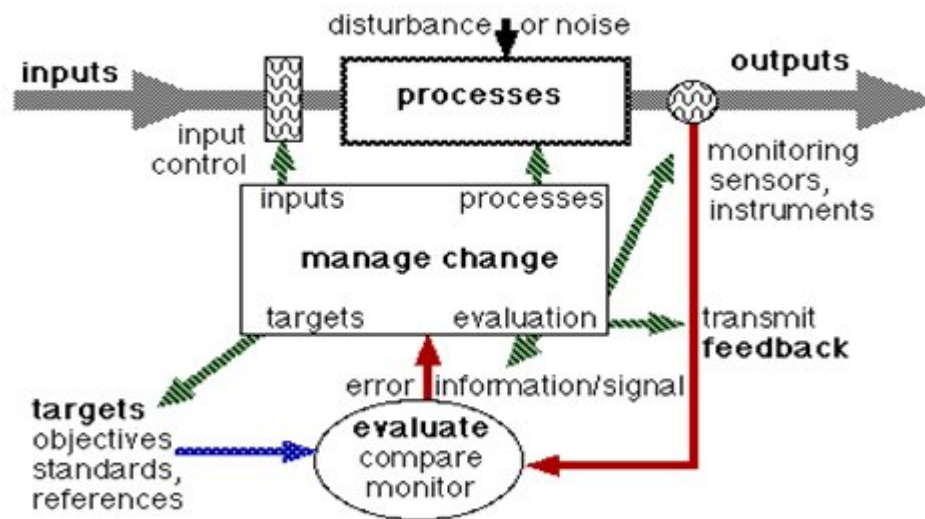


An-Najah National University
Chemical Engineering Department
Process Control Laboratory(64458)

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Preface:

In view of the increase emphasis placed on safe, efficient plant operation, it is only natural that the subject of process control has become increasingly important in recent years. Without computer- based process control system it would be impossible to operate modern plants safely and profitably while satisfying product quality and environmental requirements. Thus, it is important for chemical engineering to have an understanding of both the theory and practice of process control.

The primary objective of process control is to maintain a process at the desired operating conditions safely and efficiently.

Set of process control experiments will be studied in this lab. The study of these experiments will strengthen the understanding of process control and will aid the students to be more familiar with the practical process control operations.

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Instruction for Preparing the Laboratories Report

The formal report must be prepared according to the following outline:

Evaluation Criteria	Grade
Abstract answers of the questions: "What did you do? How did you do it? What did you find?"	15
Introduction and theory Sufficient, Clear and complete statement of objectives.	10
Procedure Procedure sufficiently described.	5
Description of Appartus main items, how it work	5
Experimental Results Results analyzed correctly. Experimental findings adequately and specifically summarized, in graphical, tabular, and/or written form.	20
Discussion Crisp explanation of experimental results. Comparison of theoretical predictions to experimental results, including discussion of accuracy and error analysis in some cases.	20
Conclusions and Recommendations Conclusions summarize the major findings from the experimental results with adequate specificity. Recommendations appropriate in light of conclusions. Correct grammar.	4
References and Nomenclature Complete and consistent bibliographic information that would enable the reader to find the reference of interest.	2
Appendices Appropriate information, block diagram and sketch of the control loop	10
Appearance Title page is complete, organization and neatness.	9
Total	100

1. Title Page

The title page should be separate from the rest of the report. It should contain:

- a. The name of the experiment
- b. The name of the course
- c. The date when experiment was done
- d. The name of the writer and his/her co-worker, ID number, and his/her group number
- e. The name of the instructor to whom the report is submitted
- f. The date of submission report

2. Abstract

The abstract should be informative, and should be written in about three to five sentences. It should cover all phases of investigation. It must include the following:

- a. An introductory statement about the subject matter
- b. Briefly describe what was done
- c. Present some selected results (numerical values, if possible)
- d. If possible, present some percentage errors in experimental results in comparison with theoretical values.

While writing the abstract, it should be kept in mind that you should not refer to any graph and table.

3. Theoretical Background

This section should include the theory behind the experiment. It should also contain all those equations, which are used to acquire a certain result. Theoretical correlation, which is used for comparison with experimental results, should also be included.

4. Procedure

Here, you should briefly describe the actual step by step procedure you followed in running the experiments and form the theoretical knowledge. It should be written in your own words.

5. Description of apparatus

This section should include a brief description of apparatus used in the experiment, include its principle and application.

6. Results

The results should be presented in the form of tables and/or graphs. The tables should contain the results obtained from experiments and from theoretical knowledge. Comparison should be presented in terms of percentage, e.g. percent deviation.

7. Discussion of Results

In this section you should discuss your experimental results. Show how you make comparison with the values obtained theoretically. Also discuss the deviation of experimental results from theoretical values. The possible source of errors should be mentioned. If the results are obtained in terms of graphs, then interpret them.

8. Conclusion and Recommendation

Conclusions are the series of numbered sentences, which answer the questions posed in the end of each experiment. Conclusions should also include the errors between the experimental and theoretical values. What you have learned from the experiment should be mentioned as well.

Recommendations are the proposals for future work, e.g. suggested changes in equipment, study of new variables, or possible experiments in relative fields. Like the conclusions, numbers usually lists the recommendations, and each consists of only a sentence or two.

9. Literature cited

Here, you should list books, journals, articles, etc. used in writing your report and analyzing the experiments. The reference should be completed (name of the book, author, volume, date of publications, pages, etc.) References should be arranged alphabetically.

10. Nomenclature

The symbols, which are used in the report, should be defined in the nomenclature in alphabetical order. The accompanying definitions must include proper units.

11. Appendices

All appendices and graphs should be attached at the end of the report.

12. Organization and Neatness

The students must organize their reports in a manner earlier. It is required/encouraged to use EXCEL, any available graphics software packaged to draw graph. The neatness will include how the students has written the report.

Safety Regulations

1. Wear suitable lab coat, suitable gloves and safety glasses or goggles should be worn whenever there is potential for contact with particulate debris, dust or corrosive or toxic materials.
2. Confine long hair and loose clothing when in the laboratory.
3. Know the location of the fire extinguisher, eye wash, safety shower and first aid kit in your lab and know how to use them.
4. Determine the potential physical and chemical hazards, and the safety precautions that apply to your apparatus before beginning.
5. No unauthorized laboratory work should be carried out in the absence of the instructor.
6. Never leave unattended an experiment that is in progress.
7. Review the safety and health hazard data of all chemicals used in the laboratory.
8. Notify your instructor immediately after any injury, fire or explosion, or spill.
9. If chemicals come into contact with your skin or eyes, **flush immediately** with copious amounts of water and consult with your instructor.

قواعد السلامة المهنية في مختبر التحكم بالعمليات

- 1- يجب استخدام الملابس الواقية والنظارات والكمادات أثناء تشغيل الأجهزة.
- 2- تعرف على أماكن مغسلة العيون والدش وطفاية الحريق قبل البدء بأي عمل داخل المختبر.
- 3- قبل استخدام أي جهاز يرجى قراءة التعليمات الخاصة به بدقة والإنتباه إلى إشارات السلامة الخاصة بالجهاز.
- 4- يمنع تشغيل الأجهزة داخل المختبر دون الرجوع للمشرف.
- 5- في حالة استخدام أي مادة كيميائية، يرجى قراءة تعليمات السلامة الخاصة بالمادة بدقة.
- 6- في حالة ملامسة أي مادة كيميائية للجسم أو العيون، يجب غسل المنطقة المصابة بالماء باستخدام مغسلة العيون أو الدش.

أنتبه:

- معظم الأجهزة تحتوي أسطح ساخنة.
- يوجد أجهزة تعمل بضغط هواء مرتفع، لا تعبث بالمحابس والوصلات.

Exp # 1

pH Control

1.1- THEORITICAL BACKGROUND:

pH control is a common issue in many industrial processes. The basic idea to control the pH variations in some liquid flow, usually making the pH as close to 7 as possible. This influent liquid flows into a tank, where it is mixed with an amount of a concentrated reagent to alter its pH. If the effluent is acidic with a pH of 4, the reagent would be basic with a pH larger than 10. The reagent is more concentrated than the effluent, since it is desirable to as little volume to the effluent as possible.

The pH is controlled in a tank - the iffluent flows into the top of the tank, and the reagent is also added to the top of the tank. The tank is well-stirred so that the pH is uniform throughout the tank. The effluent is pumped out the bottom of the tank, as shown in the figure below.

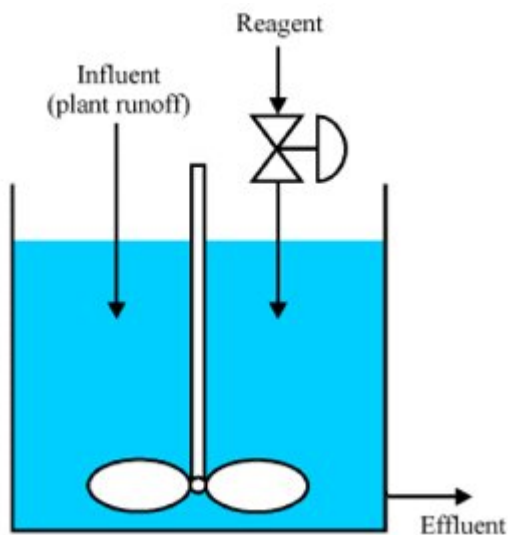


Figure 1.1

Note that pH is a very difficult control problem due to the non-linearities. This example simplifies the problem somewhat to highlight some points about control system design in general.

From elementary mass balance considerations, it can be shown that an appropriate state space model for the strong acid-strong base system is

$$\frac{dc_o(t)}{dt} = \frac{u(t)}{V}(c_u(t) - c_o(t)) + \frac{q(t)}{V}(c_i(t) - c_o(t)) \quad \dots\dots\dots (1)$$

Where

- $C_o(t)$: excess hydrogen ion concentration in the effluent stream (mol/L)
- $C_u(t)$: excess hydrogen ion concentration of the reagent (mol/L)
- $C_i(t)$: excess hydrogen ion concentration in the influent stream (mol/L)
- $u(t)$: flow rate of the reagent (L/s)
- $q(t)$: flow rate of the influent stream (L/s)
- V : volume of the tank (L)

Normally, the reagent concentration is constant, and we control the effluent pH by varying the reagent flow. Note that the concentrations are *excess* concentrations, meaning that they measure the concentration of hydrogen ions in excess to that found in water. We can convert an excess concentration C to pH using the following formula.

$$pH = -\log\left[\sqrt{0.25C^2 + 10^{-14}} + 0.5C\right] \quad \dots\dots\dots (2)$$

From this formula, we can see that an excess concentration of 0 gives a pH of 7 (which is the pH of water, as expected). Also, negative excess concentrations correspond to basic pH, and positive excess concentrations correspond to acidic pH.

NOTE: The reader should already be aware that if a weak acid or weak base is used, the titration curve will be substantially different. The differential equation (1) represents the dynamic equation for a strong acid-strong base titration curve. For any other acid-base combination (e.g. weak acid-strong base), the system model will be substantially different, as will equation (2) for finding concentration from pH. The graph below shows the titration curve for a strong acid-strong base system.

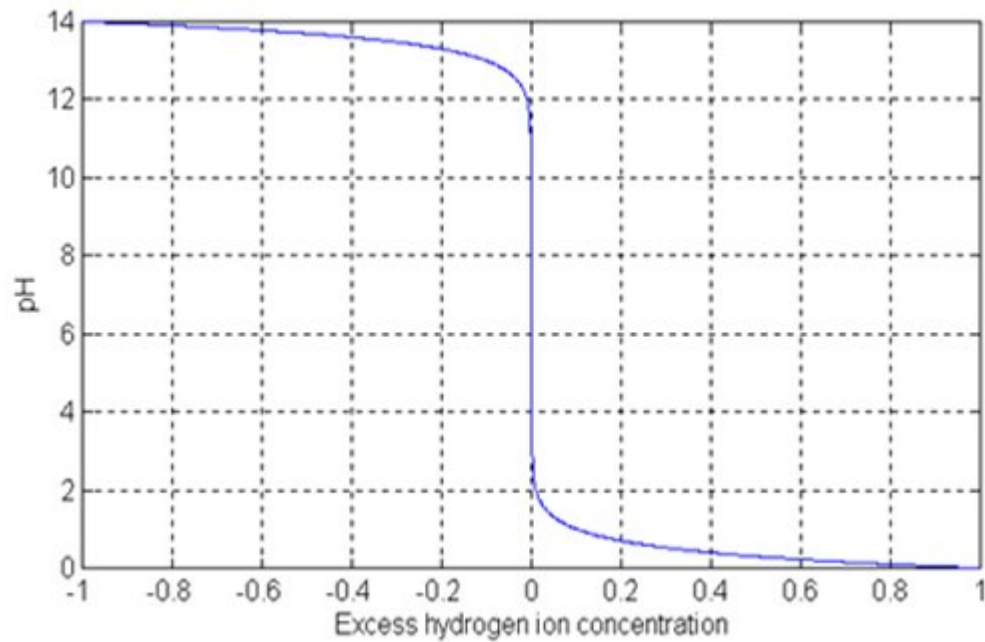


Figure 1.2 The titration curve for a strong acid-strong base system

1.2- TECHNICAL CHARACTERISTICS



Figure 1.3 pH control system

- AISI 304 stainless steel framework
- Electronic pH transmitter, range 0-14 pH, 4-20 mA output signal, code pHT1 (n° 1)
- 2 gear pumps, AISI 316 stainless steel execution, code G1 and G2 (n° 12)
- 2 variable area flow meters, glass and stainless steel execution, range 0-20 l/h, code FI1 and FI2 (n° 3 and 6)
- Microprocessor PID controller, 4-20 mA input and output signals, accuracy $\pm 0.1\%$, complete with serial card RS 232 (n° 9)
- 2 AISI 316 stainless steel feed tanks, capacity 13 liters, code D1 and D2 (n° 2)
- AISI 316 stainless steel collection tank, capacity 26 liters, code D3 (n° 7)
- AISI 316 stainless steel reactor complete of 0÷600 rpm variable speed stirrer (n° 4), capacity 3 liters, code R1 (n° 5)
- AISI 316 stainless steel connection lines and valves
- 2 measurement terminals for the 4-20 mA signal at the controller input (n° 10)
- 2 measurement terminals for the 4-20 mA signal at the controller output (n° 11)
- Electrical supply light (n° 8)
- Painted carbon steel electrical board with synoptic of the plant and E.L.C.B.

1.3- OPERATING PRINCIPLE

In this unit, the PID control is carried out on the pH inside the reactor R1. The control device consists in the pump G1 that, according to the signal coming from the PID controller, adjusts the flow rate of the basic solution at the input of the reactor and consequently the pH.

The flow rate of the acid solution is fixed adjusting the flow rate of the pump G2.

The control loop can be described as follows: the electronic transmitter, pHT1, measures the pH in the reactor R1 and sends the PID electronic controller a 4-20 mA electrical signal proportional to 2 - 12 pH.

In practice (Fig. 1.4):

- If the pH = 2, the output signal from the transmitter is 4 mA (zero).
- If the pH = 12, the output signal from the transmitter is 20 mA.
- For intermediate values the output signal from the transmitter will be proportional to pH; e.g. at pH = 7 the output signal from the transmitter will be equal to 12 mA.

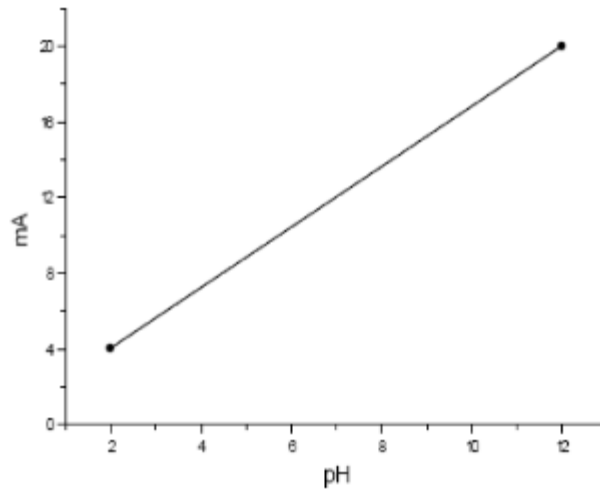


Figure 1.4

The signal sent by the transmitter pHT1 to the PID controller is compared to the set point value set on the controller. At this point, the controller sends a 4-20 mA signal to the output, function (PID) of the shift between the value of the process variable and the set point. This electrical signal is converted by an electronic card into voltage so that it controls the rpm (and so the flow-rate) of the pump G1.

Fig. 1.5 shows the proportionality between the electrical output signal of the PID controller and the rpm of the pump G1.

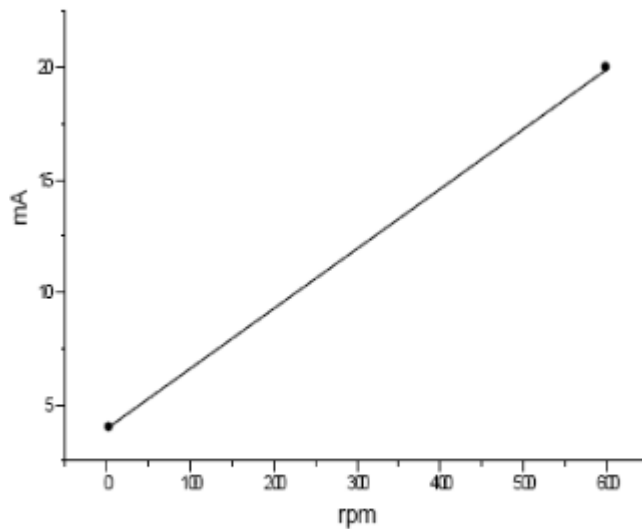


Figure 1.5

The 4-20 mA signals at the input and output to the PID controller can be measured with a milliammeter using the proper terminals set on the board.

The controller is pre-set in PI mode (proportional + integrative + derivative).

1.4- INSTALLATION

- Shut off the valves V1, V2, V3, V4, V5, and V6
- Connect the electrical board to the single-phase + G electrical line (n° 1)
- Connect the plant to the serial port COM1 of the P.C. with the serial cable (n° 2)
- Insert the E.L.C.B. (n° 3)

1.5- STOP

- Switch the selectors of G1, G2 and M1 in position “0”
- Drain the tanks and all the lines of the plant
- Wash using distilled water tanks, reactor and all the lines of the plant
- Insert the pH electrode in the protection cap filled with buffer solution at pH = 7

1.6- EXERCISE

- Set:
Gain = 0.5
I = 0.5 min
D = 0.0 min
- Set the set point to the 50% (pH = 7)
- The process variable will reach the set point value with regular behaviour. This indicates that the Gain and integrative time values are valid (Figure 1.6)

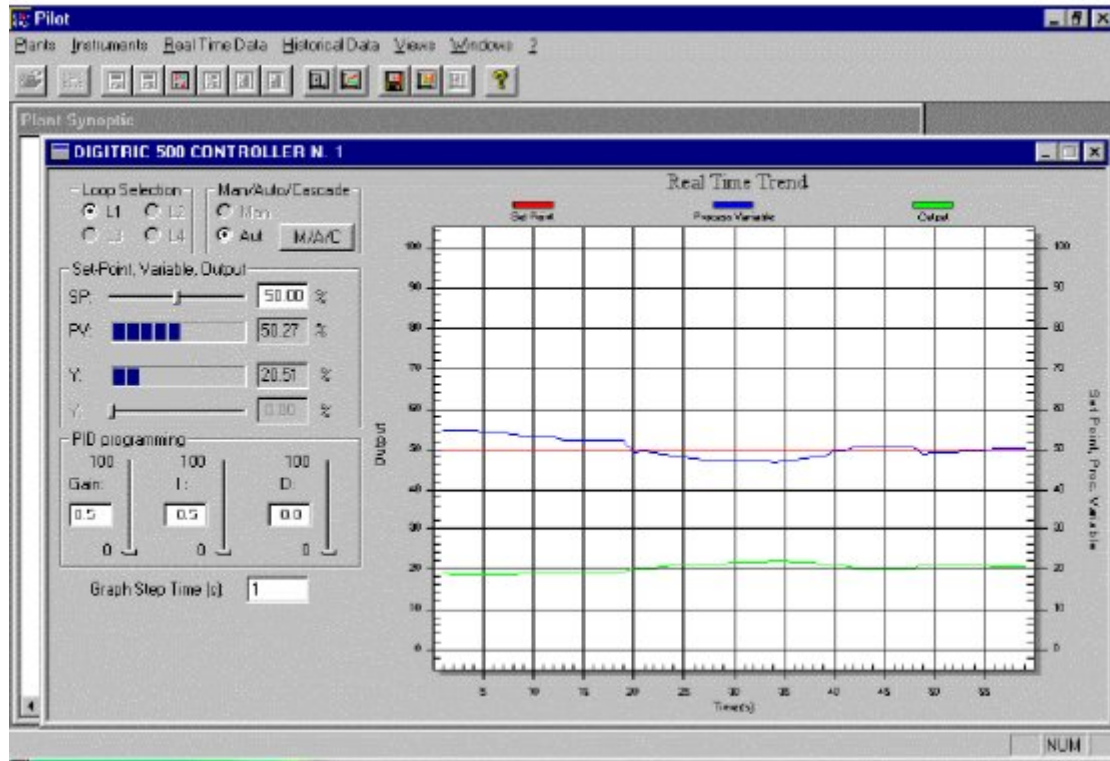


Figure 1.6

- Try to increase the flowrate of acid solution increasing the output of 2nd loop to 30%
- Consequently, the output of 1st loop increase (from 20% up to 35%) and the process variable will reach the set point value with regular behavior. At this point, you can carry out a test excluding the integrative action or the derivative action.

