COMPUTER AIDED DESIGN MODULE ON GAS ABSORPTION COLUMN USING SHERWOOD & HOLLOWAY METHOD

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DECLARATION

I, UTEBOR MICHEAL MANASSEH EMEKE (M.Eng/SEET/99/2000/436) declare that this Thesis "Computer Aided Design on Gas Absorption Packed Column", Presented for the award of Master of Engineering in Chemical Engineering, has not been presented for any other degree elsewhere.

____________________ ____________________

Signature Date

CERTIFICATION

This is to certify that this project was supervised, moderated and approved by the following under listed persons on behalf of the Chemical Engineering Department, School of Engineering and Engineering Technology, Federal University Of Technology Minna.

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DEDICATION

This project is dedicated to Almighty GOD and all members of the UTEBOR'S family, especially to my parents Mr. & Mrs. M.S.C. Utebor, who made sure I acquired sound university education and to the memories of my Late sister Christina Utebor, although you are no more but your inspirational spirit lives on Adieu sister.

My sister Rosemary, Nelly, Isioma and my brother Kester Utebor are not left-out

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ABSTRACT

Computer Aided Design [CAD] is the result of applying advanced computer technology to problems of engineering and production design. This work, a CAD modules was developed for the calculation of gas absorption column, diameter and height, where water was taken as the solute free solvent and $S0_2$ as the solute gas. The solute gas is in dilute mixture with air and both phases flow counter-currently with the gas pumped from the bottom of the column and the Liquid from the top. The modules used a data based (databank) for packings and some physical properties of both phases (Liquid and Gas phases). This capacity was tested by varying packing materials, temperature and percentage of the flooding velocity.

The result obtained from the module makes provision for optimization of design parameter varying design specification.

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CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 DESIGNING AND PROGRAMMING REQUIREMENT

A program design can be viewed as a complete program, i.e. a program in which certain entities or concepts are formalized and others that have not yet been specified or designed are left informal. The design process for information systems is a gradual development of the program. There is no clear separation between designing and programming, no single sudden transition from desired effect to means of achieving the effect. At each stage there is a current understanding, which is improved and formalized by incremental transformations of the program progressively specifying and designing during the development process. This continues throughout the software life cycle, a new development leads to amendments to specifications and the necessity for redesign depending on the case or change.

Program design consists of inventing clarifying and eventually formalizing concepts. The technique of programming in CAD allows us to do this in a coherent way, using the Language for expressing categories and properties of the concept we need. Engineers are concerned with the application of technology to satisfy human needs. The essence of engineering is characterized by the design process, in which resources are transformed in the best way possible into needed devices or systems. This transformation starts with the recognition of some need and progresses to the physical implementation, which satisfies this need. The device or system, which results, may be simple or extremely complex, as in the case of the design of gas absorption column using computer-aided design (CAD). In the general configurations of the design work, drawings and graphic display (Teicholz 1985), CAD is widely used extensively by engineering designers. In fact, CAD unites all design processes that require the effective use of the computer, which involves documentation and communication of design information, as well as modeling, analyzing and evaluation of engineering data.

1.2 **CAD AS PROGRAM DESIGN SOFTWARE.**

CAD operation occurs through interaction. This may either come from the result of calculations from the computer system to the user or the models from the user to the computer system. This development provide CAD designer with powerful and flexible tool to enhance performance and eliminate possible errors (Meyer 1992). A designer with the aid of CAD can now prepare, calculate or evaluate in hours a preliminary design that would have taken days or weeks, if not months when using manual or rigorous method.

1.3 FUNDAMENTALS OF ABSORPTION OF GASES IN PACKED COLUMN

When a soluble vapour is absorbed from its mixture with an inert gas by means of a liquid in which the solute gas is more or less soluble, we can say that gas absorption has taken place. Alternatively, it is a process, which involves the removal of one or more selected components from a mixture of gases by absorption into a suitable liquid. Absorption processes are divided into two main groups, those in which the process is mainly physical and those, which involve chemical reactions. To achieve gas absorption in equipment design, the main requirement is that the gas be brought into intimate contact with the Liquid and the effectiveness of the equipment will be determined largely by the success with which it promotes contact between the two phases. This is based on inter-phase mass transfer controlled by rates of diffusion. Thus acetone can be recovered from an acetone-air mixture by passing the gas stream into water, in which the acetone dissolves while the air passes out; that is a physical absorption process.

