STUDY OF MATLAB FOR DYNAMIC SIMULATION OF A BINARY DISTILLATION COLUMN

By

MANISH PETWAL

&

VIKASH BHUSHAN

College of Engineering

University of Petroleum & Energy Studies

Dehradun

April, 2009

CERTIFICATE

This is to certify that the work contained in this thesis titled **"STUDY OF MATLAB FOR DYNAMIC SIMULATION OF DISTILLATION COLUMN CONTROL SYSTEM"** has been carried out by *Manish Petwal and Vikash Bhushan* under my supervision and has not been submitted elsewhere for a degree.

Krishnamohan V S S

Assistant professor

Date: 30-04-09

orporate Office:
ydrocarbons Education & Research Society
'd Floor, PHD House,
'2 Siri Institutional Area
ugust Kranti Marg, New Delhi - 110 016 India
h.: +91-11-41730151-53 Fax : +91-11-41730154

Main Campus:
Energy Acres,
PO Bidholi Via Prem Nagar,
Dehradun - 248 007 (Uttarakhand), India
Ph.: +91-135-2102690-91, 2694201/ 203/ 208
Fax: +91-135-2694204

Regional Centre (NCR) :
SCO, 9-12, Sector-14,
Gurgaon 122 007
(Haryana), India.
Ph: +91-124-4540 300
Fax: +91-124-4540 330

Regional Centre (Rajahmundry):
GIET, NH 5, Velugubanda,
Rajahmundry - 533 294,
East Godavari Dist., (Andhra Pradesh), India
Tel: +91-883-2484811/ 855
Fax: +91-883-2484822

Email: info@upes.ac.in URL: www.upes.ac.in

CERTIFICATE

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27/04/09

Krishnamohan V S S

(Project Guide & Assistant professor)

UPES, Dehradun

Date: 27-04-09

ABSTRACT

As material balance control schemes are widely used in the industry to get a proper control of distillation column. Material balance control in the direction of flow for distillation column is basically used in the plants. So understanding variables to control and the controller used is important for understanding the material balance control scheme. If accumulator level will rise then the level controller will increase distillate rate. Same case for the base level, if accumulator will raise then the level controller will increase bottom product rate. Hence the type of feed forward used in the system is very important for controlling the level in the distillation column.

In this project control scheme is used to get the best possible level control system. We will look at the relationship between level control in the overhead condensate receiver and that in the column base for several different column control schemes.

The study is aimed at understanding the material balance control scheme for the distillation column and testing whether the control scheme which has been suggested is controlling the level and compositions correctly or not. In particular, we are going to study a base case by which we can show the control scheme which will give the controlled output and by using the software (MATLAB) we will simulate the control scheme to get the results in the form of graphs.

Acknowledgment

First and foremost, we are thankful to **University of Petroleum & Energy Studies** for giving us opportunity to carry out our major project on "STUDY OF MATLAB FOR DYNAMIC SIMULATION OF A BINARY DISTILLATION COLUMN We are indebted to our mentor, **Mr. Krishnamohan V S S (Assistant professor, College of Engineering)**, for his constant support and guidance during this study. We would like to express our sincere gratitude for his patience and encouragement throughout this work, without which this work would not have been possible.

We take immense pleasure in thanking **Mr. Sanjay Kumar (Professor, University of petroleum and energy studies)**, who had been a source of inspiration and for his timely guidance in the conduct of our project work. His contributions are infused throughout this report.

We are extremely grateful to the entire UPES faculty for their significant contribution to my academic and intellectual development.

At last we would like to thank all of our colleagues for making our stay at UPES memorable.

Date:

Manish Petwal

&

Vikash Bhushan

(University OF Petroleum & Energy Studies, Dehradun)

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INTRODUCTION TO DISTILLATION COLUMN

Distillation column

Distillation columns are used in chemical and petroleum industries to separate chemical components into more or less pure product streams. This separation is based upon the differences in volatilities (tendencies to vaporize) among various chemical components. For example, a mixture of methanol and water can be separated by a distillation column. More volatile compounds are removed from the top of the column, and the less volatile, or heavier, components are removed from the lower part of the column.

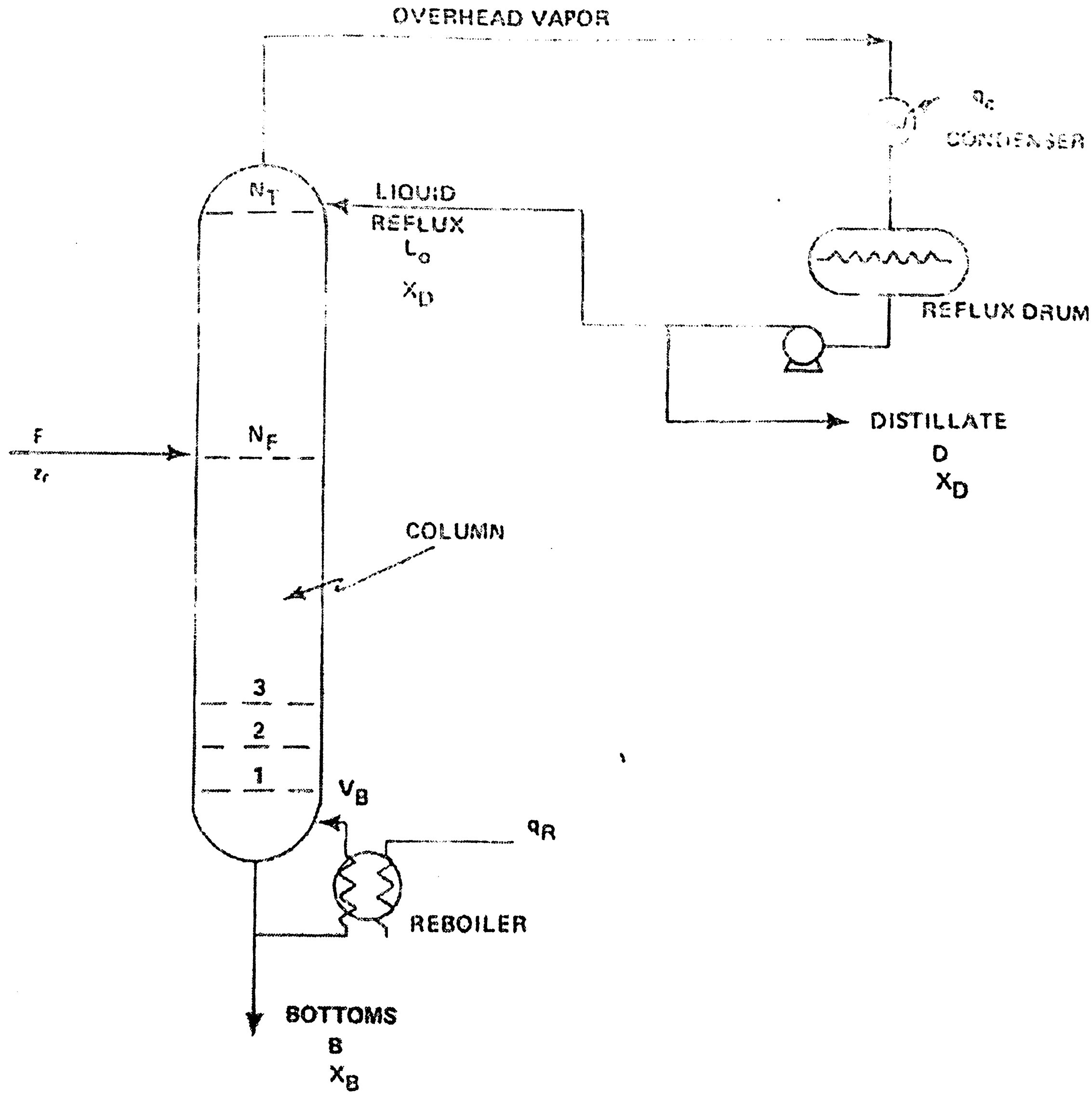


Fig.1.1 Nomenclature and conventions for a distillation column.

We will consider only a simple feed, two product columns separating a binary mixture.

Feed rate F moles per minute. Feed composition is z_f mol fraction of the more volatile component. The column trays are numbered from base upward, with feed introduced on the N_F tray. The total number of trays in the column is N_T.

Products removed from the top and bottom of the column are called distillate or top product respectively with flow rates D and B mol/min and compositions X_D and X_B mol fraction light component.

Heat is transferred into the process in the reboiler to vaporize some of the liquid from the base of the column. The heat transfer rate is q_R energy units/time.

The vapour coming from the top of the column is liquefied in another tube and shell exchanger called a condenser. Heat is transferred out of the condenser at a rate q_C, btu/hr.

Liquid from the condenser drops in the reflux drum. Distillate product is removed from this drum. In addition, some liquid called reflux (Lo, moles/min), is fed back to the top tray of the column. This liquid reflux and the vapor boilup in the base of the column are necessary to achieve the separation or fractionation of chemical components. The energy required to make the separation is approximately the heat added to the reboiler.

One can stand back and look at the distillation column with its associated reboiler, condenser, and reflux drum as a black box process. Feed, heat, and reflux are the inputs into this box. Outputs from the box are the two product streams D and B with composition X_D and X_B. The usual situation with distillation column is that the feed rate and feed composition must be considered as disturbances. Heat input q_R and external reflux Lo can be adjusted to achieve the desired control objectives. These are called manipulated variables. Distillate and bottom product rates can also be manipulated, so there are four variables that can be adjusted, Lo, q_R, D, and B. They are not independent, however. If, for example, D is controlled, then B is dependent.

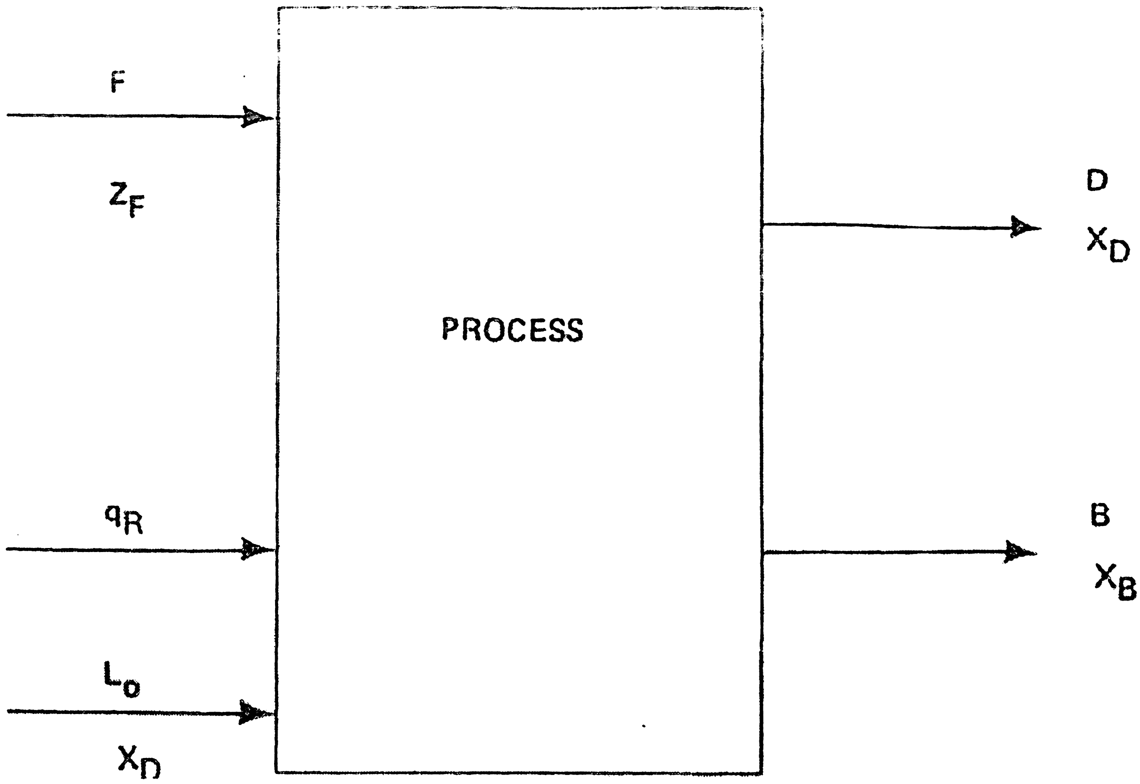


Fig.1.2 Control variables for distillation column

References

Distillation operation by Henry Z. Kister

2

CONTROL SYSTEM FOR DISTILLATION COLUMN

Need of control system for the distillation column

The central element in any control configuration is the process that we want to control.

Control objective are as follows-

- Ensuring the stability of the process
- Suppressing the influence of external disturbances
- Optimizing the economic performance of the plant
- A combination of the above

A column control system has three main objectives

- To set stable condition for column operation.
- To regulate conditions in the column so that the products always meet the required specifications.
- To achieve the above objectives most effectively. This could mean maximizing product recovery, minimizing energy consumption, and often both.

Variables typically controlled in a column are

- Flows
- Pressure
- Bottom level
- Accumulator level
- Top product composition
- Bottom product composition

These are classified into two groups –

1. **Single loop variables** – These include pressure and levels. They are controlled in order to achieve the first objective that is, setting stable conditions for column

operation. The set points at which these are controlled are established by stability considerations alone, regardless of product specifications.

Controlling levels regulation material accumulation in the column

Keeping the levels constant prevents liquid accumulation, while keeping the pressure constant prevents vapour accumulation. Unless accumulation is prevented, a continuous system will not operate at steady state and will not be stable.

1. Unit objective variables -

These include top and bottom compositions. They are regulated to achieve the second objective that is, meeting product specifications. The set points at which these are controlled are determined by purity considerations alone.

Composition controls can be direct, that is, using composition measurements of the product streams, or indirect, using a physical property representative of product composition. Typical physical properties used are refractive index, density, vapour pressure, freezing point, and, most commonly, tray temperature.

2. Manipulated streams

A stream is manipulated by varying the opening of its control valve. The stream flow rate is thereby varied to control a desired variable. Figure shows five manipulates streams – top and bottom product flow rates, condensation rate, boilup rate, and reflux flow rate.

A malfunctioning control system causes instability. The instability can adversely affect product purity, column capacity, economy, and ease of operation. Instabilities are often transmitted to downstream or upstream or upstream units, or can amplify small disturbances. In extreme cases, instability can also lead to column damage or safety hazards.

Most of these strikes a balance between theory, practice, controls design, and controls optimization. Computer controls and advanced controls are widespread and can be of primary importance for column optimization, their role in setting stable operation is usually secondary. Advanced controls often enhance column stability, but they seldom assure that the primary stability objectives are met. A troublesome computer control loop can usually be taken off control, and stable operation can be restored. On the other hand, an unstable basic control loop usually means an unstable column, even when computer control is used.

A column control philosophy that is either defective or unsuitable for the service is frequently responsible for column instability. Prediction of column dynamic behaviour during the design is extremely difficult, and designers resort to their previous experience in similar columns to guide their control philosophy. Although relative gain analysis has proved invaluable for control system synthesis; it is often helpless when data on column dynamic responses are lacking.

Main Elements of Control system

Chemical process

It represents the material equipment together with the physical or chemical operations that occur there.

The measuring instruments or sensor

Such instruments are used to measure the disturbances, the controlled output variables, or secondary output variables, and are the main sources of information about what is going on in the process.

In this project we are only dealing with the level control, so some of the instruments used for measurement of level are as follows.

Level measurement

The measurement of level can be defined as the determination of the location of the interface between two fluids, separable by gravity, with respect to a fixed datum plane. The most common level measurement is that of the interface between a liquid and a gas. Other level measurements frequently encountered are the interface between two liquids, between a granular or fluidized solid and a gas, and between a liquid and its vapour.

- **Float-Actuated Devices** - Float-actuated devices are characterized by a buoyant member that floats at the interface between two fluids. Since a significant force is usually required to move the indicating mechanism, float-actuated devices are generally limited to liquid-gas interfaces. By properly weighing the float, they can be used to measure liquid-liquid interfaces. Float-actuated devices may be classified on the basis of the method used to couple the float motion to the indicating system as discussed below.

- **Thermal Methods** - Level-measuring systems may be based on the difference in thermal characteristics between the fluids, such as temperature or thermal conductivity. A fixed-point level sensor based on the difference in thermal conductivity between two fluids consists of an electrically heated thermistor inserted into the vessel. The temperature of the thermistor and consequently its electrical resistance increase as the thermal conductivity of the fluid in which it is immersed decreases. Since the thermal conductivity of liquids is markedly higher than that of vapours, such a device can be used as a point level detector for liquid-vapour interface.

- **Sonic Methods -** A fixed-point level detector based on sonic propagation characteristics is available for detection of a liquid-vapour interface. This device uses a piezoelectric transmitter and receiver, separated by a short gap. When the gap is filled with liquid, ultrasonic energy is transmitted across the gap, and the receiver actuates a relay. With a vapour filling the gap, the transmission of ultrasonic energy is insufficient to actuate the receiver.

Transducers

Many measurements cannot be used for control until they are converted to physical quantities such as:

i) Electrical voltage or current.

ii) Pneumatic signal that is compressed air or liquids.

which can be transmitted easily. Transducers are used for that purpose.

A pneumatic actuator converts energy (in the form of compressed air, typically) into motion. The motion can be rotary or linear, depending on the type of actuator. Some types of pneumatic actuators include:

- Tie rod cylinders
- Rotary actuators

Transmission lines

These are used to carry the measurement signal from the measuring device to the controller. In the past the transmission lines were pneumatic but with the advent of electronic analog controllers and especially the expanding use of digital computers for control, transmission lines carry electric signals. Many times the measurement signal coming from a measuring device is very weak and cannot be transmitted over a long distance. In such case the transmission lines are equipped with amplifiers which raise the level of the signal.

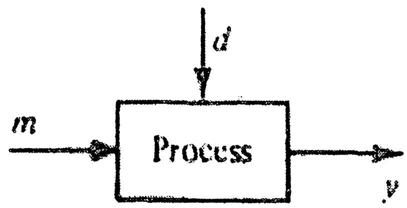
The Controller

This is the hardware element that has intelligence. It receives the information from the measuring devices and decides what action should be taken.

For example the controller decides whether that the flow rate of the outlet stream should be increased or decreased in order to keep the liquid level in a tank at the desired value.

Between the measuring device and final control element comes the controller. Its function is to receive the measured output signal Ym(t) and after comparing it with the set point Ysp to produce the actuating signal C(t) in such a way as to return the output to the desired value Ysp. Therefore, the input to the controller is the error E(t)= Ysp-Ym(t), while its output is C(t). The various types of continuous feedback controllers differ in the way they relate e(t) to C(t).

The output signal of a feedback controller depends on its construction made may be a pneumatic signal for pneumatic controllers or electrical one for electronic controllers.



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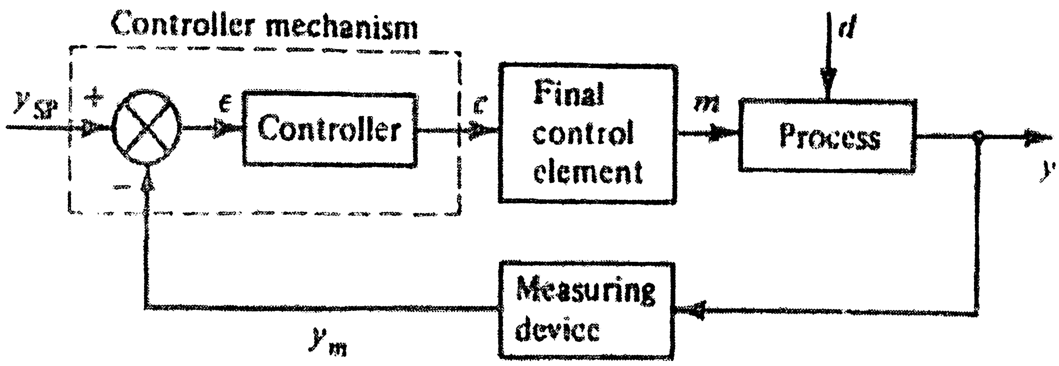

Fig. 2.1 (a) Process and (b) corresponding feedback loop

The basic types of feedback controllers are

- Proportional controller
- Proportional integral controller
- Proportional integral derivative controller

Proportional Control

A proportional controller moves its output proportional to the deviation in the controlled variable from set point:

C(t) = *Kc*E(t) + Cs

Where Kc = proportional gain of the controller
Cs= controller bias signal
E (t) = error

In some controllers, proportional gain *Kc* is expressed as a pure number; in others, it is set as 100/*P,* where *P* is the proportional band in percent. The output bias *Cs* of the controller is also known as manual reset. The proportional controller is not a good regulator, because any change in output to a change in load results in a corresponding change in the controlled variable. To minimize the resulting offset, the bias should be set at the best estimate of the load and the proportional band set as low as possible. Processes requiring a proportional band of more than a few percent will control with unacceptable values of offset.

Proportional control is most often used for liquid level where variations in the controlled variable carry no economic penalty, and where other control modes can easily destabilize the loop. It is actually recommended for controlling the level in a surge tank when manipulating the flow of feed to a critical downstream process. By setting the proportional band just under 100 percent, the level is allowed to vary over the full range of the tank capacity as inflow fluctuates, thereby minimizing the resulting rate of change of manipulated outflow. This technique is called averaging level control.

Proportional-plus-Integral (PI) Control

Integral action eliminates the offset described above by moving the controller output at a rate proportional to the deviation from set point. Although available alone in an integral controller, it is most often combined with proportional action in a PI controller:

$C(t) = \mathrm{Kc}E(t) + \mathrm{Kc/t1}\int_0^t E(t)dt + \mathrm{Cs}$

Where t1 is the integral time constant in minutes; in some controllers, it is introduced as integral gain or reset rate 1/t1 in repeats per minute. The last term in the equation is the constant of integration, the value the controller output has when integration begins. The PI controller is by far the most commonly used controller in the process industries. The summation of the deviation with its integral in the above equation can be interpreted in terms of frequency response of the controller.

. The PI controller produces a phase lag between zero and 90 degrees.

Proportional-plus-Integral-plus-Derivative (PID) Control

The derivative mode moves the controller output as a function of the rate-of-change of the controlled variable, which adds phase lead to the controller, increasing its speed of response. It is normally combined with proportional and integral modes. The no interacting form of the PID controller appears functionally as:

$C(t) = KcE(t) + Kc/t1\int_0^t E(t)dt + KcTd\ dE/dt + Cs$

where Td is the derivative time constant. Note that derivative action is applied to the controlled variable rather than to the deviation, as it should not be applied to the set point; the selection of the sign for the derivative term must be consistent with the action of the controller.