1.7- SAFETY

- During the experiments, take care in wearing the necessary protections:
 - laboratory coat
 - goggle
 - laboratory glove
- Before any maintenance operation, disconnect the plant from the electrical mains.

Table1 RAW DATA SHEET

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Exp #2

Pressure Control

2.1- INTRODUCTION

The unit enables to study the automatic pressure control using a line provided with a tank, a control valve, a pressure transmitter and a PID controller.

The line is pressurized using compressed air. The plant is provided with specific supervision software, Mod. SWPCB/EV, that enables the use from P.C. The bench can be connected in series with Mod. FCB/EV.

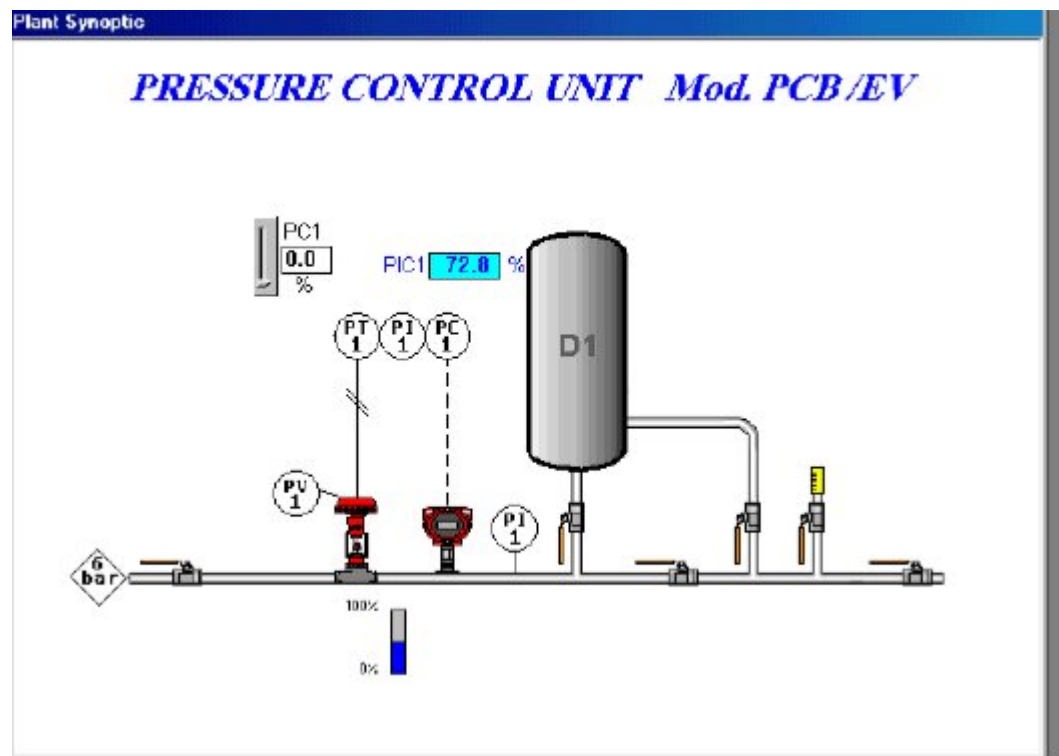


Figure 2.1

2.2- TECHNICAL CHARACTERISTICS



Fig. 2.2

- AISI 304 stainless steel framework
- Pneumatic control valve, AISI 316 stainless steel execution, DN 15, $C_v = 2.3$, code PV1 (n° 1)
- Electronic pressure transmitter, AISI 316 stainless steel execution, range 0÷6 bar, output signal 4÷20mA, code PT1 (n° 3)
- AISI 304 stainless steel tank, code D1 (n° 4)
- PID microprocessor controller, input and output signals 4÷20mA, accuracy $\pm 0.1\%$, complete with serial card RS 232 (n° 6)
- Electropneumatic converter, 4÷20mA/0.2÷1 bar (inside the switchboard)
- Safety valve calibrated at 9 bar (n° 10)
- AISI 304 and 316 stainless steel connecting lines and valves
- Bourdon spring pressure gauge, range 0÷6 bar (n° 2)
- Pressure gauge 0÷2.5 bar on switchboard
- Power supply light (n° 7)

- 2 measurement terminals for the 4-20 mA input signal of the controller (n° 8)
- 2 measurement terminals for the 4-20 mA output signal of the controller (n° 9)
- Plastic silencer (n°5)
- Painted carbon steel electrical switchboard complete with synoptic of the plant and E.L.C.B.

2.3- OPERATING PRINCIPLE

In this unit, the PID control is carried out on the air pressure inside the piping with possibility to insert a capacity into the circuit consisting in the tank D1. The control device consists in a pneumatic valve that, according to the signal coming from the PID controller, adjusts the compressed air flow rate at the system's input. The electronic transmitter PT1, measures the pressure in the line and sends an electrical signal 4 | 20 mA to the PID electronic controller proportional to 0 | 6 bar. In practice (fig. 2.3):

- If the pressure is null, the output signal from the transmitter is 4mA (zero).
- If the pressure is 6 bar, the output signal from the transmitter is 20 mA.
- For intermediate pressure values, the output signal from the transmitter will be proportional to the pressure; e.g. at 3 bar, the output signal from the transmitter is 12mA.

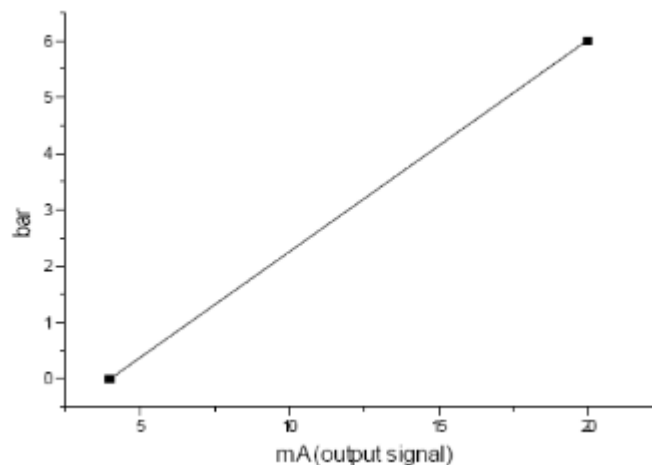


Fig. 2.3

The signal sent by the transmitter PT1 to the PID controller is compared to the set-point value set on the controller. At this point the controller sends a signal 4-20 mA to the output, function (PID) of the shift between the value of the process variable and the set-point. Such electrical

signal is converted by an electropneumatic converter into pneumatic signal controlling the opening level of the valve.

The following graphs show:

- Fig. 2.4: the proportionality between the electrical output signal of the PID controller and the pneumatic output signal of the electropneumatic converter (I/P).

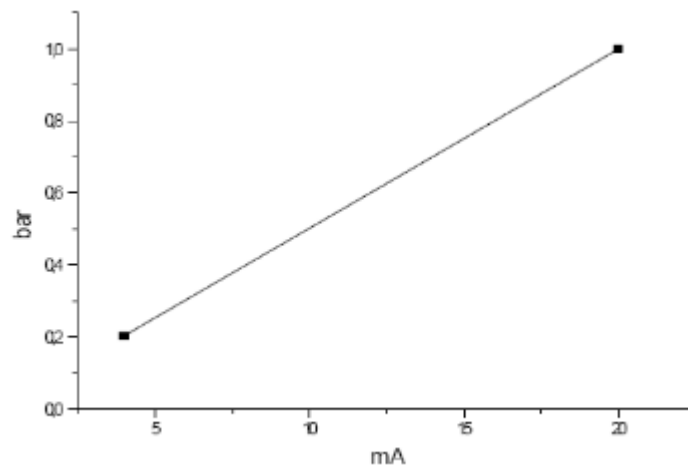


Fig. 2.4

- Fig. 2.5: the proportionality between the output signal of the electropneumatic converter (0-2-1 bar) and the opening level of the valve (0-100%).

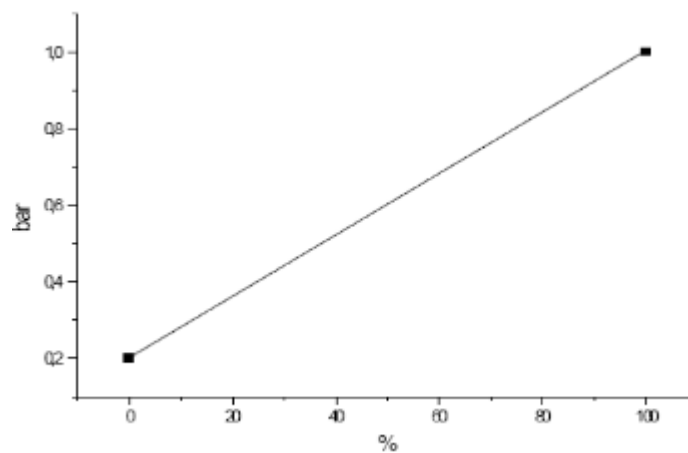


Fig. 2.5

The signals 4–20 mA and the input and output of the PID controller can be measured with a milliammeter using the proper terminals set on the board. The pneumatic signal at the output of the I/P converter can be read directly on the pressure gauge set on the board.

The controller is set at the factory to PI mode (proportional + integrative) as in the pressure control the derivative action is generally not used.

2.4- INSTALLATION

- ☐ Shut off valves V1, V2, V4 and V6.
- ☐ Open valve V3 and partially valve V5.
- Connect the electrical board to the electrical mains (n° 2)
- ☐ Connect the electrical board (n° 1) to the **compressed air** line with the provided pipe (complete with quick connections); the air pressure must be **at max. 1.5 bar** and not less than 1.2 bar.
- ☐ Connect the valve V1 to the 6 bar compressed air line (n° 5).
- ☐ Connect the plant to the serial port COM1 of the P.C. with the proper serial cable (n° 3).
- ☐ Insert the E.L.C.B (n° 4).

2.5- STOP

- ☐ Shut off valve V1
- ☐ Switch off the E.L.C.B.
- Depressurize all lines through valve V5.

2.6- EXERCISE

- Set:
 - Gain= 1.0
 - I=0.5 min
 - D=0
- ☐ Set the set-point to the 40% (approx. 2.40 bar, full scale 6 bar).
- ☐ The process variable will reach the set-point value with regular behavior. This indicates the Gain and Integrative time (I) values are valid.

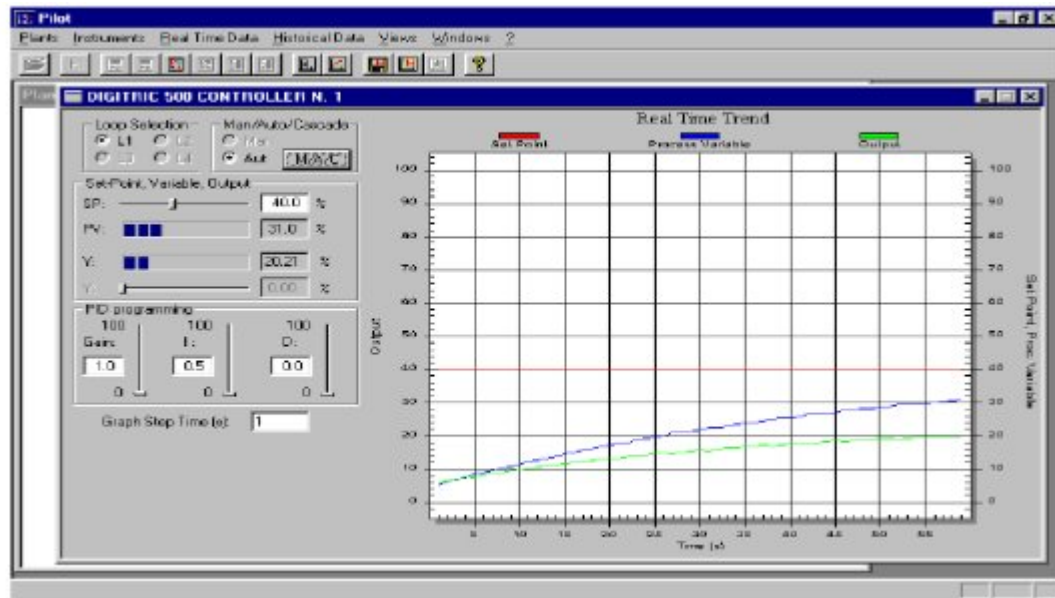


Figure 2.6

In the pressure control, the derivative time must be null, i.e. the controller operates in PI mode (the controller is programmed in PI mode); the derivative time introduction, in fact, gets the regulating action worse.

- Increase the gain to 3
- Disturb the system setting the set-point to the 50% (or by shutting or opening valve V5).
- You can note that, with the set gain value, the pressure control is impossible.

However, inserting the tank D1 into the circuit (the volume of the system increases noteworthy), there is a quick softening of the oscillations until the set-point value is reached. The tank D1

substantially acts as shock absorber). At this point a test can be carried out excluding the integrative action,

- Set:
- Gain = 1.0
- Set the set-point to the 40% (approx. 2.40 bar considering that the full scale is 6 bar).
- The process variable will get near the set-point value never reaching it: a constant shift in time called OFF SET will remain.

2.7- SAFTY

- Before any maintenance operation, disconnect the system from the electrical supply.
- Use compressed air at the maximum pressure of 6 bar as process fluid.

Table2 RAW DATA SHEET

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Exp #3

Flow Control

3.1- INTRODUCTION

The unit Mod. FCB/EV can be used to study the automatic flow-rate control through the typical system composed of calibrated diaphragm, control valve, differential pressure transmitter and PID controller. The process fluid can be water or air. The system is provided with a specific supervision software, mod. SW – FCB/EV, that provides the P.C. control. The bench can be connected in series with Mod. PCB/EV or in parallel to the other automatic control units (Mod. LCB/EV and TCB/EV).

3.2- TECHNICAL CHARACTERISTICS

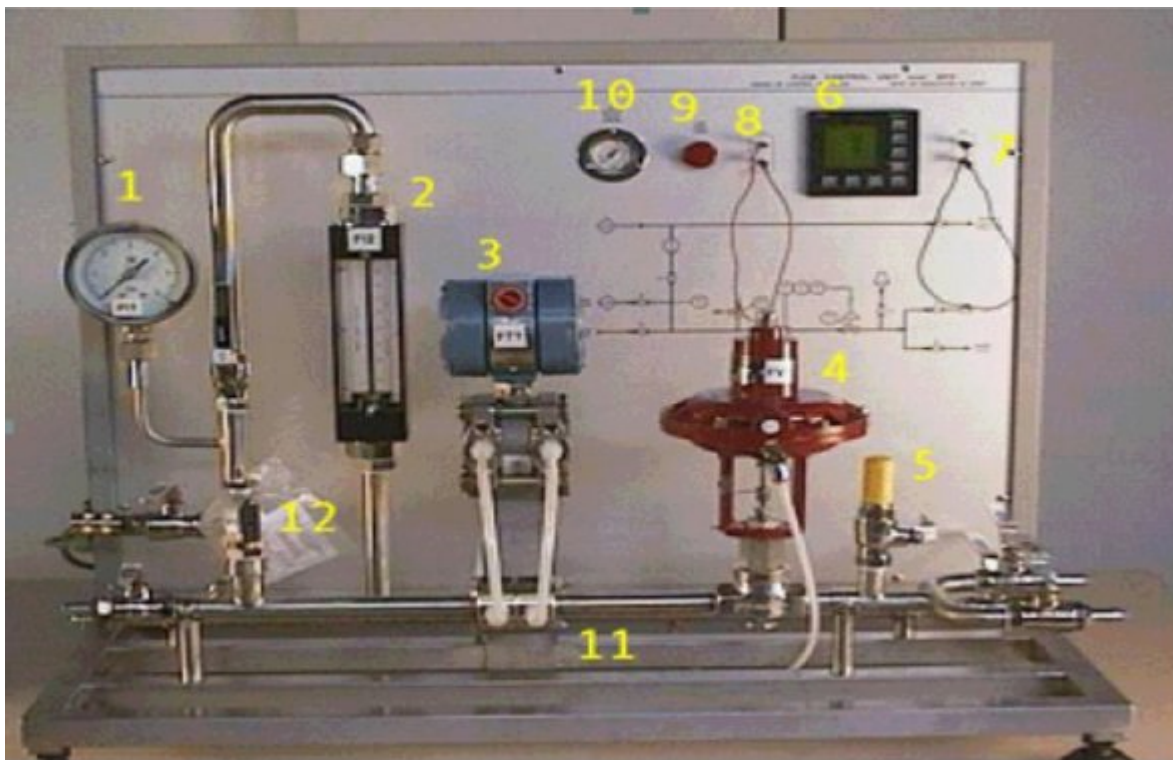


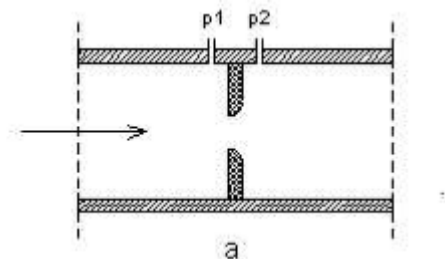
Fig. 3.1

- AISI 304 stainless steel framework
- Pneumatic control valve, AISI 316 stainless steel execution, DN 15, $C_v = 2.5$, code FV1 (n° 4)
- Electronic differential pressure transmitter, range 0-1000 l/h of water and 30 Nm³/h of air, transmitter calibration 0-500 mmH₂O, 4- 20 mA output signal, code FT1 (n° 3)
- Variable area flow meter, range 100-1000 l/h, code FI2 (n° 2)
- Calibrated diaphragm, AISI 316 stainless steel execution, $d = 10.9$ mm (n° 11)
- Microprocessor controller, PID type, 4-20 mA input and output signals, accuracy $\pm 0.1\%$, complete with serial card RS 232 (n° 6)
- Electropneumatic converter 4-20 mA/0.2-1 bar (inside the switchboard)
- Bourdon spring pressure gauge, range 0-6 bar (n° 1)
- AISI 304 and 316 stainless steel valves and connection lines
- Safety valve, calibration at 9.3 bar, code PSV1 (n° 12)
- Silencer in plastic material (n° 5)
- Pressure gauge, 0 - 2.5 bar (n° 10)
- 2 measurement terminals for the 4-20 mA signal at the controller input (n° 8)
- 2 measurement terminals for the 4-20 mA signal at the controller output (n° 7)
- Power supply light (no. 9)
- Painted carbon steel electrical board with plant synoptic and E.L.C.B.

3.3- OPERATING PRINCIPLE

The operating principle of the equipment can be described as follows.

The fluid, crossing the calibrated diaphragm, causes a pressure drop proportional to the flow rate.



The phenomenon is described by the following equation:

$$Q = \sqrt{\frac{2\Delta p}{\rho}} \frac{A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

where:

Δp = pressure drop on the diaphragm

A_1 = pipe section

A_2 = calibrated hole section

ρ = fluid density

In case of turbulent motion of the fluid, the last equation is written as follows:

$$Q = C_d \sqrt{\frac{2\Delta p}{\rho}} \frac{A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

Where C_d is the discharge coefficient and ranges between 0.6 (turbulent flow) and 1 (laminar flow). The electronic transmitter FT1 measures the pressure drop Δp (in mmH₂O), extracts the square root of the measured value, and sends the PID electronic controller a 4-20 mA electrical signal proportional to $\sqrt{\Delta p}$ and so to the flow rate.

In practice (Fig. 3.2):

- If the flow is null ($\Delta p = 0$, $Q = 0$ l/h,) the output signal to the transmitter is 4 mA (zero).
- If the flow rate is maximum ($\Delta p = 500$ mmH₂O, $Q = 1000$ l/h,) the output signal to the transmitter is 20 mA.
- For intermediate flow rate values, the output signal from the transmitter will be proportional to the flow rate; e.g. at 500 l/h the output signal from the transmitter will be equal to 12 mA.

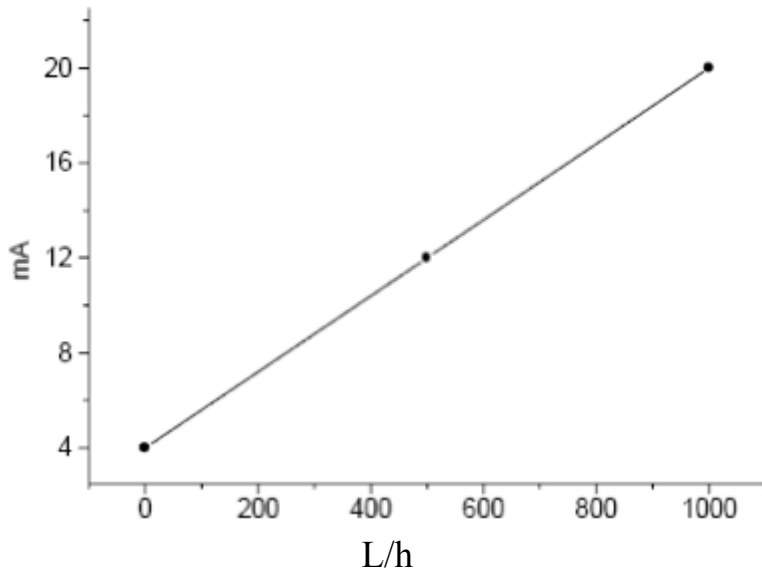


Fig. 3.2

The signal sent by the transmitter FT1 to the PID controller is compared to the set point value set on the controller. At this point, the controller sends the output a 4-20 mA signal, function (PID) of the shift between the value of the process variable and the set point. This electrical signal is converted by an electropneumatic converter into a pneumatic signal controlling the valve opening degree. The following graphs report:

Fig. 3.3: the proportionality between the electrical signal at the output of the PID controller and the pneumatic signal at the output of the electropneumatic converter (I/P).