Similarly when oxides of nitrogen are absorbed in water to give nitric acid a chemical reaction is involved. It should be noted that the liquid used in the absorption of gases is always below its boiling point. This is what gives the difference between Absorption and Distillation (Coulson and Richardson 1991).

1.4 EQUILIBRIUM CONDITIONS BETWEEN LIQUID AND GAS

In the process of bringing two phases together or coming in contact they eventually reach equilibrium. Thus, water in contact with air evaporates until the air is saturated with water vapour, and the air is been absorbed by water before it becomes saturated with the individual gases. The degree to which each gas is been adsorbed is determined by its partial pressure in any mixture of gases. At a given temperature and concentration, each dissolved gas exerts a definite partial pressure.

There are three types of gases to be considered in this aspect (Coulson and Richardson 1991). A very soluble one (Ammonia), a moderately soluble one (Sulphur dioxide), and a slightly soluble one (oxygen). From the table of partial pressure and concentrations of aqueous solutions of gases at 303K shown below in the table 1.0, it is seen that a slightly soluble gas requires a much higher partial pressure of the gas in contact with the liquid to give a solution of a given concentration. Conversely, with a very soluble gas a given concentration in the liquid phase is obtained with a lower partial pressure in the vapour phase. At 293K a solution of 4kg of sulphur dioxide per 1000kg of water exerts a definite partial pressure of 2.7KN/m^2, sulphur dioxide will be absorbed. The most concentrated solution that can be obtained is that in which the partial pressure of the solute gas is equal to its partial pressure in the gas phase. These equilibrium conditions fix the limits of operation of an absorption unit.

TABLE 1: **PARTIAL PRESSURES AND CONCENTRATIONS OF AQUEOUS SOLUTIONS OF GASES AT 303K**

PARTIAL PRESSURE OF SOLUTE IN GAS PHASE (KN/M^2)	**CONCENTRATION OF SOLUTE IN WATER kg/1000kg WATER**		
	AMMONIA	SULPHUR	OXYGEN
1.3	11	1.9	-
6.7	50	6.8	-
13.3	93	12	0.008
26.7	160	24.4	0.013
66.7	315	56	0.033

1.5 AIMS AND OBJECTIVES

The purpose of this project work is to code the design of a gas absorption packed column as a CAD module. It is hoped that the module can be used to improve the overall design of gas absorption column and save the cost and efficiency of carrying out such design.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 COMPUTER AIDED DESIGN (CAD)

The computer is infiltrating all aspects of our working lives. We are accustomed to its prominence in the world of business and finance where it has assumed many of the communications functions and bookkeeping of most organizations. It has also become a key tool for engineering design and now it is rapidly becoming indispensable for manufacturing processes (Meyers 1992).

The use of the computer as a tool for engineering design is to enhance design as a process of innovation, creativity and change. A computer aided design [CAD] system is a configuration of computer hardware and software used to create a geometric model of a product in the memory of the computer and to display a visual representation of that model on graphics screen. A CAD system can also be used to produce engineering drawings and documentation.

2.2 TECHNICAL TOOLS FOR CAD SYSTEM

The advent of less expensive hardware particularly microprocessors and more extensive and powerful applications software, has made the purchase of cost-effective CAD system for design, drafting and analysis possible for almost any engineering and manufacturing firm. This recent acceptance of CAD technology by end users has dramatically affected the way in which products are designed and manufactured. CAD results in a controlled information flow that produces better monitoring of cost expenditures, better controls security, and maintenance of data (Teicholz 1985).

In general, CAD system improves the quality of a design and result in shorter product cycles because of increased lead-time from a project's conception through the production of working drawings. The development of a single database for a project results in error reduction, better management control, and more feedback for the client. All these benefits result in more efficient design, which, in turn, result in cost saving for the company. The technical tool for CAD system is broadly divided into two, the hardware and the software. This is shown in figure 2.1.