In some analog PID controllers, the integral and derivative terms are combined serially rather than in parallel as done in the last equation.
With the presence of the derivative term,(dE/dt), the PID controller anticipates what the error will be in the future and applies a control action which is proportional to the current rate of change in the error. Due to this property, the derivative control action is sometimes referred to as anticipatory control.

The major draw backs of the derivative control action are the following-

1. For a response with constant non zero error it gives no control action since dE/dt=0.
2. For a noisy response with almost zero error it can compute large derivatives and thus yield large action, although it is not needed.

Electronic Controllers –

Almost all of the electronic process controllers used today are microprocessor-based devices. These processor- based controllers contain, or have access to, input/output (I/O) interface electronics that allow various types of signals to enter and leave the controller's processor. The controller, depending on its type, uses sufficient read-only-memory (ROM) and read/write-accessible memory (RAM) to perform the controller function. The resolution of the analog I/O channels of the controller vary somewhat, with 12-bit and 14-bit conversions quite common. Sample rates for the majority of the constant sample rate controllers range from 1 to 10 samples/second. Hard-wired single-pole, low-pass filters are installed on the analog inputs to the controller to protect the sampler from aliasing errors.

Pneumatic Controllers –

The pneumatic controller is an automatic controller that uses pneumatic pressure as a power source and generates a single pneumatic output pressure. The pneumatic controller is used in single-loop control applications and is often installed on the control valve or on an adjacent pipe stand or wall in close proximity to the control valve and/or measurement transmitter. Pneumatic controllers are used in areas where it would be hazardous to use electronic equipment, in locations without power, in situations where maintenance personnel are more familiar with pneumatic controllers, or in applications where replacement with modern electronic controls has not been justified. Process-variable feedback for the controller is achieved by one of two methods. The process variable can (1) be measured and transmitted to the controller by using a separate measurement transmitter with a 0.2–1.0-bar (3–15-psig) pneumatic output, or (2) be sensed directly by the controller, which contains the measurement sensor within its enclosure. Controllers with integral sensing elements are available that sense pressure, differential pressure, temperature, and level. Some controller designs have the set point adjustment knob in the controller, making set point adjustment a local and manual operation.

Other types receive a set point from a remotely located pneumatic source, such as a manual air set regulator or another controller, to achieve set point adjustment. There are versions of the pneumatic controller that support the useful one-, two-, and three-mode combinations of proportional, integral, and derivative actions. Other options include auto/manual transfer stations, anti reset windup circuitry, on/off control, and process-variable and set point indicators. Pneumatic controllers are made of Bourdon tubes, bellows, diaphragms, springs, levers, cams, and other fundamental transducers to accomplish the control function. If operated on clean, dry plant air, they offer good performance and are extremely reliable. Pneumatic controllers are available with one or two stages of pneumatic amplification, with the two-stage designs having faster dynamic response characteristics.

The final control element

This is the element that implements in real life the decision taken by controller. For example, if the controller decides that the flow rate of the outlet stream should be increased or decreased in order to keep the liquid level in a tank at the desired value, it is the valve that will implement this decision, opening by the commanded amount

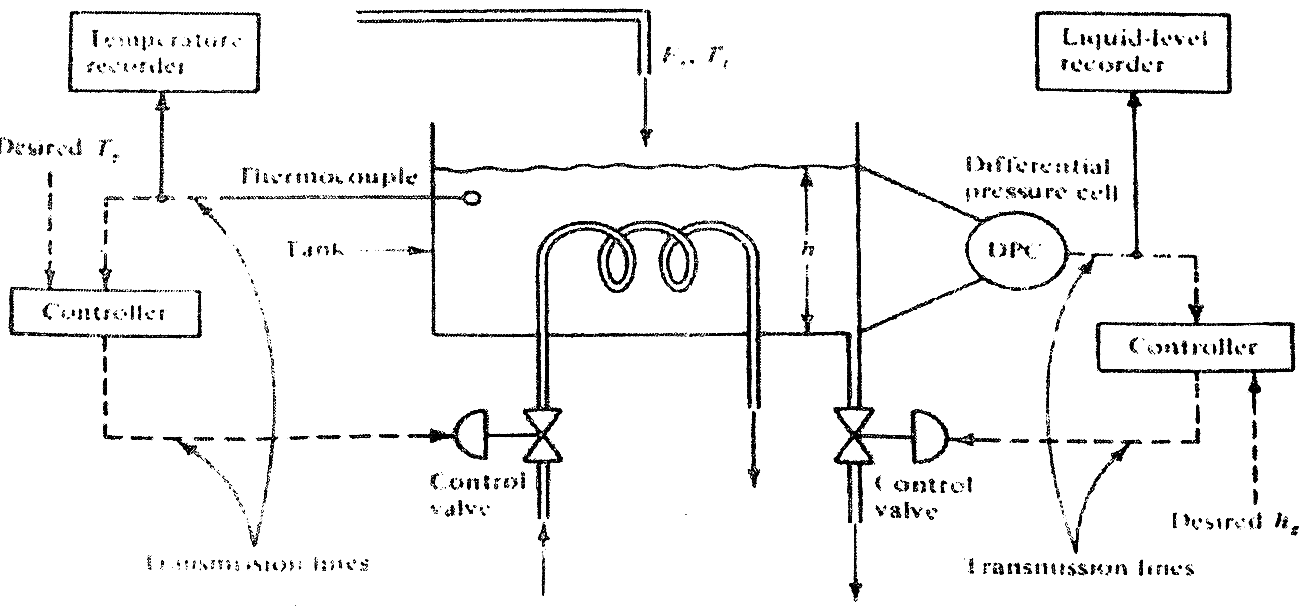

Fig. 2.2 Elements of control system

Closed loop control system

In a closed-loop control system, a sensor monitors the output and feeds the data to a computer which continuously adjusts the control input as necessary to keep the control error to a minimum. A closed-loop system uses the measurement of one or more process variables to move the manipulated variable to achieve control. Closed loop systems may include feed forward, feedback, or both

Advantages of closed loop control system are:

- Guaranteed performance even with model uncertainties, when the model structure does not match perfectly the real process and the model parameters are not exact.
- Unstable processes can be stabilized.
- Reduced sensitivity to parameter variations.

Feedback Control -

In a feedback control loop, the controlled variable is compared to the set point *R,* with the difference, deviation, or error *e* acted upon by the controller to move *m* in such a way as to minimize the error. This action is specifically negative feedback, in that an increase in deviation moves *m* so as to decrease the deviation (Positive feedback would cause the deviation to expand rather than diminish and therefore does not regulate.) The action of the controller is selectable to allow use on process gains of both signs.

Objective of feedback control system are

- To get the fastest possible response to set point.
- To compensate for or to attenuate disturbances as much and as quickly as possible. These must be accomplished with a reasonable degree of closed loop stability.

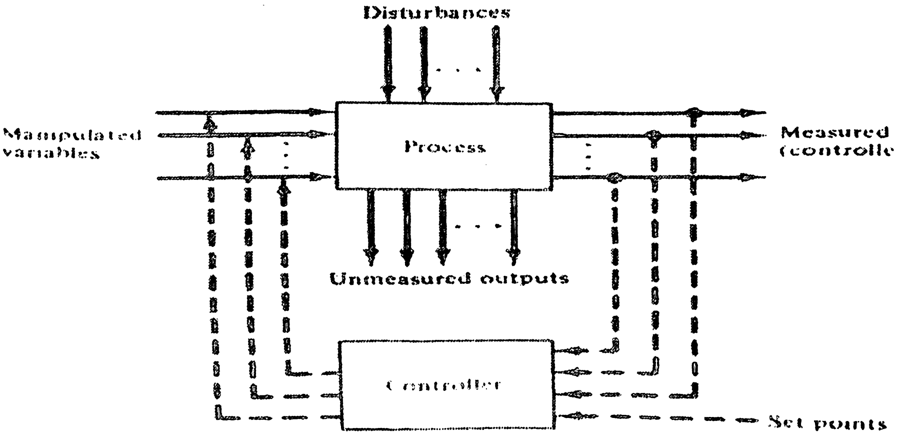

Fig.2.3 General Structure of feedback control configuration

Feed forward Control –

A feed forward system uses measurements of disturbance variables to position the manipulated variable in such a way as to minimize any resulting deviation. The disturbance variables could be either measured loads or the set point, the former being more common. The feed forward gain must be set precisely to offset the deviation of the controlled variable from the set point.

Feed forward control is usually combined with feedback control to eliminate any offset resulting from inaccurate measurements and calculations and unmeasured load components. The feedback controller can either bias or multiply the feed forward calculation.

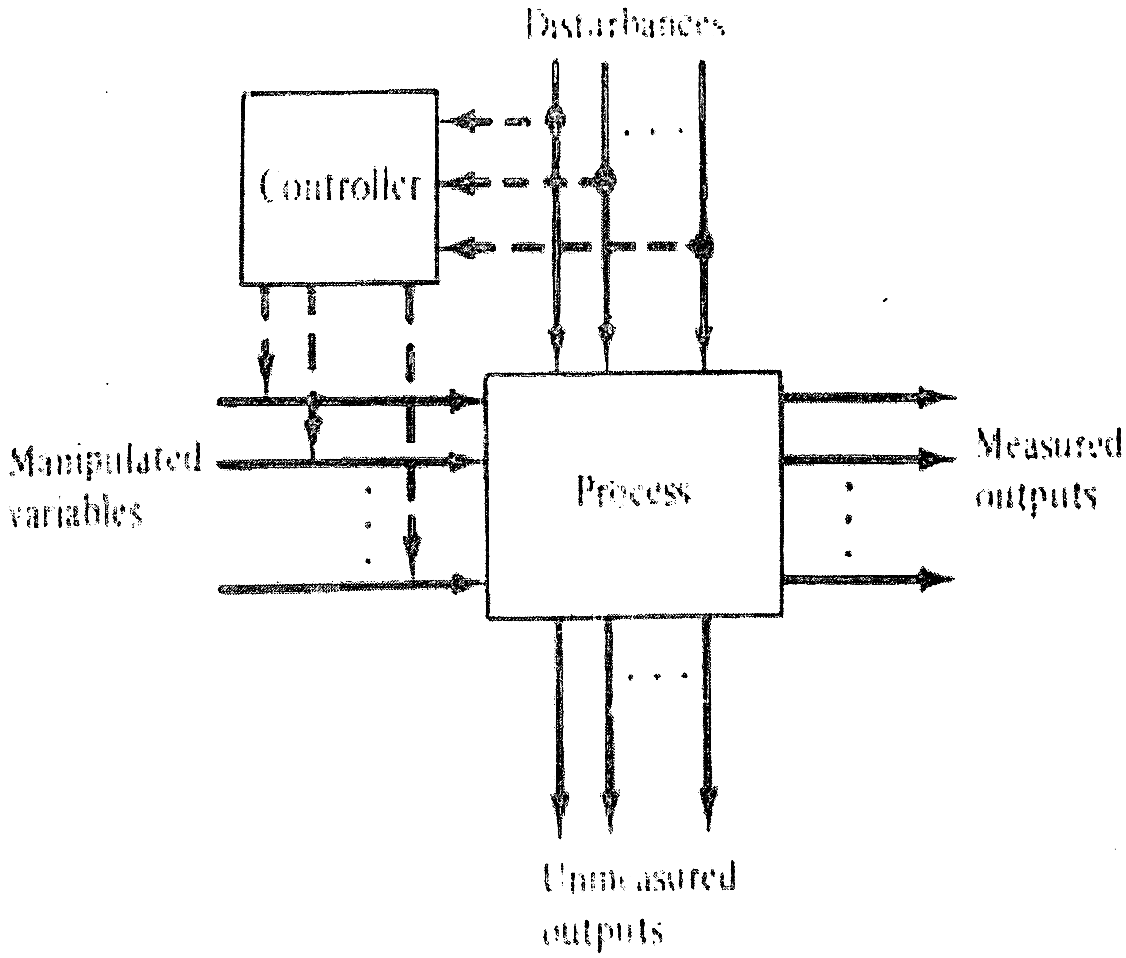

Fig.2.4 General structure of feed forward control configuration

Closed-loop transfer function

The output of the system y (t) is fed back through a sensor measurement *F* to the reference value *r* (t). The controller *C* then takes the error *e* (difference) between the reference and the output to change the inputs *u* to the system under control *P*. This kind of controller is a closed-loop controller or feedback controller.

This is called a single-input-single-output (SISO) control system;

MIMO (i.e. Multi-Input-Multi-Output) systems, with more than one input/output, are common. In such cases variables are represented through vectors instead of simple scalar values.

To avoid the limitation of single loop design and to provide a more flexible and sophisticated process operating logic than can be implemented by human operators, we use an approach we call multivariable control.

We define multivariable control system as one that has built in intelligence to look simultaneously at two or more process variables and to choose in a given situation, the best pre-programmed strategies for manipulating one or more control valves.

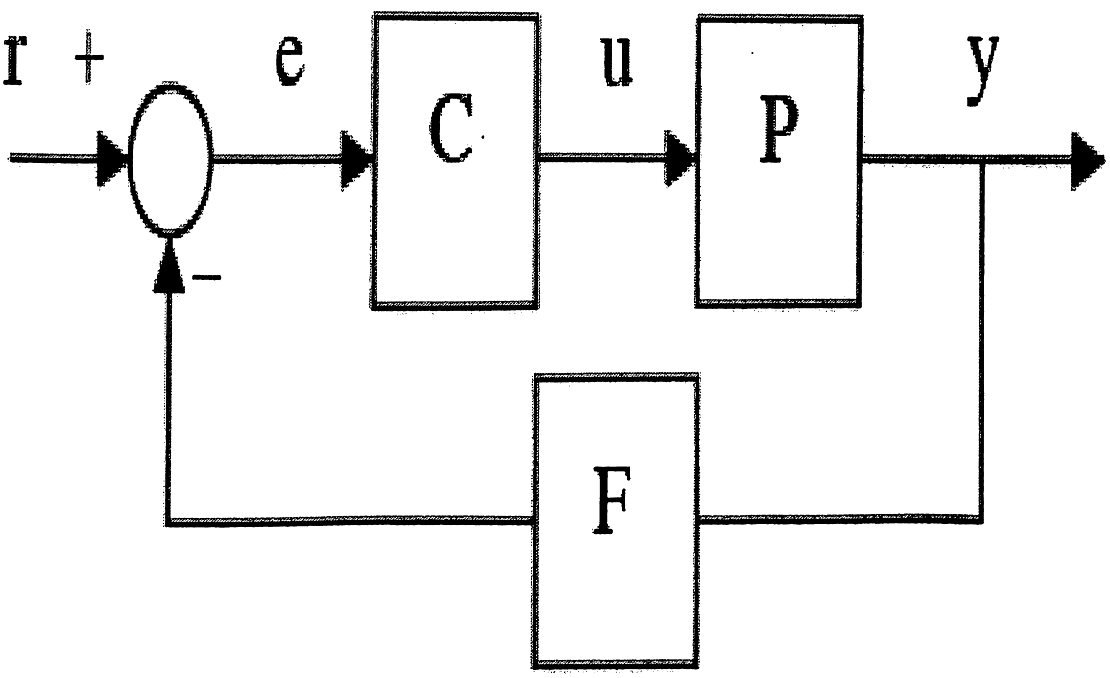

Fig.2.5 Closed loop system

If we assume the controller *C*, the process *P*, and the sensor *F* are linear and time-invariant (that is elements of their transfer function *C(s)*, *P(s)*, and *F(s)* do not depend on time), the systems above can be analysed using the Laplace transform on the variables. This gives the following relations:

$$Y(s) = P(s)U(s)$$
$$U(s) = C(s)E(s)$$
$$E(s) = R(s) - F(s)Y(s).$$

Solving for $Y(s)$ in terms of $R(s)$ gives:

$$Y(s) = \left(\frac{P(s)C(s)}{1 + F(s)P(s)C(s)}\right) R(s)$$

= H(s) R(s)

The expression represented by H(s) is referred to as the closed-loop transfer function of the system.

$$H(s) = \frac{P(s)C(s)}{1 + F(s)P(s)C(s)}$$

The numerator is the forward (open-loop) gain from *r* to *y*, and the denominator is one plus the gain in going around the feedback loop, the so-called loop gain.

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www.wikipedia.org

3

MATERIAL BALANCE CONTROL FOR DISTILLTION COLUMN

Arrangements for material balance control

The size and location of tanks and the concept of overall material balance control used can have a great influence on plant investment and process control. If the design engineer uses the concept of control in the direction opposite to flow, tanks may be smaller and plant fixed investment and working capital can be lower than if control in the direction of flow is used.

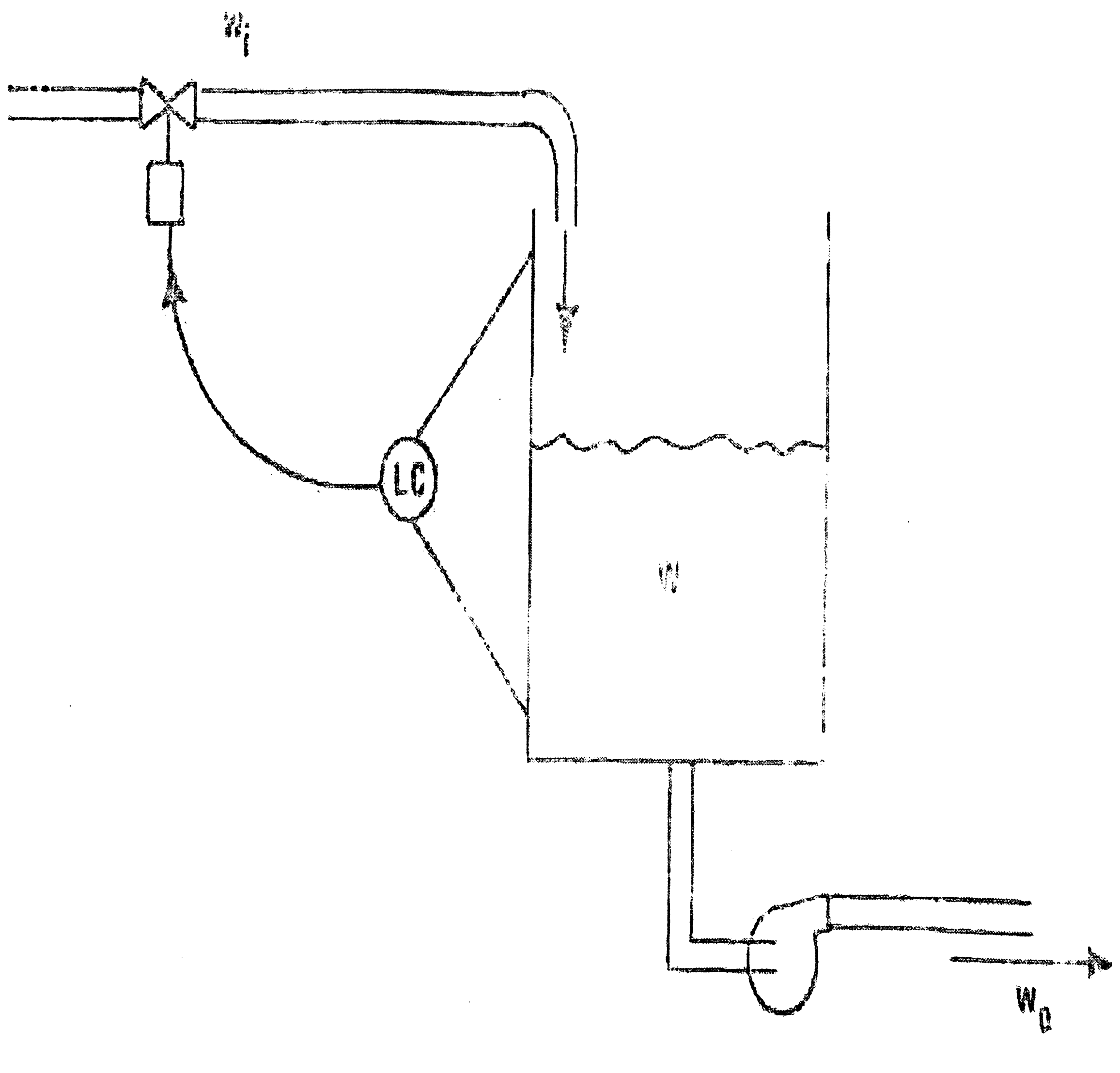


Fig.3.1 Material balance in the direction opposite to flow

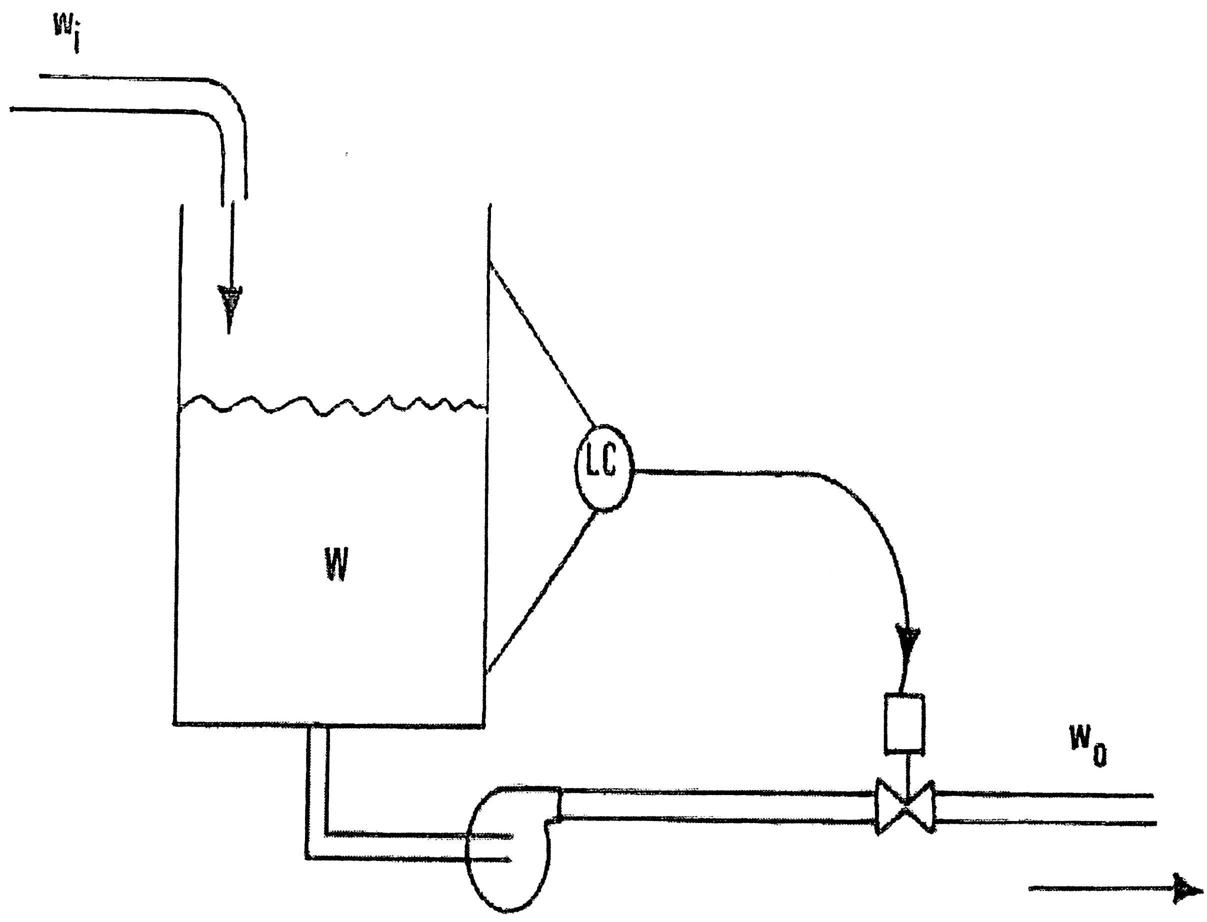


Fig.3.2 Material balance control in the direction of flow

When more than one tanks are involved, other advantages of control in the direction opposite to flow are

1) Less difficulty with stability problems
2) Reduced internal turndown requirements
(Turndown as used here is the ratio of maximum required flow rate to minimum required flow rate)

Once the basic concept of material balance control has been selected for a process, one must apply the same concept to all process steps. It is for this reason that the first step in designing column controls is to determine the material balance control arrangement. Control in the direction of the flow is most commonly used concept.