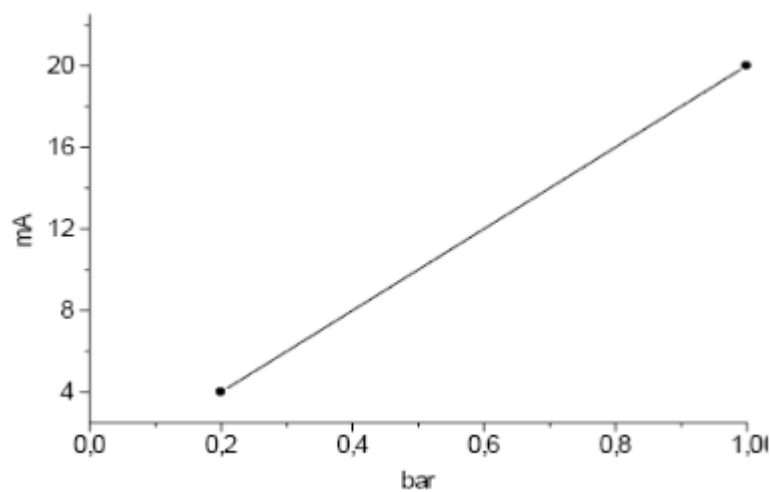


Fig. 3.3

Fig. 3.4: the proportionality between the output signal of the electropneumatic converter (0.2-1 bar) and the valve opening degree (0- 100%).

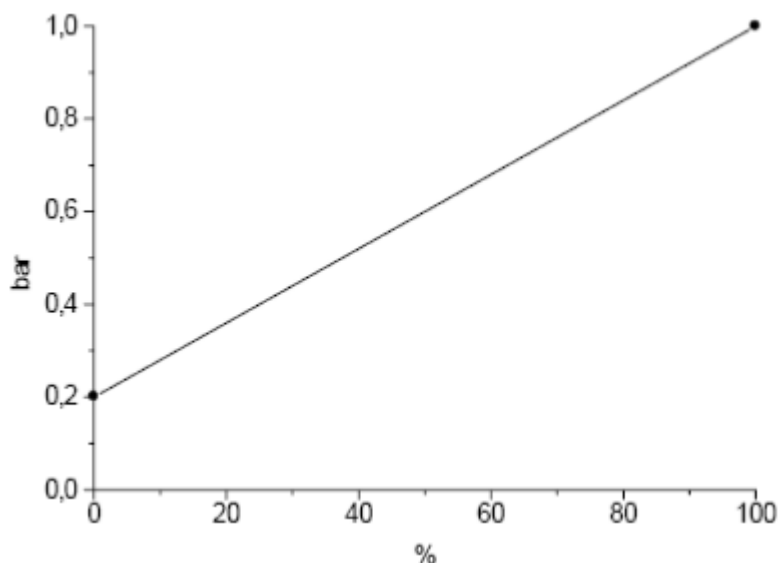


Fig. 3.4

The 4-20 mA signal at the input and output of the PID controller can be measured with a milliammeter using the proper terminals (Fig. 3.1 – no.7 and 8) set on the board.

The output signal to the I/P converter can be read directly on the pressure gauge (Fig. 3.1 – no. 10) set on the board. The controller is pre-set to PI mode (proportional + integral) as the derivative action is not generally used in the flow rate control.

3.4- INSTALLATION

- Shut off the valves V1, V2, V3, V4, V6 and V7
- Open the valve V5
- Connect the electrical board to the single-phase + G electrical supply (Fig. 3.1 – n° 2)
- Connect the electrical board to the **compressed air** line using the provided pipe (complete with quick connections); the air pressure must be at max. of **1.4 bar** (Fig. 3.1 – n° 1) and not less than 1.2 bar.
- Connect the installation to the water line with the provided rubber pipe (Fig. 3.1 – n° 4) using metal hose clamps to fix it to the hose connector; the line water flow rate must be about 1000 l/h

ATTENTION! ALWAYS SHUT OFF THE VALVE V3 BEFORE OPENING THE VALVE V2 TO PREVENT DAMAGING THE FLOWMETER FI2.

- In case air is to be used as process fluid, connect the system to the compressed air line at 6 bar through the valve V2 (Fig. 3.1 – n° 5) using the proper provided pipe (complete with quick connections).
- Connect the plant to the serial port COM1 of the P.C. with the serial cable (Fig. 3.1 – n° 3)
- Connect the valve V5 to a drain by means of a rubber pipe (Fig. 5.2)
- Insert the E.L.C.B.

3.5- STOP THE SYSTEM

- Shut off the valve V3
- Disconnect the E.L.C.B.

In case of long period of inactivity:

- Open the exhaust valve V5, the valve V7, the valve FV1 and the valve V1
- Drain the line

3.6- EXERCISES

Process fluid: Water

- Set:
Gain = 0.2
I = 0.3 min
D = 0
- Set the set point to the 50% (500 l/h about, full scale 1000 l/h) (Fig.3.5)
- Wait until the process variable reaches the set point value.

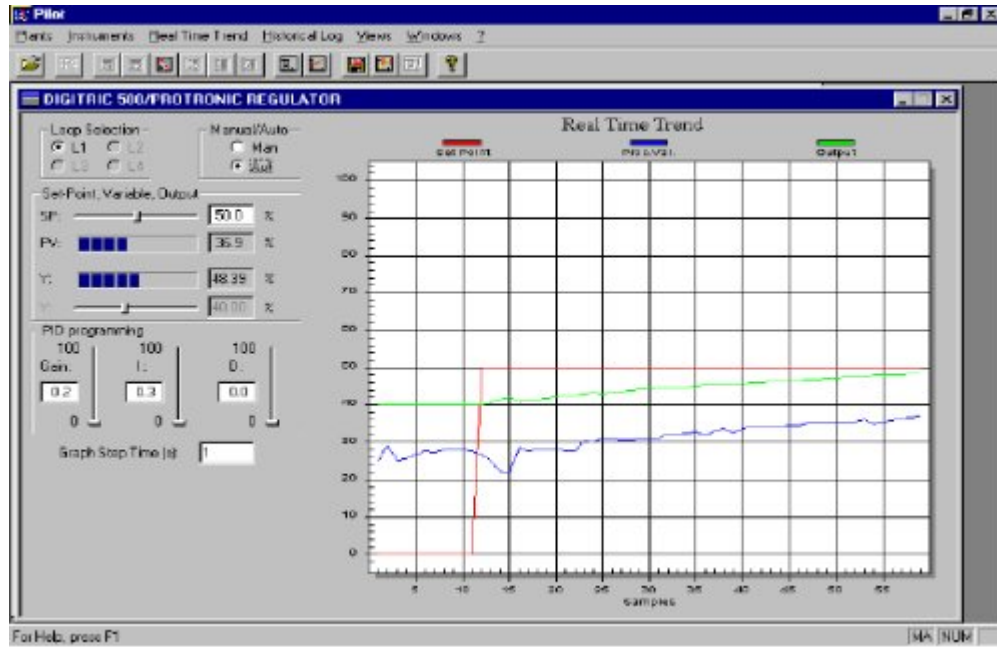


Fig. 3.5

- Wait until the process variable reaches the set point value. As you can note, the gain and integrative time values are valid. In the flow rate control, the derivative time must be null, i.e. the controller operates in PI mode; the introduction of the derivative time, in fact, makes the controlling action worse.
- Increase the gain to 2
- Perturbate the system by closing and opening the valve V5
- You can note that the flow rate control is impossible with the set gain value.

Process fluid: Air

SHUT OFF THE VALVE V3 TO PREVENT DAMAGES ON THE FLOW METER FI2

- Set:
 - Gain = 0.2
 - I = 0.3 min
 - D = 0
- Set the set point to the 50% (full scale 30 Nm³/h about)

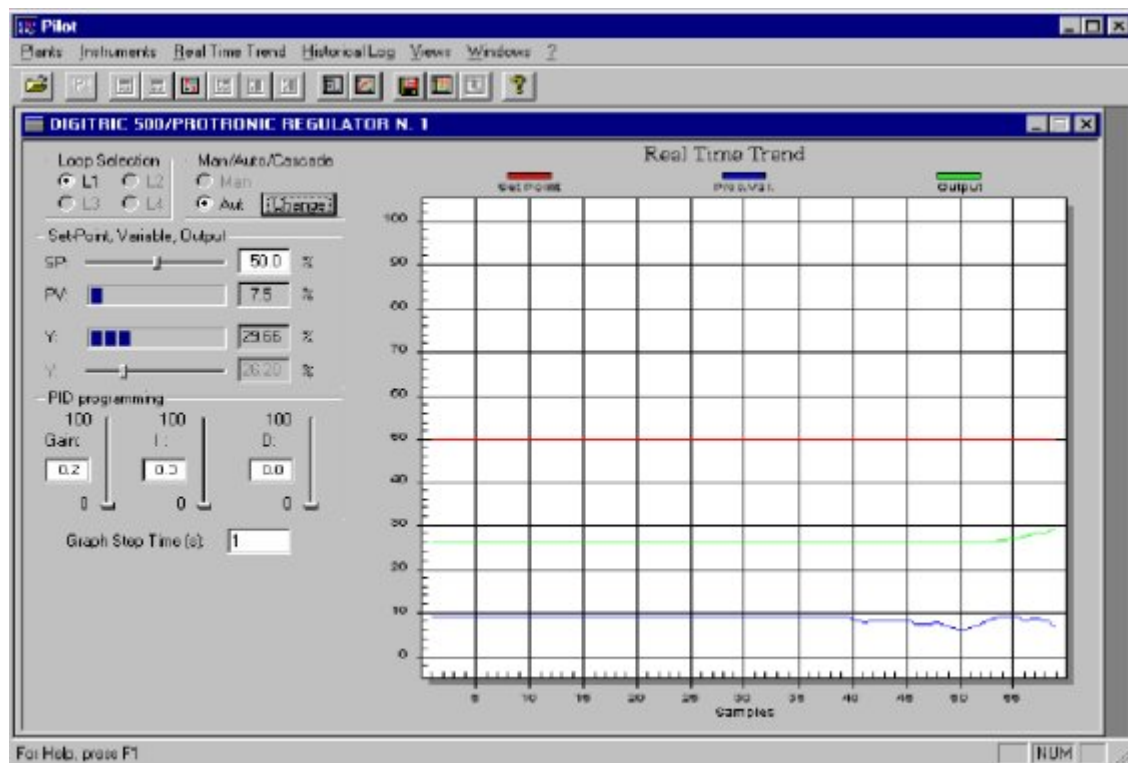


Fig. 3.6

- Wait for the process variable to reach the set point value.

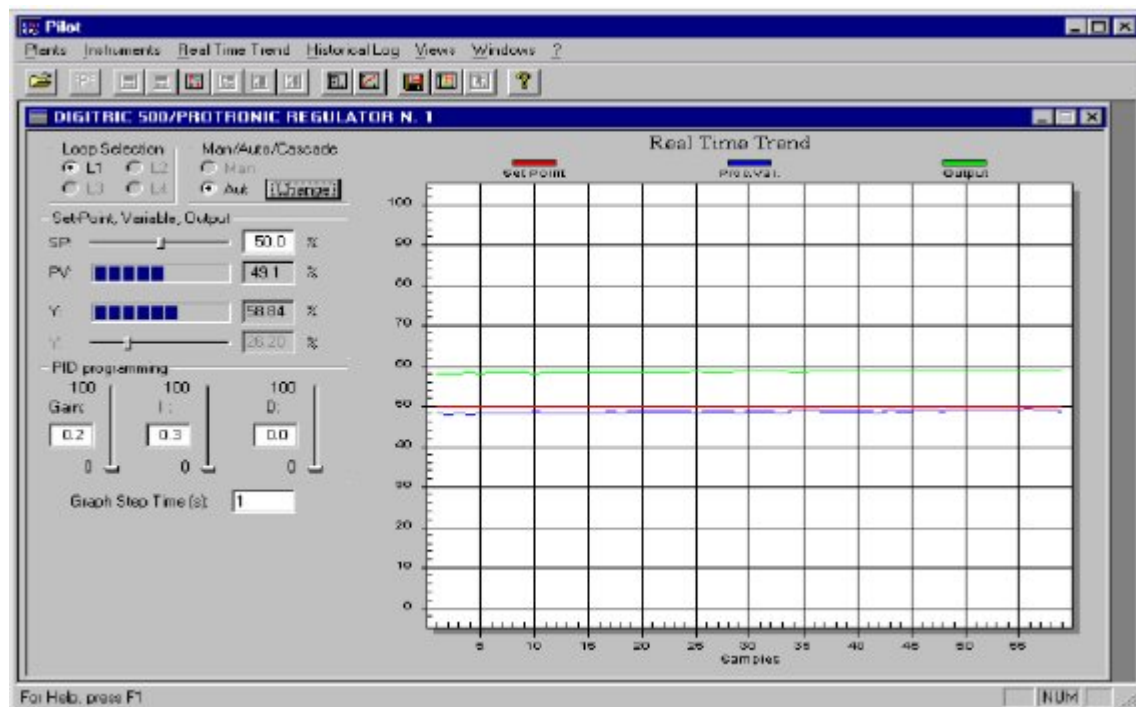


Fig. 3.7

- Set the controller with the single action P and take the set point to the 30%.

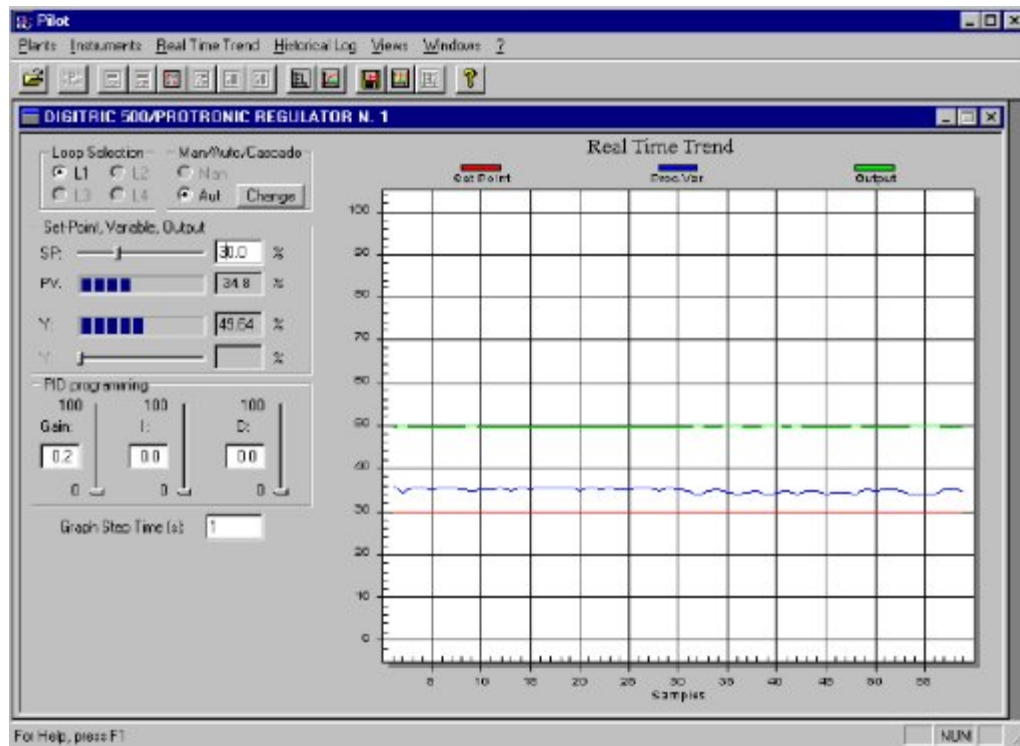


Fig. 3.8

As you can note, in absence of integrative action there is a permanent off-set of the process variable in respect to the set point.

3.7- SAFETY

- Before any maintenance operation, disconnect the plant from the electrical mains.
- In case compressed air is used as process fluid, keep the valve V3 always closed.

Table3 RAW DATA SHEET

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Exp #4

Temperature Control

4.1- INTRODUCTION

General guidelines for temperature control loops are difficult to state because of the wide variety of process and equipment involving heat transfer and their different time scales. For example, the temperature control problems are quite different for heat exchangers, distillation columns, chemical reactors and evaporators. The presence of time delay and/or multiple thermal capacitances will usually place a stability limit on the controller gain. PID controllers are commonly employed to provide more rapid response than can be obtained with PI controllers.

Heat exchanger is a good example for temperature control, figure (1) illustrates a set up of the heat exchanger. It is required to heat the process fluid to a specific temperature (T_2) by adjusting the inlet flow rate of the steam. If the outlet temperature of the process fluid decreases then the temperature transmitter will measure it and send an electrical signal to the temperature controller that will compute the error and give appropriate action to the inlet steam valve. Finally steam flow will increase and inherently T_2 will increase.

→

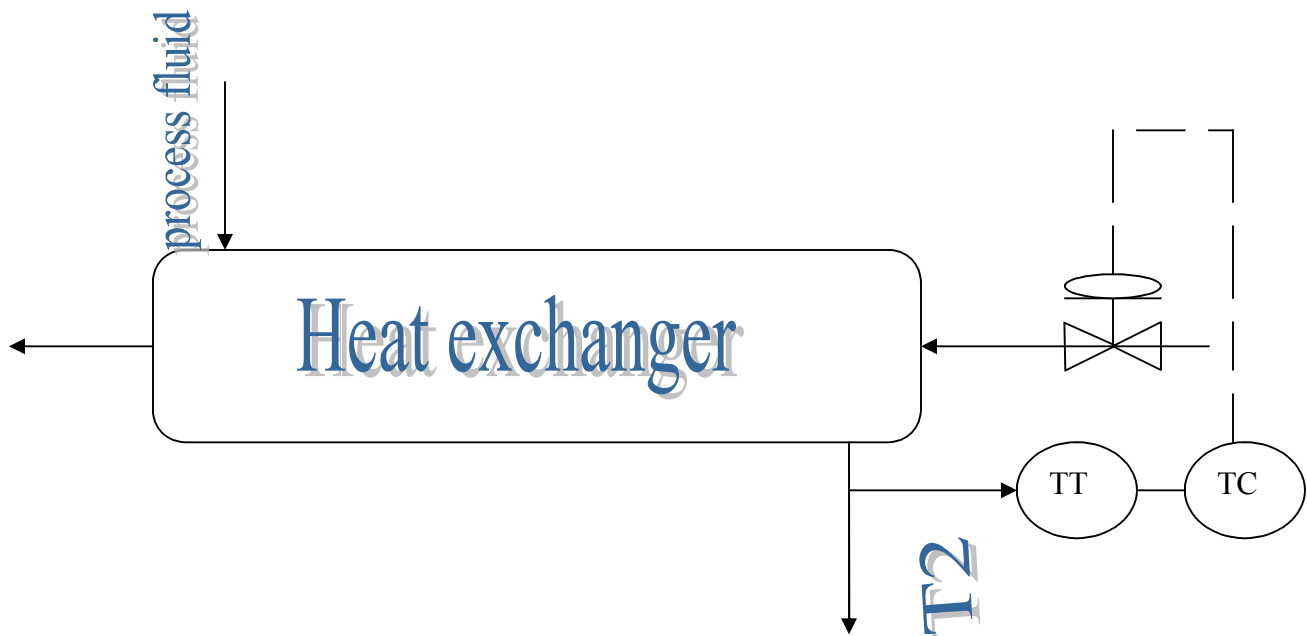


Figure 4.1

4.2- TECHNICAL CHARACTERISTICS

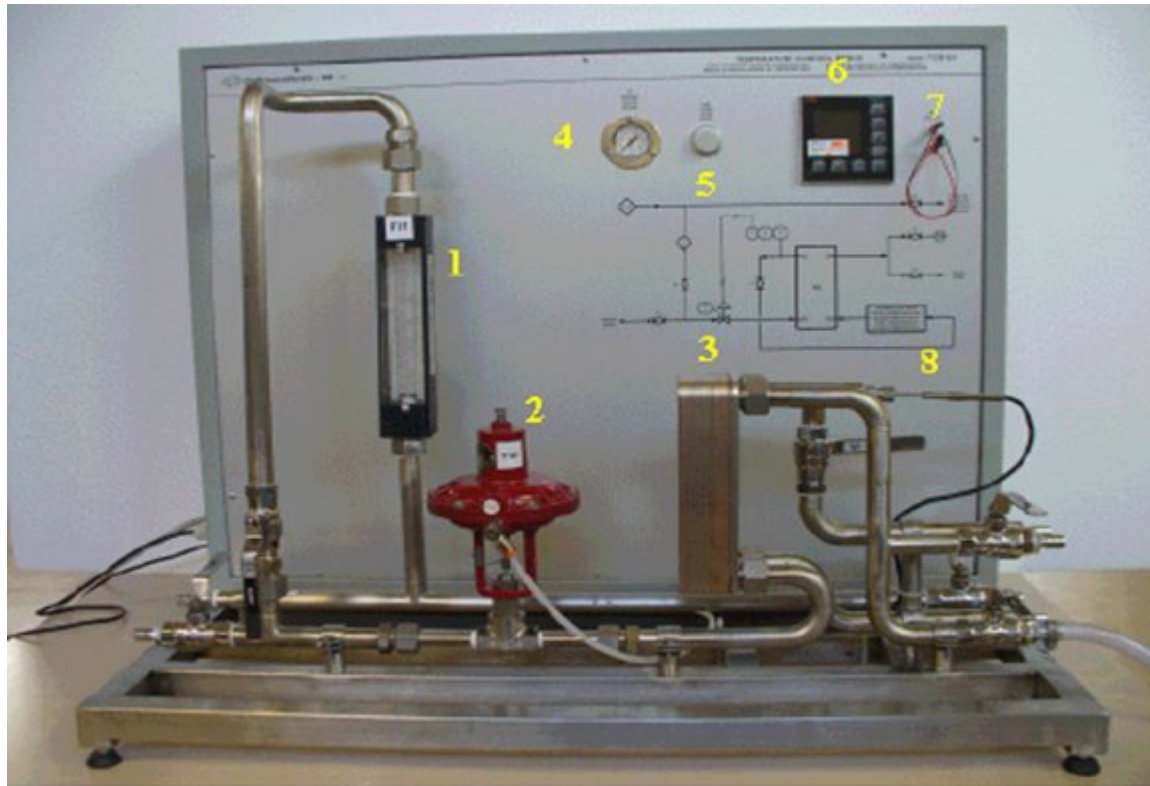


Fig. 4.2

- AISI 304 stainless steel framework
- Pneumatic control valve, AISI 316 stainless steel execution, DN 15, $C_v = 0.13$, code TV1 (n° 2)
- RTD Pt100 with AISI 316 stainless steel sheath, code TT1 (n° 8).
- Microprocessor controller, PID type, 4-20 mA output signals, accuracy $\pm 0.1\%$, complete with serial card RS 232 (n° 6)
- Electropneumatic converter 4-20 mA/0.2-1 bar (inside the switchboard)
- AISI 304 and 316 stainless steel connection lines and valves
- Pressure gauge 0 - 2.5 bar (n° 4).
- 2 measurement terminals for the 4-20 mA output signal of the controller (n° 7)
- Electrical supply light (n° 5)
- Painted carbon steel electrical board with synoptic of the plant and E.L.C.B.