THE HARDWARE:- The Hard-copy devices are an important element of computer graphics and CAD systems. It is made-up of the central processing unit (CPU), which can be called the heart of the computer as well as the handling of arithmetic and logic unit and the control and the command unit. The magnetic tapes, disks (Floppy and Hard) storage devices that store data and programs in the computer memory, input devices such as Digitizer Key Board, Trackball, and Mouse etc. Output devices that communicate computed results to human are monitors, printer plotter, etc.

Some displays have local graphic "intelligence" and are able to generate various system geometric shapes such as circles, ellipses, curves and rectangles based on simple commands (Neill1985). Another common feature is "Polygon full", in which an enclosed area can be filled or flooded with a specific colour, the speed of the fill function varies considerably from one unit to another.

SOFTWARE:- Is the "intelligence" within the "Mind" of the Computer. The term is used to refer to both programs and data. Programs are sets of instructions to the computer, indicating to it a series of actions to take; data is the term used for the information on which these actions are performed in response to the instructions of the program.

Programs can be batch or interactive. In working with a batch program, the user enters data but does not interact with the computer during the processing of data. Interactive programs on another hand, provides a variety of immediate responses to the user. The user in turn, can respond by modifying earlier actions or performing additional ones. Most CAD systems are interactive. However, it is appropriate in some instances to consider batch programs.

The software consists of all the programs, commands and firmware, which direct the computer to carryout or to execute a function (a task). It is classified into two, System Software, and Application Software.

The system software surrounds and controls access to the hardware. It manages the working of the hardware components as well as the software aspect; an example is the operating system. (Neill 1985).

Application software must work through the system software in other to operate. It refers to the programs that are written for or by a user in other to accomplish a specific task. Fig2.1 illustrates the usefulness of the computer system.

