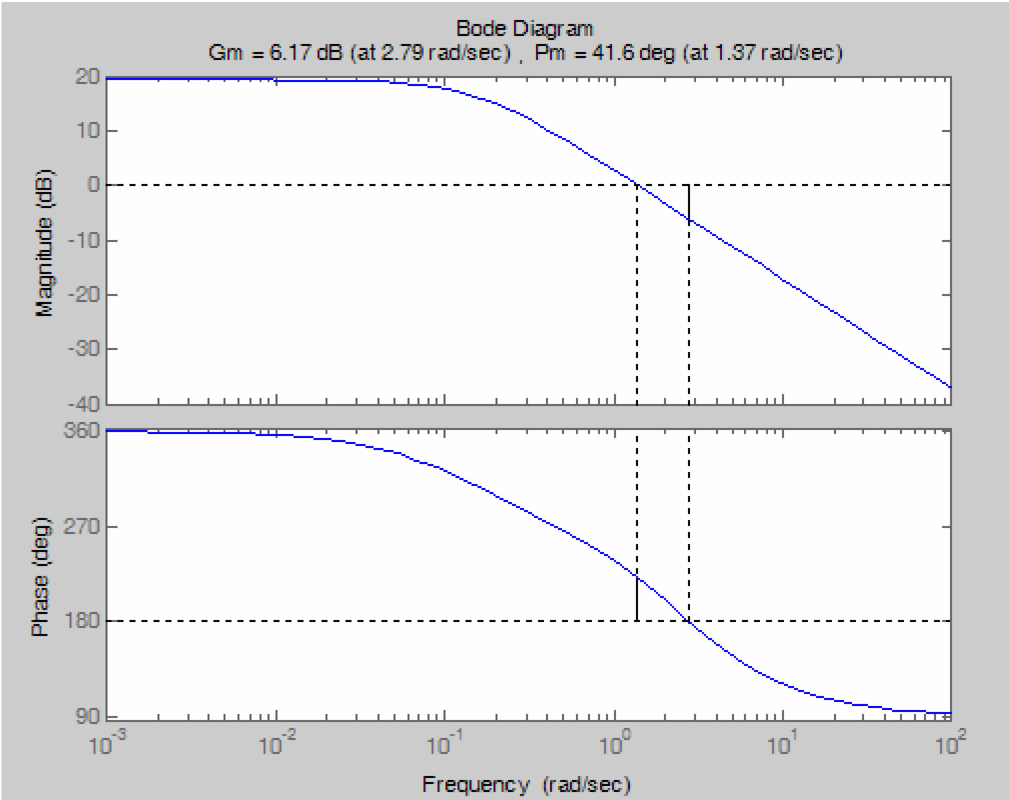

Figure (4-13) Frequency response of closed loop system with P controller (Cohen-Coon tuning)

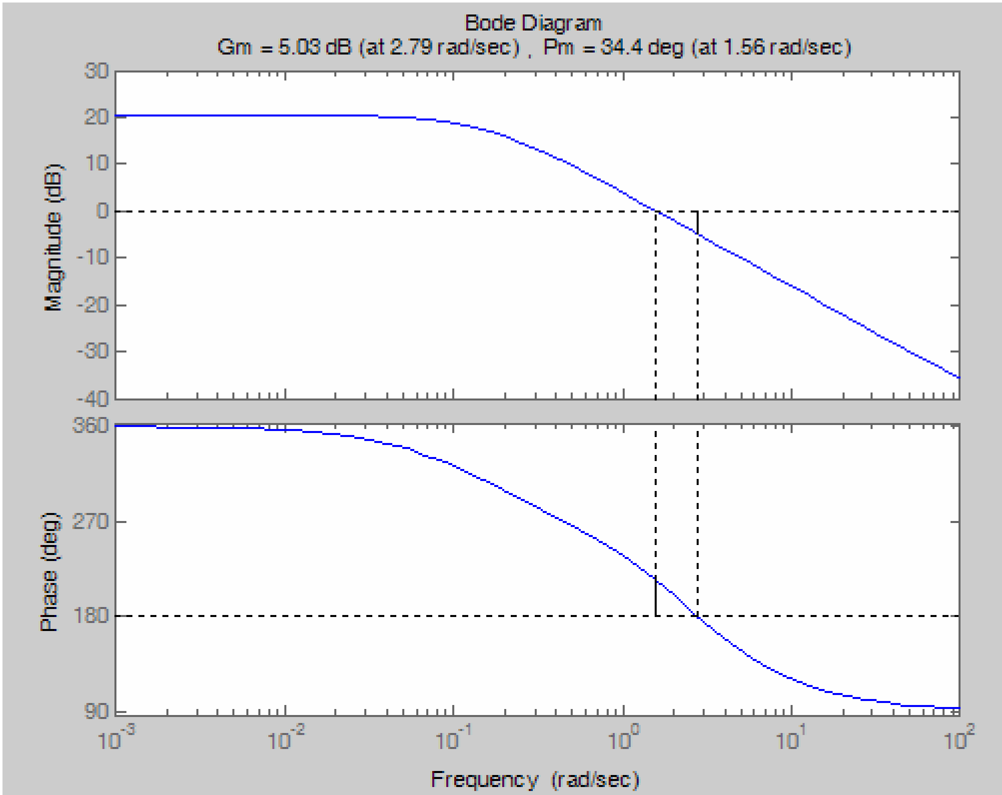

Figure (4-14) Frequency response of closed loop system with P controller (Ziegler-Nichols tuning)

Figures (4.13) and (4.14) show that after using the P controller in Cohen-Coon tuning and Ziegler-Nichols tuning, a stable state is obtained because in both methods we have a positive gain margin and positive phase margin.

After using the P controller, now the PI controller is used.

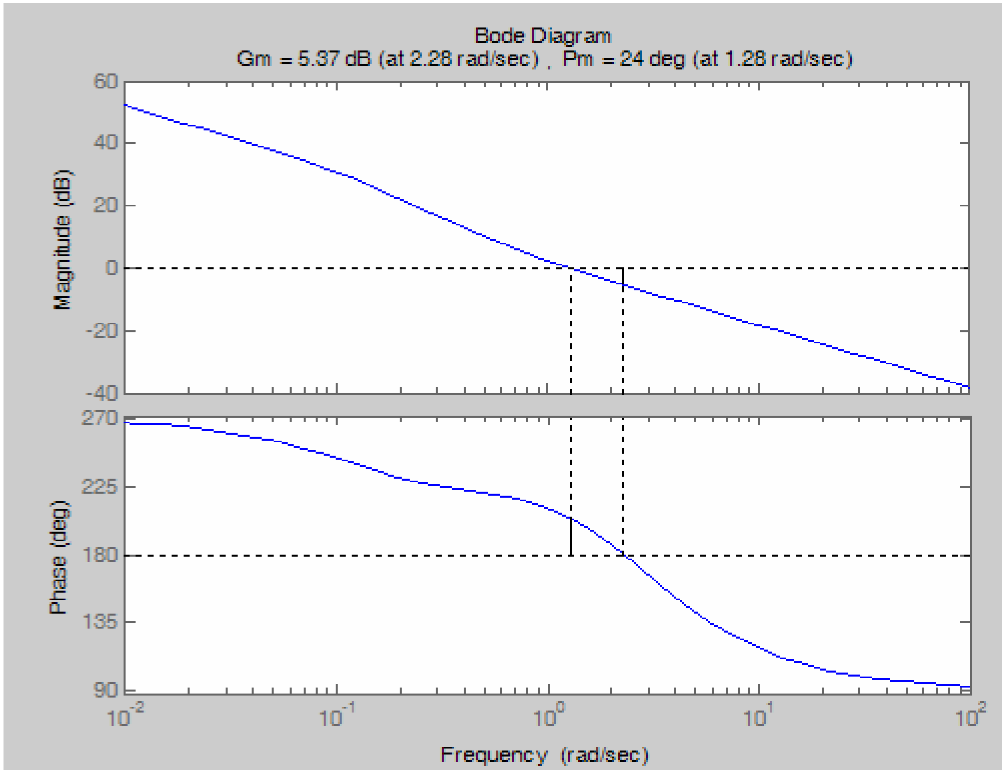

Figure (4-15) Frequency response of closed loop system with PI controller (Cohen-Coon tuning)