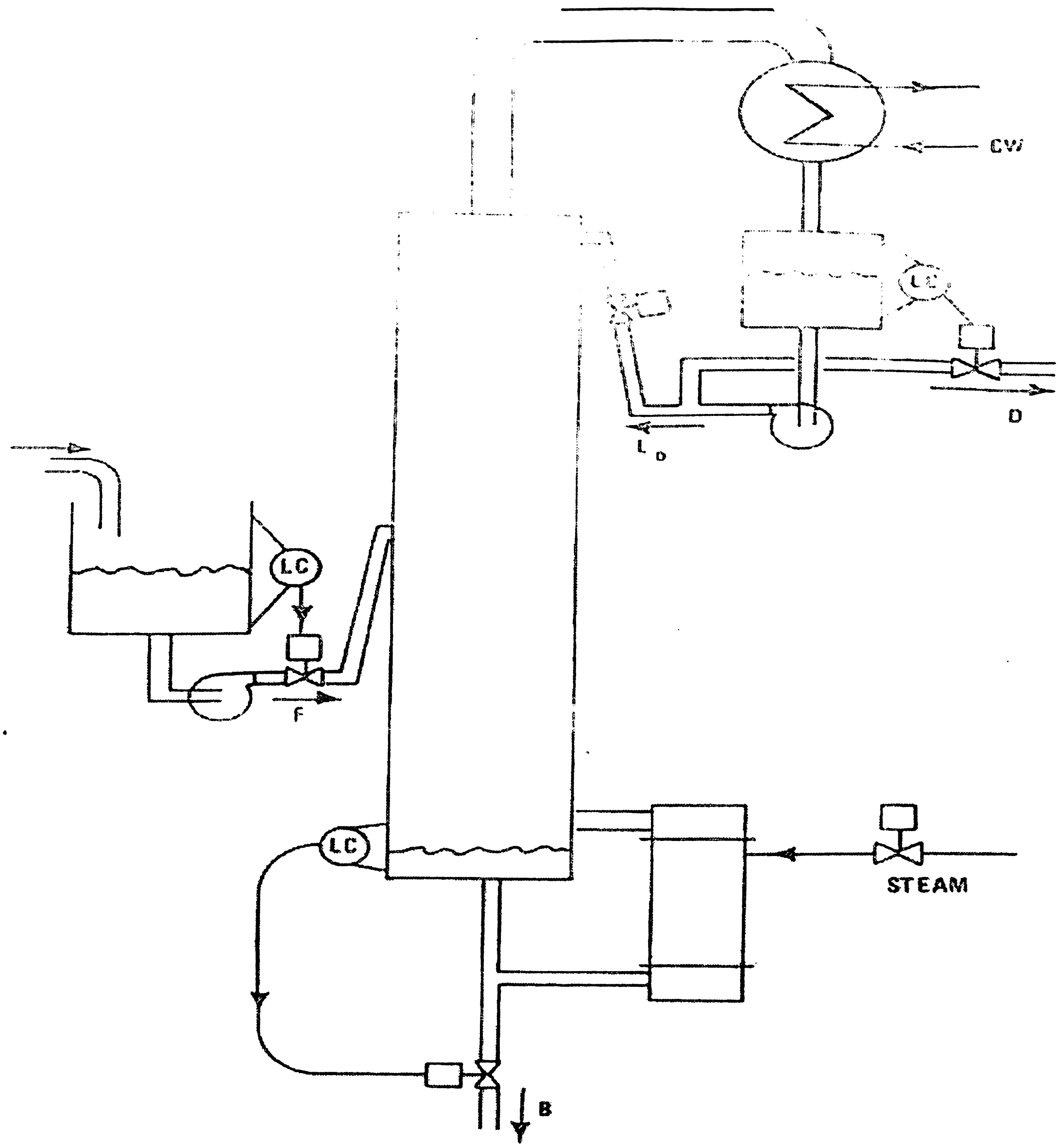


Fig.3.3 simple distillation column control system

Here level in the condensate receiver (reflux drum) sets the top product, or distillate flow, while the level in the base of the column sets the bottom product flow. The direction of material balance control is determined by the demand stream. In recycle stream we may find some material balance controls in the direction of the flow while others in the direction opposite to the flow.

Overhead system arrangements

The column overhead system is generally more complicated than either the feed system or the bottom systems. It usually must condense the vapour flow from the top tray, remove inerts, provide reflux flow back to the column, maintain column pressure in the right range, and satisfy part of the material balance requirements.

Condensate is generally subcooled at least slightly, partly to minimize the likelihood of flashing and cavitation in valves and pumps, partly to control the amount of inerts in the system, and partly to control product losses through the vent. Material balance control on the condensate may be accomplished in several ways:

1) Flow control of reflux is cascaded, if possible, from column overhead composition, and distillate overflows from the vapour liquid disengagement space beneath the condenser.
2) Same as foregoing except that the distillate flow is set by reflux drum level control.

If a smooth flow to the next step in the process is needed, a reflux drum with averaging level control of distillate should be employed.

Horizontal shell and tube condenser

This type of condenser with liquid coolant in the tubes and vapour on the shell side is most common in petroleum refineries. By comparison with the vertical design, it is much better suited to partially "flooded" operations. In addition, at startup time, column inerts are usually vented more easily (with less pressure drop) through condenser of this design.

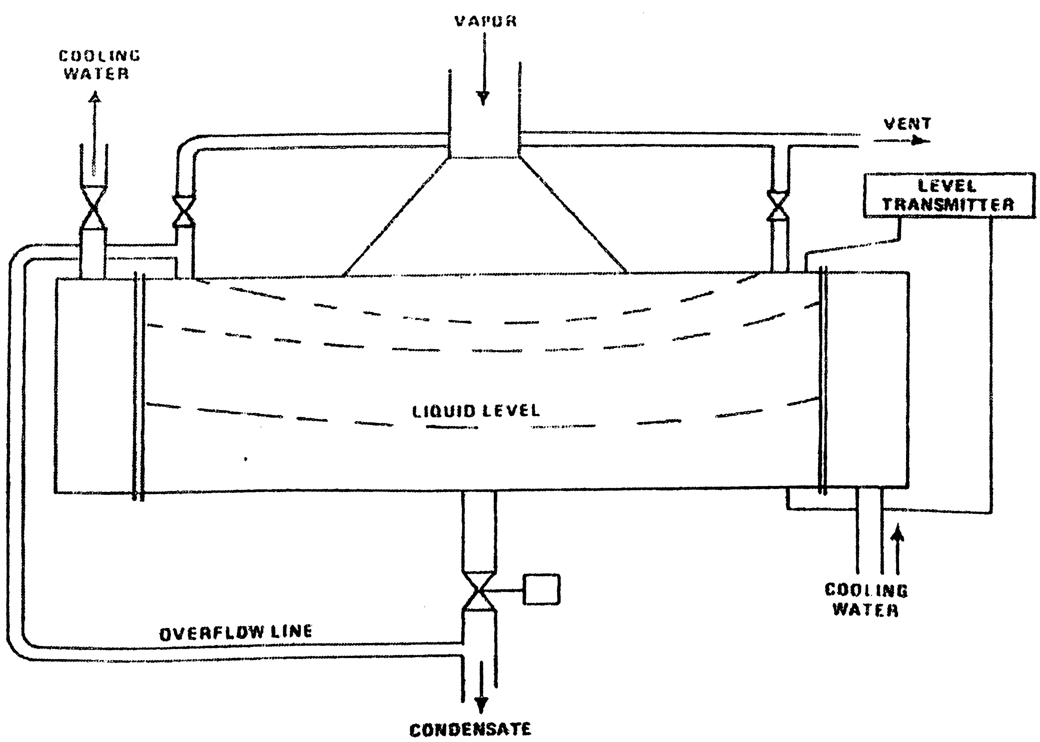


Fig.3.4 Horizontal condenser, vapour in shell

This design has two vents, each with a valve if the exchanger is operated flooded. Some designs bring the vapour in at one end and vent uncondensables at the other. Sometimes condensate is taken out through two drawoffs instead of one. The cooling water valve is normally at the exchanger exit to make sure the tubes are filled at all times. Since the exit water is hot, the valve may need anticavitation trim.Example showing the Overhead system arrangement for atmospheric columns generally used in the petroleum industry.

Atmospheric columns

The condensed vapour falls into a reflux drum that should have 5-10 min. holdup (relative to condensate rate), and inerts are vented to a flare or cleanup system. At startup time total reflux may be achieved by using the reflux valve to control the level in the condensate receiver.

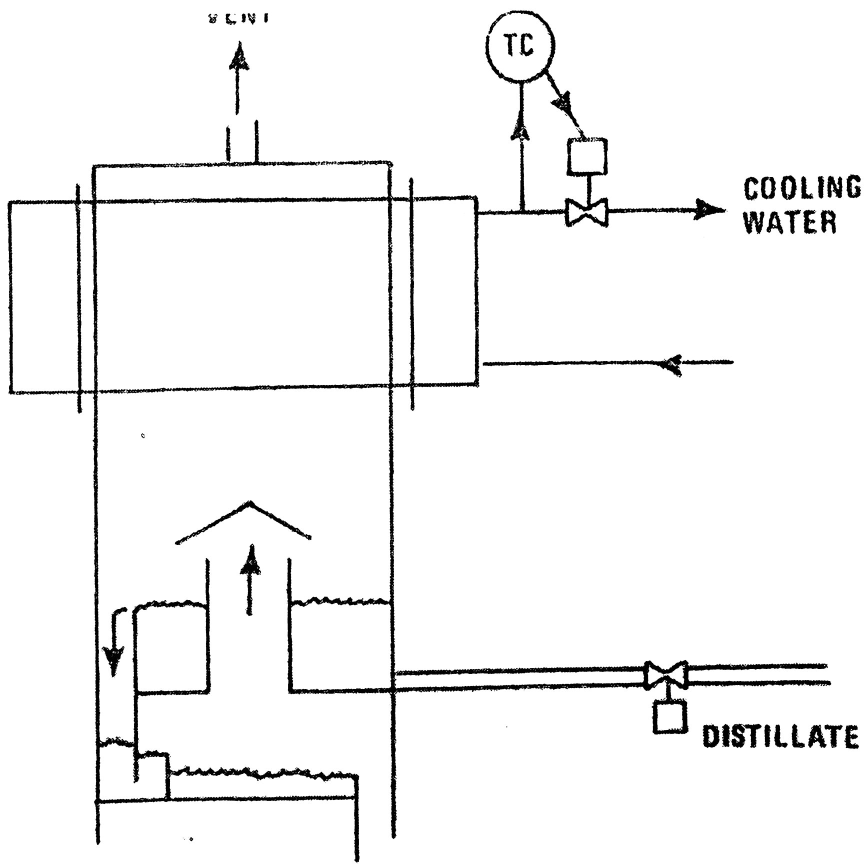


Fig3.5 Overhead system arrangement for atmospheric columns

A potential and frequent source of trouble with the arrangement is the control of condensate temperature via cooling water. For a constant subcooled temperature, process gain and dominant time constant both decrease as heat load increases. This compounds stability problems, we need an increasing controller gain and decreasing reset time as total heat load increases. Further, subcooling heat load must be a reasonable fraction of total heat load- say 5 percent- or the system will lack adequate sensitivity.

The suggested approaches to avoiding these difficulties are as follows:

1) Select the number of degrees of subcooling] so that the sensible heat load will be at least 5 percent of the total heat load. This will have a secondary advantage of reducing the probability of cavitation in control valves and pumps.
2) If water header fluctuations are a problem, use a cascade temperature water flow control system.

Gravity return reflux vs pumped back reflux

With the condenser overhead, the vapour and reflux lines can be short, which favours good compositional control. On the other hand, a ground level condenser is often easier to maintain particularly where fouling is a problem. If an overhead condenser is used, a more expensive column supporting structure is required, particularly if the overhead surge drum is also located at the top of the column. The support problem can be minimized, however, one uses the arrangement of direct return reflux and overflow distillate, then the reflux does not come from overhead surge drum and this vessel can be located at ground level. Since this tank with its contents is often far heavier than condenser, the condenser can be located overhead with only modest increase in structural requirements over a ground located condenser. Overall a properly designed gravity flow reflux systems, is significantly cheaper than a pumped back reflux system, it is also probably safer since there is no pump to fail.

Reflux flow or flow ratio control

When reflux is flow or flow ratio controlled, piping and instrumentation can be very simple. Here reflux drum level is controlled by throttling distillate flow. A disadvantage, unless the drum has a large cross section, is that variation in level will cause a momentary change in both reflux and distillate flows. The reflux flow or flow ratio controller will usually be fast enough that this will not be a problem for reflux flow. The level controller on the other hand, may have to be cascaded to distillate flow control.

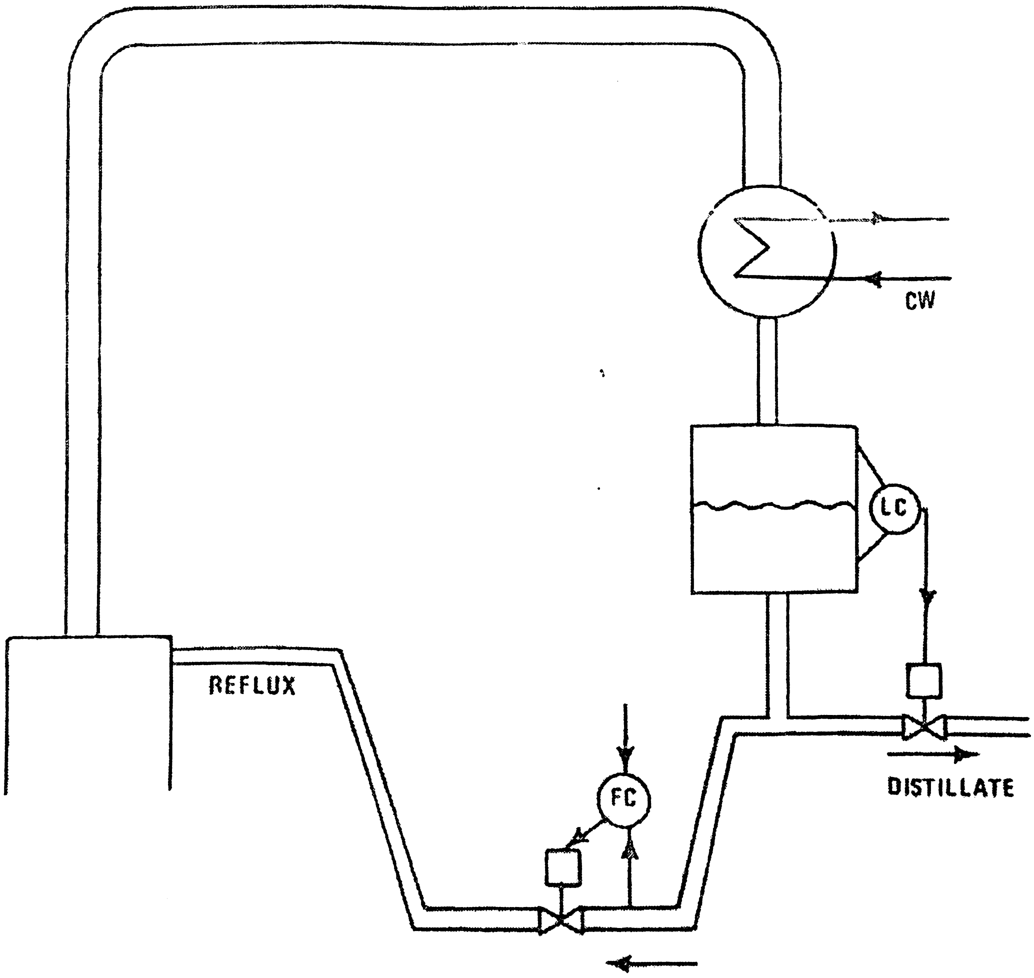


Fig.3.6 Gravity flow reflux (flow controller) and distillate (level controlled)

To avoid this problem, one may design a distillate overflow system that provides constant head for reflux.

Here a vapour liquid disengagement space is built into the lower section of a vertical tube, coolant in shell condenser. For maximum effectiveness the liquid pool in the vapour liquid disengagement space should have large cross sectional area and the overflow weir should permit a wide range of overflows with only a small change in head. Then, with the head across the reflux line fixed, flow will vary only when the valve position is changed. For this application a valve with linear trim will have a linear installed characteristic if line drop is negligible; that is, a plot of reflux flow vs. valve stem position will be a straight line. If the individual valve is shop calibrated, then the valve stem position can be accurately related to reflux flow.

Since the surge tank needs a level controller, there is no savings in instrumentation, but the equipment that needs to be installed at high elevation is minimized

Column base and reboiler arrangements-

The design of the column base with its associated reboiler can be a complex matter. It requires simultaneous consideration of fluid mechanics, heat transfer, mass transfer, and process control. For example, the following must be considered when a vertical-thermosyphon, forced –circulation or kettle- type reboiler is used.

- Spacing between the vapour – return nozzle and the lowest tray should be large enough to minimize entrainment of liquid drops in the rising vapour. This is typically one vapour nozzle diameter and normally will be specified by the column designer.
- The maximum liquid level should not be too close to the vapour nozzle as this promotes turbulence in the liquid surface and liquid entrainment into the rising vapour.
- Minimum liquid level should not be too far below the vapour nozzle, or the falling liquid drops will entrain too much vapour into liquid pool. In severe cases this may cause foaming in the column base and gassing of the reboiler.
- There should be a minimum liquid level depth the nozzle to the drawoff line from the column base or vaporizer separator. This is required for two reasons- first, to permit entrained vapour bubbles to rise and spate from the liquid pool, and second, to minimize the like hood of vortex formation at the drawoff nozzle. Vortexing is undesirable since it promotes entrainment of vapour into the drawoff line, which may cause gassing of the reboiler or bottom product pump or circulating pump. Vortex breakers should be installed routinely.
- If level measurement nozzles are not protected by an internal damping chamber, they should have an orientation no more than 90 deg from the vapour return nozzle and should not be located under the down comer.

Material balance control scheme -

There are basically two types of arrangements-

1. Material balance control in the direction of flow.
2. Material balance control in direction opposite to the flow.

Procedure for designing control system for a distillation column

1. Start with writing the material balance for the binary distillation column.

2. Then after writing all the material balance equation for distillation column we will find the transfer function for stripping section liquid and enriching section liquid.

3. Then we draw the signal flow diagram for distillation column material balance. By using the material balance equation we combine all of them to form a signal flow diagram.

4. We will find the overhead level and column base control equation of material balance control scheme that is in the direction of flow. From these control and material balance equation we draw the signal flow diagram for material balance in the direction of flow.

5. Now showing the control scheme which has been made is controlling the level and composition correctly or not. So we draw the basic diagram of the control scheme in the software (MATLAB) with four manipulated variable with outputs are distillate and bottom composition.

6. For ease of modelling, it is assumed that the manipulated inputs are reflux flow rate and vapour boil up rate.

7. By using data we can see the open loop behaviour for the control scheme. Then we show the response to reflux change and response to boil up change.

8. Now we can plot the graph and see the response of control scheme over the bottom composition and distillate composition.

DISTILLATION COLUMN MATERIAL BALANCE

The feed w_F, is split by the column into two parts; top product w_D, and the bottom product, w_B. It is assumed that vent losses overhead are negligible. It is further assumed that the heat transfer dynamics of both the condenser and reboiler are negligible; this will be true for most columns.