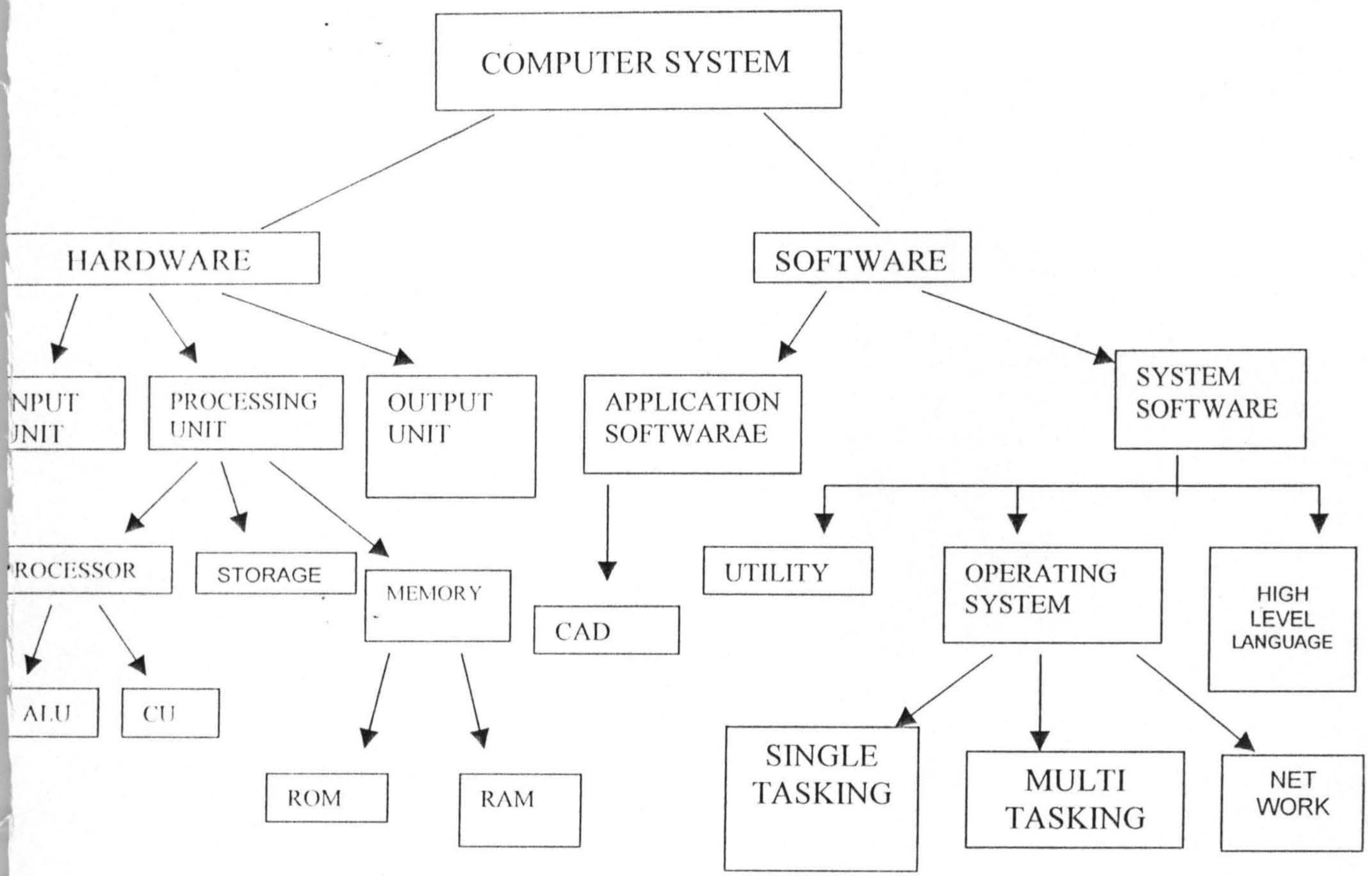


Figure: 2.1 ***Computer System***

2.3 BASIC TOOLS FOR CAD DATABASE

Data concerning physical size or configuration of equipment, flow of materials, chemical properties (such as Kinetic, concentration etc.) and cost information of the required materials are the information needed to develop a database. A database refers to the collection of data that can be used by different programs in a system.(Teicholz 1985). The designer calls upon the large amount of information or data to achieve his/her objectives using the computer system for the analysis of complex design processes.

A database requires two dimensional data representation but when in doubt, a designer should choose a three-dimensional system. Generally, database management system is a complex software package that allows users to define, maintain, and protect files and create reports.

2.4 DATABASE FOR PHYSICAL PROPERTIES AND THEIR USES.

The physical properties of any component involved in a design work are one of the basic requirements the engineer would need. During the earlier years of CAD, such information was obtained which is difficult and time consuming considering the mode of operation of the data supplied. This shortcoming is due to technological development leading to changes or variations in the physical properties. (Neill 1985) Modern technology has provided a component package.

THE USES OF DATABASE PACKAGE

- The Package allows for flexibility in terms of the end user and involvement of another of computer system.
- It avoids duplication of effect resulting in reduced economic cost. Its single system allows for more sophistication in the program.
- A general supply of physical properties and the thermodynamics calculations will be available to any individual user.
- Considering process evaluations, unit operations modeling, process simulation, optimization and economic evaluation, the designer requires the use of physical properties package.
- The system package should be able to generate the engineering accuracy for many types of compounds and their mixture over a wide range of temperature and pressure. The large data set resident on the computer disk involves a self-contained data bank of various compounds, which is the basis of any physical property package.

2.5 APPLICATION OF COMPUTER TO ENGINEERING DESIGN PROCESSES.

In the anatomy of design, the solution of a design problem, involves three phases (Harold 1975). In the first, the problem is defined. In the second, various solutions are synthesized, and finally the solutions are evaluated and a decision made as to which is best.

(i) **Analysis And Testing:** The greatest effort in the design process is usually devoted to the analysis or testing of the alternative solutions proposed. (Harold 1975). Up to this point the designer has been putting things together, or synthesizing. Now it is necessary to analyze the performance of the alternatives for comparison with the needed specifications. Actual experimental testing may also be called for, since there are distinct limits to what may be adequately represented and solved with analytical models. Computer techniques are of great assistance here. Much effort are devoted to the development of skills in computer Aided Design (CAD) operations. (Teicholz 1985).

(ii) **Evaluation And Decision**: This involves comparison with the criteria and constrains that made up the original specifications. The comparison permit a decision to be made as to which of the alternative approaches is the most suitable. It is quite conceivable, however, that the decision made at this point will, from later evidence, have to be rescinded. The solutions chosen requires some manipulation before it changes to its best form. This process of refinement uses a highly developed group of techniques, which will be discussed in more detailed form in absorption procedures.