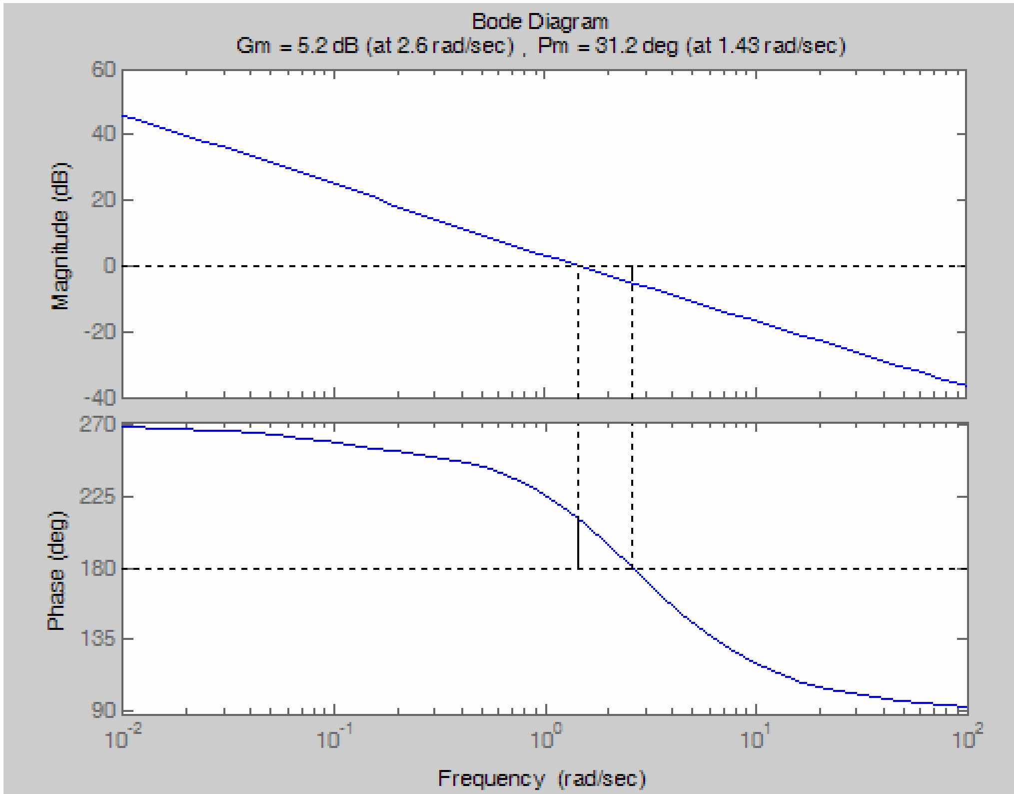

Figure (4-16) Frequency response of closed loop system with PI controller (Ziegler-Nichols tuning)

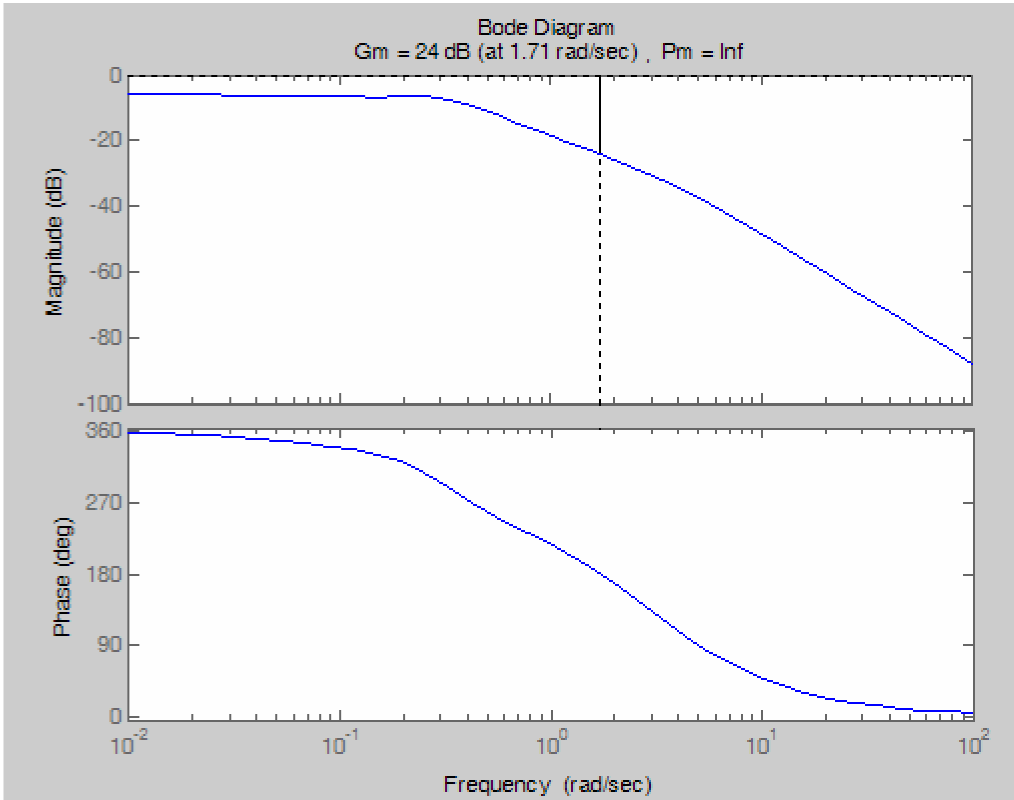

Figure (4-17) Frequency response of closed loop system with PI controller (Internal Model Control)

Figures (4.15), (4.16) and (4.17), show that by using the PI controller in Cohen-Coon tuning and Ziegler-Nichols tuning a stable state is obtained because both of the gain margin and phase margin are positive.

While in the Internal Model Control the closed loop system is unstable because the gain margin is positive but the phase margin is infinity.

After using the P and PI controller we use the PID controller and obtain the following diagrams:

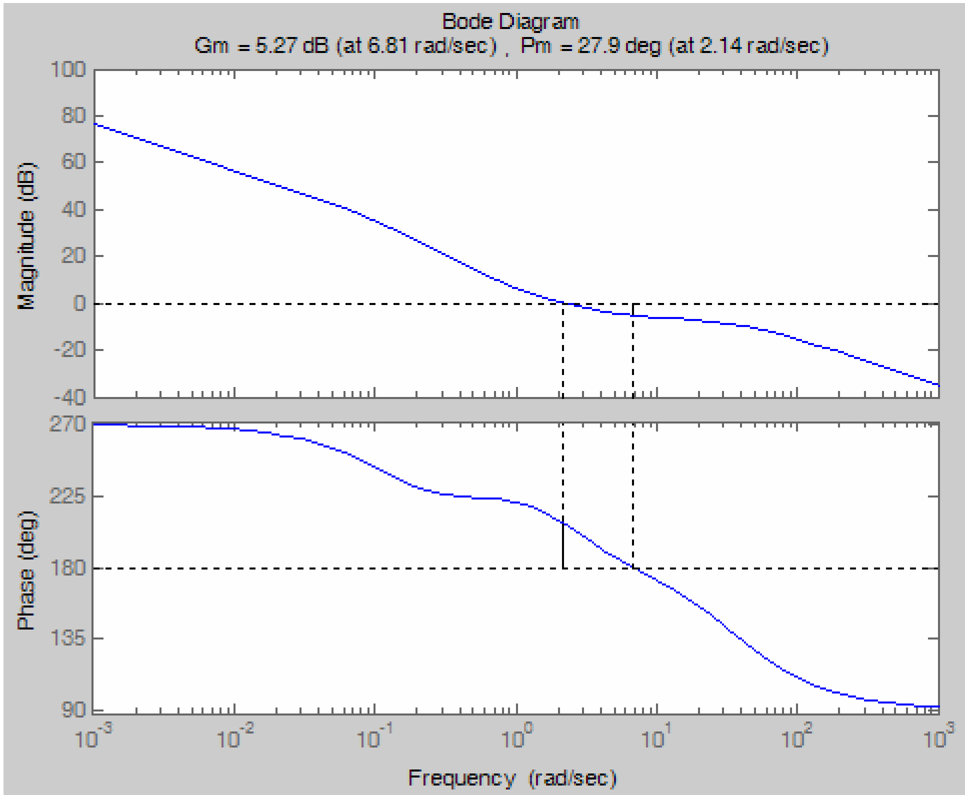

Figure (4-18) Frequency response of closed loop system with PID controller (Cohen-Coon tuning)

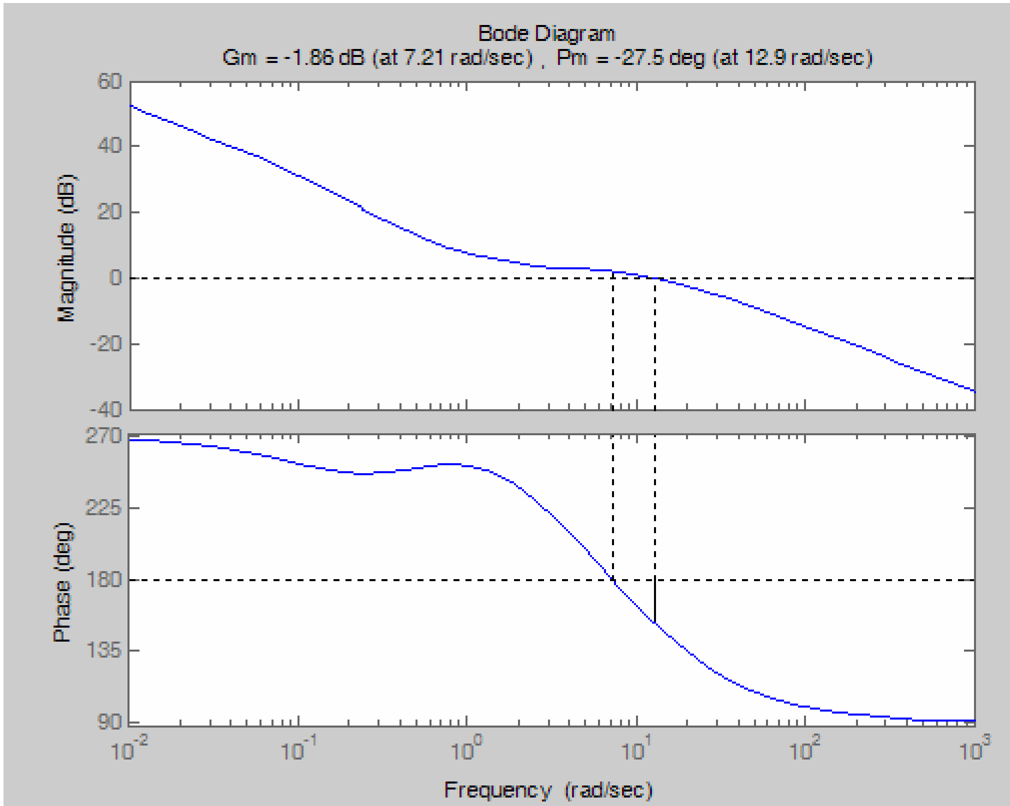

Figure (4-19) Frequency response of closed loop system with PID controller (Ziegler-Nichols tuning)

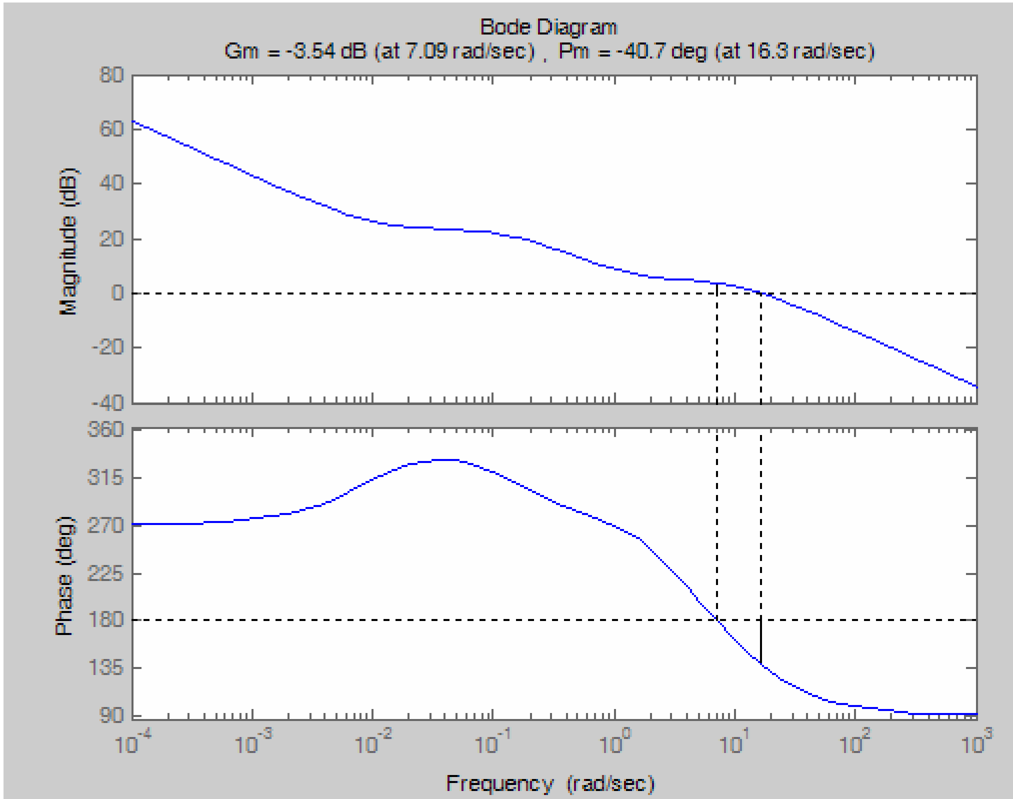

Figure (4-20) Frequency response of closed loop system with PID controller (Internal Model Control)

Figure (4.18), (4.19) and (4.20), show that the closed loop system is stable only in the Cohen-Coon tuning since both of the gain margin and phase margin are positive. While in Ziegler-Nichols tuning and the Internal Model Control the closed loop system is unstable because the gain margin is negative and also the phase margin is negative.

From this analysis it is found find that Cohen-Coon tuning is the best method for closed loop system because it gives a stable loop system in the P, PI and PID controllers.

Tables (4-2), (4-3) and (4-4) show the characteristics of closed loop system with P, PI and PID controllers which include the gain and phase margin values.