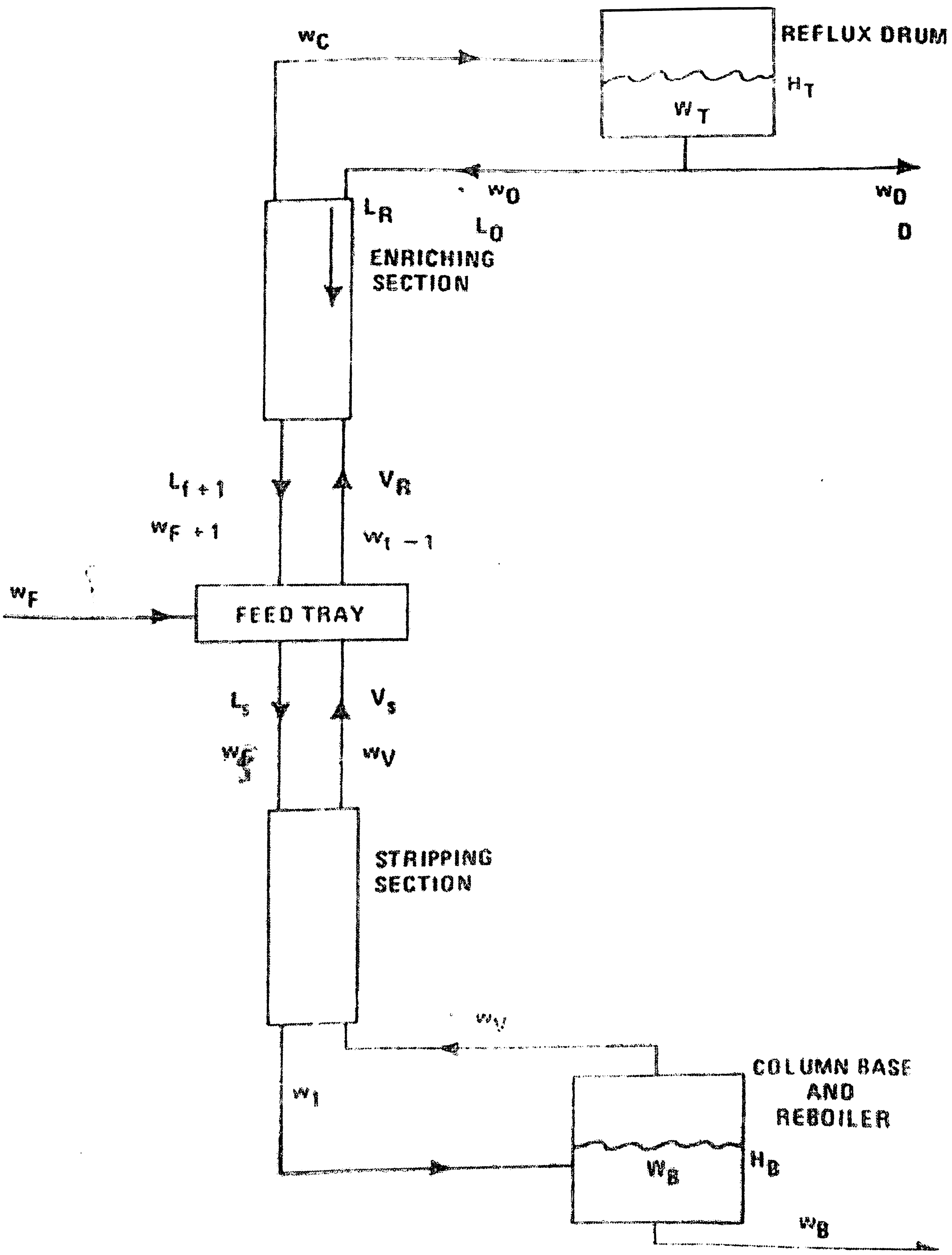


Fig.3.7 Distillation column material balance

Column base, including reboiler

$\{w_l(s)- w_v(s)-w_B(s)\}/s = W_B(s)$

Where

W_l = liquid flow from first tray, lbm/min.

W_v = vapor flow from column base, lbm/min

w_B = bottom product flow, lbm/min.

W_B = liquid inventory in column base, lbm, within the level transmitter span

s = Laplace transformation variable

Next:

$W_B(s)/\rho_B A_B = H_B(s)$

ρ_B = density, lbm/ft3 of liquid in column base

A_B = cross sectional area of the column base, ft3

H_B = liquid level in base, feet

Feed tray-

The feed tray material balance in terms of molar flow is:

$V_R = F\,(1\text{-}q) + Vs$ ....eq. 1

Where

V_R = vapor flow leaving feed tray, mol/min

F = feed flow, mol/min

V_S = vapor flow entering feed tray, mol/ Min

q = enthalpy factor

= (enthalpy of feed as vapor as dew point – actual feed enthalpy)/molar latent heat of vaporization of feed

$(L_S - L_R)/ F$

L_R = liquid flow from top tray, mol/min

L_S = liquid flow from feed tray, mol/min.

If the feed is a liquid at its boiling point, q=1 and $V_R = V_S$. If the feed is subcooled liquid, q is greater than 1 and V_R is less than V_S.

It is also true that:

$V_S + F + L_{f+1} = L_f + V_R$

From the definition of q above, we can write

$L_{f+1} - L_f = -F_q$

In terms of weight units

$w_f+1/(w_f+1/L_f+1) - w_f/(w_f/L_f) = -w_f/(w_f/F)\ q$..eq. 2

w_F= feed, lbm/min.

W_f = liquid flow from the feed tray, lbm/min.

From the eq. no. 2

$w_f = [\ w_{f+1}/(w_{f+1}/L_{f+1}) + \{w_f/(w_f/F)\}\ q](w_f/L_f)$

Since w_f+1/L_f+1, w_f/F, and w_f/L_f are constants, we can rewrite equation in Laplace transformation notation

$w_f(s) = (w_f/L_f)(L_{f+1}/w_{f+1})w_{f+1}(s) + (w_f/L_f)(F/w_f)qw_f(s) + (w_f/L_f)(F/w_f)q(s)\ w_f$

$w_f(s) = k_2\ w_f+1(s) + k_3\ w_f(s) + k_4 q(s)$

Usually $k_2 = 1$, $k_3 = q$, and $k_4 = w_f$

In going back to the equation no.1 and expressing it in weight units, we obtain.

$w_{t-1}/(w_{t-1}/V_R) = w_F/(w_F/F)*(1-q) + w_v/(w_v/V_S)$

$w_{t-1} = (w_{t-1}/V_R)*(V_S/w_v)*w_v + (1-q)(F/w_F)*(w_{t-1}/V_R)*w_F(s) -$

$(w_{t-1}/V_R)*w_F(F/w_F)q(s)$

$w_{t-1} = k_6 w_v(s) + k_7 w_F(s) - k_8 q(s)$

Usually k6 = 1, $k_7 = 1-q$, $K_8 = w_F$

Stripping section liquid flow dynamics-

The transfer function between w_l and w_f is:

$W_l(s)/w_f(s) = G_2(s)$

Where $G_2(s)$ is the cumulative effect of the individual tray hydraulic lags,

$G_2(s) = 1/(\tau T_R s + 1)\ N_s = e^{-a2s}$

N_s = number of trays from the column base to the feed tray

$a_2 = N_S \tau_{TR}$

Enriching section liquid flow dynamics-

$w_{f+1}(s)/w_{lR}(s) = G_l(s)$

Where

w_{lR} = liquid flow(internal reflux) from top tray, lbm/min

$G_l(s) = 1/(\tau T_R s + 1) Nr = e\text{-}^{als}$

Where

N_R = number of trays above the feed tray

$a1 = N_R \tau T_R$

$w_{lR} = K_{sc}\, w_R$

where

$K_{sc} = 1 + cp/\lambda PT\ (To - TR)$

w_R = external reflux flow, lbm/min.

Overhead material balance-

The vapor flow to the condenser is:

$W_c(s) = w_{t-1}(s) - w_r(s)[\ c_p/\lambda_{PT}\ (To - T_R)]$

Where

λ_{PT} = latent heat of vaporization of process fluid specific heat, pcu/lb

c_P = process fluid specific heat, pcu/lbm°C

To = average vapor temperature

T_R = average external reflux temperature

W_c = vapor flow to condenser

If there is no subcooling $w_c = w_t$-1

Condensate receiver material balance

$[W_c(s) - w_D(s) - w_R(s)]/s = W_T(s)$

Where

w_D = top product flow rate, lbm/min

W_T = condensate receiver inventory, lbm

If the condensate receiver is a vertical, cylindrical vessel:

$W_T(s)/ \rho_T A_T = H_T(s)$

Where

H_T = height of liquid, feet, in receiver

ρ_T = density of top product, lbm/ft^3

A_T = cross sectional area of receiver, ft^2

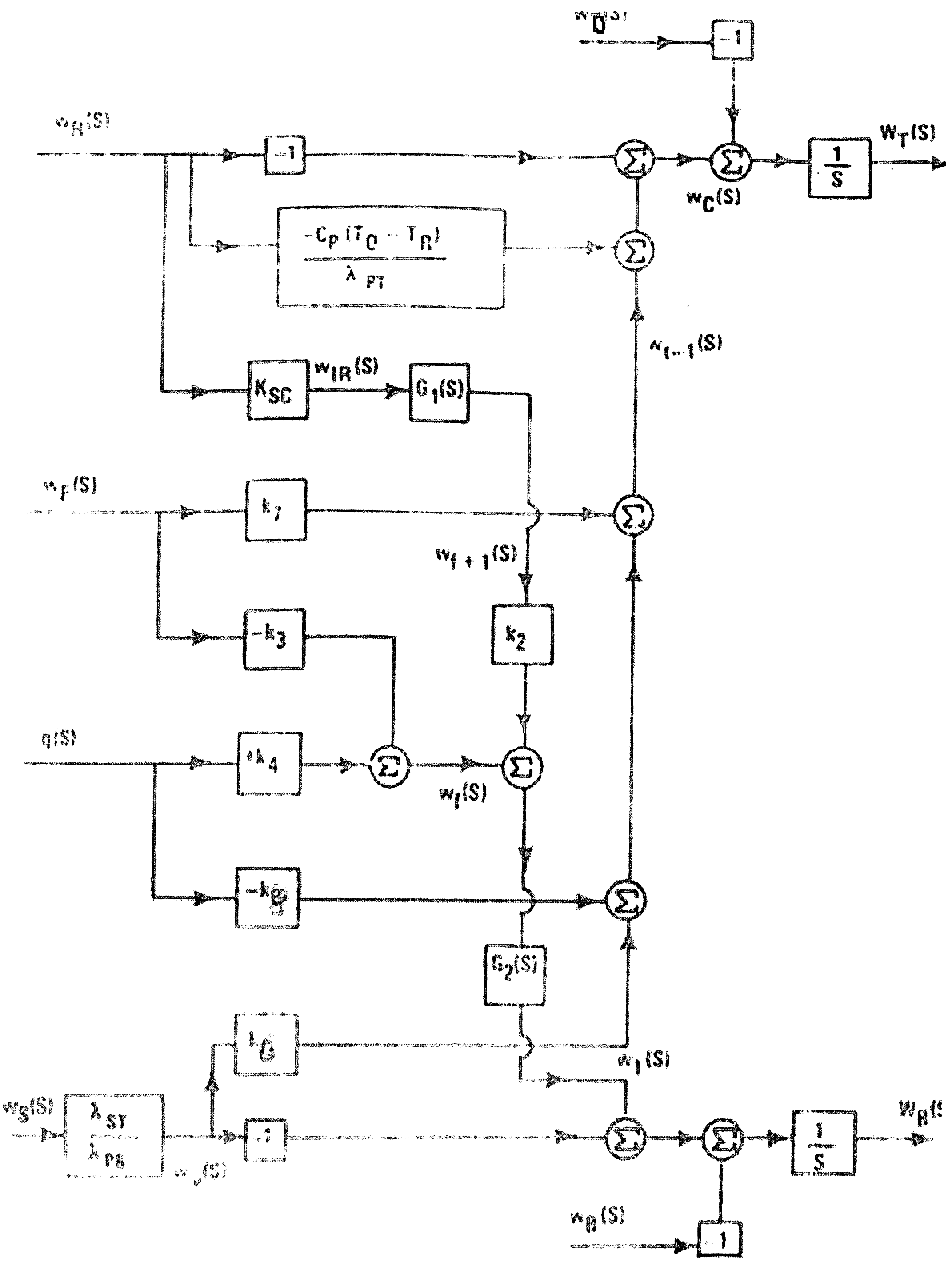


Fig.3.8 Signal flow diagram for column material balance

Control in the direction of flow-

Let condensate receiver level set top product flow and let column base level set bottom product flow. We wíll assume that each level is cascaded to appropriate flow controller.

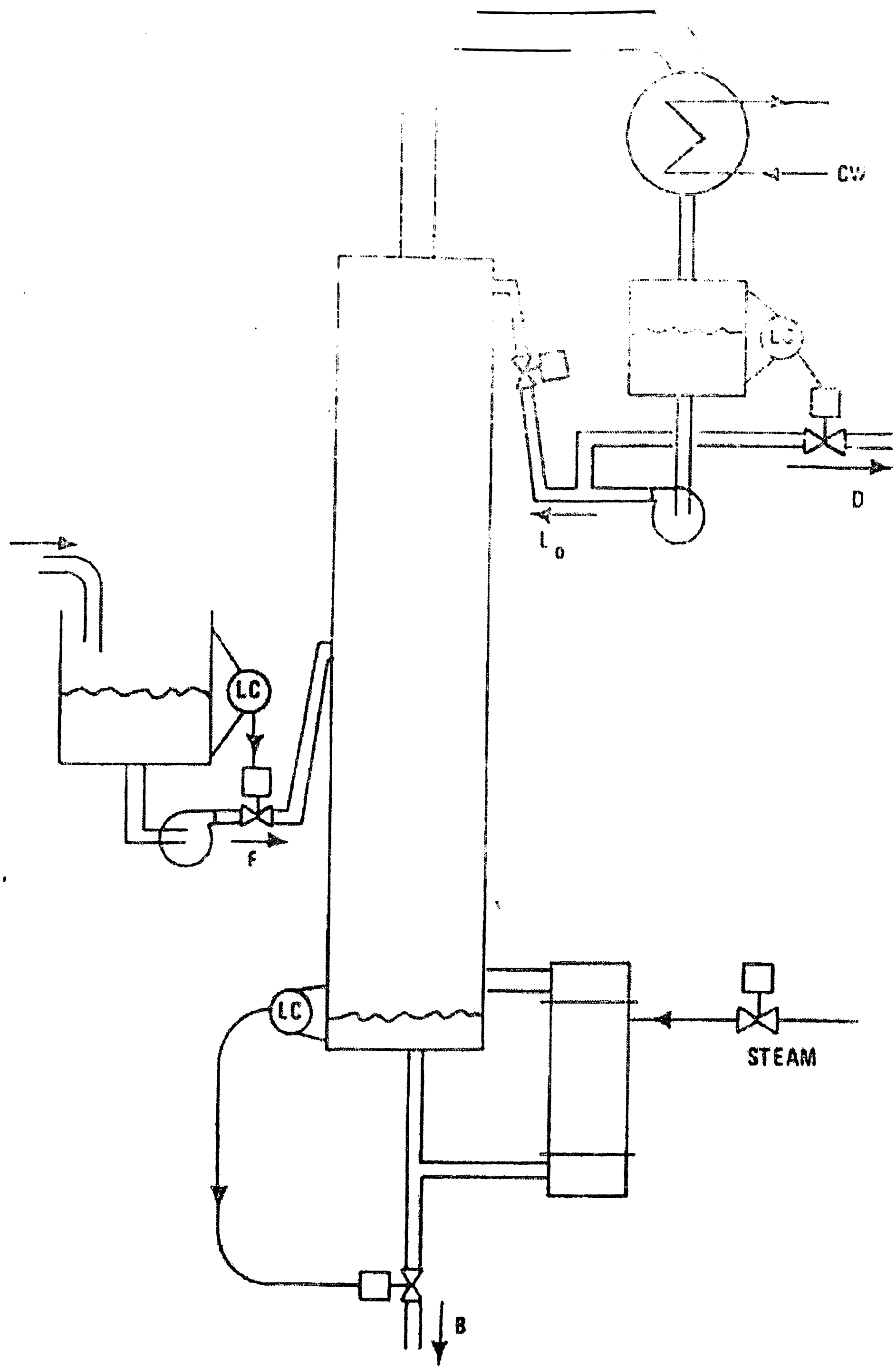


Fig.3.9 Distillation column with material balance control in direction of flow

Overhead level control-

The necessary addition equation (no subcooling) is:

$w_D(s) = H_T(s)K_{mht}\ K_{cht}\ G_{cht}(s)$ x $1/K_{mfD}$

where

K_{mfD} = distillate flow meter gain psi/lbm/min

$12/(W_D)max$

$(W_D)max$ = top product flow meter span, lbm/min.

K_{cht} = controller gain

$G_{cht}(s)$ = controller dynamic gain

K_{mhT} = receiver level transmitter gain, psi/ft

From the signal flow diagram

$w_D(s)/[w_c(s) - w_R(s) = 1/[\ 1 + (K_{cht}G_{cht}(s)K_{mht}/A_T p_T K_{mfD})]$

$= K_{HT}G_{HT}(s)$

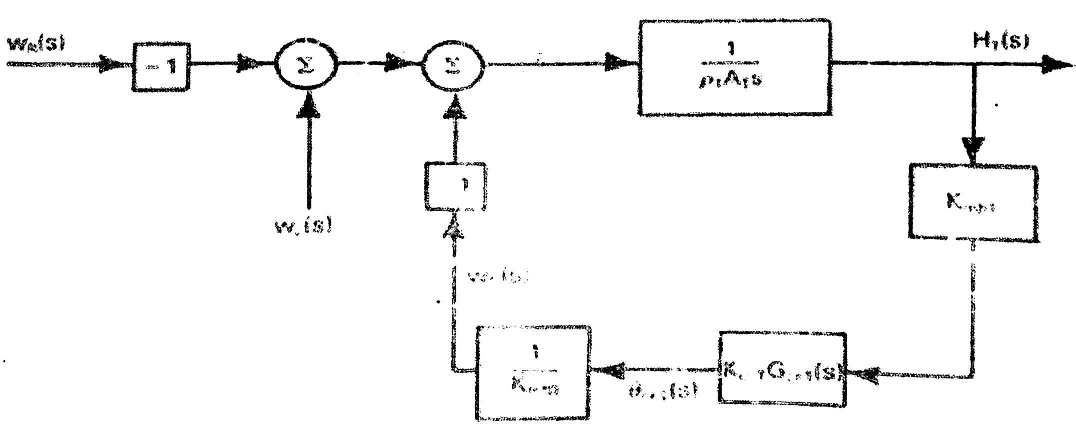


Fig.3.10 Signal flow diagram- condensate receiver

Base level control-

$w_B(s) = (1/K_{mfB})\, k_{chB}\, G_{chB}(s)\, K_{mhB}\, H_B(s)$

where

K_{mfB} = bottom product flow transmitter gain, psi/lbm/min

$= 12/(w_B)max$; $(w_B)max$ = flow meter span, lbm/min

K_{chB} = controller gain

K_{mhB} = base level transmitter gain

From the signal flow diagram, we see that

$w_B(s)/[w_I(s)- w_v(s)] = 1/[1+(K_{chB}\, G_{chB}(s)\, K_{mhB}/p_B A_B K_{mfB})]$

$= K_{HB}\, G_{HB}(s)$

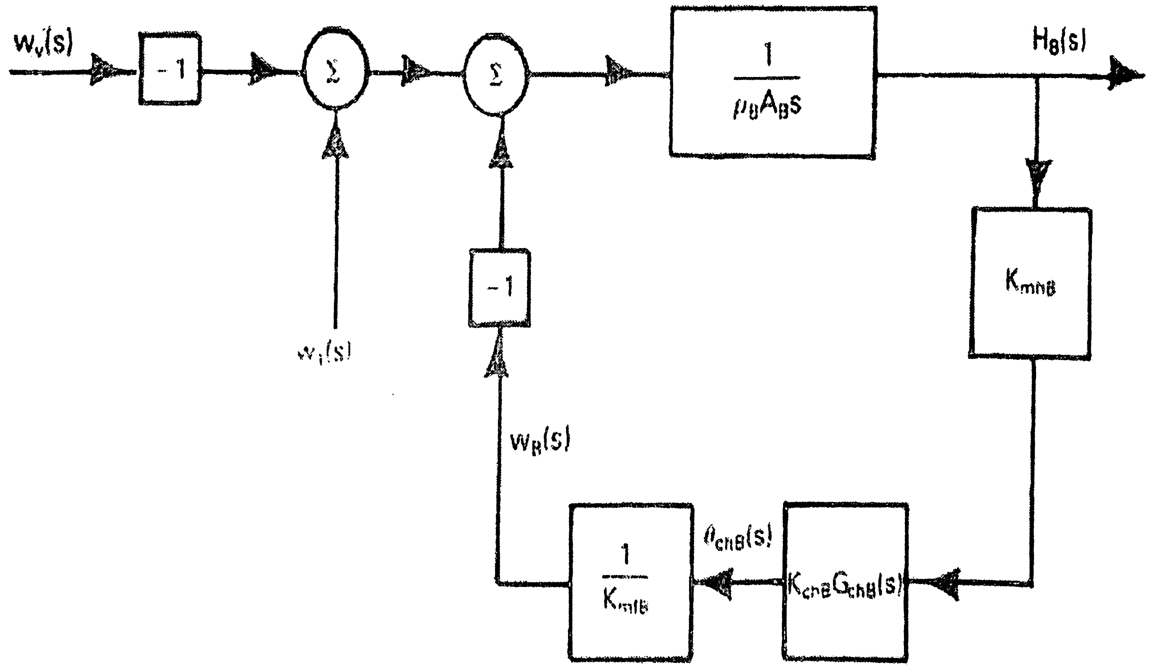


Fig.3.11 Signal flow diagram – column base

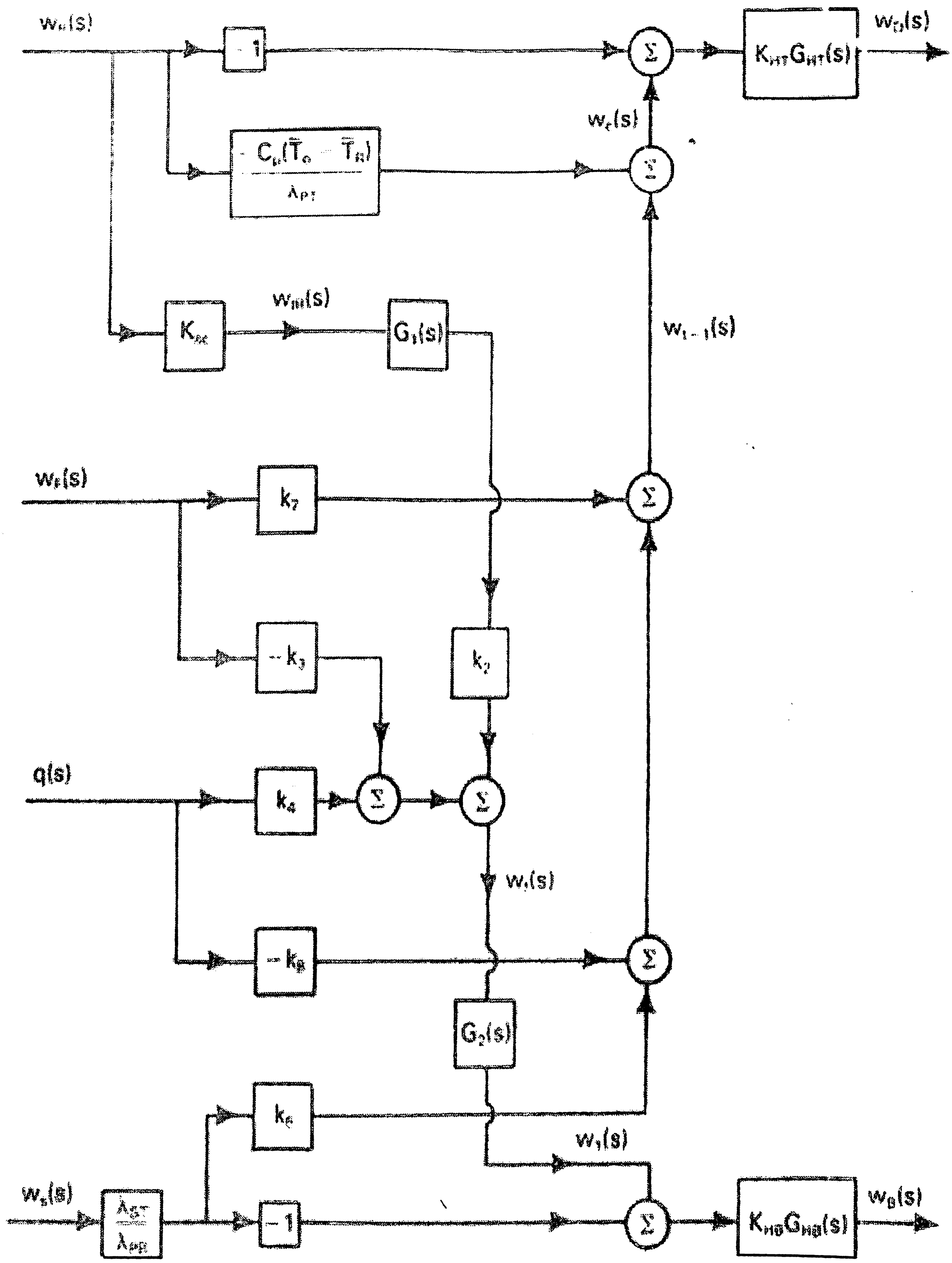


Fig.3.12 Signal flow diagram for column material balance in direction of flow

Case study

A schematic diagram of typical binary distillation column is shown below. Notice that there are four measured variable (distillate receiver level, base level, distillate composition, and bottom composition) and four manipulated variable (reflux flow rate, distillate flow rate, bottom flow rate, and reboiler heat duty). If feed is regulated then there is another measurement (feed flow rate) and manipulated input (also feed flow rate). Normally it is assumed that the distillate receiver level is controlled by manipulating the distillate product flow rate, and that the base level is controlled by manipulating the bottom product flow rate. It is also assumed that these are tightly tuned, and the process outputs are perfectly controlled at their set point values