4.3- OPERATING PRINCIPLE

In this unit, the PID control is made on the output temperature of the hot current coming from the plate heat exchanger E1. The control device consists in a pneumatic valve that, according to the signal coming from the PID controller, adjusts the cold current flow-rate.

The temperature measurement is carried out by means of an RTD which operating principle can be summed up as follows. The electrical resistor of a conductor generally increases with the temperature, so from the resistor measurement, obtained with a bridge

circuit, you can find out the temperature of the ambient with which a resistor is in thermal balance. The instruments of this kind have the double advantage to be very accurate and very simple and are used in industrial devices with direct reading as well as in temperature measurements with the maximum accuracy (in these cases a wire of pure platinum is used as resistor, in the temperature range between —258 °C and 900 °C).

The RDT is composed of a very thin metal wire, wound around a small porcelain cylinder and included into an insulating sheath. The wire, that represents the thermometric substance, is connected to a proper electrical circuit created to provide a measurement of the resistance with the maximum accuracy. The RTDs are indicated according to the atomic element that constitutes the wire and according to the zero degree resistance; e.g., the most used ones are the Pt100: platinum RTDs from 100 to 0°C. 4 wires normally exit from the RDT: two primaries for the current and two secondaries for the voltmeter.

The relation that enables to measure the resistance from the temperature is:

$$R = R_0(1 + \alpha T)$$

where R_0 is the resistance of the material at 0°C and α is a coefficient the most common values of which we report on a table:

Material	Resistivity $\rho = \Omega \cdot \text{mm}^2 / \text{m}$	Coefficient of temperature $\alpha \cdot 10^{-3} (0^\circ \text{C})$
Silver.....	0.015	3.6
Electrolytic copper.....	0.016	4.2
Copper.....	0.017	4.3
Phosphor bronze	0.018	4.0
Gold.....	0.021	3.6
Aluminum.....	0.028	4.3
Tungsten.....	0.050	4.2
Brass.....	0.085	3.9
Pure iron	0.100	5.0
Platinum.....	0.103	3.6
Sweet iron	0.130	4.8
Tin.....	0.130	4.5
Lead.....	0.200	4.3
Nickel silver.....	0.350	0.17
Manganin.....	0.400	0.001
Ferrosilicon.....	0.500	1
Constantan.....	0.500	0.0008
Ferronickel.....	0.800	0.07
Quicksilver.....	0.940	0.089
Nickel-chromium.....	1	0.01
Coal.....	30	-0.04
Germanium.....	$47 \cdot 10^1$	negative
Silicon.....	$2.3 \cdot 10^9$	negative
Dry paper	10^{11}	
Bakelite.....	$5 \cdot 10^{16}$	
Glass.....	$9 \cdot 10^{16}$	
Mineral oil	10^{17}	
Porcelain	$2 \cdot 10^{19}$	
Araldite.....	10^{20}	
Polystyrene.....	10^{22}	

Qualities:

- It is a stable instrument so it is always precise and quite accurate;
- It is strong;
- It changes very slowly in time and so it must not be calibrated continuously;
- It has an electrical output, for this reason, it is particularly recommended for industrial accuracy measurements.

Defects:

- It is quite expensive;
- It needs auxiliary instruments;
- The heating by Joule effect can be consistent (the dissipated heat is $Q=R \cdot I^2$) and can ruin the device;;
- It has a thermal inertia as it is not too small (it is more proper for industrial uses). The RTD TI1 measures the temperature and sends the electronic PID controller a signal in Ohm proportional to it.
- If the temperature is 0 degrees, the signal of the Pt100 is equal to about 100 Ω ;
- If the temperature is 100 degrees, the signal of the Pt100 is equal to 138.5 Ω ; for intermediate temperature values the output signal from the Pt100 will be proportional. The signal in Ω is converted by the PID controller into $^{\circ}\text{C}$ and compared with the fixed set-point value. At this point, the controller sends a signal of 4-20 mA across the output, function (PID) of the shift between the value of the process variable and the set point. Such electrical signal is converted by an electropneumatic converter into pneumatic signal that controls the valve opening degree. The following graphs shows:
- Fig. 4.3: the proportionality between the output electrical signals of the PID controller and the pneumatic output signal of the electropneumatic converter (I/P)

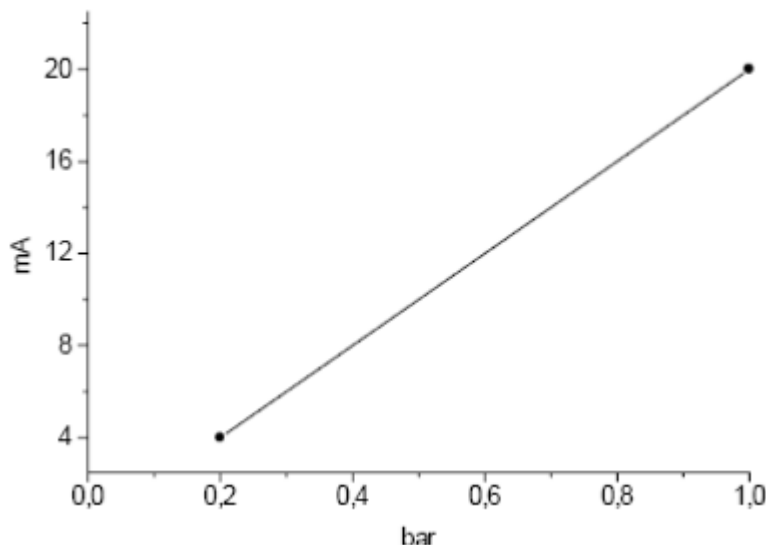


Fig. 4.3

- Fig. 4.4: the proportionality between the output signal of the electropneumatic converter (0.2-1 bar) and the valve opening degree (0-100%).

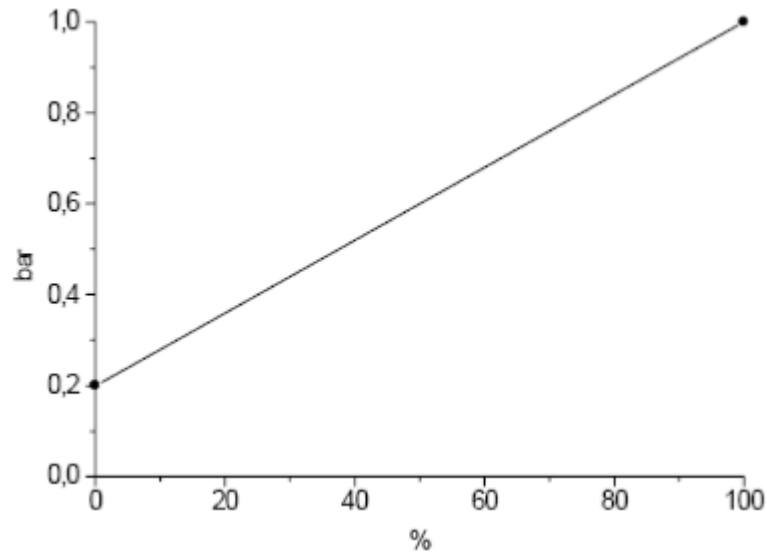


Fig. 4.4

The 4-20 mA signals at the output of the PID controller can be measured with a milliammeter using the proper terminals set on the board. The output signal from the I/P converter can be read directly on the pressure gauge set on the board.

4.4- INSTALLATION

- Shut off the valves V1, V4 and V6
- Open the valves V2, V3, V5
- Connect the electrical board to the single-phase + G electrical supply (Fig. 5.1 – n° 2)
- Connect the electrical board to the compressed air line with the provided pipe complete with quick connections (Fig. 5.1 – n° 1); the air pressure must be at max. of **1.5 bar** and not less than 1.2 bar.
- Connect the unit to the tap water with the rubber pipe provided using metal hose clamps to fix it to the hose connector (Fig. 5.1 – n°4); the line water flow rate must be about 300 l/h
- Connect the system to the thermostatic bath with the provided pipes respecting the direction of the adhesive arrows set on the pipes.

- Fill the tank of the thermostatic bath with **distillated** water or with silicon oil (with viscosity around 100 mm²/s); with silicon oils (specific heat = ½ water specific heat) the temperature set on the thermostatic bath is reached more quickly.
- Switch on the thermostatic bath and fix the temperature e.g. to 50 °C (see related technical manual).
- Connect the system to the serial port COM1 of the P.C. with the serial cable (Fig. 5.1 – n° 3).
- Connect the valve V5 to a drain by means of the provided rubber pipe and metallic clamp
- Insert the E.L.C.B. (Fig. 5.1 – n° 5)

4.5- Stop of the system

- Shut off the valve V2.
- Switch off the thermostatic bath.
- Disconnect the E.L.C.B. set on the electrical control board.

In case of long period of inactivity:

- Drain all lines of the unit.

4.6- EXERCISES

No.1

- Set the thermostatic bath at 50 °C
- Set:
Gain = 3.0
I = 0.4 min
D = 0.1
- Set the set point e.g. to 45°C.

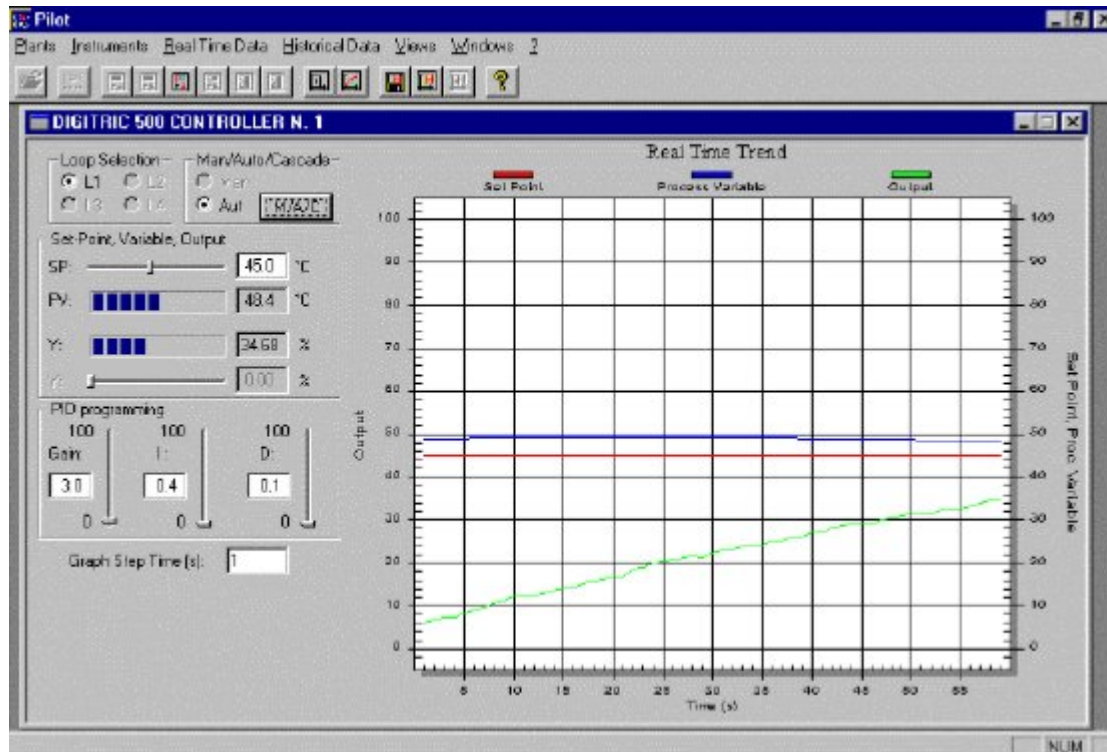


Fig. 4.5

- Wait for the process variable to reach the set point value. As you can note the gain, integrative and derivative time values are valid as the temperature control is good.
- Exclude the integrative action from the controller.
- Change the set point, e.g. 40°C.
- The process variable will get near the set point value never reaching it: a constant shift in time called OFF SET will persist.
- Reintroduce the integrative action on the controller and set I = 0.3 min; the off set will be quickly canceled.

No.2

- Set:

Gain = 3.0

I = 0.4 min

D = 0.1

- Set the set point e.g. to 45°C.
- While the process variable tends to reach the set point, increase the Gain, e.g. to 6.0; you will observe an increase of the inclination of the graph of Out (controller output) in time as the gain has been increased.

When the value of gain is too high, the controller output starts to oscillate.

4.7- SAFETY

- Before any maintenance operation, disconnect the plant from the electrical mains

Table4 RAW DATA SHEET

[illegible]

Exp#5

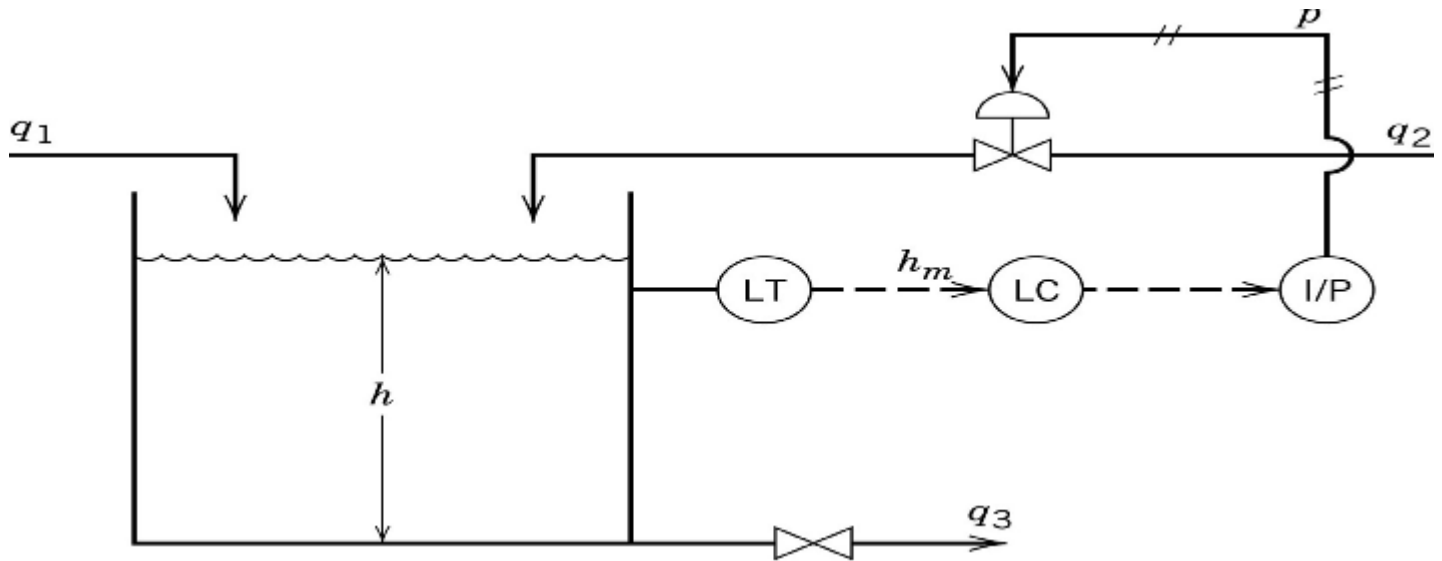
Level Control

5.1- THEORITICAL BACKGROUND:

The liquid-level control system shown in the following figure. The liquid level is measured and the level transmitter (**LT**) output is sent to a feedback controller (**LC**) that controls liquid level by adjusting volumetric flow rate q_2 . A second inlet flow rate q_1 is the disturbance variable. If the inlet flow rate q_1 is decreased the level in the tank will drop, the level transmitter (**LT**) output will be sent to the controller, the controller will compare between the measuring value and the set point value to evaluate the error, depending on the error the controller will give appropriate action to the final control element and in our case the controller will send an electrical signal to **I/P** transducer which change the electrical signal to pneumatic action to the valve (final control element) to adjust the manipulated variable q_2 (increase it) to reach the set point value of the level.

Assume:

1. The liquid density ρ and the cross-sectional area of the tank A are constant.
2. The flow-head relation is linear, $q_3 = h/R$.
3. The level transmitter, **I/P** transducer, and control valve have negligible dynamics.



Consider the unsteady-state mass balance for the tank contents:

$$\rho A \frac{dh}{dt} = \rho q_1 + \rho q_2 - \rho q_3$$

Substituting the flow-head relation, $q_3 = h/R$, and introducing deviation variables gives

$$A \frac{dh'}{dt} = q'_1 + q'_2 - \frac{h'}{R}$$

Thus, we obtain the transfer functions

$$\frac{H'(s)}{Q'_2(s)} = G_p(s) = \frac{K_p}{\tau s + 1}$$

$$\frac{H'(s)}{Q'_1(s)} = G_d(s) = \frac{K_p}{\tau s + 1}$$

Where $K_p = RA$. Note that $G_p(s)$ and $G_d(s)$ are identical because q_1 and q_2 are both inlet flow rates and thus have the same effect on h .

5.2- TECHNICAL CHARACTERISTICS



Fig. 5.1

- AISI 304 stainless steel framework
- Pneumatic control valve, AISI 316 stainless steel execution, DN 15, $C_v = 1.25$, code LV1 (n°3)
- Differential pressure electronic transmitter, AISI 316 stainless steel execution, range 0 - 500 mmH₂O, output signal 4-20 mA, code LT1 (n°2)
- Variable area flow meter, range 100-1000 l/h, code FI2 (n° 1)
- Microprocessor controller, PID type, 4-20 mA input and output signals, accuracy $\pm 0.1\%$, complete with serial card RS 232 (n°7)
- Electropneumatic converter, 4-20 mA/0.2-1 bar (inside the switchboard)
- Transparent plastic tank, capacity 5 litres, code D1 (n° 9)
- Power supply light (n° 5)
- 2 measurement terminals for the 4-20 mA input signal of the controller (n° 6)

- 2 measurement terminals for the 4-20 mA output signal of the controller (n° 8)
- Pressure gauge, range 0÷2.5 bar (n° 4)
- AISI 304 and 316 stainless steel valves and connection lines
- Painted carbon steel electrical switchboard complete with synoptic of the plant and E.L.C.B.

5.3- OPERATING PRINCIPLE

In this unit, the PID control is made on the water level inside the tank D1. The control device consists in a pneumatic valve that, according to the signal from the PID controller, adjusts the inlet water flow rate to the tank and consequently the level. The electronic transmitter, LT1, measures the pressure at the base of the tank (directly proportional to the level) and sends the PID electronic controller a 4-20 mA electrical signal proportional to 0 - 500 mmH₂O.

In practice:

- If the level is null, the output signal from the transmitter is 4 mA (zero).
- If the level is to 500 mm, the output signal from the transmitter is 20 mA.
- For intermediate values, the output signal from the transmitter will be proportional to the level; e.g. at 250 mm the output signal from the transmitter will be equal to 12 mA.

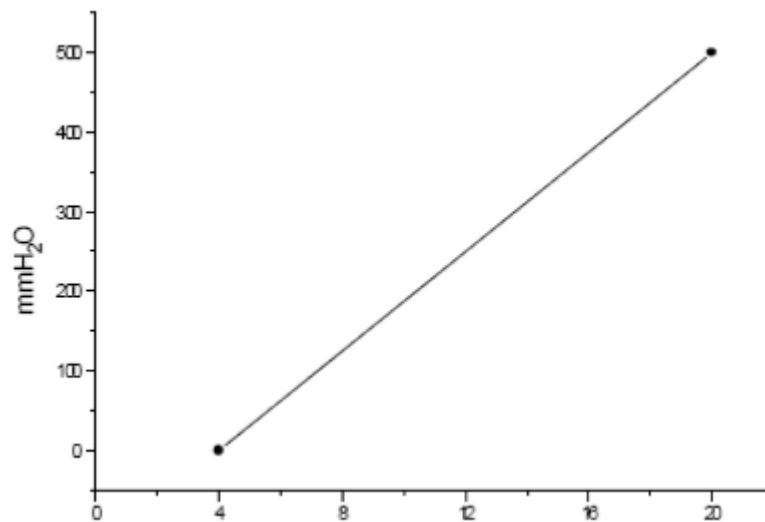


Fig. 5.2

The signal sent by the transmitter LT1 to the PID controller is compared to the set point value set on the controller. At this point, the controller sends a 4-20 mA signal to the output, function (PID) of the shift between the value of the process variable and the set point. This electrical

signal is converted by an electropneumatic converter into a pneumatic signal that controls the valve opening level. The following graphs show:

- The proportionality between the output electrical signal of the PID controller and the pneumatic output signal of the electropneumatic converter (I/P).