Table (4-2) The characteristics of closed loop system with P controller

	P			
Method	Gain margin (dB)	Gain frequency rad/sec	Phase margin (dB)	Phase frequency rad/sec
Cohen-coon	6.71	2.79	41.6	1.37
Ziegler-Nichols	5.03	2.79	34.4	1.56

Table (4-3) The characteristics of closed loop system with PI controller

	PI			
Method	Gain margin (dB)	Gain frequency rad/sec	Phase margin (dB)	Phase frequency rad/sec
Cohen-coon	5.37	2.28	24	1.28
Ziegler-Nichols	5.2	2.6	31.2	1.43
Internal Model control	24	1.71	∞	

Table (4-4) The characteristics of closed loop system with PID controller

	PID			
Method	Gain margin (dB)	Gain frequency rad/sec	Phase margin (dB)	Phase frequency rad/sec
Cohen-coon	5.27	6.81	27.9	2.14
Ziegler-Nichols	-1.86	7.21	-27.5	12.9
Internal Model Control	-3.54	7.09	-40.7	16.3

From these tables it can be noticed that the Cohen-Coon tuning and Ziegler-Nichols tuning in P and PI controller have positive gain margin and phase margin so they give stability to the system in both P and PI, while Internal Model Control in PI and PID has negative gain margin and phase margin, so we can not depend on Internal Model Control because it does not give stability to the system.

After it is shown the three methods of control which are Cohen-Coon tuning, Ziegler-Nichols tuning and Internal Model Control can be used in closed loop system with P, PI or PID controllers, now we see the Fuzzy control and notice its effect on stability of the system.

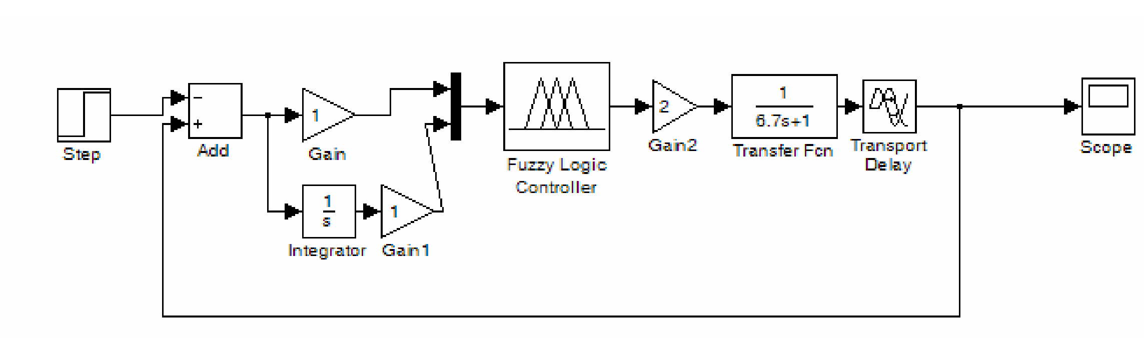

Figure (4-21) Block diagram of Fuzzy control

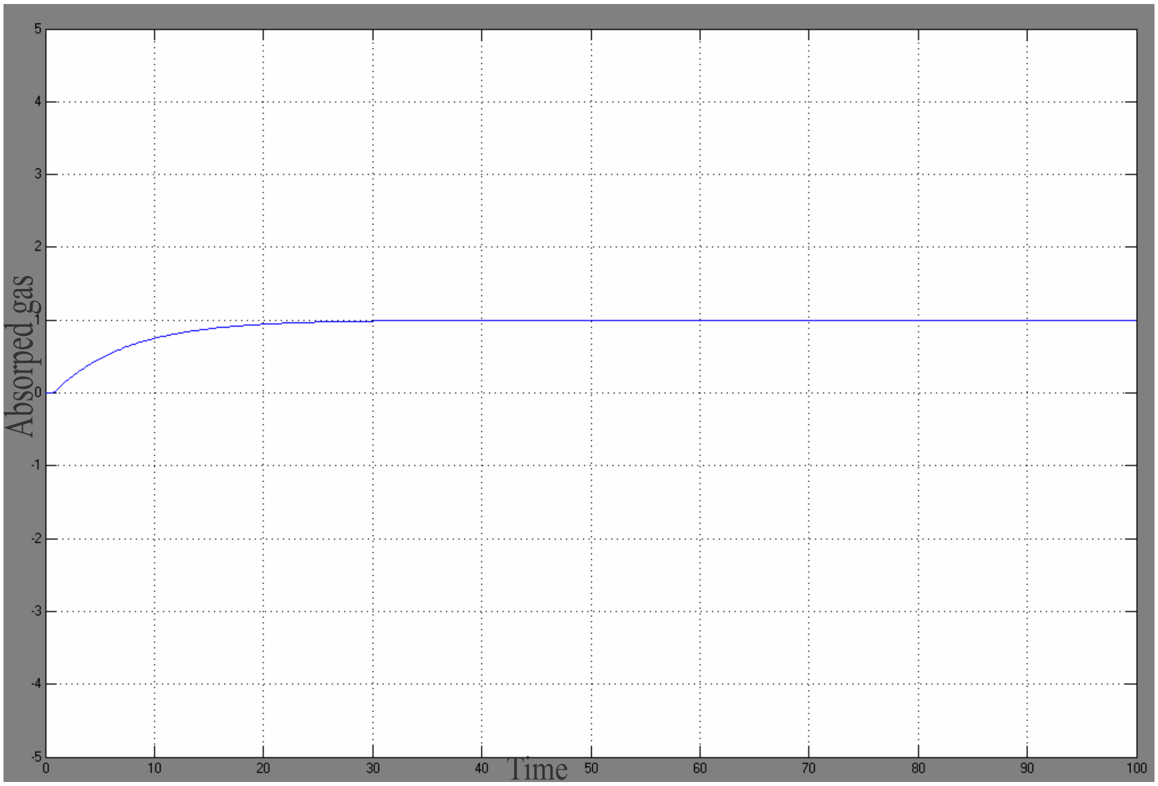

Figure (4-22) Response of control variable with Fuzzy control

Figure (4.22) shows that the rise in the controlled variable is arrested more quickly, and it is returned rapidly to the original value with little or no oscillation so the system is more stable with Fuzzy control.

4.4 Root Locus Diagrams

Root locus is a graphical technique that consists of graphing the roots of the characteristic equation, as a gain or any other control loop parameter changes. The resulting graph allows seeing at a glance whether a root crosses the imaginary axis to the right-hand side of the s-plane. This crossing would indicate the possibility of instability of the control loop [53].

4.5 Analyzing Absorption Column by Using Root Locus (Closed Loop System)

This section shows the diagrams of Root Locus for P, PI and PID controllers for each of the used methods.

By using of P controller the following Root Locus diagrams are obtained:

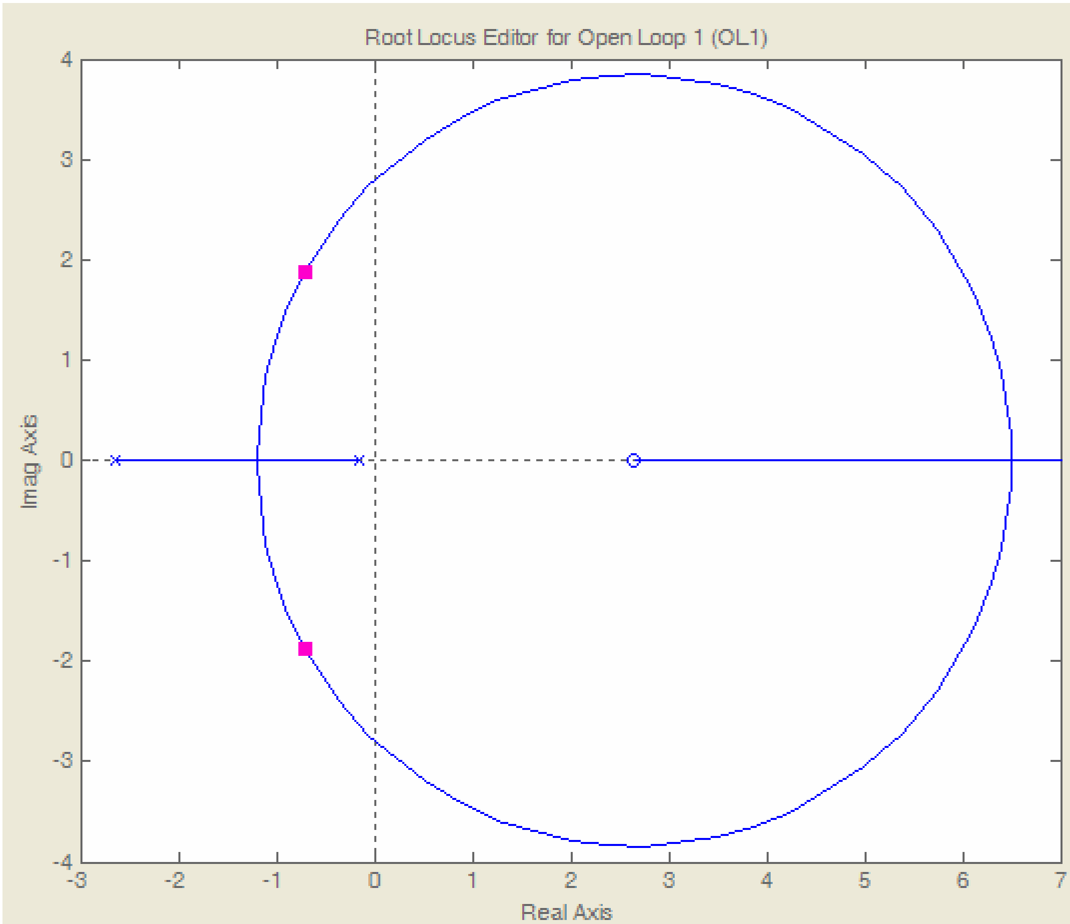

Figure (4-23) Root Locus diagram for the closed loop system with P controller. (Cohen-Coon tuning)

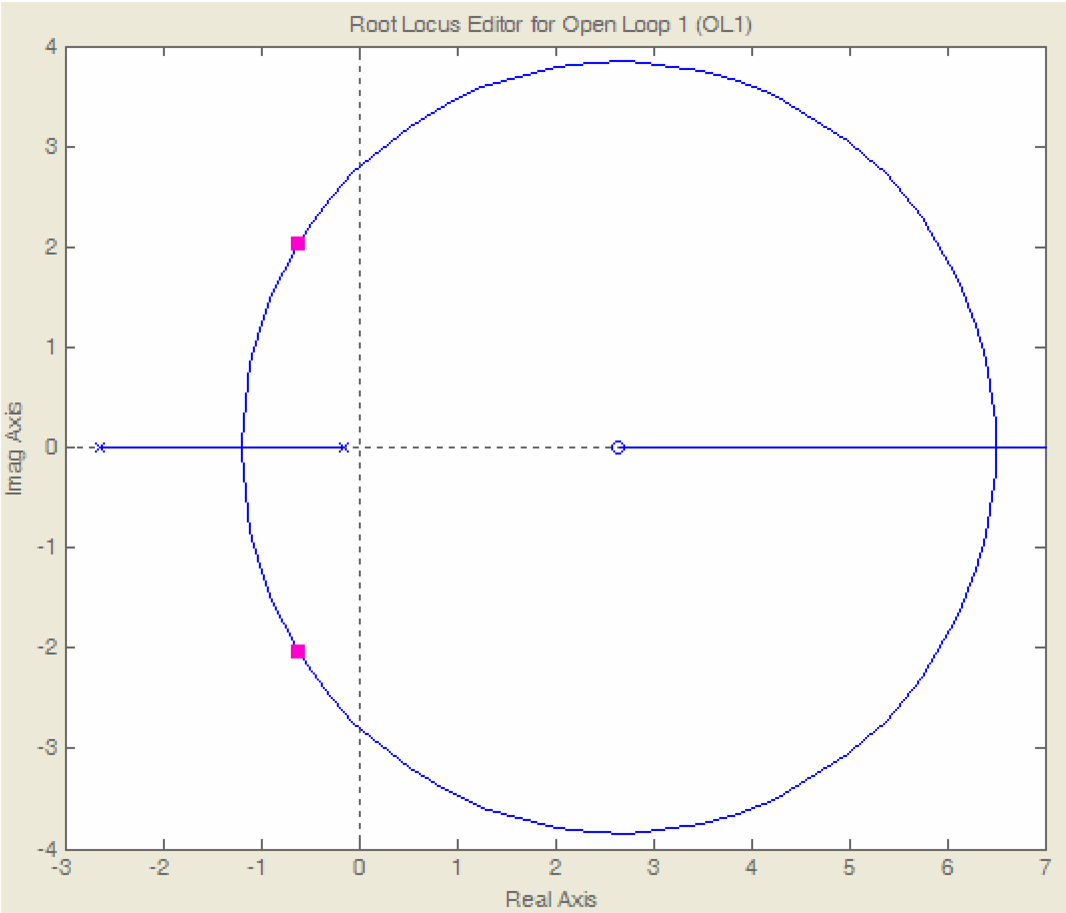

Figure (4-24) Root Locus diagram for the closed loop system with P controller. (Zigler-Nichols tuning)

Figures (4.23) and (4.24) show that the Root Locus values are on the left-hand side which means that the system is stable.

Now the PI controlleris used.

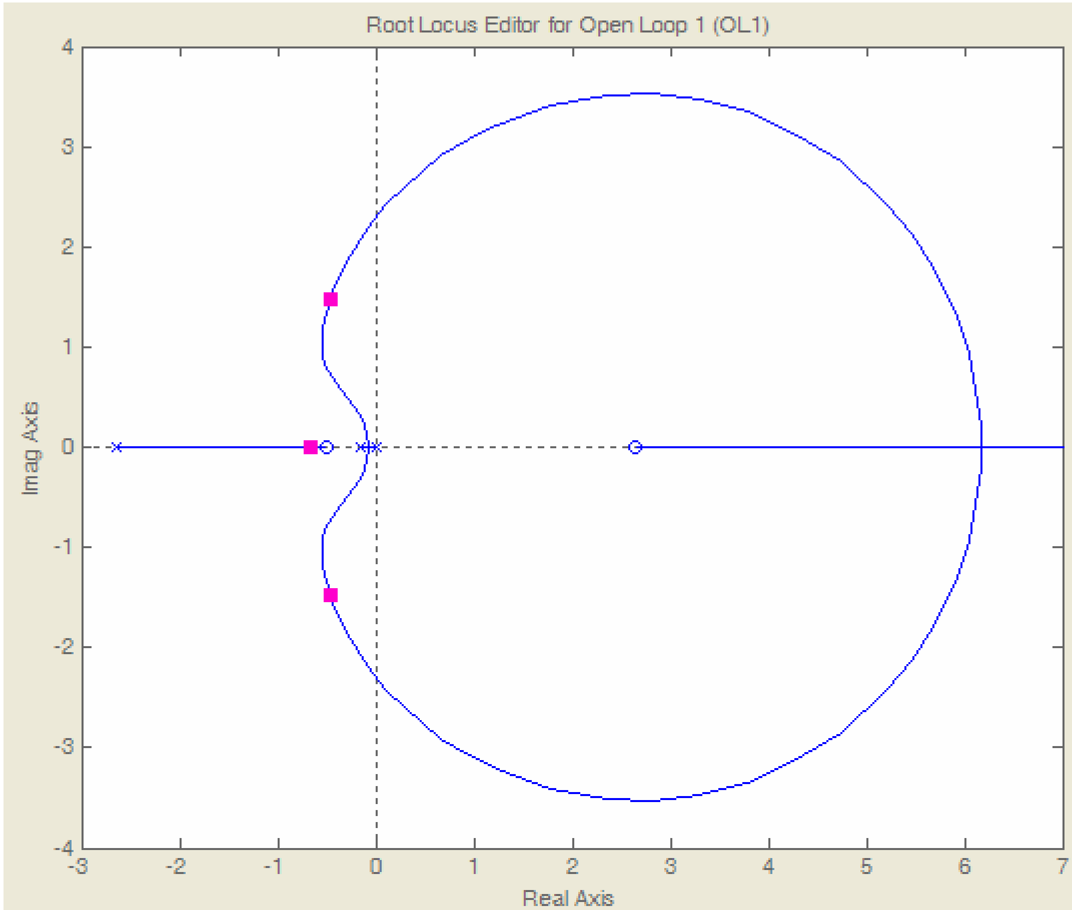

Figure (4-25) Root Locus diagram for the closed loop system with PI controller. (Cohen-Coon tuning)