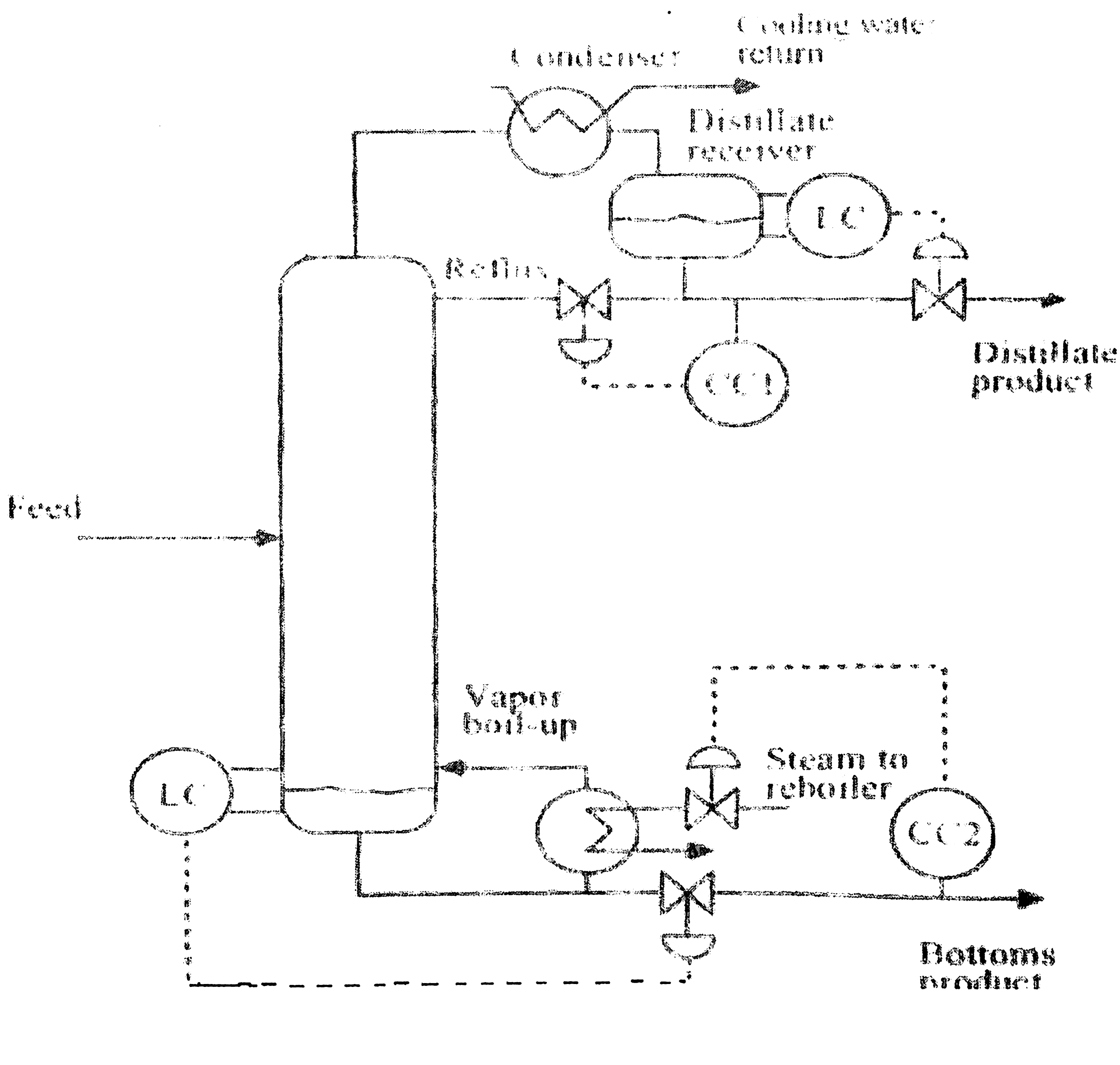


Fig. 3.13 Basic diagram of dual composition control scheme

The column studied is 41 stage binary separation. For ease of modelling, it is assumed that the manipulated inputs are reflux flow rate and vapour boil up rate. In practice the steam flow rate to the reboiler would be manipulated, but it is related to the vapour boil up by heat of vaporization of the bottom stream and the steam.

An input output transfer function model is

$$\begin{bmatrix} x_D(s) \\ x_B(s) \end{bmatrix} = \begin{bmatrix} \frac{0.878}{75s+1} & \frac{-0.864}{75s+1} \\ \frac{1.082}{75s+1} & \frac{-1.096}{75s+1} \end{bmatrix} \begin{bmatrix} L(s) \\ V(s) \end{bmatrix} + \begin{bmatrix} \frac{0.394}{75s+1} & \frac{0.881}{75s+1} \\ \frac{0.586}{75s+1} & \frac{1.119}{75s+1} \end{bmatrix} \begin{bmatrix} F(s) \\ z_F(s) \end{bmatrix}$$

The outputs are the distillate x_D and bottom x_B composition, in mole fraction of light component. The manipulated inputs are reflux (L) and vapour boil up (V) rates in kilo moles per minute. The disturbance inputs are feed flow rate (F, k mole/min) and feed light component mole fraction (z_F). The unit of time are in minutes. The steady state compositions are 0.99 and 0.01 mol fraction light component for the distillate and bottom product streams respectively. The steady state manipulated inputs(reflux and vapor flow rates) are 2.706 and 3.206 kmol/min respectively. The feed to the column is 1 kmol/min, with a feed composition of 0.5 mol fraction light component and a feed quality of 1.

Open loop behaviour

Response to reflux change

Here we consider open loop step changes in the manipulated inputs, with additional time delays of 2 minutes in the concentration measurement. The response of step change of +_0.01 k mole/min in reflux at t = 10 minutes, while keeping vapor boil up constant are shown in the graph

Response to vapor boilup change

Response to the vapor boilup change is shown in the graph

References

Module 13 distillation control, process control modelling, design and simulation B. Wayne Bequette.

Design of distillation column control Systems by Page S. Buckley, William L. Luyben, Joseph P. Shunta.

4

SOFTWARE (MATLAB) ASSOCIATED WITH MATERIAL BALANCE CONTROL SCHEME FOR DISTILLATION COLUMN

MATLAB-

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

Uses of MATLAB are as follows

Math and computation

Algorithm development

Data acquisition

Modelling, simulation, and prototyping

Data analysis, exploration, and visualization

Scientific and engineering graphics

Application development, including graphical user interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non interactive language such as C or FORTRAN.

The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects. Today, MATLAB engines incorporate the LAPACK and BLAS libraries, embedding the state of the art in software for matrix computation.

MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis.

MATLAB features a family of add-on application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others.

The MATLAB System

The MATLAB system consists of these main parts:

- Desktop Tools and Development Environment

This is the set of tools and facilities that help you use MATLAB functions and files. Many of these tools are graphical user interfaces. It includes the MATLAB desktop and Command Window, a command history, an editor and debugger, a code analyzer and other reports, and browsers for viewing help, the workspace, files, and the search path.

- The MATLAB Mathematical Function Library

This is a vast collection of computational algorithms ranging from elementary functions, like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigenvalues, Bessel functions, and fast Fourier transforms.

- The MATLAB Language

This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create large and complex application programs.

- Graphics

MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow you to fully customize the appearance of graphics as well as to build complete graphical user interfaces on your MATLAB applications.

- MATLAB External Interfaces

This is a library that allows you to write C and FORTRAN programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files

Simulink

Simulink is software for modelling, simulating, and analyzing dynamic systems. Simulink enables you to pose a question about a system, model it, and see what happens. With Simulink, you can easily build models from scratch, or modify existing models to meet your needs. Simulink supports linear and nonlinear systems, modelled in continuous time, sampled time, or a hybrid of the two. Systems can also be multi rate — having different parts that are sampled or updated at different rates. Thousands of scientists and engineers around the world use Simulink to model and solve real problems in a variety of industries, including:

- Aerospace and Defense
- Automotive
- Communications
- Electronics and Signal Processing
- Medical Instrumentation

Tool for Model-Based Design

With Simulink, you can move beyond idealized linear models to explore more realistic nonlinear models, factoring in friction, air resistance, gear slippage, hard stops, and the other things that describe real-world phenomena. Simulink turns your computer into a laboratory for modelling and analyzing systems that would not be possible or practical otherwise. Whether you are interested in the behaviour of an automotive clutch system, the flutter of an airplane wing, or the effect of the monetary supply on the economy, Simulink provides you with the tools to model and simulate almost any real-world problem. Simulink also provides demos that model a wide variety of real-world phenomena (see Simulink Demo Models).Simulink provides a graphical user interface (GUI) for building models as block diagrams, allowing you to draw models as you would with pencil and paper. Simulink also includes a comprehensive block library of sinks, sources, linear and nonlinear components, and connectors. If these blocks do not meet your needs, however, you can also create your own blocks. The interactive graphical environment simplifies the modeling process, eliminating the need to formulate differential and difference equations in a language or program. Models are hierarchical, so you can build models using both top-down and bottom-up approaches. You can view the system at a high level, then double-click blocks to see increasing levels of model detail. This approach provides insight into how a model is organized and how its parts interact.

Tools for Simulation

After you define a model, you can simulate it, using a choice of mathematical integration methods, either from the Simulink menus or by entering commands in the MATLAB® Command Window. The menus are convenient for interactive work, while the command line is useful for running a batch of simulations (for example, if you are doing Monte Carlo simulations or want to apply a parameter across a range of values). Using scopes and other display blocks, you can see the simulation results while the simulation runs. You can then change many parameters and see what happens for "what if" exploration. The simulation results can be put in the MATLAB workspace for post processing and visualization.

Tool for Analysis

Model analysis tools include linearization and trimming tools, which can be accessed from the MATLAB command line, plus the many tools in MATLAB and its application toolboxes. Because MATLAB and Simulink are integrated, you can simulate, analyze, and revise your models in either environment at any point.

How Simulink Interacts with MATLAB

Simulink is tightly integrated with MATLAB. It requires MATLAB to run, depending on MATLAB to define and evaluate model and block parameters. Simulink can also utilize many MATLAB features. For example, Simulink can use MATLAB to:

- Define model inputs.
- Store model outputs for analysis and visualization.
- Perform functions within a model, through integrated calls to MATLAB operators and functions.

Model-Based Design

Model-Based Design is a process that enables faster, more cost-effective development of dynamic systems, including control systems, signal processing, and communications systems. In Model-Based Design, a system model is at the centre of the development process, from requirements development, through design, implementation, and testing. The model is an executable specification that is continually refined throughout the development process. After model development, simulation shows whether the model works correctly. When software and hardware implementation requirements are included, such as fixed-point and timing behaviour, you can automatically generate code for embedded deployment and create test benches for system verification, saving time and avoiding the introduction of hand-coding errors.

Model-Based Design allows you to improve efficiency by:

- Using a common design environment across project teams
- Linking designs directly to requirements
- Integrating testing with design to continuously identify and correct errors
- Refining algorithms through multidomain simulation
- Automatically generating embedded software code
- Developing and reusing test suites
- Automatically generating documentation
- Reusing designs to deploy systems across multiple processors and hardware targets

Modelling Process

There are six steps to modelling any system:

- Defining the System.
- Identifying System Components.
- Modelling the System with Equations.
- Building the Simulink Block Diagram.
- Simulating the Model.
- Validating the Simulation Results

You perform the first three steps of this process outside of Simulink before you begin building your model.

Defining the System

The first step in modelling a dynamic system is to fully define the system. If you are modelling a large system that can be broken into parts, you should model each subcomponent on its own. Then, after building each component, you can integrate them into a complete model of the system.

For example, the demo model used later in this guide models the heating system of a house. This system can be broken down into three main parts:

- Heater subsystem
- Thermostat subsystem
- Thermodynamic model subsystem

The most effective way to build a model of this system is to consider each of these subsystems independently.

Identifying System Components

The second step in the modelling process is to identify the system components. There are three types of components that define a system:

Parameters — System values that remain constant unless you change them

States — Variables in the system that change over time

Signals — Input and output values that change dynamically during the simulation

In Simulink, parameters and states are represented by blocks, while signals are represented by the lines that connect blocks.

For each subsystem that you identified, ask yourself the following questions:

How many input signals does the subsystem have?

How many output signals does the subsystem have?

How many states (variables) does the subsystem have?

What are the parameters (constants) in the subsystem?

Are there any intermediate (internal) signals in the subsystem?

Once you have answered these questions, you should have a comprehensive list of the system components, and are ready to begin modelling the system.

Modelling the System with Equations

The third step in modelling a system is to formulate the mathematical equations that describe the system. For each subsystem, use the list of system components you identified to describe the system mathematically. Your model may include:

Algebraic equations

Logical equations

Differential equations, for continuous systems

Difference equations, for discrete systems

You use these equations to create the block diagram in Simulink.

Building the Simulink Block Diagram

After you have defined the mathematical equations that describe each subsystem, you can begin building a block diagram of your model in Simulink.

Build the block diagram for each of your subcomponents separately. After you have modelled each subcomponent, you can then integrate them into a complete model of the system.

Running the Simulation

The final step in modelling a system is to run the simulation and analyze the results.

Simulink allows you to interactively define system inputs, simulate the model, and observe changes in behaviour. This allows you to quickly evaluate your model.

Validating the Simulation Results

After you simulate your model, you must validate that the model accurately models the physical characteristics of the system. You can use the linearization and trimming tools available from the MATLAB command line, plus the many tools in MATLAB and its application toolboxes to analyze and validate your model.

Starting Simulink

MATLAB must be running before you can open Simulink. You start Simulink from within MATLAB.

To start Simulink:

Start MATLAB. For more information, see Starting MATLAB in Getting Started with MATLAB.

- Enter Simulink in the MATLAB Command Window.
- The Simulink Library Browser opens.

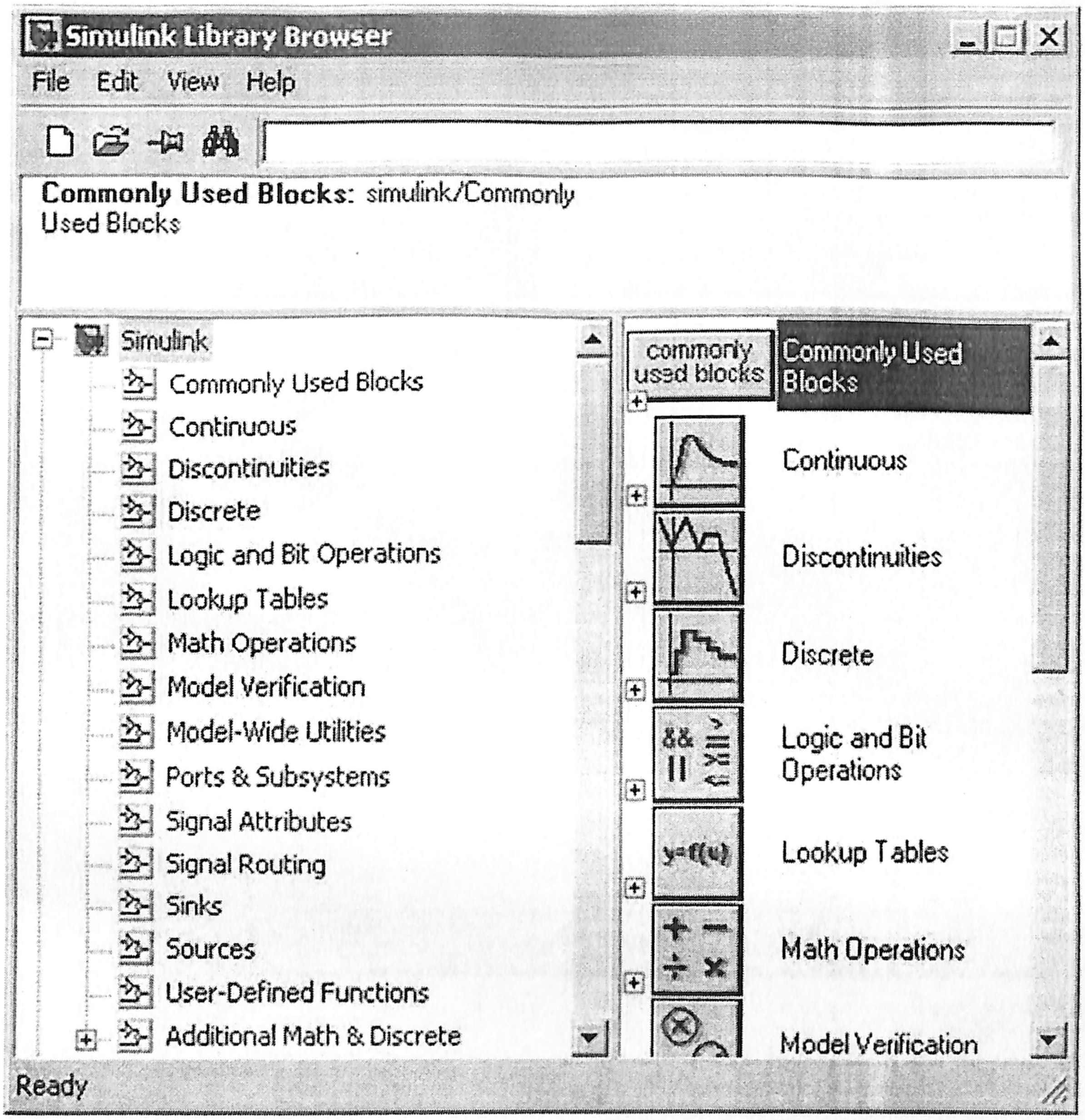


Fig 4.1

Opening a model

You can open existing Simulink models or create new models from the Simulink Library Browser.

To create a new model:

- Select File > New > Model in the Simulink Library Browser.
  Simulink opens an empty model window.

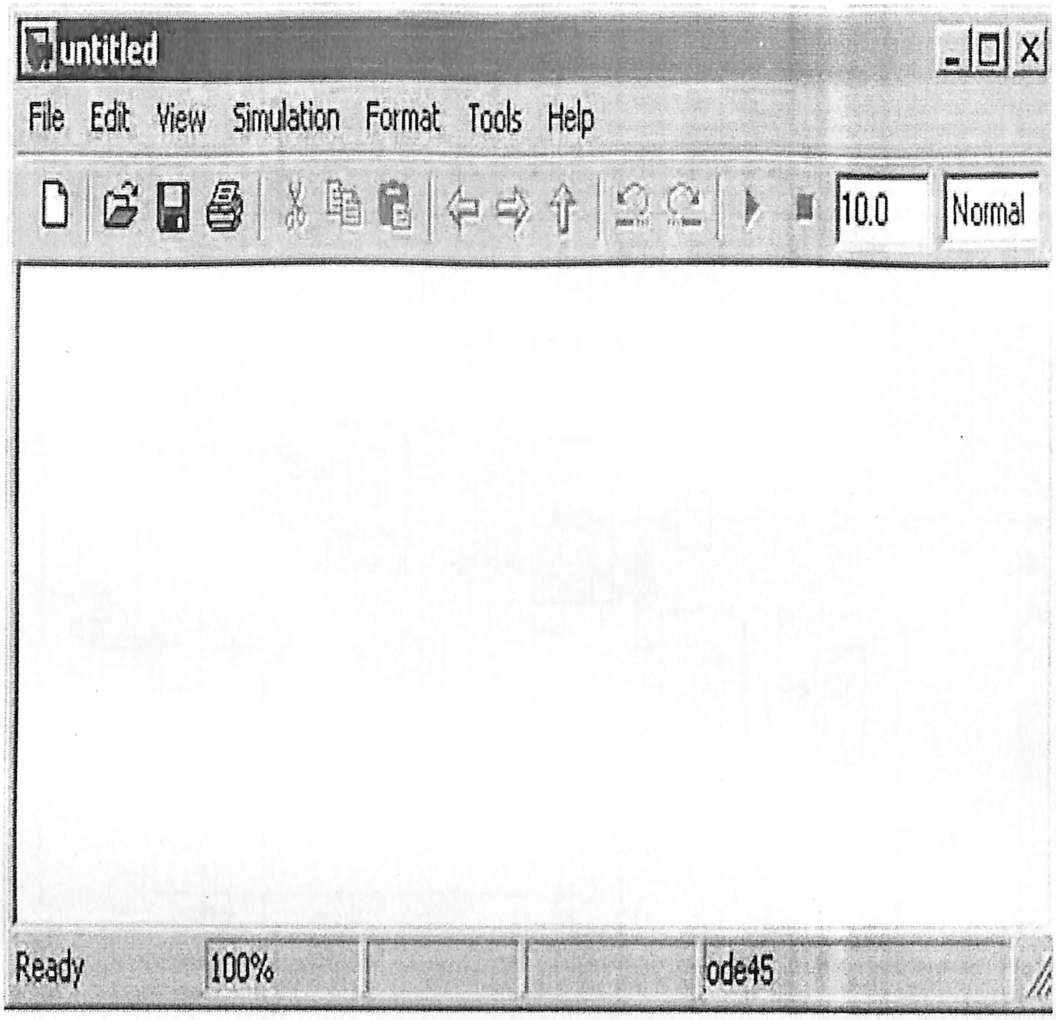


Fig 4.2

To open an existing model

- Select File > Open in the Simulink Library Browser. The Open dialog box appears.
- Select the model (.mdl file) you want to open, and then click Open. Simulink opens the selected model in the model window.