(iii) **Optimization:** The solution chosen requires some manipulation before it changes to its best form. This process of refinement uses a highly developed group of techniques, such as mathematical formulation, differential calculus, numerical methods, iteration etc. Trying to get the best out of a design situation entails the choice of methods, systems, and design parameters that will give the best result. Great reliance is usually placed on the high-speed computer in performing optimization calculations (Harold 1975).

(iv) **Implementation:** A simple view of entire design process is that information initially gathered, is then processed in a creative fashion, and finally is sent out in its new form. A broader view sees the input of various resources, followed by their processing and application. Finally, one must expect that most of the resources can be recycled in some sense into the same design, its modification or a new design.

2.6 USEFULNESS OF COMPUTER IN ENGINEEING DESIGN PROCESSES

The recommendations made by the designer regarding the functional feasibility of automating specific computer aided design operations is to experience and be creative in defining the system and making preliminary layout (Teicholy 1985).The basic importances of the computer system in CAD operations are:

Increased productivity: This is evident primarily in increased production. More parts or assemblies can be designed or produced in a specified time. The time required to design and produce a part is reduced. Also, because production results in fewer errors, less time is spent compensating for mistakes and producing replacement parts. Overall, production costs tend to be lower, which amounts to getting more work from the same work force. The work tends to be of higher quality, because people in a computer based environment can do things more quickly and thus have more time to devote to thinking, evaluating, and improving their ideas.

Improved quality:- CAD tends to produce better products. At the design phase, the engineer has a better understanding of a particular design, has subjected it to a variety of analysis, and has often evaluated it in comparison with several alternative design for the same concept.

Improved internal communication:- In a CAD environment, the computer becomes a communication medium as well as a design and fabrication tool. This requires the various functional units in the company to adhere to standards, pay attention to documentation, and strive for an integrated, coherent, and complete database for a product. This gives or leads to a more shared information about the product and better understanding of the product or system.

As a result of computer technology, conceptions of what is possible to do in design and production are changing, due to the interative level of the computer system, it produces design drawings at different levels, varying physical properties such as temperature, pressure etc.

In conclusion, the computer system serves as an extension to the memory of the designer as illustrated in figure 2.1.

CHAPTER THREE

3.0 PACKED GAS ABSORPTION COLUMN.

3.1 INTRODUCTION:

Packed columns are used for distillation, gas absorption and liquid-liquid extraction. It is shown in figure 3.1 but for this work we will be concerned with gas absorption, which is the reverse of desorption, which is the entrainment of gas on solid or liquid on solid surface. The liquid or gas- liquid contact in a packed bed column is continuous, not stage-wise, as in a plate column. The liquid flows down the column over the packing surface and the gas or vapour, counter-currently flows up the column. In some packed columns co-current flow can be used. The performance of a packed column is dependent on the maintenance of good liquid and gas distribution throughout the packed bed, it is important to note this in design [Coulson & Richardson 1991].