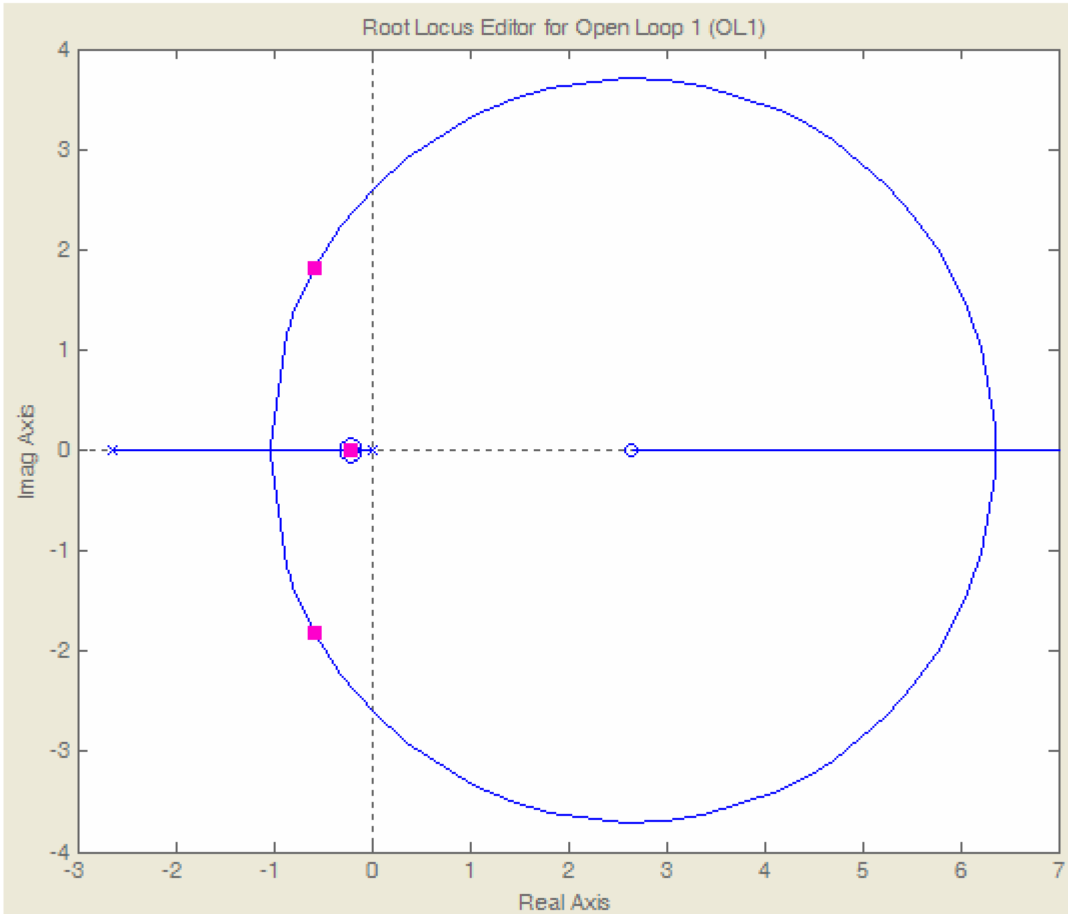

Figure (4-26) Root Locus diagram for the closed loop system with PI controller. (Ziegler-Nichols tuning)

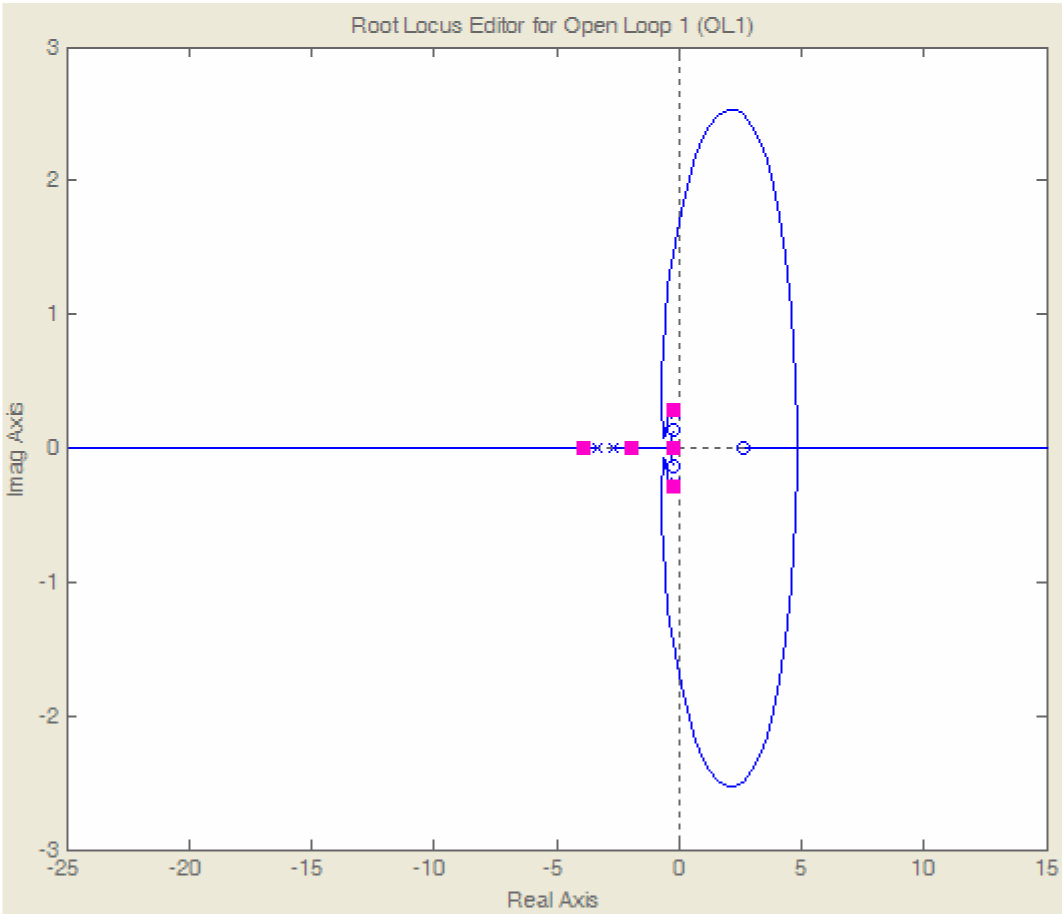

Figure (4-27) Root Locus diagram for the closed loop system with PI controller. (Internal Model Control)

Figures (4.25), (4.26) and (4.27) show that root values of the Cohen-Coon tuning and Ziegler-Nichols tuning are on the left-hand side so the system in these methods is stable. But in the Internal Model Control the root values is on the right-hand side which indicate the instability of the system.