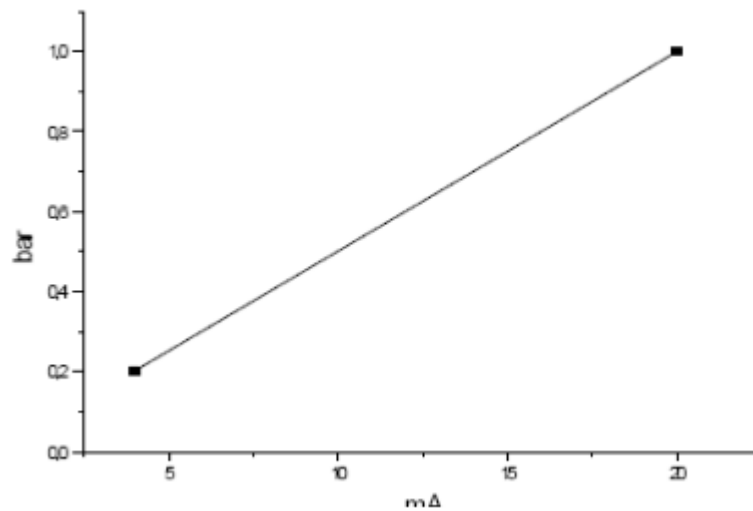


Fig. 5.3

- Fig. 5.4: the proportionality between the output signal of the electropneumatic converter (0.2-1 bar) and the opening level of the valve (0-100%).

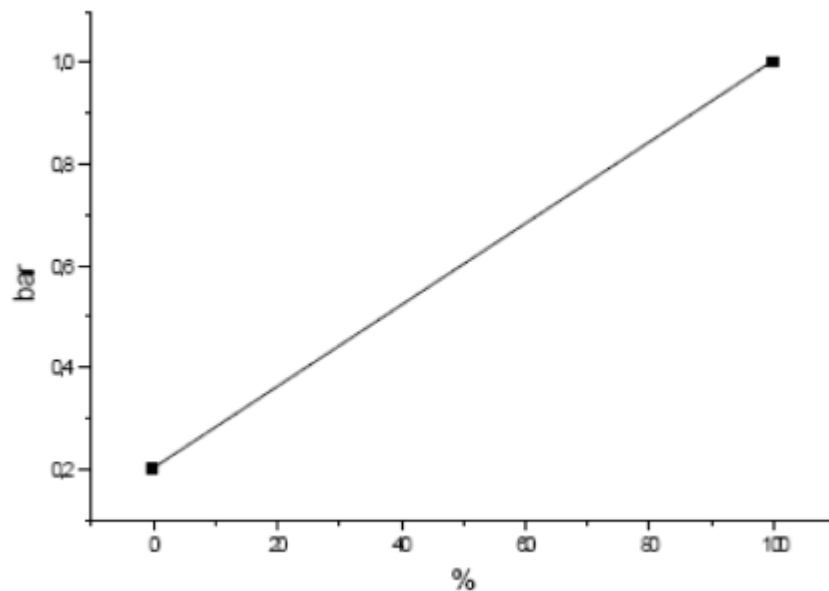


Fig. 5.4

The 4-20 mA signals at the input and output of the PID controller can be measured with a milliammeter using the proper terminals set on the board. The pneumatic output signal from the I/P converter can be read directly on the pressure gauge set on the board. The controller is pre-set to PID mode (proportional + integral + derivative).

5.4- INSTALLATION

- Close valves V1, V2, V3 and V4
- Open valve V5
- Connect the electrical control board to the single-phase + G electrical line, (n° 2)
- Connect the electrical board to the **compressed air** line using the provided pipe, complete with quick connections (n° 1); the air pressure must be at max. **1.4 bar** and not less than 1.2 bar.
- Connect the plant to the serial port COM1 of the P.C. with the serial cable (n° 3)
- Connect the installation to the water line with the provided rubber pipe (n° 1) using metal hose clamp to fix it to the hose connector; the line water flow rate must be about 1000 l/h
- Connect valves V5 and V6 to a drain by means of the provided rubber pipe using metal hose clamps to fix it to the hose connectors (n° 1 and 2).
- Connect the E.L.C.B. (n° 4)

5.5- STOP

- Close valve V2
- Disconnect the E.L.C.B.
- Empty the tank D1 and all lines from the water

5.6- EXERCISE

- Set:
Gain = 2.0
I = 1 min
D = 0.5 min
- Set the set point to the 50% (250 mm bar about, full scale 500 mm)

- The process variable will reach the set point value with regular behavior. This indicates that the Gain, derivative and integrative time values are valid (Fig.5.5)

5.7- SAFETY

- Before any maintenance operation, disconnect the plant from the electrical mains

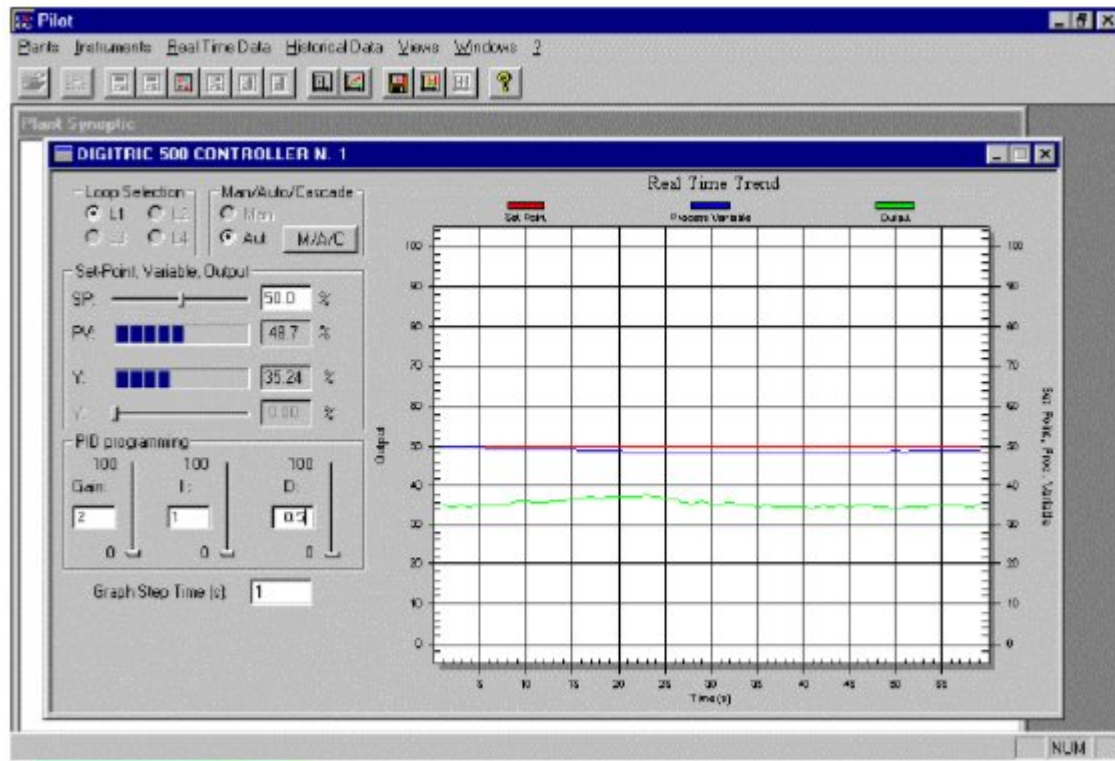


Fig. 5.5

- Switch the loop in manual mode
 - Set the setpoint at 60%
 - Increase the gain to 6
 - Switch the loop in automatic mode
 - You can note that, with the set gain value, the level control is impossible.
- At this point, you can carry out a test excluding the integrative action or the derivative action.

Table5 RAW DATA SHEET

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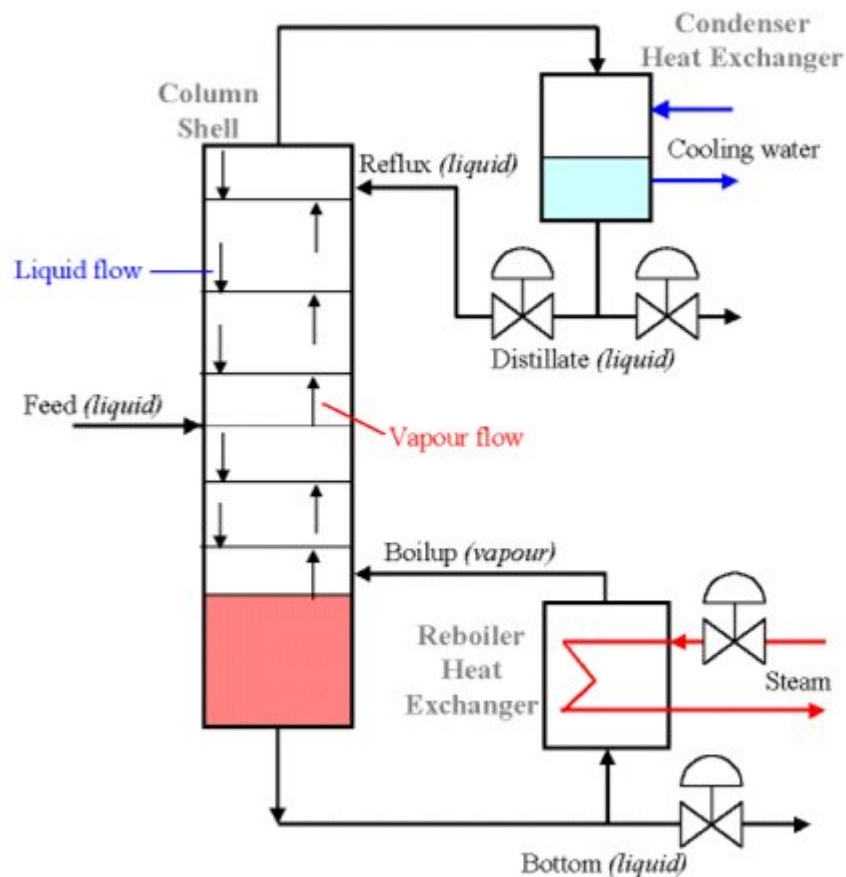
Exp #6

Distillation Control

6.1- THEORETICAL BACKGROUND

The process of distillation should be familiar to most readers. The basic concept is that we can separate a mixture of two pure liquids with different boiling points by heating the mixture to a temperature between their respective boiling points. For example, water boils at 100°C and ethanol boils at around 83°C at atmospheric pressure. If we heat the mixture to say 92°C, the ethanol will boil and be transformed into vapor (which is collected and condensed) while the water will remain as a liquid. This phenomenon is usually quantified by the relative volatility of the two components.

A distillation column is used to make this process more efficient. A schematic diagram of a distillation column is shown below.



The distillation column itself is made up of a series of stacked plates. A liquid feed containing the mixture of both liquids enters the column at one or more points. The liquid flows over the

plates, and vapor bubbles up through the liquid via holes in the plates. As liquid travels down the column, vapor comes in contact with it many times (due to the multiple plates). This is the critical process in distillation columns. The liquid and vapor phases are brought into contact because as one molecule of higher boiling material converts from vapor to liquid phase by energy release, another molecule of the low boiling material utilizes the free energy to convert from liquid to vapor phase.

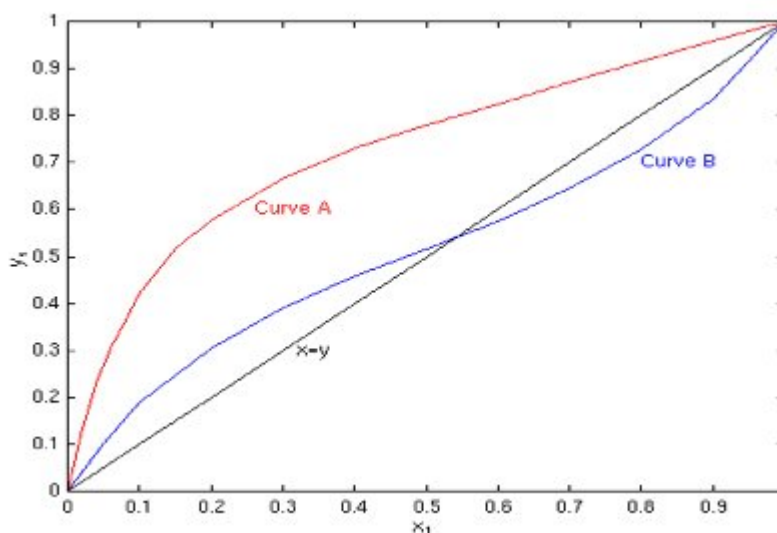
The base of the distillation column contains a large volume of liquid, which is mostly the liquid with higher boiling point (in our example, this would be water). Out of the base flows some of this liquid, some of which is heated in the reboiler and returned to the column. This is called the boil up, and is labeled V . The remaining liquid is the bottom product, labeled B .

Some vapor escapes from the top of the column and is returned to a liquid state in the condenser. Some of this liquid is returned to the column as reflux L , and the remainder is the top product or distillate D .

Vapor and liquid phases on a given plate approach thermal, pressure and composition equilibrium to an extent depending upon the efficiency of the plate

6.1.1 Design of Columns

The design of multistage columns for binary mixtures can be accomplished graphically, via equilibrium curves. This is called the McCabe-Thiele Method. Equilibrium curves plot the volatility of components in a mixture; that is, the proportion of species 1 in the vapor phase (y_1) compared with the proportion of species 1 in the liquid phase (x_1). The figure below shows two common curves: curve A is a species with normal volatility, and curve B is a system with a homogeneous azeotrope. The curves allow us to determine y_1 from x_1 given constant temperature and pressure.



The azeotrope indicates that a component that is more volatile at low x_1 becomes less volatile at high x_1 (above the azeotrope). This limits the separation that can be achieved between components.

As an example, for an ethanol-water mixture, there is an azeotrope at $x_1 = 0.8943$ (for pressure of 101.3 kPa and temperature of 78.15 °C) thus the maximum distillate composition that can be achieved is $x_d = 0.8943$. The distillate cannot have higher purity than this value from binary separation.

The McCabe-Thiele Method allows the designer to determine the number of trays needed to distil a mixture to the required purity. As well as the equilibrium curve, other factors such as the feed quality (i.e. the thermal condition of the feed, which could be sub cooled, saturated, superheated etc), the ratio of liquid to vapor flow and the proportion of species 1 in the feed are used in distillation column design.

Based on these calculations, and the required spacing between plates, the theoretical height of the column can be determined. For example, for a certain configuration the required number of trays for an ethanol-water mixture may be 60. At a spacing of 25 cm, this will give a height of 15 m. This may be excessive, and so the usual practice is to set the number of trays and then set the reflux ratio L/D . e.g. for our example the number of trays are set to 12, and the reflux ratio is then set to 5 ($5 \times 12 = 60$). Thus only 1/5th of the product is being drawn out at any time, which means that product is recirculating through the column about five times.

Thus it is important to have a fixed reflux ratio in steady state. The optimum feed tray can also be determined using this method.

6.1.2 Pressure drop over the distillation column:

The total pressure drop across each tray is the sum of that caused by the restriction of the holes in the sieve tray, and that caused by passing through the liquid (foam) on the top of the tray.

As the velocity of the vapors passing up the column increases then so does the overall pressure drop. Varying the boil-up rate, which is done by varying the power input to the reboiler, controls the velocity. Under conditions with no liquid present, the sieve trays will behave like an orifice in that the pressure drop will be proportional to the square of the velocity.

The readings of the pressure drops over the rectifying (above the feed plate) and the stripping (below the feed plate) sections will be taken by opening valves V6 and V7 on the manometer.

6.1.3 The boil-up rate:

Can be measured by operating valve V3 so that all the condensate is diverted into a measuring cylinder and the time observed to collect a set quantity.

6.1.4 Equilibrium condition

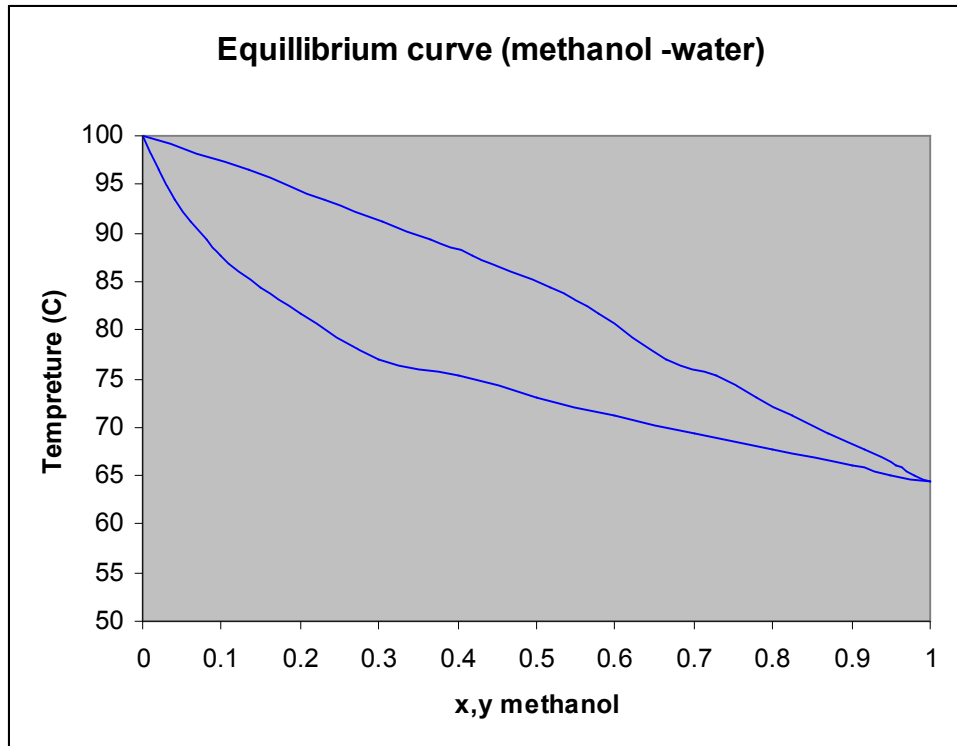
The system will have reached an equilibrium condition when the T1, T2, T3, T4, T5, T6, T7 and T8 are constant.

6.1.5 Refractometer

It is essential to have a convenient quick method of determining the composition of the binary mixture taken from the various sample points on the equipment. Such a method involves the use of a refractometer since the refractive index of these mixtures varies with composition.

6.1.6 PROPERTIES OF METHANOL AND WATER

Equilibrium Data For The Methanol- Water @ Atmospheric Pressure		
Depend on % mole of Methanol		
Liquid	Vapor	Temperature °C
0	0	100
0.02	0.134	96.4
0.04	0.23	93.5
0.06	0.304	91.2
0.08	0.365	89.3
0.1	0.418	87.7
0.15	0.517	84.4
0.2	0.579	81.7
0.3	0.665	87.0
0.4	0.729	75.3
0.5	0.779	73.1
0.6	0.825	71.2
0.7	0.87	69.3
0.8	0.915	67.6
0.9	0.958	66
0.95	0.979	65
1	1	64.5



Equation for Equilibrium

$$y = -21.98x^6 + 76.67x^5 - 106.23x^4 + 74.875x^3 - 28.67x^2 + 6.33x + .01$$

$$R^2 = 0.9997$$

6.1.7 CALCULATION OF REFLUX

The minimum reflux can be calculated using the following equation:

$$R_{\min} = \frac{x_d - y_f}{y_f - x_f}$$

Where:

X_d : the required distillation composition (liquid).

Y_f : the vapor composition in equilibrium with x_f .

X_f : the liquid feed composition

Then $R_{\text{required}} = 1.5R_{\min}$

6.1.8 CALCULATION OF SET POINT

Set point: is the desired value and is supplied externally by the person in charge the production. In determination of set point many of factors must be considered like:

1. The type of the system (binary or multi-component system).
2. The system operates at atmospheric pressure.
3. Depending on purity of methanol required the temperature of mixture at the top and bottom was calculated (dew and bubble temperature).

6.1.9 DEW POINT AND BUBBLE POINT CALCULATION

6.1.9.1 Bubble point calculation

The basic equations for the bubble point are:

$$\sum_{i=1}^{N_c} y_i = \sum_{i=1}^{N_c} K_i x_i = 1$$

Where:

K: is the ratio of mole fractions in the vapor and liquid at equilibrium.

$$K_i = \frac{y_{ie}}{x_{ie}}$$

If Raoult's law and Dalton's law hold, values of K_i can be calculated from the vapor pressure and the total pressure of the system.

$$K_i = \frac{P'_i}{P}$$

P: total pressure.

P'_i : vapor pressure.