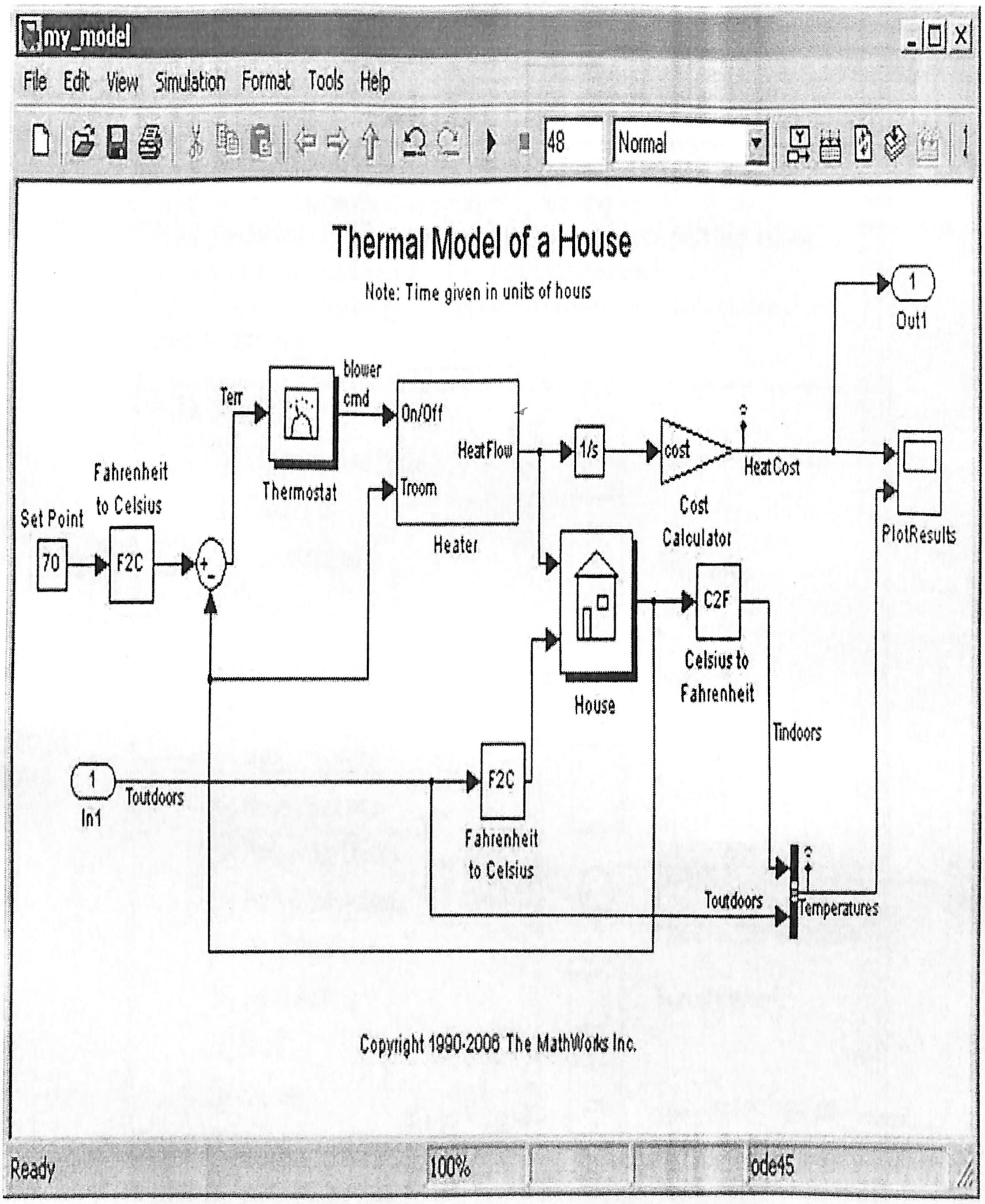


Fig 4.3

Simulink Library Browser

The Library Browser displays the Simulink block libraries installed on your system. You build models by copying blocks from a library into a model window.

Simulink Library Browser (Windows)

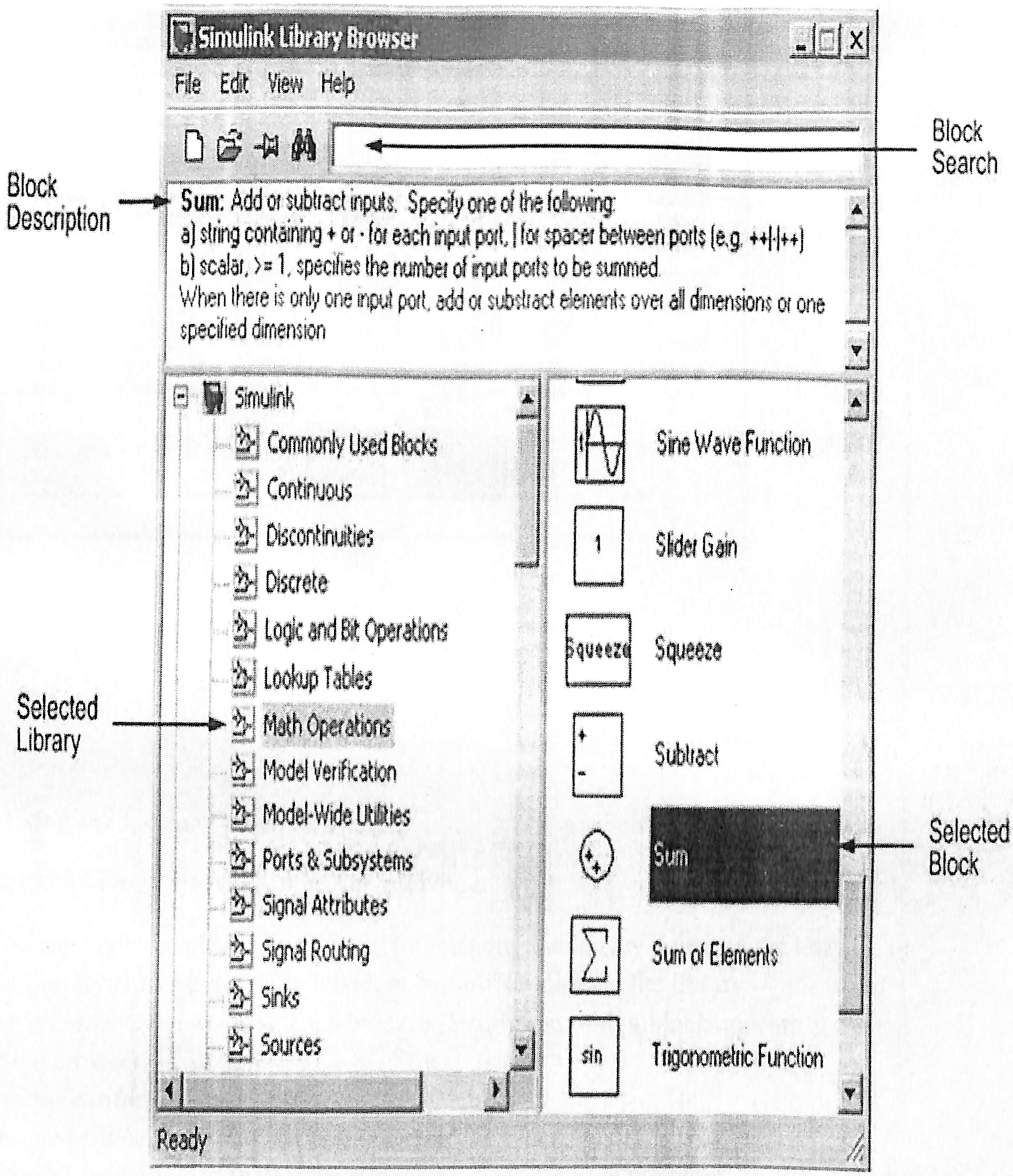


Fig 4.4

Simulink Library Window (UNIX)

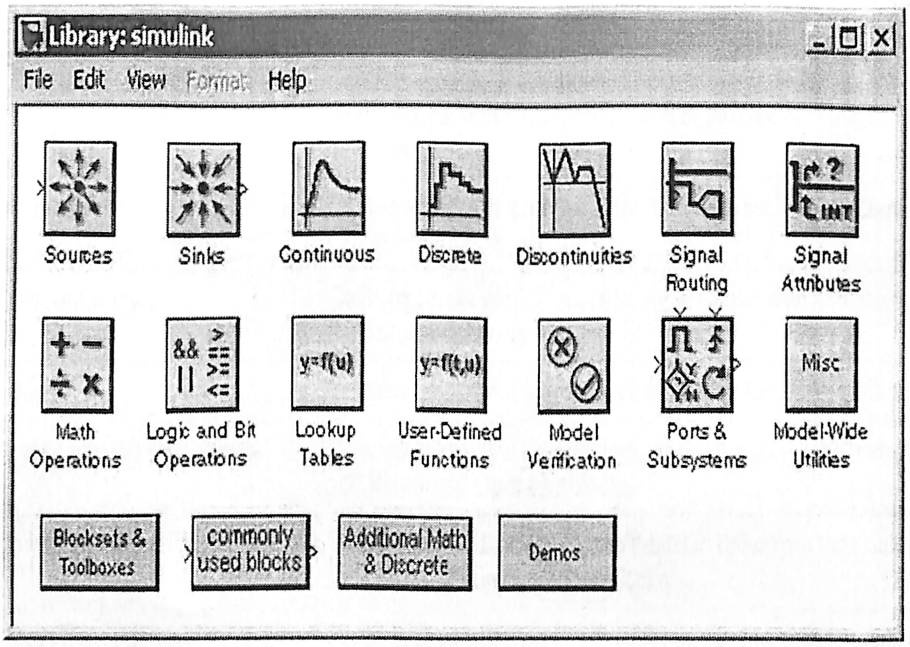


Fig 4.5

Tips for Using the Library Browser

When using the Library Browser, note the following:

- You can view the blocks in a library by selecting the library name on the left side of the Library Browser (on Windows), or by double-clicking the library.
- On Windows, when you select a block, a description of that block appears at the top of the browser.
- For more information on a block, select the block, then select Help > Help on the Selected Block to display the help page for the block.
- You can view the parameters for a block by right-clicking the block, then selecting Block Parameters.On Windows, you can search for a specific block by entering the name of the block in the block search field, then clicking the Find block icon.

Standard Block LibrariesSimulink provides 16 standard block libraries.

The following table describes each of these libraries.

Block Library	Description
Commonly Used Blocks	Contains a group of the most commonly used blocks, such as the **Constant, In1, Out1, Scope,** and **Sum** blocks. Each of the blocks in this library are also included in other libraries.
Continuous	Contains blocks that model linear functions, such as the **Derivative** and **Integrator** blocks.
Discontinuities	Contains blocks with outputs that are discontinuous functions of their inputs, such as the **Saturation** block.
Discrete	Contains blocks that represent discrete time functions, such as the **Unit Delay** block.
Logic and Bit Operations	Contains blocks that perform logic or bit operations, such as the **Logical Operator** and **Relational Operator** blocks.
LookUp Tables	Contains blocks that use lookup tables to determine their outputs from their inputs, such as the **Cosine and Sine** blocks.
Math Operations	Contains blocks that perform mathematical and logical functions, such as the **Gain, Product,** and **Sum** blocks.
Model Verification	Contains blocks that enable you to create self-validating models, such as the **Check Input Resolution** block.

Block Library	Description
Model-Wide Utilities	Contains blocks that provide information about the model, such as the **Model Info** block.
Ports & Subsystems	Contains blocks that allow you to create subsystems, such as the **In1, Out1,** and **Subsystem** blocks.
Signal Attributes	Contains blocks that modify the attributes of signals, such as the **Data Type Conversion** block.
Signal Routing	Contains blocks that route signals from one point in a block diagram to another, such as the **Mux** and **Switch** blocks.
Sinks	Contains blocks that display or export output, such as the **Out1** and **Scope** blocks.
Sources	Contains blocks that generate or import system inputs, such as the **Constant, In1,** and **Sine Wave** blocks.
User-Defined Functions	Contains blocks that allow you to define custom functions, such as the **Embedded MATLAB™Function** block.
Additional Math & Discrete	Contains two additional libraries for mathematical and discrete function blocks.

Simulink Model Window

The model window contains the block diagram of the model. You build models in the model window by arranging blocks logically, setting the parameters for each block, and then connecting the blocks with signal lines.

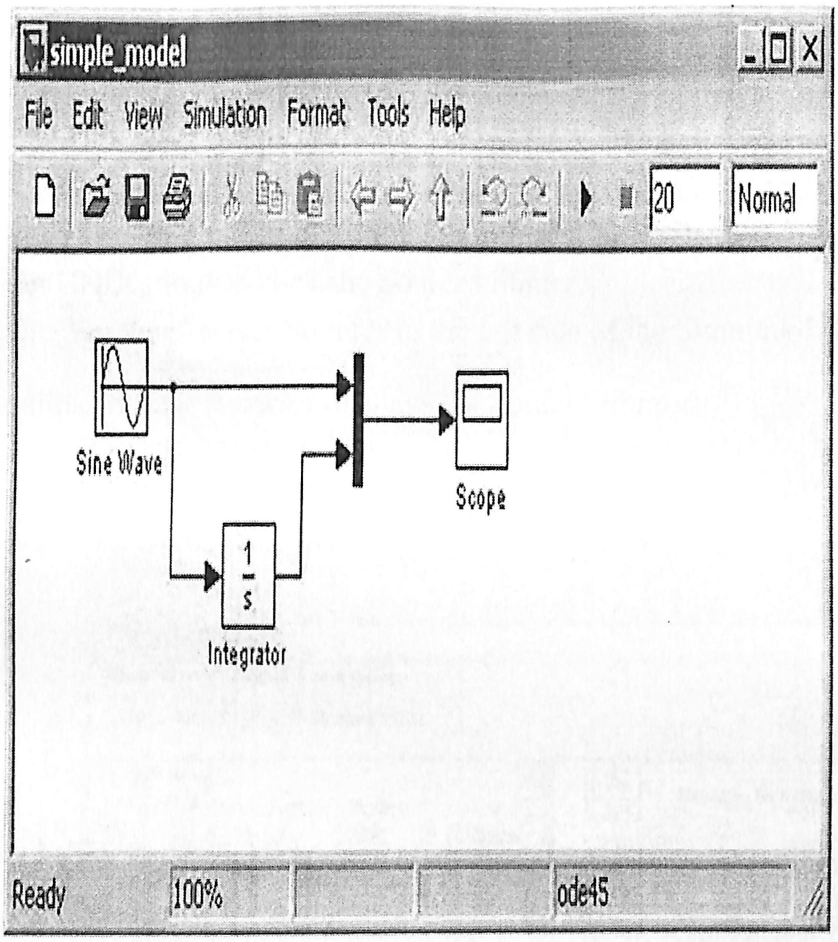


Fig 4.6

The model window also allows you to:

- Set configuration parameters for the model, including the start and stop time, type of solver to use, and data import/export settings.
- Start and stop simulation of the model.Save the model.Print the block diagram.

Adding Blocks to Your Model

To construct a model, you first copy blocks from the Simulink Library Browser to the model window. To create the simple model in this chapter, you need four blocks:

Sine Wave — To generate an input signal for the model

Integrator — To process the input signal

Scope — To visualize the signals in the model

Mux — To multiplex the input signal and processed signal into a single scope

To add blocks to your model:

1. Select the Sources library in the Simulink Library Browser.
- On UNIX, double-click the Sources library.
- On Windows, select Sources in the left side of the Simulink Library Browser.

The Simulink Library Browser displays the Sources library.

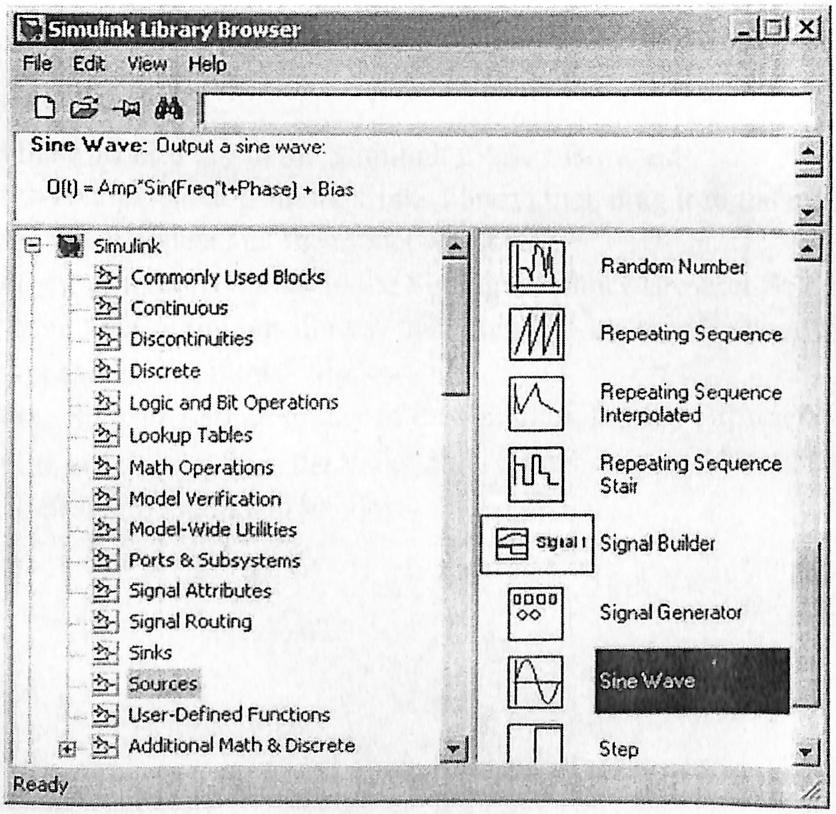


Fig 4.7

2. Select the Sine Wave block in the Simulink Library Browser, then drag it to the model window.A copy of the Sine Wave block appears in the model window.

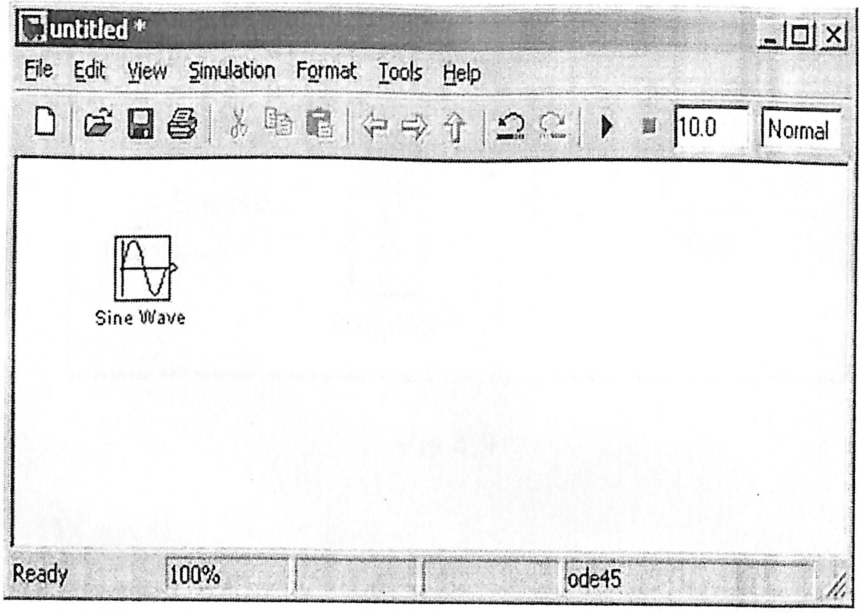


Fig 4.8

3. Select the Sinks library in the Simulink Library Browser.
4. Select the Scope block from the Sinks library, then drag it to the model window.
5. A Scope block appears in the model window.
6. Select the Continuous library in the Simulink Library Browser.Select the Integrator block from the Continuous library, then drag it to the model window.An Integrator block appears in the model window.
7. Select the Signal Routing library in the Simulink Library Browser.
8. Select the Mux block from the Sinks library, then drag it to the model window.A Mux block appears in the model window.

Moving Blocks in the Model Window

Before you connect the blocks in your model, you should arrange them logically to make the signal connections as straightforward as possible.

To move a block in the model window, you can either:

- Drag the block.

- Select the block, then press the arrow keys on the keyboard.

Arrange the blocks in the model to look like the following figure.