Now the PID controlleris used.

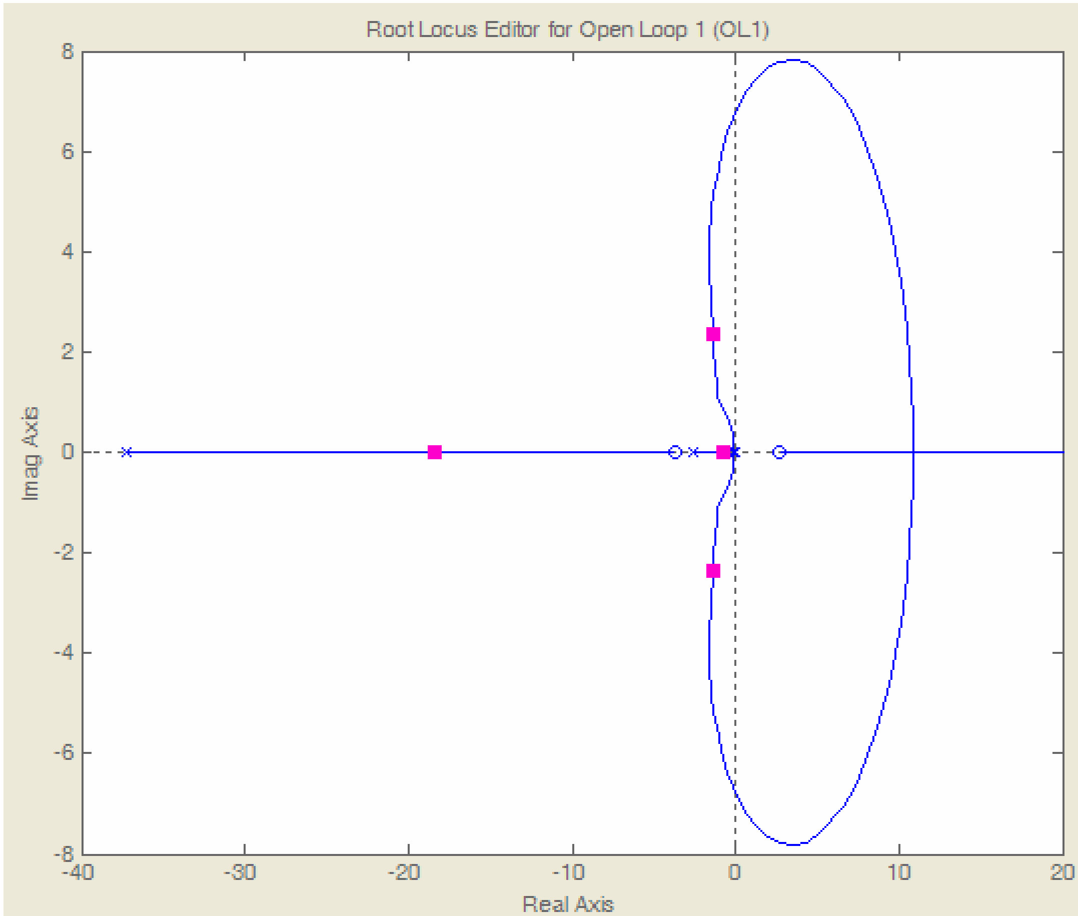

Figure (4-28) Root Locus diagram for the closed loop system with PID controller. (Cohen-Coon tuning)

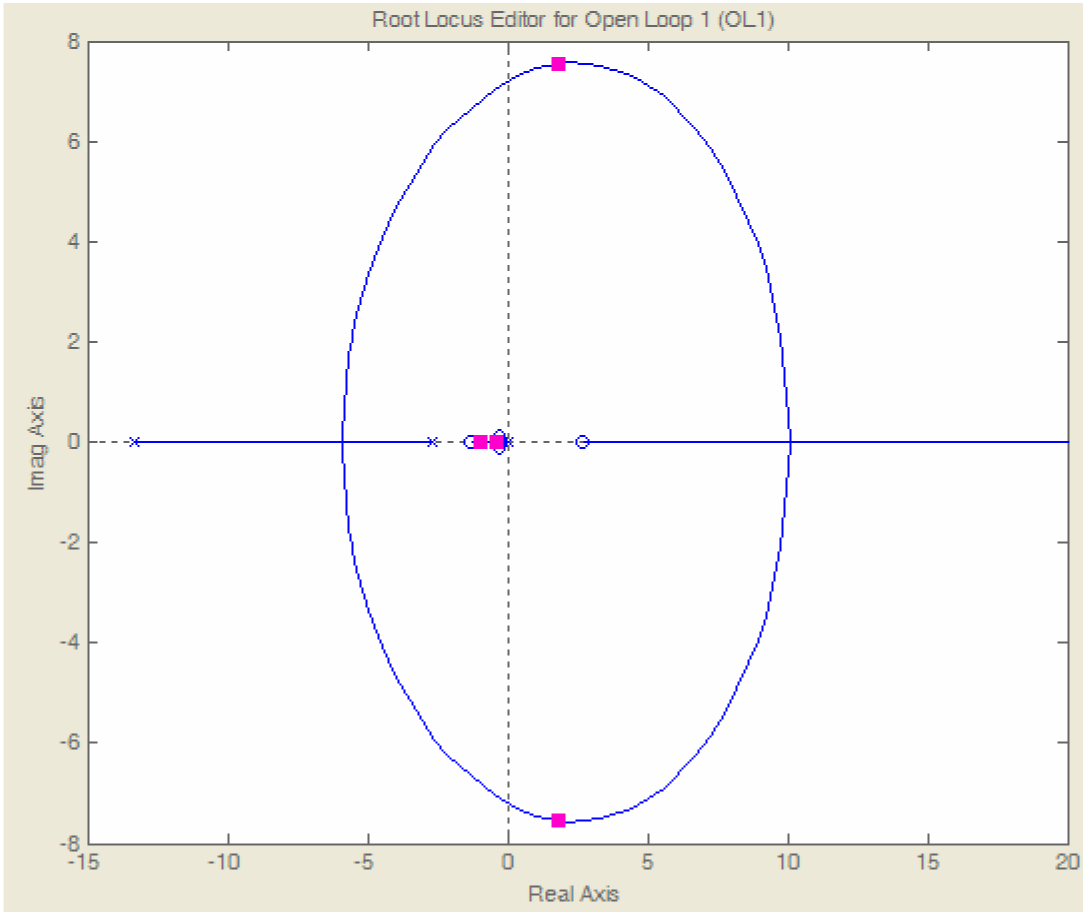

Figure (4-29) Root Locus diagram for the closed loop system with PID controller. (Ziegler-Nichols tuning)