Procedure:

1. Assume Initial guess of T_{mix} .
2. Calculate vapor pressure of each component from Antoine equation:

$$\ln P = A - \frac{B}{C + T} \quad (P \text{ in KPa, } T \text{ in K})$$

Antoine constant

Component	A	B	C
Methanol	16.4948	3593.39	-35.2249
water	16.5362	3985.44	-38.9974

3. Complete the following table:

Component	P_i at T_{guess}	K_i	x_i	$y_i = x_i K_i$
Methanol				
Water				

4. If $\sum y_i$ is too large try lower temperature.

6.1.9.2 Dew point calculation

The basic equations for the dew point are:

$$\sum_{i=1}^{N_c} x_i = \sum_{i=1}^{N_c} \frac{y_i}{K_i} = 1$$

Procedure:

1. Assume Initial guess of T_{mix} .
2. Calculate vapor pressure of each component from Antoine equation:
3. Complete the following table:

Component	P_i at T_{guess}	K_i	y_i	$x_i = y_i / K_i$
Methanol				
Water				

4. If $\sum x_i$ is too large try a higher temperature.

6.2- DISTILLATION CONTROL

In distillation control there are several requirements that must satisfy such as:

1. Safety.
2. Production specification: a plant should produce the desired amounts and quality of the final products.
3. Environmental regulations.
4. Operational constraints.
5. Economics

The input variables can be further classified into the following categories:

1. Manipulated (or adjustable) variables: values can be adjusted freely by the human operator or a control mechanism.
2. Disturbance: if their values are not the result of adjustment by an operator or a control system.

At First the manipulated variables and disturbances and set point must be considered.

There are four values which are used to control, the flow rate of B (the bottom product), the temperature of V (the boil up), the flow rate of L (the reflux) and the flow rate of D (the distillate).

The system as shown above has four inputs and four outputs

Input Variables	Output Variables
Distillate flow rate D	Condenser level
Bottom product flow rate B	Reboiler level
Reflux flow rate L	Distillate composition
Steam flow (which affects the temperature of V)	Bottom product composition

The overhead vapor V_T is also generally considered an input variable and is mainly used to control the column pressure. Since this is usually a self-regulating loop, we will ignore it in this discussion.

Obviously, it is desirable to maximize the purity of the top and bottom products. Normally in industry, the control variables are set manually by human operators. Some plants use automatic control for only one product, and manual control for the other. Manual control can result in over purification or loss of valuable product. These difficulties can be overcome by using *dual composition control*, i.e. automatic control for both products.

There are some difficulties involved in designing a dual composition controller. In particular, the system is both strongly nonlinear and strongly interactive. Also, the system has a very sluggish response, and there are many problems with measuring the output variables (including dead times for composition measurements).

Choosing the control structure is the most important step in designing a controller for the system. The column pressure and reboiler and condenser levels must be controlled very carefully to maintain stable operation. The control systems for these variables are called *inventory controllers*. This leaves two degrees of freedom to control the top and bottom concentrations. Deciding the control structure then amounts to choosing which two inputs will control the compositions.

The most common is called the LV configuration, where the reflux flow rate L is used to control the composition of the top product, and the boilup temperature V is used to control the composition of the bottom product. In this case, the distillate flow rate D and bottom product flow rate B are used to control the levels of the condenser and reboiler respectively. The

variables L and V are the ones most likely to be used by a manual operator to control the product compositions.

Another common choice is the DV configuration, where the distillate flow rate D is used to control the composition of the top product, and the boilup temperature V is used to control the composition of the bottom product. For this configuration, the reflux flow rate L and bottom product flow rate B are used to control the levels of the condenser and reboiler respectively.

USING A PID CONTROLLER WITH UOP3CC

The UOP3CC distillation column can be used for single loop process control demonstrations using a PID process controller. It is possible to configure 2 different control loops:

1. Reboiler power control from a column temperature (T7).
2. Reflux control from the top tray temperature (T1).

The object of the experiment can be:

1. Demonstrate a typical application of a PID process controller.
2. Observe the response of the process to a change in set point or disturbances.
3. Adjust the settings of the controller from optimum control of the process.

A PC microcomputer with GENESIS is available; the response of the process under PID control can be monitored and logged using data logging screen.

6.2.1 REBOILER POWER CONTROL:

6.2.1.1 Procedure

1. Ensure that the reboiler power control selector switch is set to the "I/O PORT".
2. Ensure that the reflux control and feed pump control selector switches are set to the 'MANUAL' position.
3. Select reboiler control from the main menu of the appropriate UOP3CC Genesis application.

Reboiler power control from the tray temperature T7.

6.2.1.2 Open Loop System

- For such system the manipulated variable T7 allows to reach the steady state without using controller.
-

Time (min)	T7 (°C)

- Plot T7 versus Time

6.2.1.3 Close Loop System

The controller setting for this control demonstration are listed below:

Initial value:

P	50%	
I	4	RPM
D	0	MIN

Adjust the manual output from the controller until the tray temperature T7 has stabilized at the required value then select AUTO to allow the controller to maintain T7.

Time (min)	T7 (°C)

- Plot T7 versus Time

Experiment May Be Performed To Establish:

1. Optimize the P, I, D settings.
2. The effect of disturbances

6.2.1.4 OPTIMIZE THE P, I, D SETTINGS.

6.2.1.4.1 Optimize The P Setting:

This part aims to study the response of P controller:

Feed pump _____ RPM

Reflux ratio _____

Set point _____ °C

I _____ 0

D _____ 0

P = _____ %		P = _____ %		P = _____ %	
Time (min)	T7 (°C)	Time (min)	T7 (°C)	Time (min)	T7 (°C)

- Plot T7 versus Time
- Repeat the above steps with another values of P and observe the results.

6.2.1.4.2 Optimize The I Controller Setting:

This part aims to study the response of I controller:

Feed pump _____ RPM
 Reflux ratio _____
 Set point _____ °C
 P _____ 0 %
 I _____
 D _____ 0

I =		I =		I =	
Time (min)	T7 (°C)	Time (min)	T7 (°C)	Time (min)	T7 (°C)

- Plot T7 versus Time
- Repeat the above steps with another values of I and observe the results.

6.2.1.4.3 Optimize The D Controller Setting:

This part aims to study the response of D controller:

Feed pump _____ RPM
Reflux ratio _____
Set point _____ °C
P _____ 0 %
I _____ 0
D _____

D =		D =		D =	
Time (min)	T7 (°C)	Time (min)	T7 (°C)	Time (min)	T7 (°C)

- Plot T7 versus Time
- Repeat the above steps with another values of D and observe the results.

6.2.1.4.4 Optimize The PI Controller Setting:

This part aims to study the response of PI controller:

Feed pump _____ RPM

Reflux ratio _____

Set point _____ °C

P _____ %

D 0

[illegible]

- Plot T7 versus Time
- Repeat the above steps with another values of PI and observe the results.

6.2.1.4.5 Optimize The PID Controller Setting:

This part aims to study the response of PID controller:

Feed pump _____ RPM

Reflux ratio _____

Set point _____ °C

P _____ %

I _____

D _____

Time (min)	T7 (°C)

- Plot T7 versus Time
- Repeat the above steps with another values of PID and observe the results.

6.2.1.5 EFFECT OF EXTERNAL DISTURBANCE

In this section the effect of external disturbances must be studied

Type of disturbance must be studied:

1. Feed composition
2. Feed flow rate.
3. Reflux ratio.

6.2.1.5.1 Feed Composition

Set point _____ °C
 Feed pump _____ RPM
 Reflux ratio _____
 P _____ %
 I _____
 D _____

Feed composition before change Methanol _____ Water _____
 Feed composition after change Methanol _____ Water _____

Time (min)	T7 (°C)

•Plot T7 versus Time

6.2.1.5.2 Feed Flow Rate

Set point _____ °C
 Reflux ratio _____
 Feed pump before change _____ RPM
 Feed pump after change _____ RPM
 P _____ %
 I _____
 D _____

Time (min)	T7 (°C)

- Plot T7 versus Time

6.2.1.5.3 Reflex Ratio

Set point _____ °C
Feed pump _____ RPM
Reflux ratio before change _____
Reflux ratio after change _____
P _____ %
I _____
D _____

Time (min)	T7 (°C)

- Plot T7 versus Time

6.2.2 REFLUX CONTROL

6.2.2.1 Procedure:

1. Ensure that the reflux control selector switch is set to the “I/O PORT”.
2. Ensure that the reboiler power control and feed pump control selector switches are set to the “MANUAL” position.
3. Select reboiler control from the main menu of the appropriate UOP3CC Genesis application.

Reflux control from tray temperature T1

1. Enter typical values in constant reflux controller:
 Cycle time 10 secs.
 Required ratio 4:1
 Then select constant reflux and allow the column to stabilize.
2. Enter typical values in temperature proportional controller:
 Cycle time 10 secs.
 Required ratio 4:1
 Rate of change 1.0/deg
 Required temperature value to suit binary mixture (T1).
3. Select temperature proportional reflux control to allow the controller to maintain T1.

Experiment may be performed to establish

1. The effect of disturbances
2. Optimize the controller settings.

6.2.2.2 OPTIMIZE THE CONTROLLER SETTINGS

6.2.2.2.1 Optimize The Cycle Time

Set point	_____ °C
Feed pump	_____ RPM
Power Input	_____ kW
Required ratio	_____
Rate of change	_____ /deg
Cycle time before change	_____ sec.

Cycle time = sec.		Cycle time = sec.		Cycle time = sec.	
Time (min)	T1 (°C)	Time (min)	T1 (°C)	Time (min)	T (°C)

- Plot T1 versus time
- Repeat the above steps with another values another cycle time and observe the results.

6.2.2.2.2 Optimize Rate of Change

Set point _____ °C
 Feed pump _____ RPM
 Power Input _____ kW
 Cycle time _____ sec.
 Required ratio _____
 Rate of change before change _____ /deg

Rate of change = deg.		Rate of change = deg.		Rate of change = deg.	
Time (min)	T1 (°C)	Time (min)	T1 (°C)	Time (min)	T (°C)

- Plot T1 versus time
- Repeat the above steps with another values another rate of change and observe the results.

6.2.2.3 EFFECT OF EXTERNAL DISTURBANCE

In this section the effect of external disturbances must be studied

Type of disturbance:

4. Feed composition
5. Feed flow rate.
6. Power input

6.2.2.3.1 Feed Composition

Set point °C

Feed pump RPM

Power Input kW

Cycle time sec.

Required ratio

Rate of change /deg

Feed composition initial Methanol . Water .

Feed composition after change Methanol . Water .

Time (min)	T1 (°C)

- Plot T1 versus time

6.2.2.3.2 Feed Flow Rate

Set point _____ °C
 Power Input _____ kW
 Cycle time _____ sec.
 Required ratio _____
 Rate of change _____ /deg
 Feed pump before change _____ RPM
 Feed pump after change _____ RPM

Time (min)	T1 (°C)

- Plot T1 versus time

6.2.2.3.3 Power Input

Set point _____ °C
 Feed pump _____ RPM
 Cycle time _____ sec.
 Required ratio _____
 Rate of change _____ /deg
 Power Input before change _____ kW
 Power Input after change _____ kW

Time (min)	T1 (°C)

- Plot T1 versus time

Exp #7

Tunning

Learning objectives

The learning objectives includes,

- How to identify low order process models from simple process reaction curve data
- Using a relay feedback experiment to adaptively tune simple process models
- How to tune PID controller using an inverse process model-based technique
- Understanding and using the idea of controller assessment based on classical performance indices

7.1 Introduction

In model-based controller design, simple models are used to characterize the dynamics of a given process. Based on the simple dynamic model obtained, the PID controller parameters are then computed. For example, in the parametric Ziegler-Nichols tuning method, a process model of the following form was assumed,

$$G_p(s) = \left[\frac{K e^{-\theta s}}{\tau s + 1} \right] \approx \left[\frac{K e^{-\theta s}}{\tau s} \right] = \left(\frac{K\theta}{\tau} \right) \left[\frac{e^{-\theta s}}{\theta s} \right]$$

Where the process gain, the time-constant and the delay-time are denoted by K , τ , θ respectively. Identification of this simple model structure used the step response of the process as shown in Figure 7.1. In process engineering this type of system response is termed a process reaction curve or an S-curve and this is the origin of the name for the family of tuning methods.

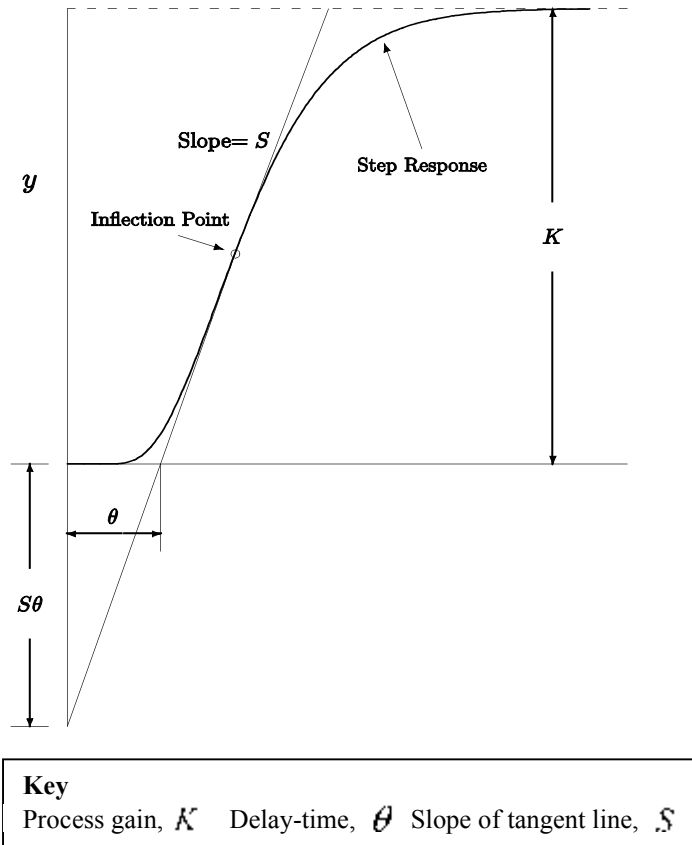


Figure 7.1 Process reaction curve of a system

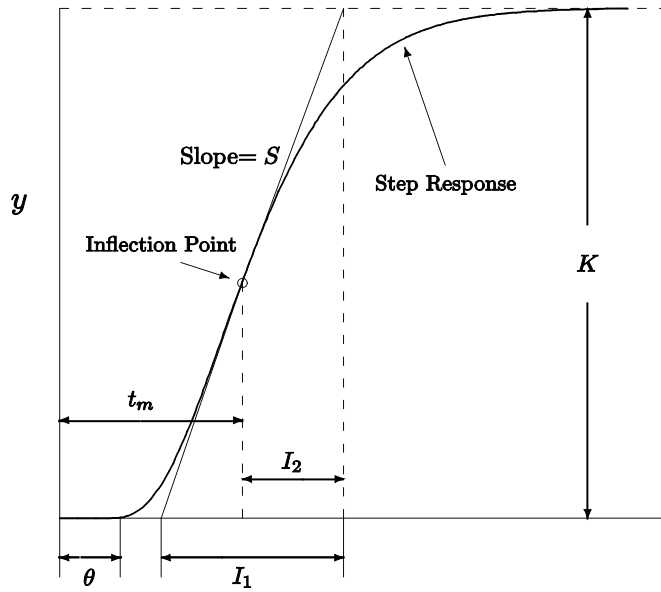
The process reaction curve would be recorded and various response measurements made. As can be seen on Figure 7.1, the process gain, K can be measured and the intersection of the tangent line with the base line provides an estimate of the dead time, θ . The slope of the tangent at the inflection point on the S-curve can also be measured. This measured slope has the theoretical formula, $S = K\theta / \tau$. Although the PID tuning is based on an inherent process model with parameters, K , τ , θ , the PID controller coefficients are computed from formula given in terms of the measured values of K , S , θ . Modeling for controller design in this way is pretty rough due to the need for a tangent line at the inflection point of the S-curve.

There are also quite a few methods in the literature which propose to model the S-shape step response curve with the so called First-Order-Plus-Dead-Time (FOPDT) models or alternatively, over-damped Second-Order-Plus-Dead-Time (SOPDT) models. Parametric methods to tune the PID controllers have been presented in many different ways for the FOPDT model given by,

$G_p(s) = \left[\frac{Ke^{-\theta s}}{\tau s + 1} \right]$. For example, tuning rules to minimize an integral performance index based

on the FOPDT dynamics have been given in the forms, $P = a \left(\frac{\theta}{\tau} \right)^b$ and $P = a + b \left(\frac{\theta}{\tau} \right)^c$, where P is controller parameters (such as: k_c , τ_R , and τ_D) to be tuned for a PID controller, and a , b , c are regression constants. Furthermore, since the years of 80, the Internal Model Control (IMC) theory has been used to formulate PID controllers. As a result, the need for simple models is even more emphasized.

There are a few methods reported in the literature for identifying simple SOPDT models. In an early work of Oldenbourg and Sartorius (1948), the model being identified is $G_p(s) = \left[\frac{Ke^{-\theta s}}{(\tau_1 s + 1)(\tau_2 s + 1)} \right]$, where the process gain, the two process time-constants and the delay-time are denoted by K , τ_1 , τ_2 , θ , respectively. From the response as shown in Figure 7.2, the initial delay-time θ and the length of segments I_1 and I_2 are measured.



Key
Process gain, K Delay-time, θ Slope of tangent line, S

Figure 7.2 Process step response of a system

Mathematically, the value of $\frac{\tau_1}{I_1}$ is related to $\frac{\tau_2}{\tau_1}$ by the following equations:

$$\frac{\tau_1}{I_1} = \left(\frac{\tau_2}{\tau_1} \right)^{\frac{\tau_2}{\tau_1 - \tau_2}} = x^{\frac{x}{1-x}}$$

$$\frac{\tau_1}{I_1} \cdot x = \frac{\tau_2}{I_1}, \quad \text{where } x = \frac{\tau_2}{\tau_1}$$

On the other hand, the point $(\tau_1/I_1, \tau_2/I_1)$ also satisfies the following:

$$\frac{\tau_1}{I_1} + \frac{\tau_2}{I_2} = \frac{I_2}{I_1}$$

Consequently, based on the above equations and the measured segments, the two time constants can be solved.

In an alternative method, Sundaresan *et al.* (1978) derived the following relation,

$$\lambda = (t_m - m)S = \chi e^{-\chi}, \quad \text{where } \chi = \frac{\ln \eta}{\eta - 1} \text{ and } \eta = \frac{\tau_2}{\tau_1} \leq 1$$

The value of t_m is taken as the time at the inflection point of the response, and the quantity m is computed from the integration of the following:

$$m = \int_0^{\infty} [y(t_{\infty}) - y(t)] dt$$

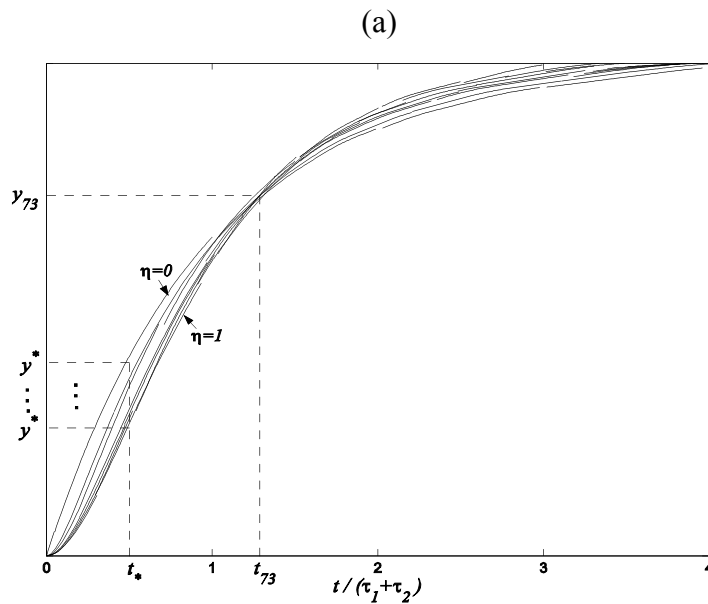
As the input is a unit step change, $y(t_{\infty})$ equals K (see as Figure 7.2). A plot of η versus λ can thus be prepared. Thus, by calculating the value of λ from the response, the value of η can be calculated, then, the two time constants and the dead time can be obtained from the following formulas,

$$\tau_1 = \eta^{\frac{1}{1-\eta}} / S, \quad \tau_2 = \eta \cdot \tau_1, \quad \text{and} \quad \theta = m - \tau_1 - \tau_2$$

As mentioned, S is the slope of the tangent at the inflection point of the response.

Another method for identifying simple over-damped SOPDT models is found in an early text book of Harriott (1964). The Harriott's method is derived based on two observations from a class

of step responses of the process represented by the transfer function $\frac{1}{(\tau_1 s + 1)(\eta \tau_1 s + 1)}$, $\eta \in [0, 1]$. First, it is found that almost all the step responses mentioned reach 73 % of its final steady state approximately at a time of 1.3 times $\tau_1 + \tau_2$. For easy reference, this response position and time are designated as y_{73} and t_{73} , respectively, as shown in Figure 7.3(a). Second, at a time of $0.5(\tau_1 + \tau_2)$, all the step responses separate from each other most widely. Again, for easy reference, the time at $0.5(\tau_1 + \tau_2)$ is designated as t_* , and the corresponding response position is denoted as y^* . It is found that y^* is a function of $\tau_1/(\tau_1 + \tau_2)$ as shown in Figure 7.3(b). In other words, from the experimental response, the position of y_{73} is identified and the t_{73} is read from the corresponding time. Upon having t_{73} , the value of t_* can be calculated. From this t_* , the position of y^* can be read from its step response again. When y^* is found, the value of $\tau_1/(\tau_1 + \tau_2)$ can be obtained by making use of Figure 7.3(b), and the two time constants can be computed.