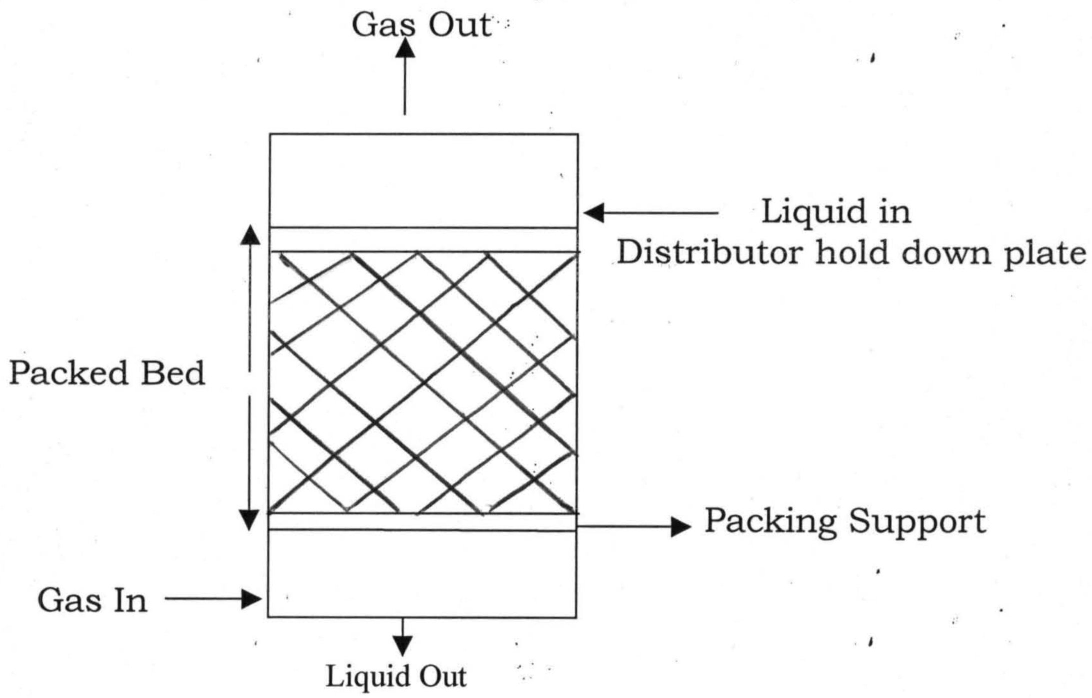
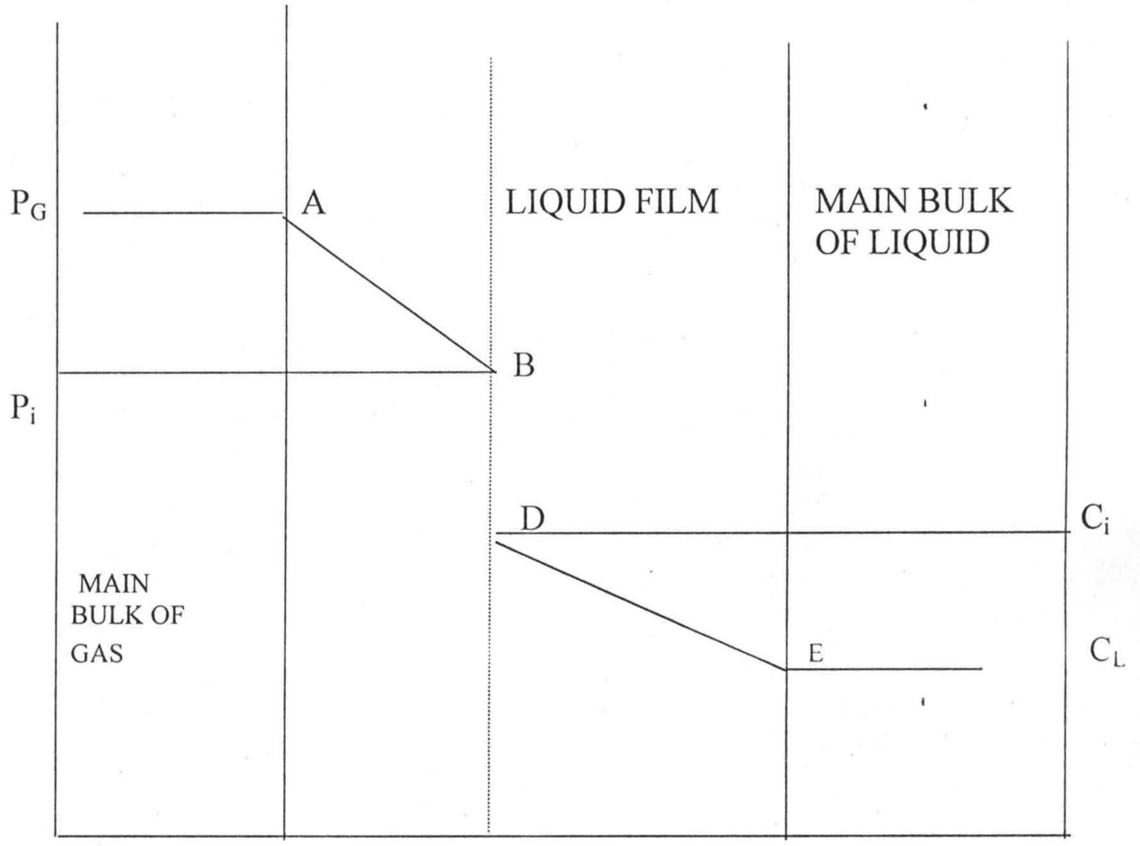


Fig. 3.1 Packed Absorption Column

3.2 INFORMATION ON ABSORPTION

One of the most useful concepts of the process of absorption was postulated by the two-film theory due to WHITMAN (Coulson & Richardson 1991). A material is transferred in the bulk of the phases by convection currents, and concentration differences are negligible except in the vicinity of the interface, between the phrases. On either side of this interface, it is supposed that the currents die out and that there exists a thin film of fluid through which the transfer is affected solely by molecular diffusion.