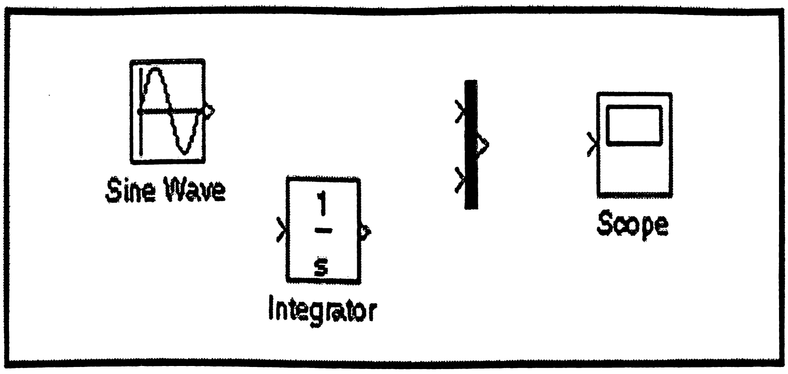
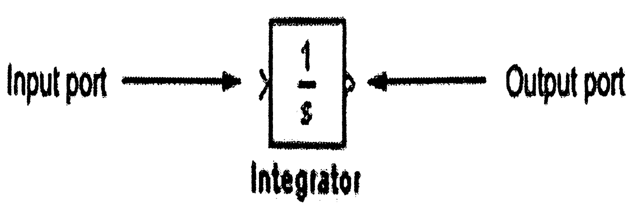


Fig 4.9

Connecting Blocks in the Model Window

After you add blocks to the model window, you must connect them to represent the signal connections within the model. Notice that each block has angle brackets on one or both sides. These angle brackets represent input and output ports:

- The > symbol pointing into a block is an input port.
- The > symbol pointing out of a block is an output port.



The following sections describe how to connect blocks by drawing lines from output ports to input ports:

- Drawing Lines Between Blocks
- Drawing a Branch Line

Drawing Lines Between Blocks

You connect the blocks in your model by drawing lines between output ports and input ports. To draw a line between two blocks:

1. Position the mouse pointer over the output port on the right side of the Sine Wave block.Note that the pointer changes to a crosshairs (+) shape while over the port.

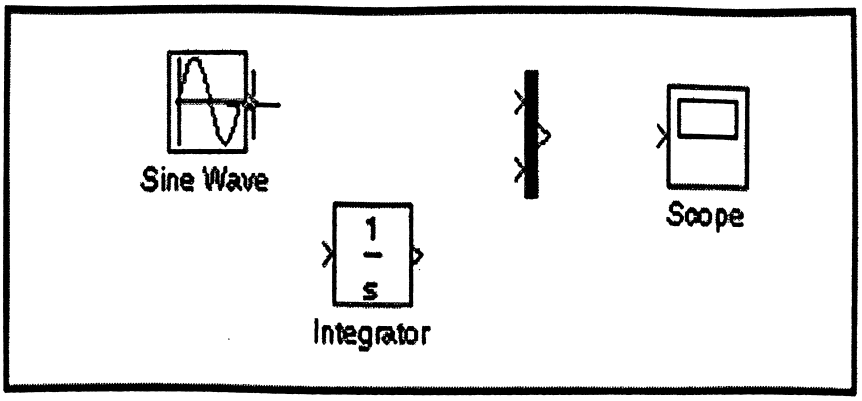


Fig 4.10

2. Drag a line from the output port to the top input port of the Mux block.

Note that the line is dashed while you hold the mouse button down, and that the pointer changes to a double-lined crosshairs as it approaches the input port of the Mux block.

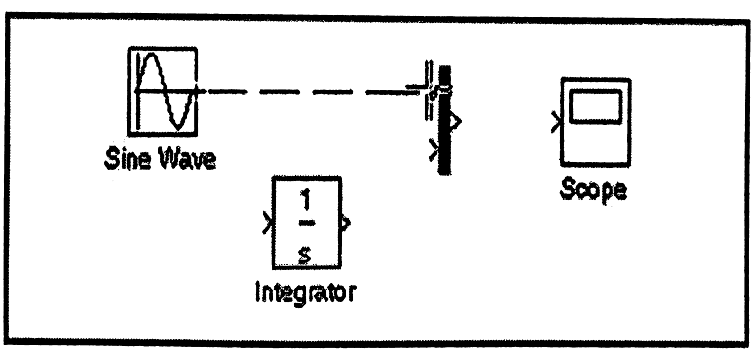


Fig 4.11

3. Release the mouse button over the output port.
   Simulink connects the blocks with an arrow that indicates the direction of signal flow.

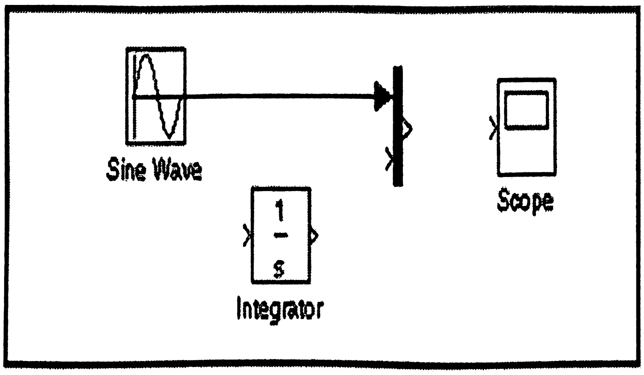


Fig 4.12

4. Drag a line from the output port of the Integrator block to the bottom input port on the Mux block.

Simulink connects the blocks.

5. Select the Mux block, then Ctrl+click the Scope block.

Simulink automatically draws the connection line between the blocks.

The model should now look similar to the following figure.

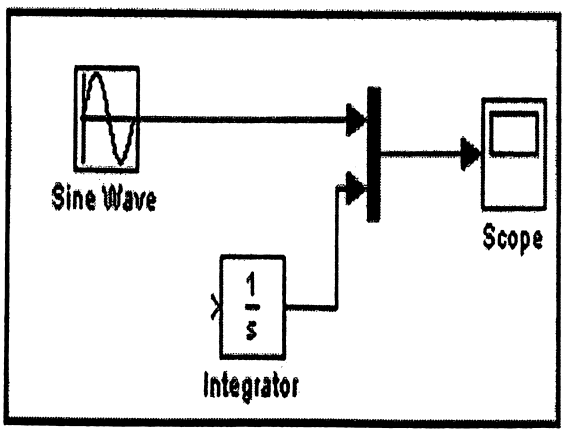
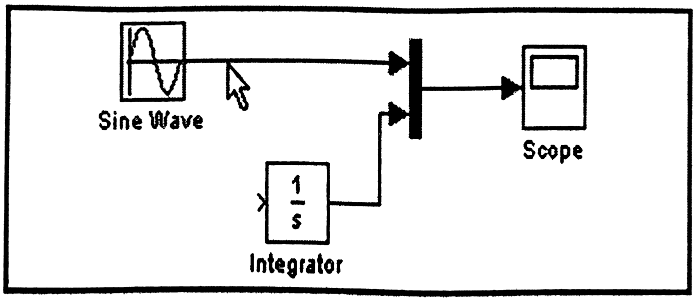


Fig 4.13

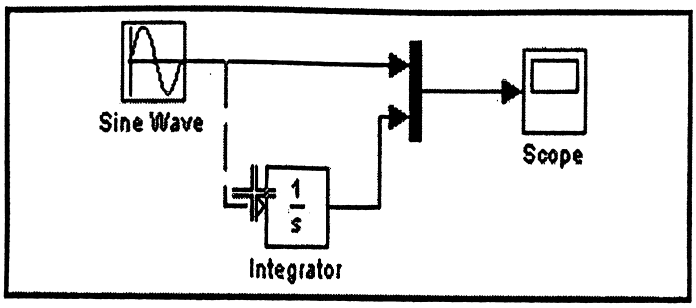
Drawing a Branch Line The model is almost complete, but one connection is missing. To finish the model, you must connect the Sine Wave block to the Integrator block. This final connection is somewhat different from the other three, which all connect output ports to input ports. Because the output port of the Sine Wave block already has a connection, you must connect this existing line to the input port of the Integrator block. The new line, called a branch line, carries the same signal that passes from the Sine Wave block to the Mux block.

To weld a connection to an existing line:

1. Position the mouse pointer on the line between the Sine Wave and the Mux block.



2. Press and hold the **Ctrl** key, then drag a line to the Integrator block's input port.



Simulink draws a line between the starting point and the input port of the Integrator block.

The model is now complete. It should look similar to the following figure.

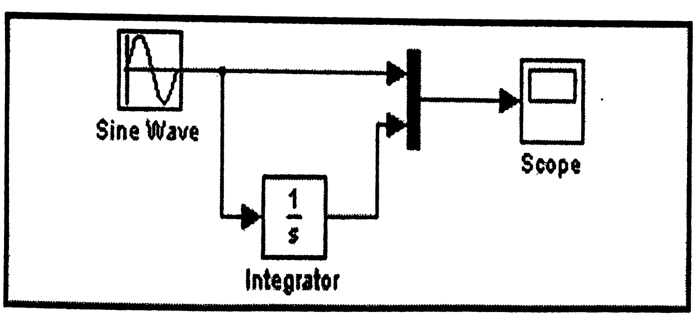


Fig 4.14

Saving the Model

After you complete the model, you should save it for future use.

To save the model:

- Select File > Save in the model window.
- Specify the location in which you want to save the model.
- Enter simple_model in the File name field.
- Click Save.
  Simulink saves the model with the file name simple_model.mdl.

Simulating the model

Overview

After you complete the model block diagram, you can simulate the system and visualize the results. This section describes how to simulate the sample model you created in the previous section, creating a Simple Model.

Setting Simulation Options

Before simulating a model, you can set simulation options such as the start and stop time, and the type of solver that Simulink uses to solve the model at each time step. You specify these options using the Configuration Parameters dialog box.

1. To specify simulation options for the sample model:

- Select Simulation > Configuration Parameters in the model window.
- Simulink displays the Configuration Parameters dialog box.

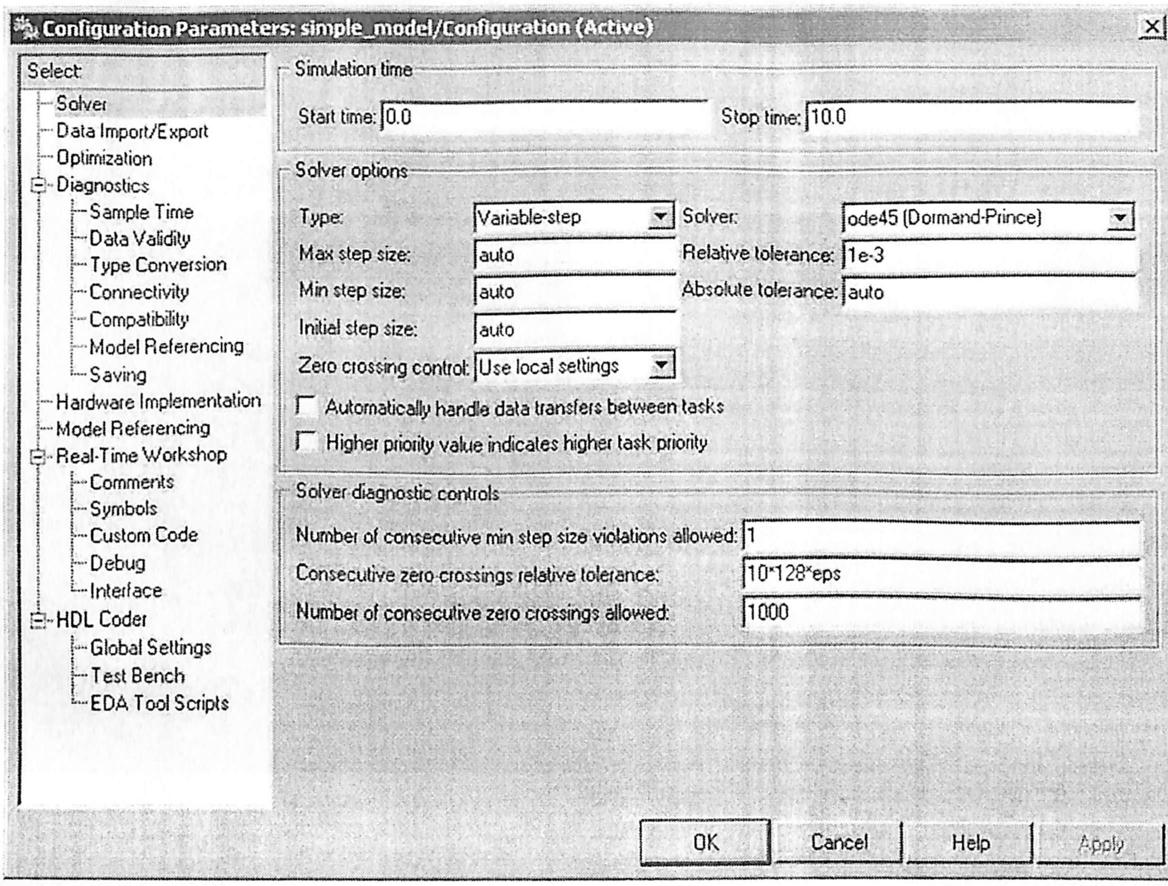


Fig 4.15

2. Enter 20 in the Stop time field.

3. Click OK.

Simulink applies your changes to the parameters and closes the Configuration Parameters dialog box.

Running the Simulation and Observing Results

Now you are ready to simulate your example model and observe the simulation results.

To run the simulation:

- Select Simulation > Start in the model window.

Simulink runs the model, stopping when it reaches the stop time specified in the Configuration Parameters dialog box.

- Double-click the Scope block in the model window.

The Scope window displays the simulation results.

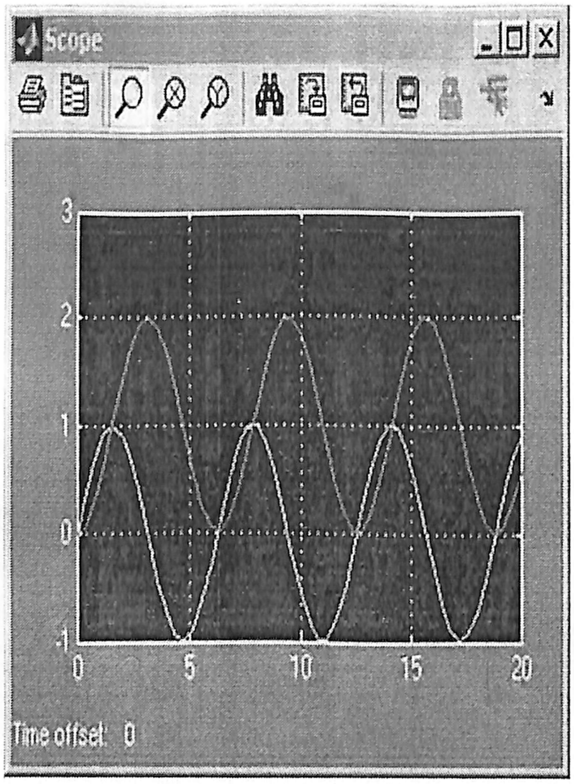


Fig 4.16

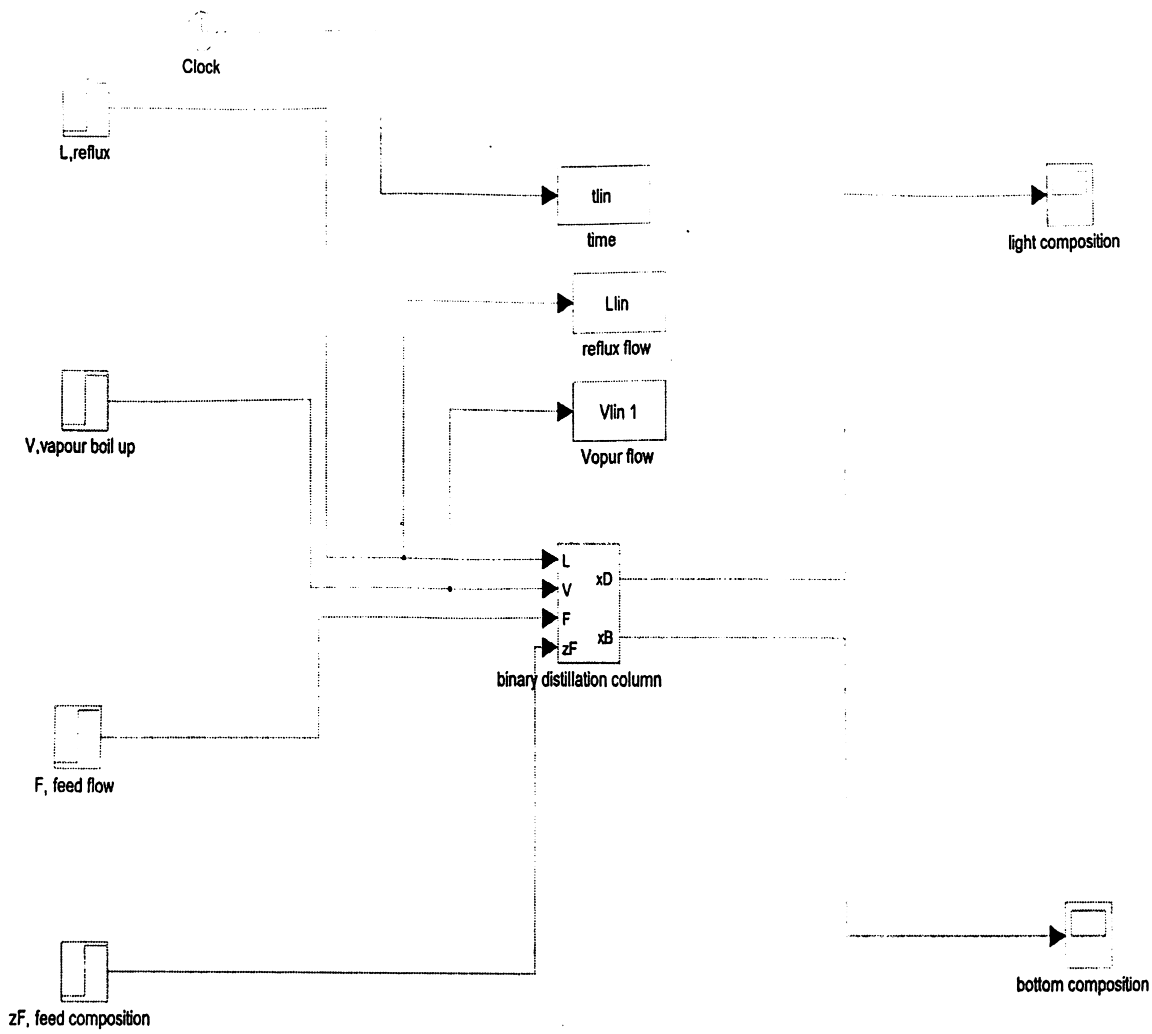


Fig 4.17 Basic diagram of control system in the distillation column (a)

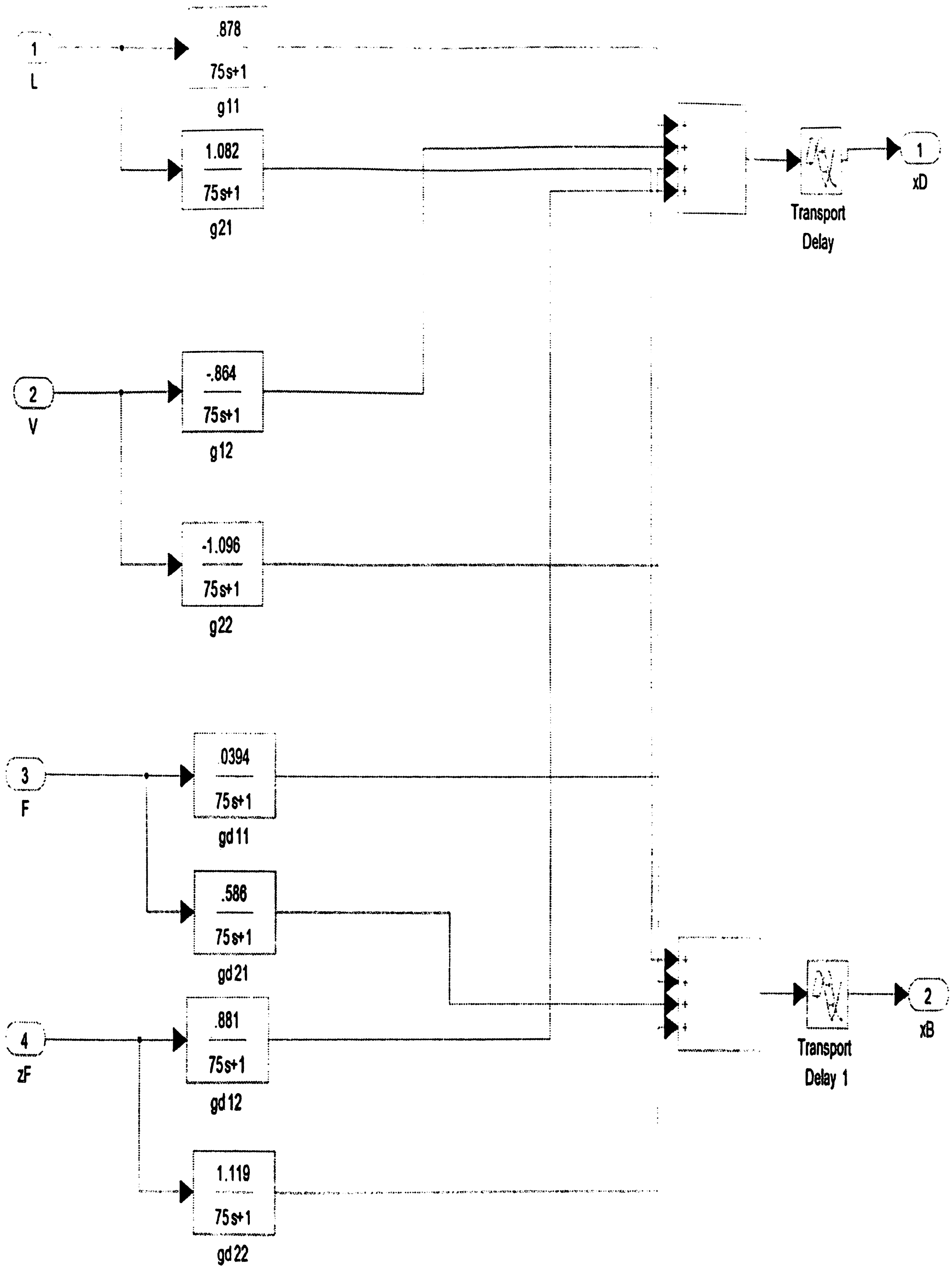
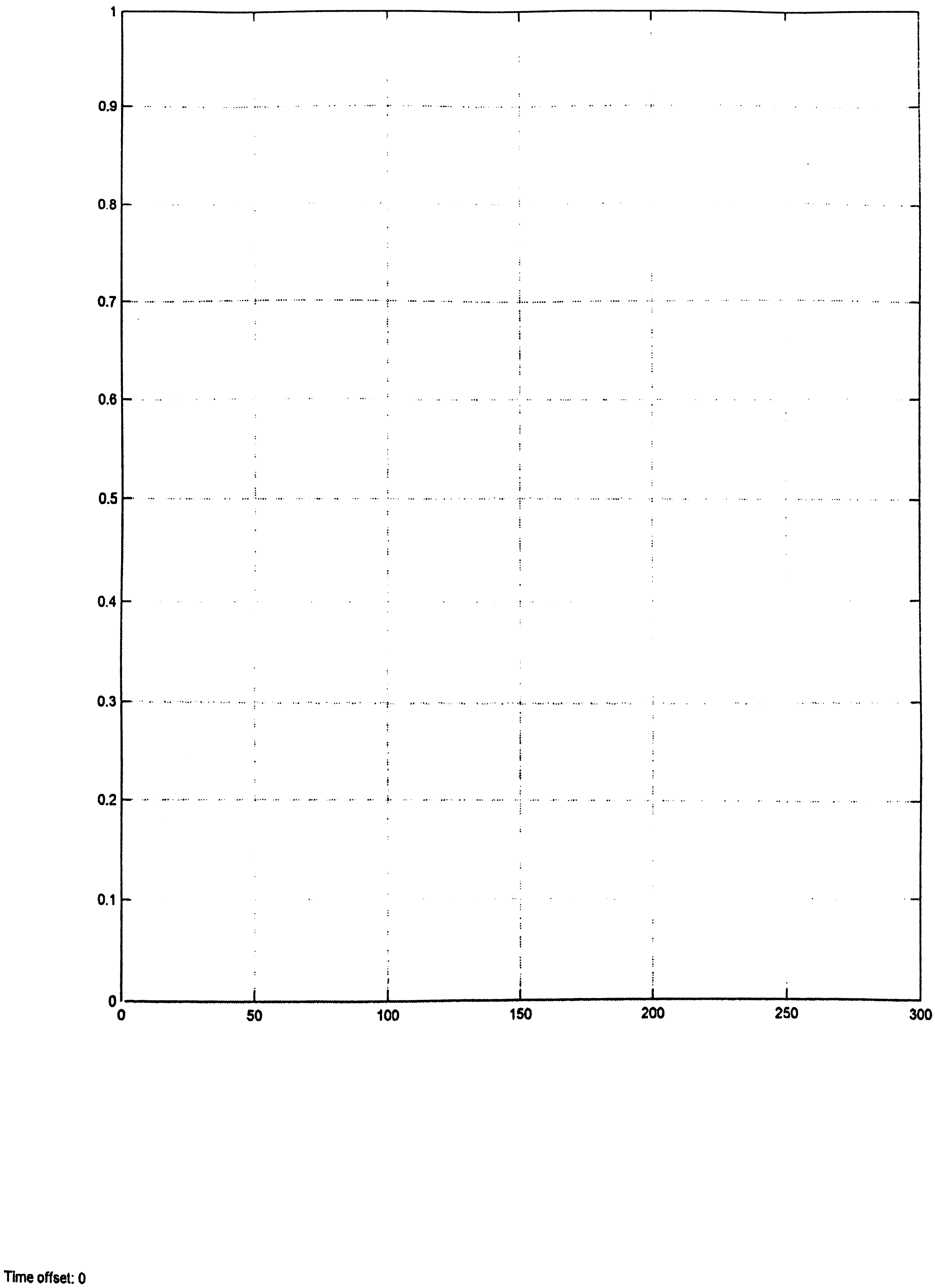