(b)

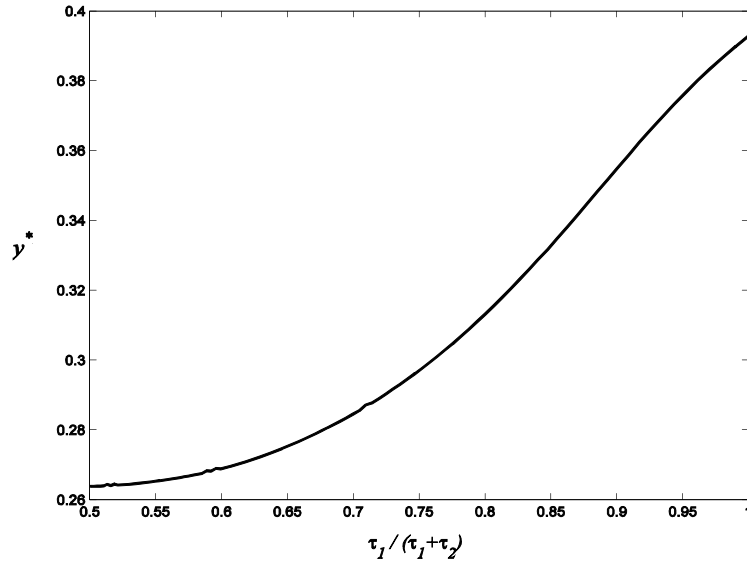


Figure 7.3 (a) Step responses (b) Relation between y^* and $\tau_1/(\tau_1 + \tau_2)$

Key	
Process time constants, τ_1, τ_2	Response position at 73% complete, y_{73}
Response time at 73% complete, t_{73}	Time at $0.5(\tau_1 + \tau_2)$, t_c
Response position at t_c , y_*	Fractional constant, $\eta = 0 \sim 1$

The method as given above was originally formulated for systems without delay-time, but it can be easily extended to include the estimation of delay-time by using the relationship for the area, m given as,

$$m = \tau_1 + \tau_2 + \theta$$

Thus, the parameters can be estimated from the following equation set,

$$\theta = m - \frac{t_{73}}{1.3}$$

$$\tau_1 = \left(\frac{\tau_1}{\tau_1 + \tau_2} \right)_{at \ y^*} \times \left(\frac{t_{73} - t_0}{1.3} \right)$$

$$\tau_2 = \left\{ 1 - \left(\frac{\tau_1}{\tau_1 + \tau_2} \right)_{at \ y^*} \right\} \times \left(\frac{t_{73} - t_0}{1.3} \right)$$

where t_0 is the time at which the process begins to response initially.

All of the above methods for developing SOPDT models are characterized by the use of data

from the step responses instead of using whole sets of time series data of both input and output as might typically occur for classical parameter estimation procedures. In this chapter, the focus will be on developing a systematic procedure to identify these simple models from transient step response curves or from relay feedback experiments. Following this, PID controllers will be synthesized using these simple models and a proposed inverse-based method. This methodology will not resort to rule-based methods based on optimization procedures.

Exp #8

Dynamic of Stirred Tanks

8.1 Introduction

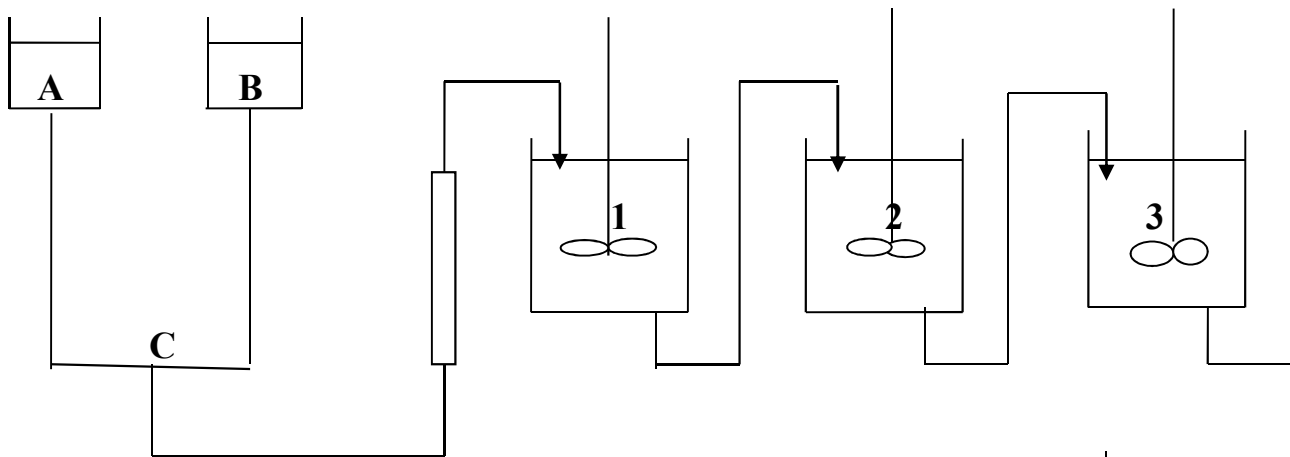


Figure 8.1 shows the schematics of the experimental set-up

Tank (A) and (B) contain water of differing salt concentration, and provide solution at constant head. Item (C) is a three way valve which can be positioned to select the flow from either tank (A) or (B). The solution passes through a rotameter and then to first tank (1) in series. The overflow from this tank passes successively to 2 and 3 tanks in series before being discharged. The tanks 1, 2 and 3 are stirred continuously. A conductivity cell immersed in the solution is connected to a conductivity bridge and a recorder.

8.2 Experimental Procedure:

1. Prepare NaCl solution (about 6 gm/l) in the big storage tank.
2. Fill the other storage tank with distilled water.
3. Adjust the zero of the recorder.
4. Place the three way valve such that the distilled water flows through the tanks.
5. Start the pumps and adjust the flow to about 0.2 l/min.
6. Place conductivity meter in the first and second tanks.
7. Introduce a step change in concentration by shifting the position of the three way valve such that saline water flows through the tank. Mark this time as zero time on recorder.
8. Observe the recorder and wait for system to attain steady state (i.e. when concentration becomes constant).
9. Introduce the change in reverse direction and again mark time equal to zero on the recorder, then wait for the new steady state.
10. Increase the flowrate to 0.3 l/min. repeat steps 7 to 9.
11. Measure the liquid hold-up of each tank and record the flowrate for each process step.
12. Switch off recorder agitator and pumps.

8.3 Experimental Programs:

1. Study dynamics of a stirred tank by subjecting the system to a step and pulse input.
2. Study the dynamics of stirred tanks in series.
3. Demonstrate use of conductivity as a method of concentration measurement.

8.4 Data analysis required

1. Derive the dynamic model equations for pulse input for the first and the second tank.
2. Calculate the dead time for all process steps. Clearly indicate what experimental results you are using to do this.
3. Convert the chart recorder readings into concentrations at different times. The time is obtained by taking distances at different points and dividing by the chart speed. Thence into deviation variables. Place results in

appropriate appendix. Note that the y-axis of the chart represents conductivity and readings vary from 0-100 mV.

4. Calculate the time constant of the 1st tank by plotting $\ln(1-C_1(t)/A)$ versus $(t-t_d)$ for all step changes.
5. Calculate the time constant of all the tanks for all step changes from the volumetric and flow measurements and compare your time constant in tank 1 with that that calculated from the previous step.
6. Plot $C_1(t)$ versus $(t-t_d)$ both experimentally and theoretically for both step and pulse inputs and compare the results.
7. Plot $C_2(t)$ versus $(t-t_d)$ both experimentally and theoretically for both step and pulse inputs and compare the results.

Exp #9

Simulink

9.1 Introduction to SIMULINK

Although the standard MATLAB package is useful for linear systems analysis, SIMULINK is far more useful for control system simulation. SIMULINK enables the rapid construction and simulation of control block diagrams. The goal of the tutorial is to introduce the use of SIMULINK for control system simulation. The version available at the time of writing of this textbook is SIMULINK 4, part of Release 12 (including MATLAB 6) from MATHWORKS. The version that you are using can be obtained by entering **ver** in the MATLAB Command Window.

The easiest way to learn how to use SIMULINK is to implement each step of the tutorial, rather than simply reading it. The basic steps to using SIMULINK are independent of the platform (PC, MAC, UNIX, LINUX...).

9.1.1 Background

9.1.2 Open-loop Simulations

9.1.3 Closed-loop Simulations

9.1.4 Developing Alternative Controller Icons

9.1.1 Background

The first step is to start up MATLAB on the machine you are using. In the Launch Pad window of the MATLAB desktop, select SIMULINK and then the SIMULINK Library Browser. A number of options are listed, as shown in Figure 9.1. Notice that **Continuous** has been highlighted; this will provide a list of continuous function blocks available. Selecting Continuous will provide the list of blocks shown in Figure 9.2. The ones that we often use are **Transfer Fcn** and **StateSpace**.

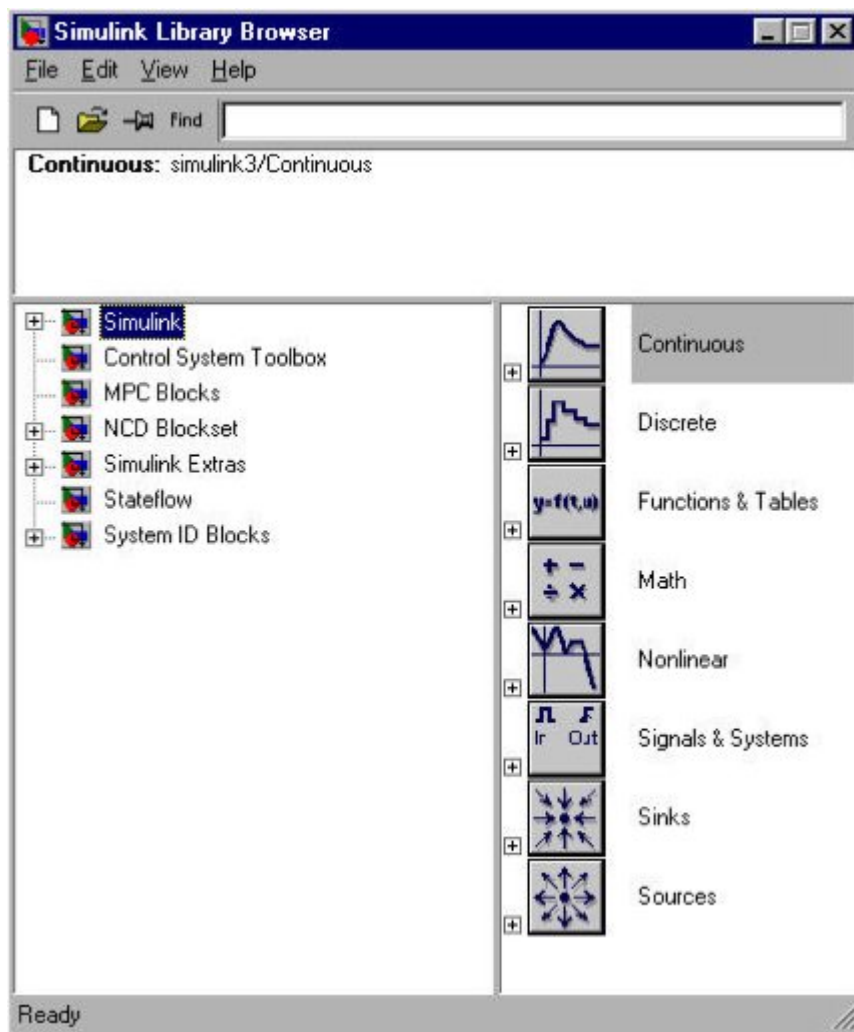


Figure 9.1 SIMULINK Library Browser.

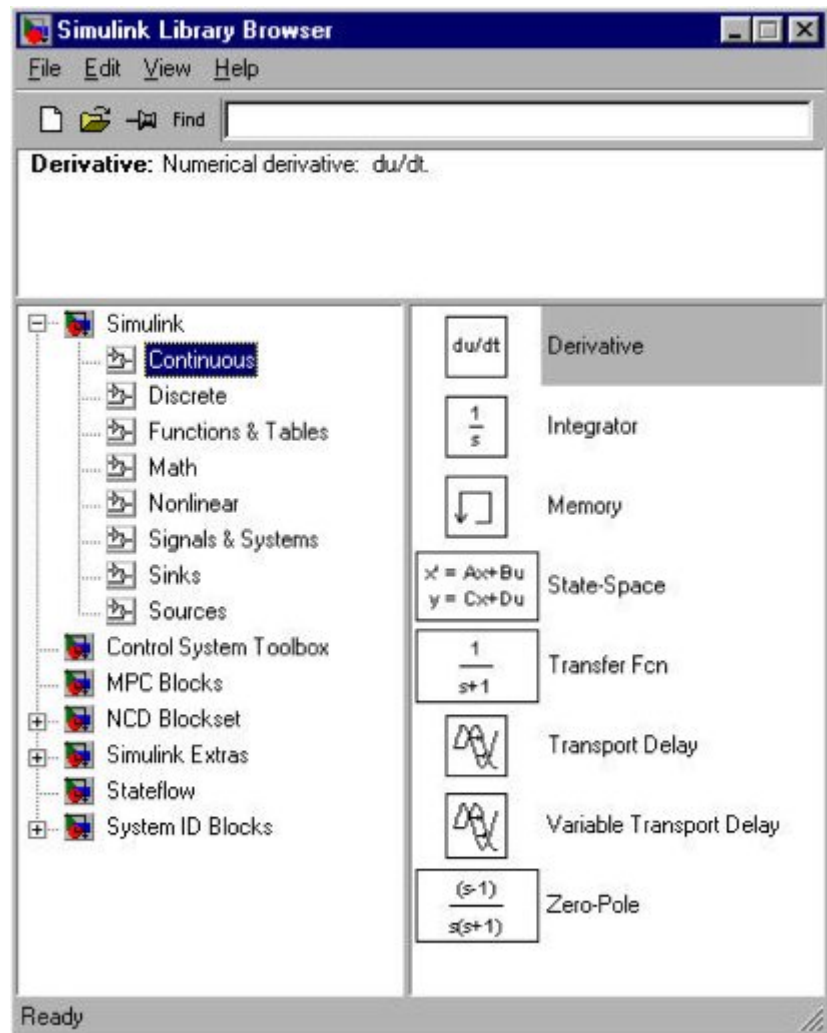


Figure 9.2 SIMULINK Continuous Blocks.

Selecting the Sources icon yields the library shown in Figure 9.3. The most commonly used sources are Clock (which is used to generate a time vector), and Step (which generates a step input).

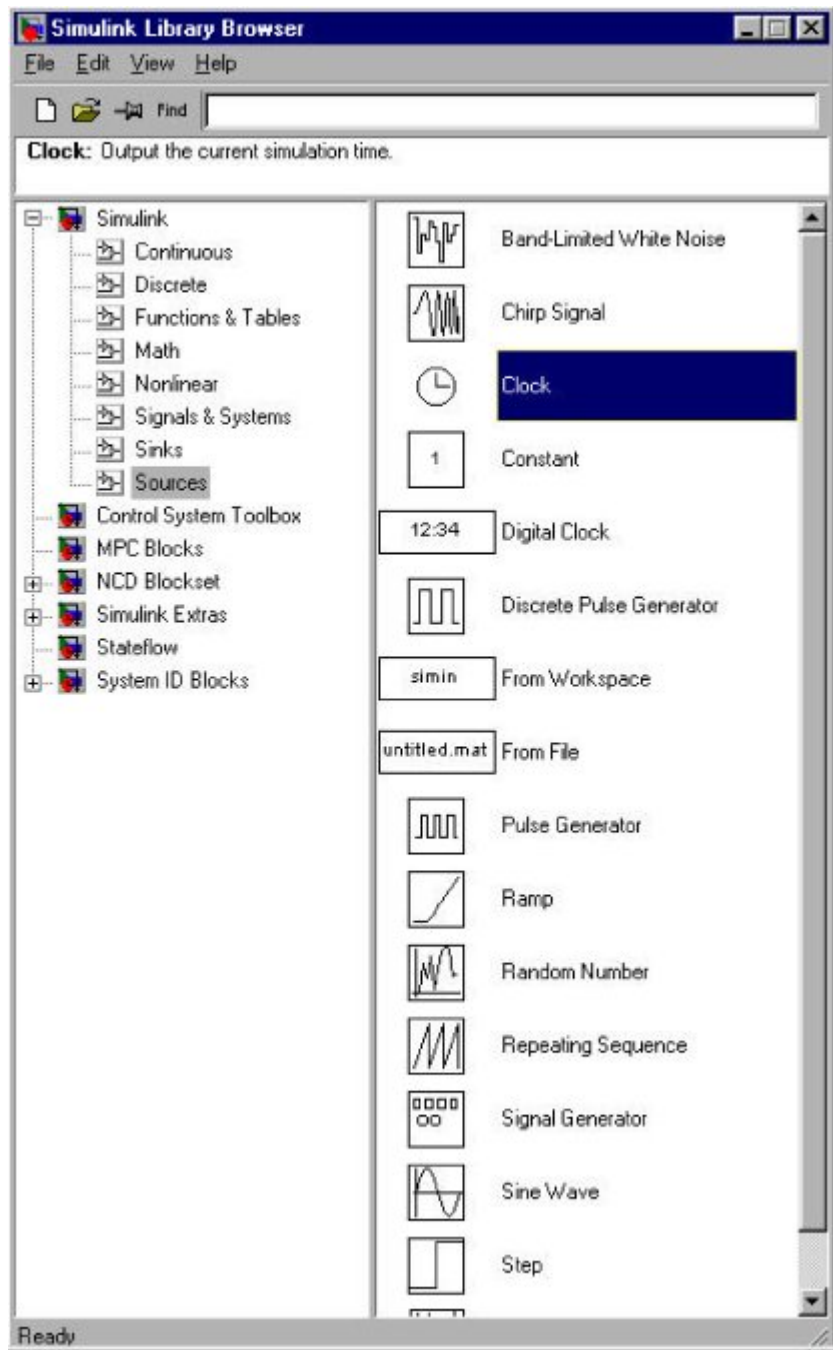


Figure 9.3 SIMULINK Sources.

The Sinks icon from Figure 9.1 can be selected to reveal the set of sinks icons shown in Figure 9.4. The one that we use most often is the To Workspace icon. A variable passed to this icon is written to a vector in the MATLAB workspace. The

default data method should be changed from “structure” to “matrix” in order to save data in an appropriate form for plotting.

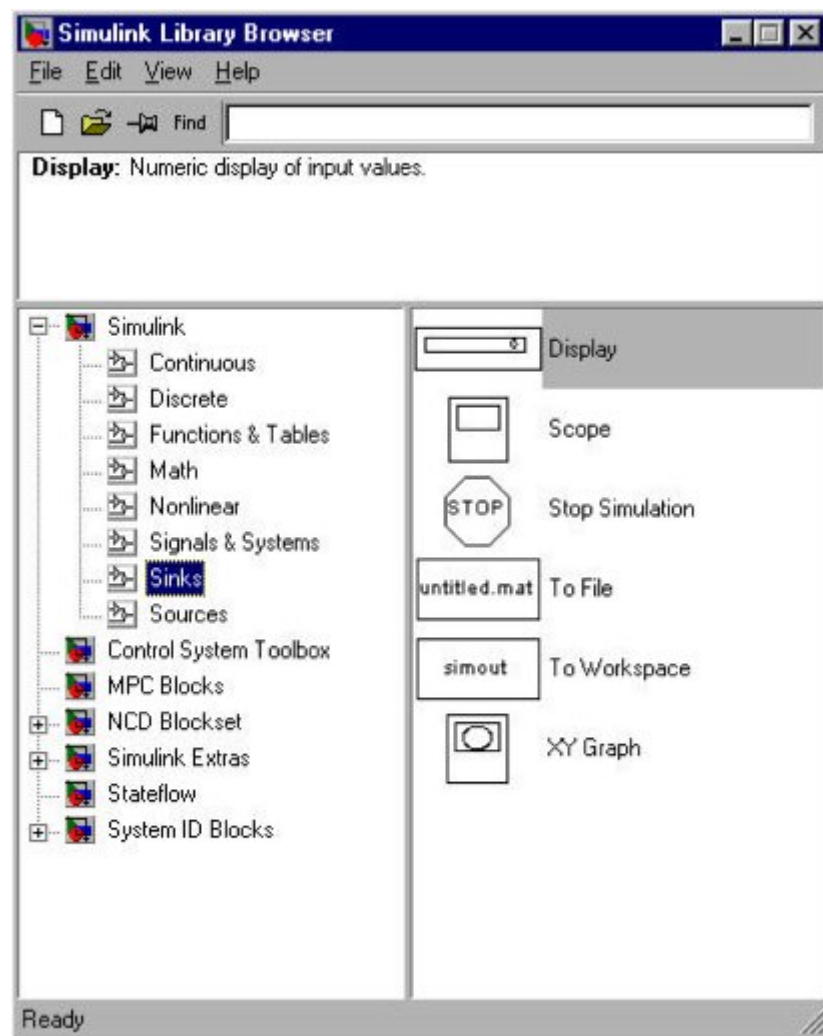


Figure 9.4 SIMULINK Sinks.

9.1.2 Open-loop Simulations

You now have enough information to generate an open-loop simulation. The Clock, simout, step and Transfer function blocks can be dragged to a model (.mdl) workspace, as shown in Figure 9.5a. Renaming the blocks and variables, and connecting the blocks, results in the model shown in Figure 9.5b. The transfer function studied is the Van de Vusse reactor (Module 5).