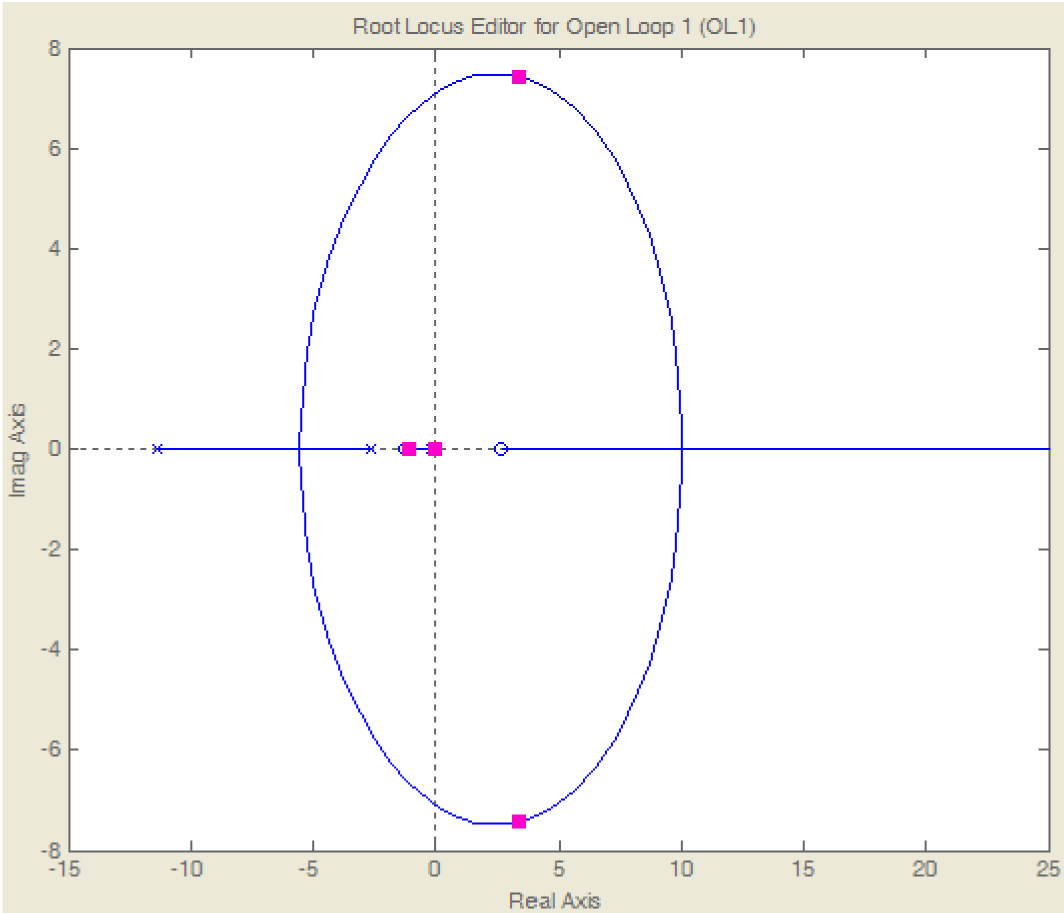

Figure (4-30) Root Locus diagram for the closed loop system with PID controller. (Internal model Control)

Figures (4.28), (4.29) and (4.30) show that only in the Cohen-Coon tuning the root values are on the left-hand side. While in the Ziegler-Nichols tuning and the Internal Model Control the root values are on the right-hand side. So only the Cohen-Coon tuning in the PID controller is stable. On the other hand the Ziegler-Nichols tuning and Internal Model Control are unstable in the using of the PID controller.

From this analysis it is found that Cohen-Coon tuning is the best method for closed loop system because it gives a stable loop system in the P, PI and PID controllers.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORKS

5.1 Conclusions

The present work was carried out to study the “real time” process simulation in process control and process control for different control strategies

1. The time response which includes settling time, rise time and steady state is listed in Table (4.1). From this table it can be seen that Cohen-Coon method in PID controller has the lowest settling and rise time with steady state equal to one. This means that the Cohen-Coon method is the best to get stability.

2. To improve process response we must use P, PI and PID controller and compare between them.
3. The response Figure for the system without controller is unstable as showed in Figure (4-2), but when controller is used the system is more stable as showed in Figures (4-4) to (4-11). These Figures show that the Cohen-Coon tuning with PI controller is more stable and the controlled variable ultimately returns to the original value.
4. Figure (4.22) shows that the Fuzzy Control is the best one of other methods

5. Frequency response of absorption column with closed system is stable in Cohen-Coon tuning with all required controllers (P, PI and PID) because all gain margins are positive with all root value on the left part of plot.
6. Figures (4-23) to (4-30) show that the system is stable in Cohen-Coon tuning with P, PI and PID controller because all root values are on the left part of plot.

5.2 Rrecommendations For Future Work

1. The same procedure of this work is useful with different absorption columns, example {multi input/ multi output (MIMO) system}.
2. Application of this work practically .

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APPENDIX "A"

Table (1) Controlled variables of Ziegler-Nichols method

	P	PI	PID
Kc	Ku/2	Ku/2.2	Ku/1.7
τ_I	0.0	Pu/1.2	Pu/2
τ_D	–	–	Pu/8

Table (2) Values of controlled variables of Ziegler-Nichols method

	P	PI	PID
Kc	10.5	9.545	12.352
τ_I	0.0	5	3
τ_D	–	–	0.75

Table (3) Controlled variables of Cohen-Coon method

Controller	K_C	τ_I	τ_D
P	$\frac{1}{K_p}\frac{\tau}{\tau_d}(1+\frac{\tau_d}{3\tau})$	—	—
PI	$\frac{1}{K_p}\frac{\tau}{\tau_d}(\frac{9}{10}+\frac{\tau_d}{12\tau})$	$\tau_d\frac{30+3(\tau_d/\tau)}{9+20(\tau_d/\tau)}$	—
PID	$\frac{1}{K_p}\frac{\tau}{\tau_d}(\frac{4}{3}+\frac{\tau_d}{4\tau})$	$\tau_d\frac{32+6(\tau_d/\tau)}{13+8(\tau_d/\tau)}$	$\tau_D\frac{4}{11+2(\tau_d/\tau)}$

Table (4) Values of controlled variables of Cohen-Coon method

Controller	K_C	τ_I	τ_D
P	9.207504	—	—
PI	8.070092	2.035344	—
PID	12.08223	1.774663	0.269034

Table (5) Controlled variables of Internal Model Control method

Controller	K_C	τ_I	τ_D
PI	$\frac{\tau_p}{K_p(\tau_c + t_d)}$	τ_P	—
PID	$\frac{1}{K_p}\frac{2\tau_p / t_d + 1}{2\tau_c / t_d + 1}$	$\tau_p + t_d / 2$	$\frac{\tau_p}{2\tau_p / t_d + 1}$

Table (6) Values of controlled variables of Internal Model Control method

Controller	K_C	τ_I	τ_D
PI	5.3246	6.7	—
PID	13.3135	7.0775	0.8775

شكر وتقدير

في البداية اشكر الله عز و جل الذي وفقني لاكمال متطلبات هذا البحث. وانا انهي بحثي لا يسعني واعترافا بالفضل الا ان انتقدم بوافر الشكر والامتنان للاستاذ المشرف الدكتور خالد مخلف لاقتراحه موضوع الرسالة واشرافه عليها ولمواصلته ومتابعته العلمية للبحث وما ترتب على ذلك من توجيهات قيمة واراء سديدة.

كما اتقدم بجزيل الشكر الى رئيس قسم الهندسة الكيمياوية، وجميع اساتذة قسم الهندسة الكيمياوية لمساعدتهم القيمة لي طيلة فترة الدراسة ولمدهم يد العون لي خلال اعداد هذه الرسالة.

واتقدم بشكري وامتناني الى عمادة جامعة النهرين/كلية الهندسة، لمساعدتهم ودعمهم الدائم لي طيلة فترة الدراسة.

وشكري الجزيل الى جميع زملائي وزميلاتي الذين مدوا يد العون عند حاجتي اليها في البحث.

ولا انسى ان اتقدم بجزيل الشكر والتقدير الى من ساندني وساعدني على تخطي الصعوبات خلال فترة البحث زوجي الحبيب.

م. داليا سمير مكي

دراسةالسيطرة على عمود الامتصاص

رسالة

مقدمة الى كلية الهندسة في جامعة النهرين

وهي جزء من متطلبات نيل درجة ماجستير علوم

في الهندسة الكيمياوية

من قبل

داليا سمير مكي

(بكالوريوس علوم في الهندسة الكيمياوية ٢٠٠٥)

محرم ١٤٣١

كانون الاول ٢٠٠٩