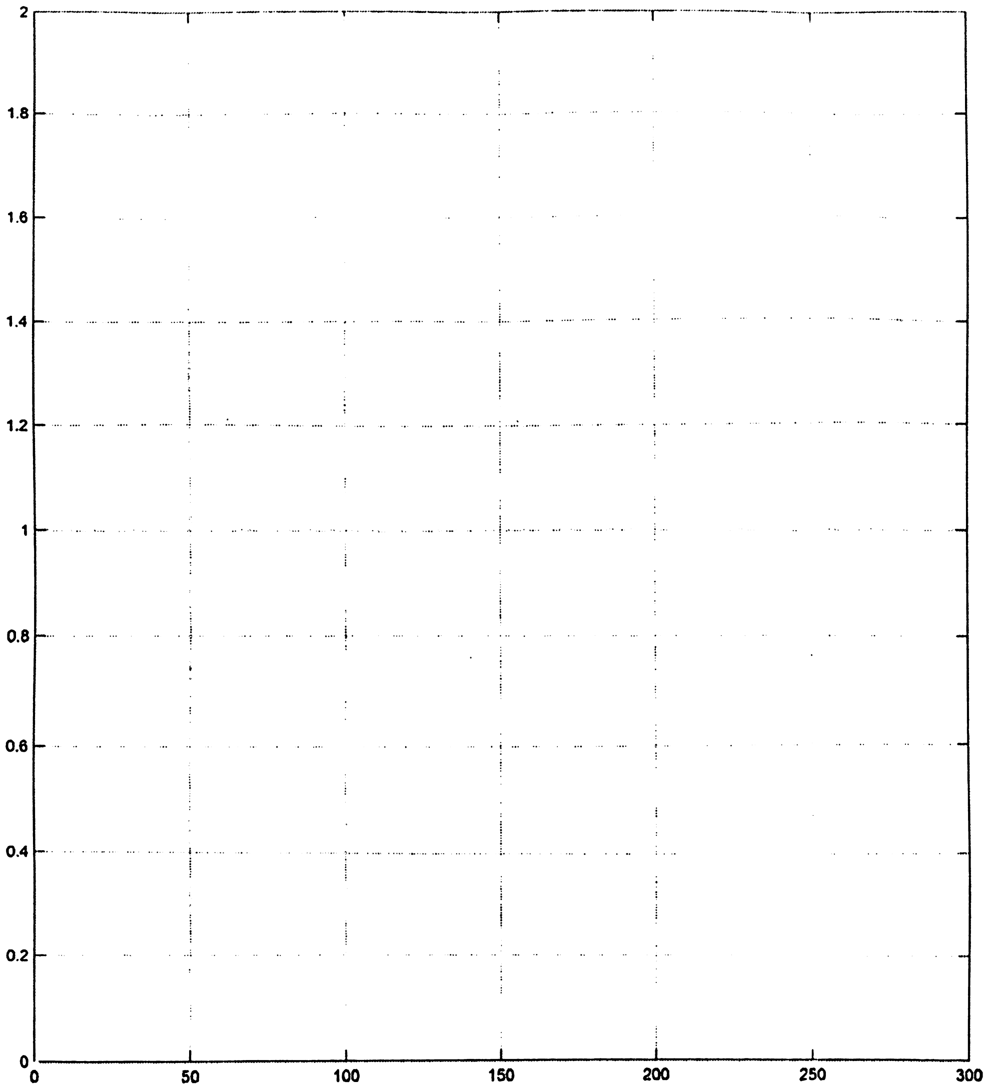
Fig 4.18 masked portion part a

Graph between distillate composition (y axis) and time (x axis)



Graph 1

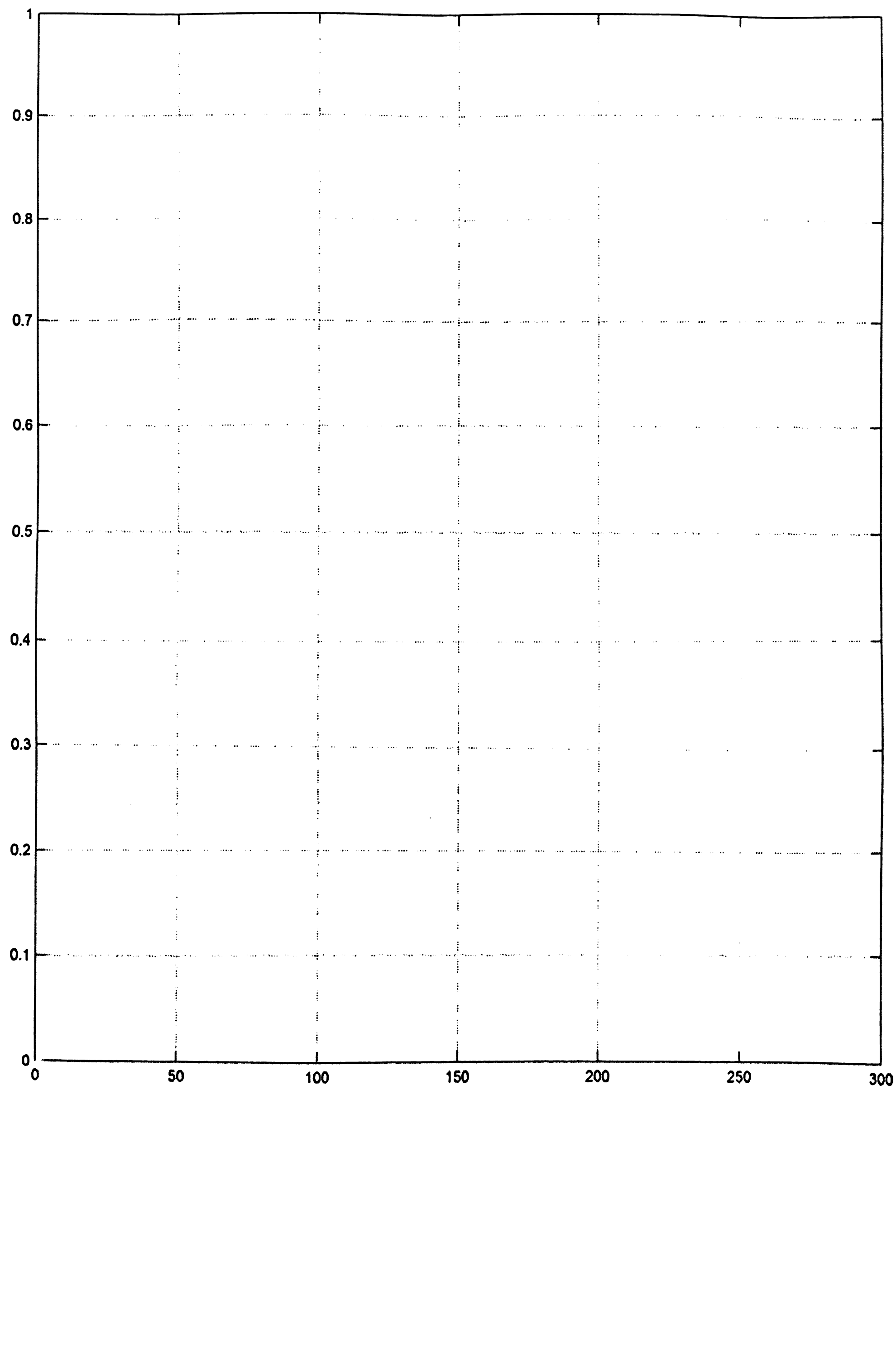
Graph between bottom composition (y axis) and time (x axis)



Time offset: 0

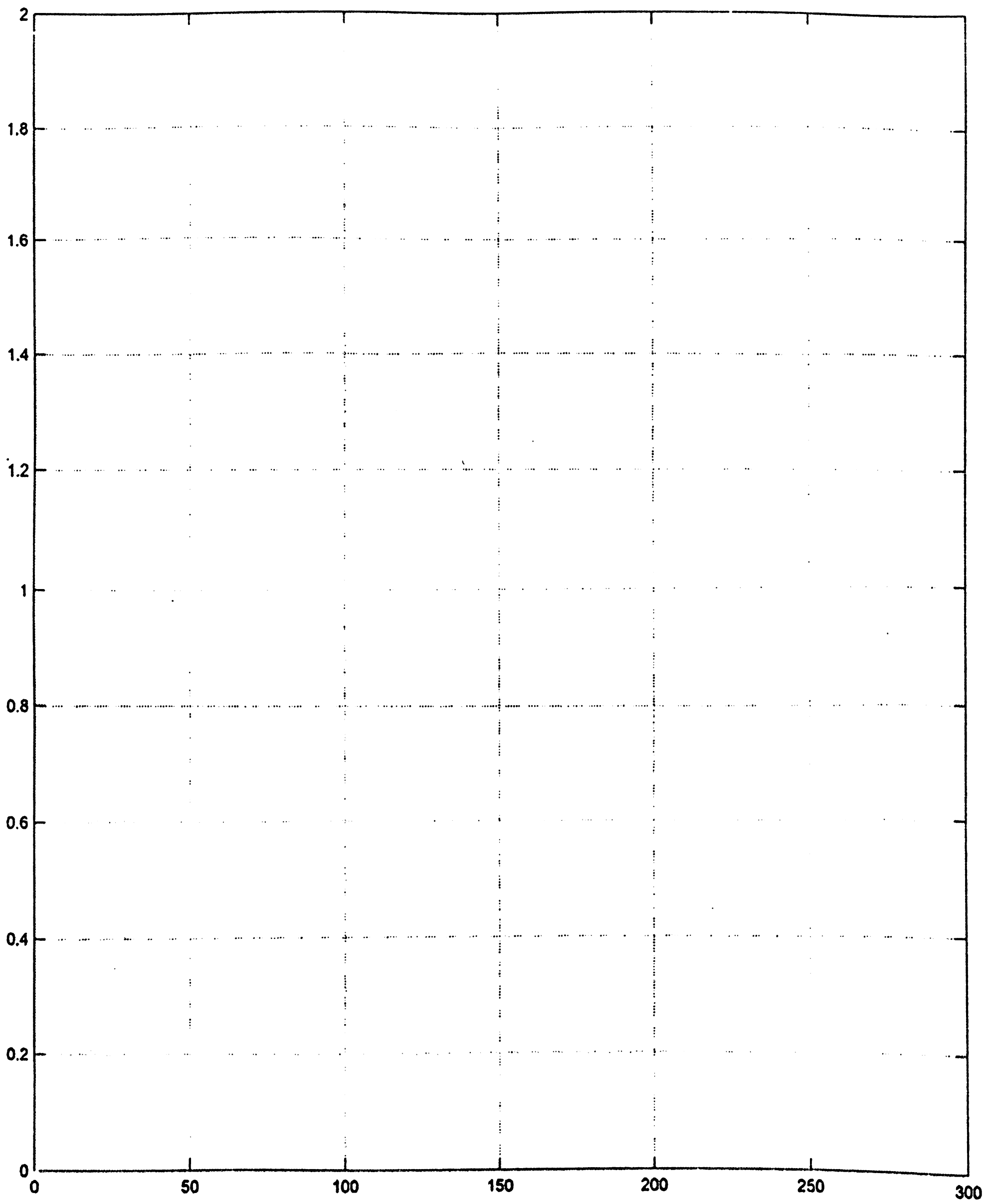
Graph 2

Graph between distillate composition (y axis) and time (x axis) when there is change of ± .01kmol/minute in reflux flow rate



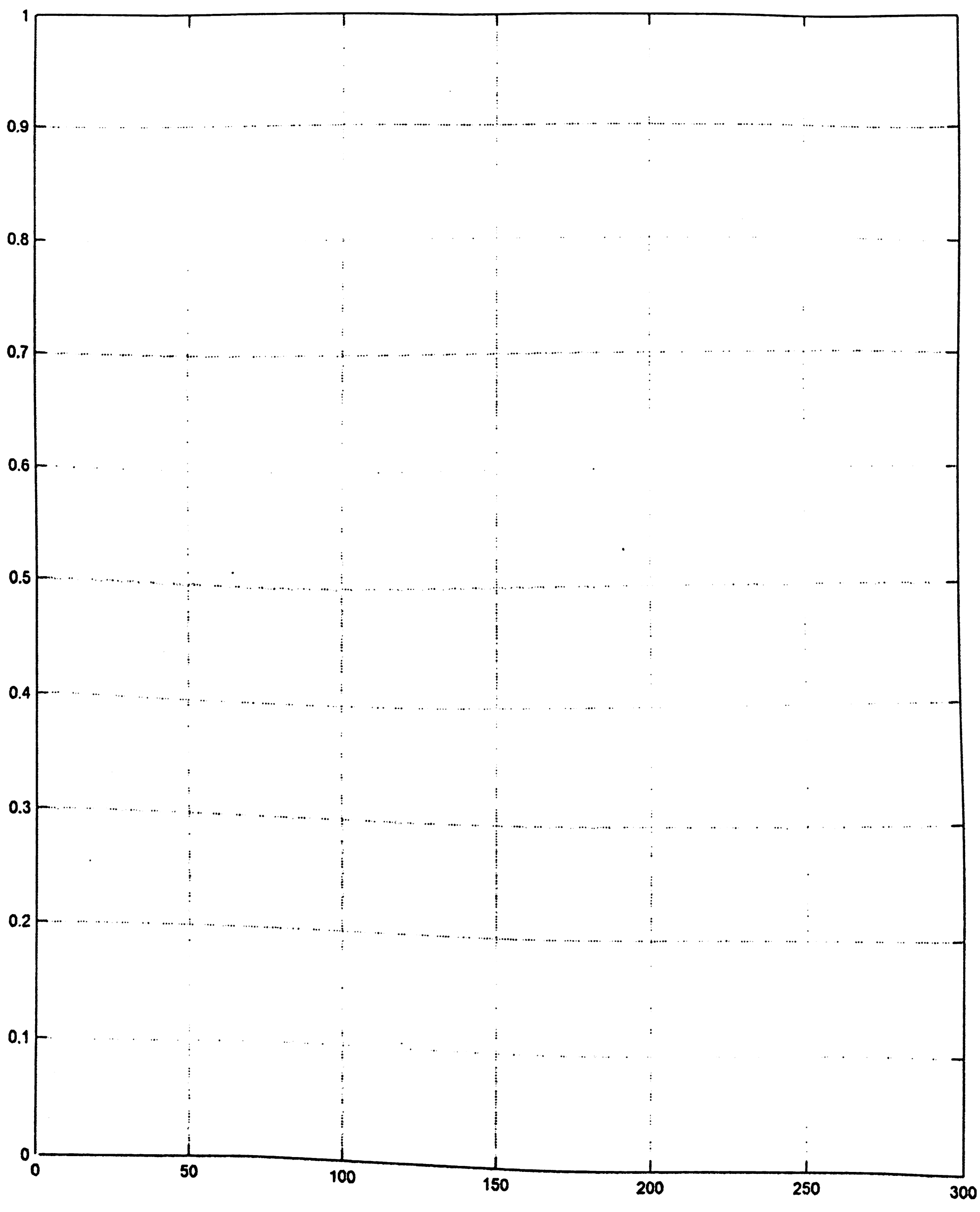
Graph 3

Graph between bottom composition (y axis) and time (x axis) when there is change of ± .01kmol/minute in reflux flow rate.



Graph 4

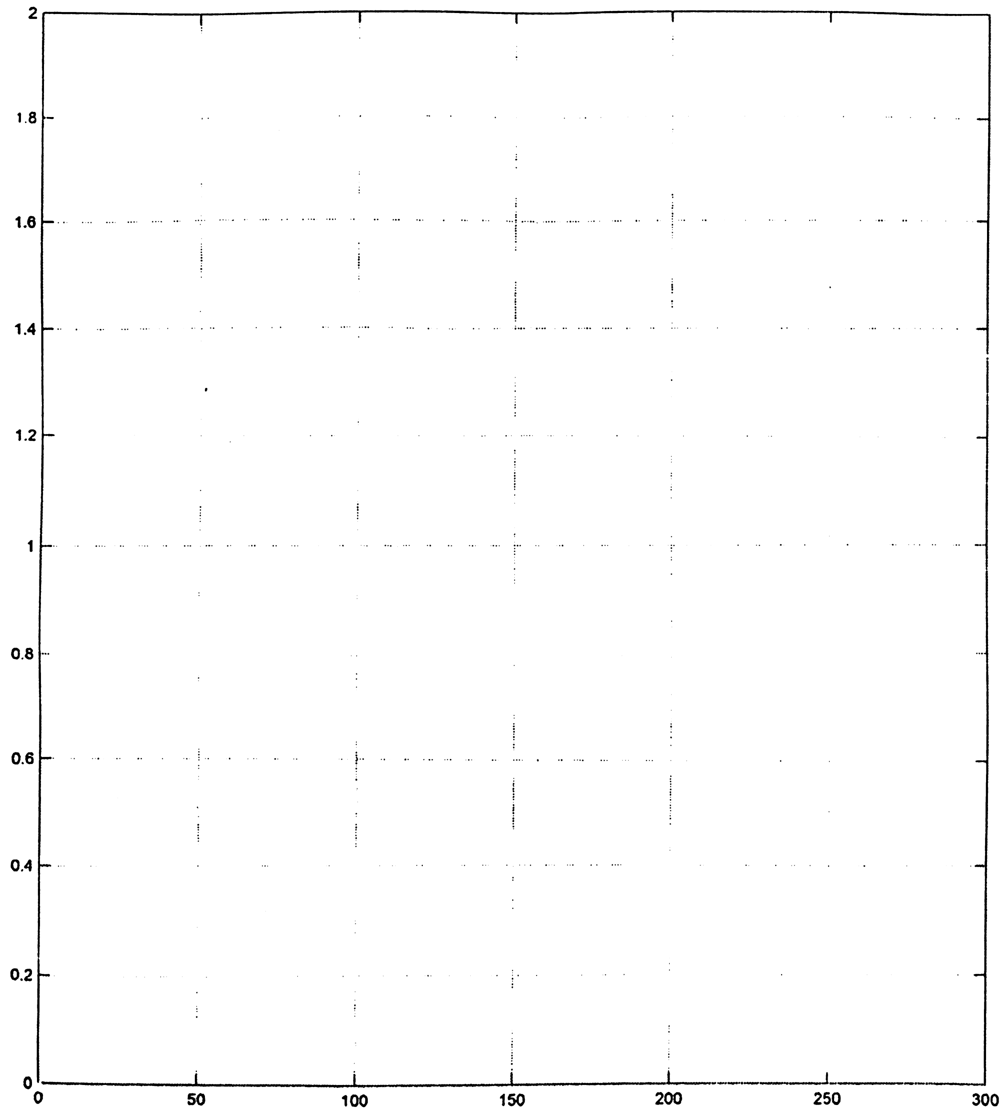
Graph between distillate composition (y axis) and time (x axis) when there is change of ± .01kmol/minute in vapour boil up



Time offset: 0

Graph 5

Graph between bottom composition (y axis) and time (x axis) when there is change of ± .01kmol/minute in vapour boil up



Graph 6

Conclusion

From the above graphs it is clear that the signal flow diagram which has been made for one of the control scheme is controlling the column properly.

The graph which has been made from the basic diagram of control system of the distillation column is showing the correct results. Initially the composition is increasing from zero as the production starts, then it becomes constant as the level of the top and the bottom composition is adjusted according to the set point available. So the system is controlling in a proper manner. The bottom and the top composition is adjusted by varying the reflux and vapour boil up and we get more accurate graph.