The s-polynomials in the process transfer function were entered by double-clicking on the transfer function icon and entering the coefficients for the

numerator and denominator polynomials. Notice also that the default step (used for the step input change) is to step from a value of 0 to a value of 1 at $t = 1$. These default values can be changed by double-clicking the step icon. The simulation parameters can be changed by going to the Simulation “pull-down” menu and modifying the stop time (default = 10) or the integration solver method (default = ode45).

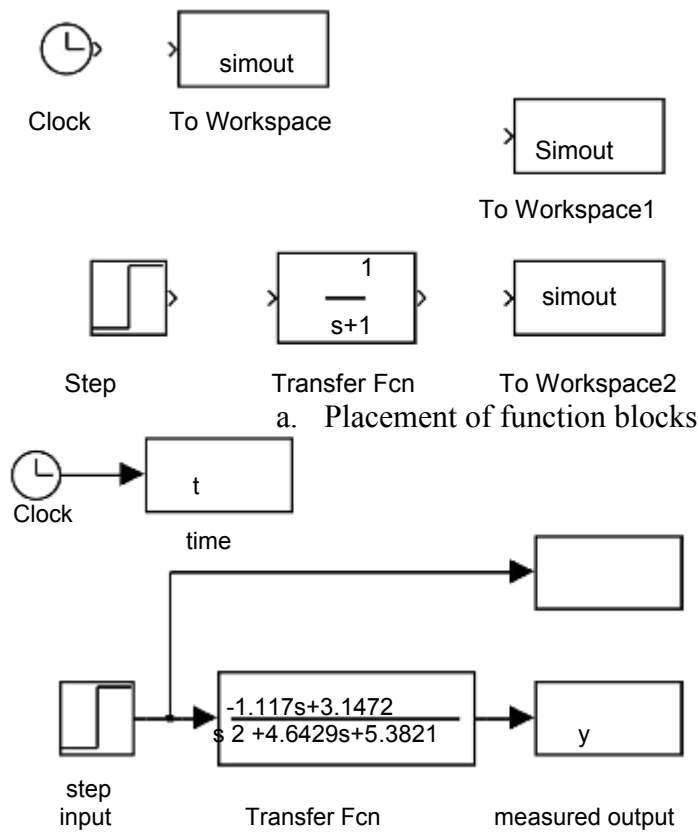


Figure 9.5 Development of an Open-loop Simulation.

The reader should generate simulations and observe the “inverse response” behavior of the output with respect to a step input change. Use the subplot command to place the process output (y) on the top plot, and the manipulated input

(u) on the bottom plot. *Perform this now.* If desired, change the default simulation stop time by selecting the parameters “pull down” menu.

9.1.3 Feedback Control Simulation

The Math icon from Figure M2.2 can be selected, resulting in the functions shown in Figure M2.6. Additional icons can be found by selecting the Simulink Extras icon in Figure M2.1. Selecting the Additional Linear icon from this group yields the set of icons in Figure M2.7. The most useful icon here is the PID Controller. Any icon can be “dragged” into the untitled model workspace. In Figure M2.8 we show the preliminary stage of the construction of a control block diagram, where icons have been dragged from their respective libraries into the untitled model workspace.

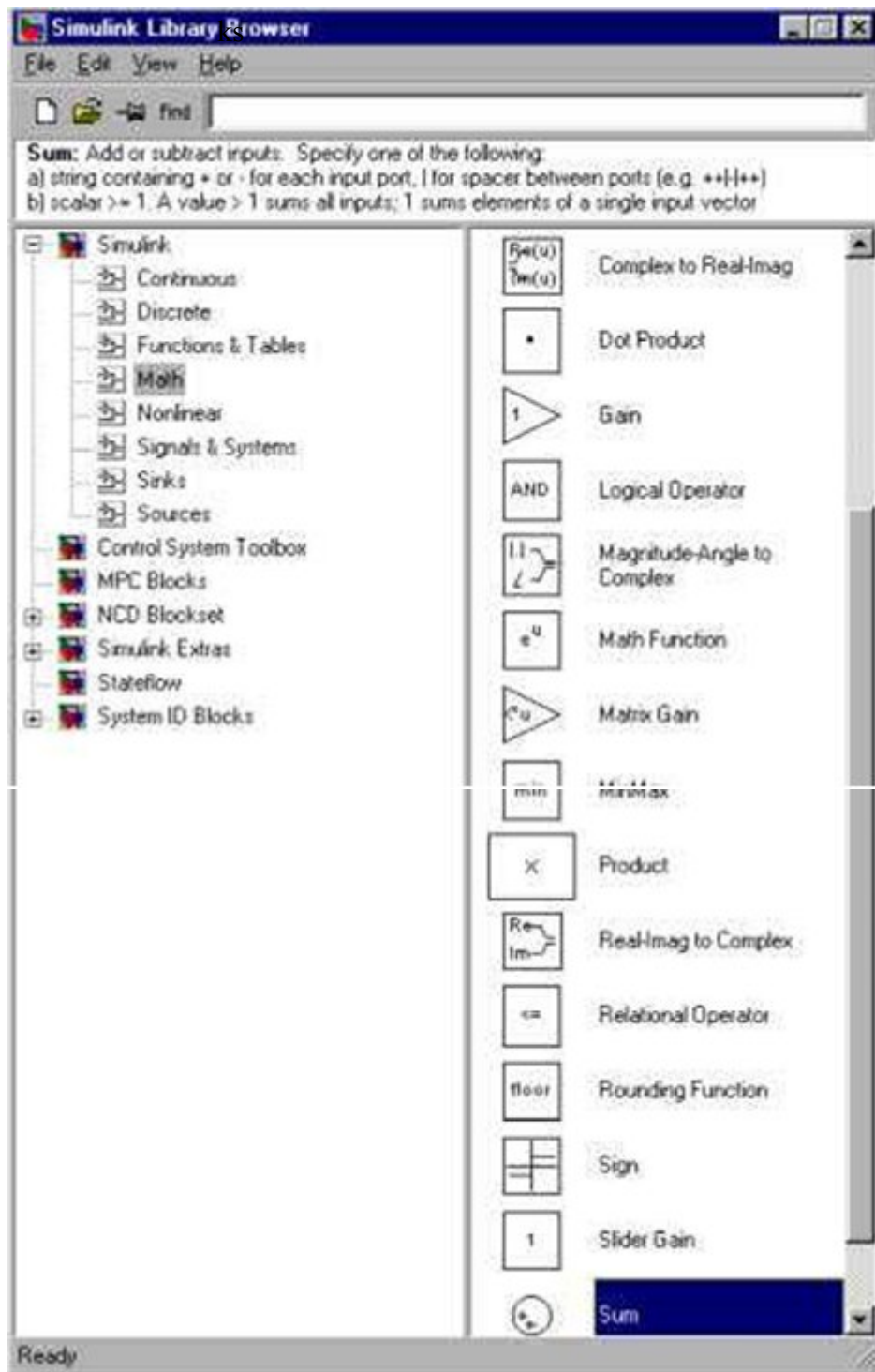


Figure 9.6 SIMULINK Math.

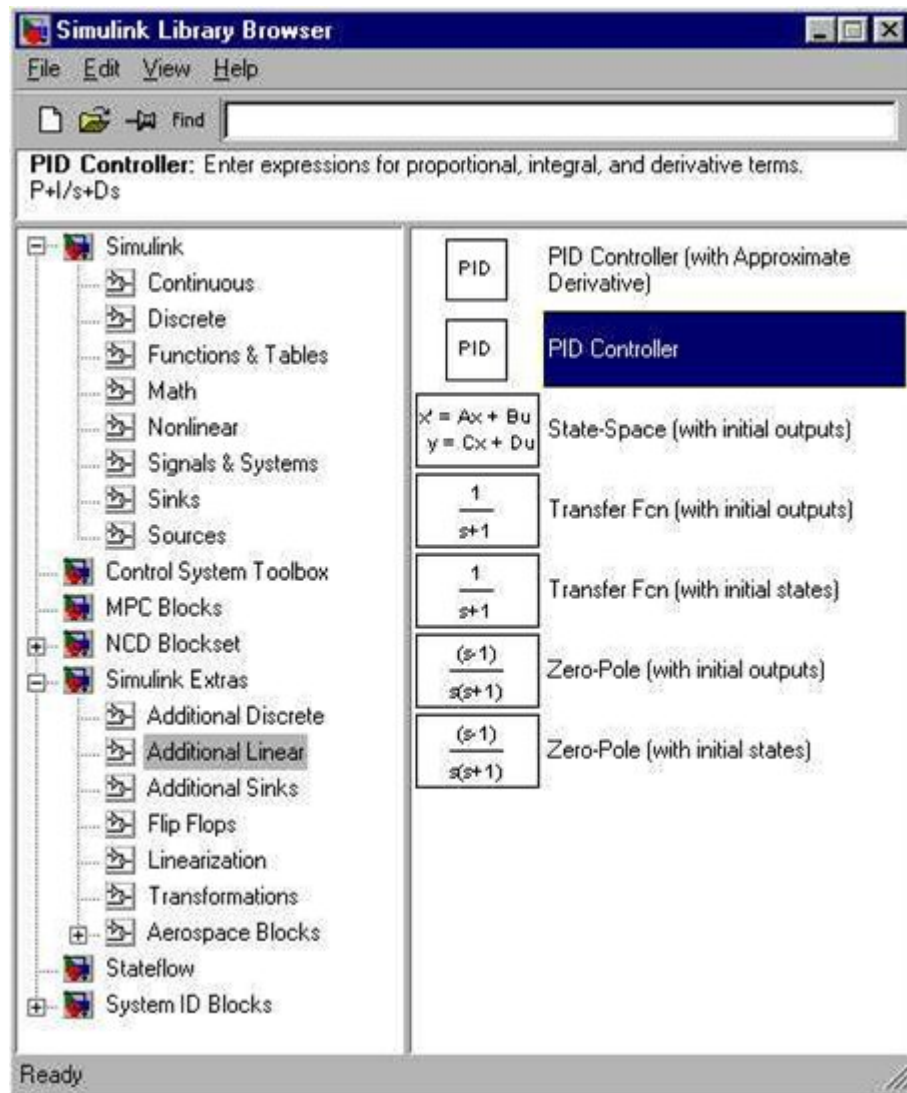


Figure 9.7 SIMULINK Additional Linear.

The labels (names below each icon) can easily be changed. The default parameters for each icon are changed by double clicking the icon and entering new parameter values. Also, connections can be made between the outputs of one icon and inputs of another. Figure M2.8b shows how the icons from Figure M2.8a have been changed and linked together to form a feedback control block diagram. It should be noted that the form of the PID control law used by the SIMULINK PID Controller icon is not the typical form that we use as process control engineers. The form can be found by double-clicking the icon to reveal the following controller transfer function representation

$$G_c(s) = P + \frac{1}{s} + Ds$$

while we normally deal with the following PID structure

$$g_c(s) = k_c(1 + 1/\tau_I S + \tau_D S)$$

so the following values must be entered in the SIMULINK PID Controller

$$p = k_c \quad I = k_c/\tau_I \quad D = k_c\tau_D$$

The s-polynomials in the process transfer function were entered by double-clicking on the transfer function and entering the coefficients for the numerator and denominator polynomials. Notice also that the default step (used for the step setpoint change) is to step from a value of 0 to a value of 1 at $t = 1$. These default values can be changed by double-clicking the step icon. The simulation parameters can be changed by going to the Simulation “pull-down” menu and modifying the stop time (default = 10) or the integration solver method (default = ode45).

The controller tuning parameters of $k_c = 1.89$ and $t_I = 1.23$ are used by entering $P = 1.89$ and $I = 1.89/1.23$ in the default PID Controller block. The following plot commands were used to generate Figure 9.9.

```
» subplot(2,1,1),plot(t,r,'--',t,y)
» xlabel('t (min)')
» ylabel('y (mol/l)')
» subplot(2,1,2),plot(t,u)
» xlabel('t (min)')
» ylabel('u (min^-1)')
```

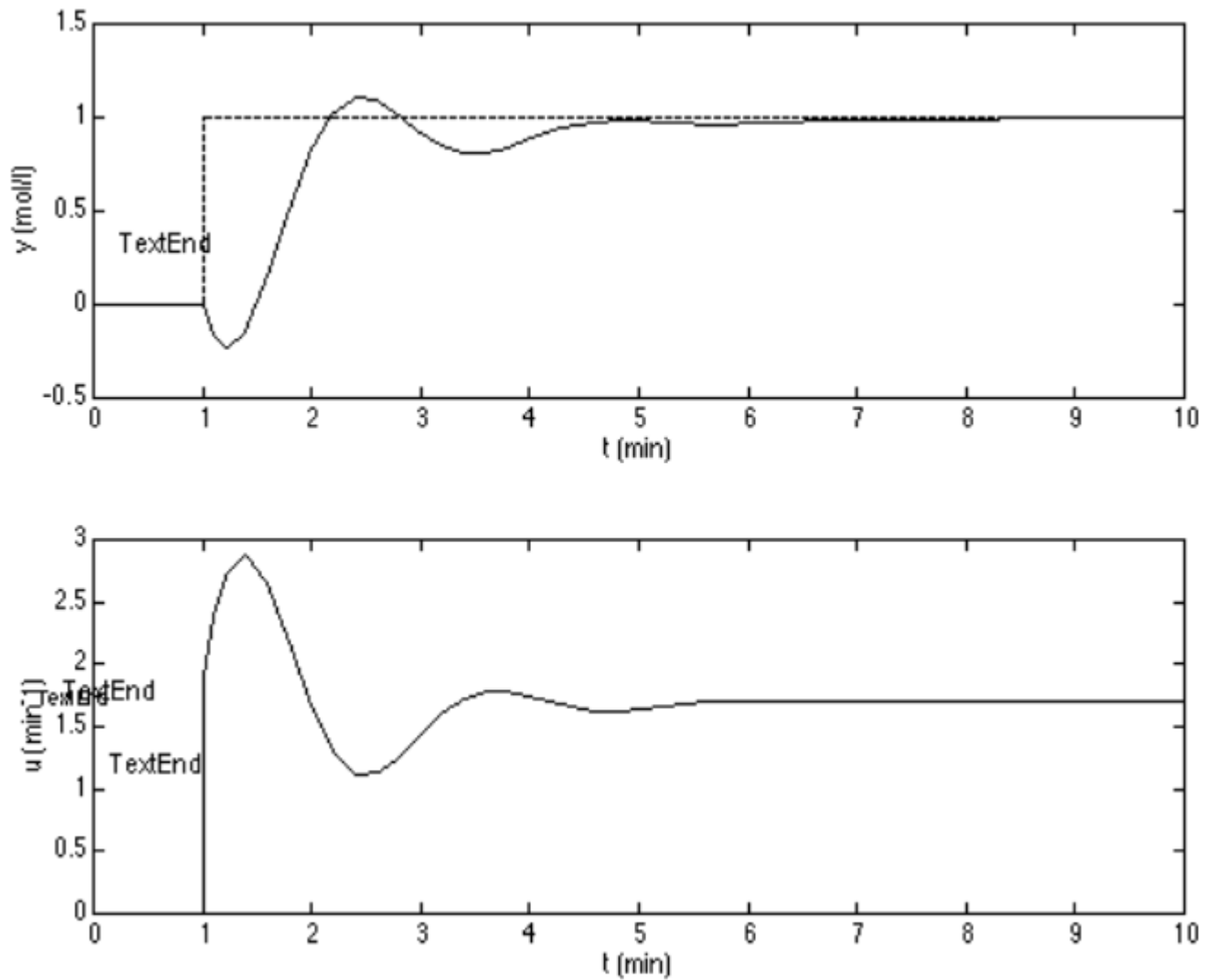


Figure 9.9. Measured Output and Manipulated Input Responses to a Unit Step Setpoint Change.

This brief tutorial has gotten you started in the world of SIMULINK-based control block diagram simulation. You may now easily compare the effect of different tuning parameters, or different formulations of a PID controller (“ideal” vs. “real”, for example).

Let’s say you generated responses for a set of tuning parameters that we call case 1 for convenience. You could generate time, input and output vectors for this case by setting:

```
» t1 = t;
» y1 = y;
» u1 = u;
```

after running the case 1 values. You could then enter case 2 values, run another simulation, and create new vectors

```
» t2 = t;  
» y2 = y;  
» u2 = u;
```

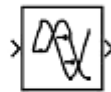
then, compare the case 1 and case 2 results by:

```
» subplot(2,1,1),plot(t1,y1,t2,y2,'--')  
» xlabel('t (min)')  
» ylabel('y (mol/l)')  
» subplot(2,1,2),plot(t1,u1,t2,u2,'--')  
» xlabel('t (min)')  
» ylabel('u (min^-1)')
```

which automatically plots case 1 as a solid line and case 2 as a dashed line. Similarly, you could modify the controller type by placing a transfer function block for the controller and using a “real PID” transfer function (this only differs when there is derivative action).

Other Commonly Used Icons

Often you will want to simulate the behavior of systems that have time delays. The Transport Delay icon can be selected from the Continuous library shown in Figure 9.2. The transport delay icon is shown in Figure 9.10. Our experience is that simulations can become somewhat “flaky” if 0 is entered for a transport delay. We recommend that you remove the transport delay block for simulations where no time-delay is involved.



Transport Delay

Figure 9.10. Transport Delay Icon

Manipulated variables are often constrained to between minimum (0 flow, for example) and maximum (fully open valve) values. A saturation icon from the Nonlinear library can be used to simulate this behavior. The saturation icon is shown in Figure 9.11.

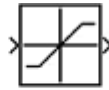


Figure 9.11. Saturation Element

Actuators (valves) and sensors (measurement devices) often have additional dynamic lags that can be simulated by transfer functions. These can be placed on the block diagram in the same fashion that a transfer function was used to represent the process earlier. It should be noted that icons can be “flipped” or “rotated” by selecting the icon and going to the format “pull-down” menu and selecting Flip Block or Rotate Block. The block diagram of Figure 9.8 has been extended to include the saturation element and transport delay, as shown in Figure 9.12.

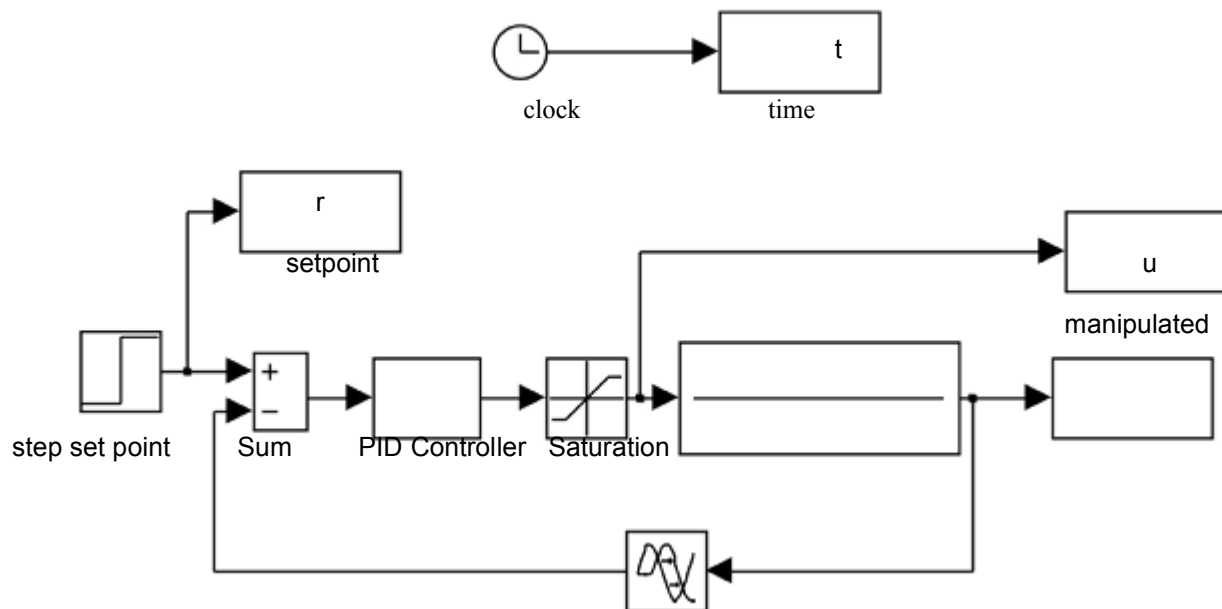


Figure 9.12. Block Diagram with Saturation and Time-Delay Elements

The default data method for the “to workspace” blocks (r,t,u,y in Figure 9.12) must be changed from “structure” to “matrix” in order to save data in an appropriate form for plotting.

9.1.4 Developing Alternative Controller Icons

It was noted earlier that the default SIMULINK PID controller block uses a different form than that used by most process engineers. It is easy to generate new PID controller blocks as shown below. The default PID controller icon is shown in Figure M2.13a. This is “unmasked” to yield the diagram shown in Figure M2.13b. Again, this has the form

$$G_c(s) = P + 1/s + Ds$$

while we normally prefer the following PID structure

$$g_c(s) = k_c(1 + 1/\tau_I s + \tau_D s)$$

Of course, the two algorithms are related by

$$p = k_c \quad I = k_c/\tau_I \quad D = k_c \tau_D$$

but it would be much less confusing to work with our standard form.

Summary

SIMULINK is a very powerful block diagram simulation language. Simple simulations, including the majority of those used as examples in this textbook, can be set-up rapidly (in a matter of minutes). The goal of this module was to provide enough of an introduction to get you started on the development of open- and closed-loop simulations. With experience, the development of these simulations will become second-nature. It is recommended that you perform the simulations shown in this module, as well as the practice exercises, to rapidly acquire these simulation skills.