The concentration difference depends not solely on the direction of transfer of material across the interface, but also on the equilibrium relationship. Very big concentration gradient across the interface does not make a difference, since this is not the controlling factor in the mass transfer, as it is generally assumed that there is no resistance at the interface itself that is where equilibrium conditions exist. The controlling factor will be the rate of diffusion through the two films where all the resistance is considered to lie. The phenomenon is explained in figure 3.2.



INTERFACE

FIG. 3.2 CONCENTRATION PROFILE FOR ABSORBED COMPONENT A [THE CHANGE IN CONCENTRATION OF A COMPONENT THROUGH THE GAS AND LIQUID PHASE]

P_g = Partial pressure in the bulk of the gas phase.

P_i = Partial pressure at the interface.

C_i = The concentration in the bulk of the liquid phrase.

C_L = The concentration at the interface.

The Rate of Absorption

Considering the absorption in a steady state process [Coulson & Richardson 1991], the rate of transfer of material through the gas film will be the same as that through the liquid film and the equation for mass transfer may be given as

$$N'_A = K_G (P_G - P_i) = K_L (C_i - C_L) \quad \text{\_\_\_\_\_} \quad 2.1$$

Where equilibrium conditions are assumed to exist, we have

$$\frac{K_G}{K_L} = \frac{C_i - C_L}{P_G - P_i} \quad \text{\_\_\_\_\_} \quad 2.2$$

The above equations present the mass transfer based on the overall transfer coefficients.

Rate of absorption in terms of mole fraction:

$$N'_A = K_G (Y - Y_i) = K_G (Y - Y_e) \quad \text{\_\_\_\_\_\_\_\_\_\_} \quad 2.3$$

$$N'_A = K_L (X_i - X) = K_L (X_e - X) \quad \text{\_\_\_\_\_\_\_\_\_\_} \quad 2.4$$

Considering m as the slope of the equilibrium curve, which is approximately. $(Y_i - Y_e) / (X_i - X)$, it can be represented as thus,

$$\frac{I}{K''_G} = \frac{I}{K''_G} + \frac{M}{K''_L} \quad \text{\_\_\_\_\_} \quad 2.5$$

Where,

N'_A = The rate of mass transfer for Liquid and gas phase,

K_G = Gas – phase mass-transfer coefficient, kmol/m^{2}s atm,

K_L = Liquid- phase mass – transfer coefficient, Kmol/m^{2}s,

C_L = The concentration in the bulk of the Liquid phase, kgmol/m^3,

C_i = The Concentration at interface, kgmol/m^3,

P_G = Partial pressure in the bulk of the gas phase, atm, bar,

P_i = Partial pressure at the interface, atm, bar

M = Slope of the equilibrium curve.

3.3. Pressure Drop in a Packed Column.

The drop in pressure is an important factor in the design of packed column because the liquid downward flows occupies the same channels as the gas up-flows. Hence, the pressure drop in a packed column is influenced by both the gas and liquid flow rates. The gas flow, through the column packing is usually turbulent. The liquid entering the column top, flows downward and the gas entering from the bottom must be moved by a fan (Alan 1976). Considering the graph of the characteristics pressure drop in packed column, it is observed from line G in figure 3.3 that for a constant gas velocity, the pressure drop increases with increasing liquid rate. Type of packing material has a fixed void volume for liquid passage so that, as the liquid rate increases, the voids fill with liquid, thus reduces the cross sectional area available for gas flow.

In random packing, a myriad of expansion and contraction losses, and considerable turbulence is created by the flow of the two fluids around the individual solid packing elements, with a predominant form drag (at higher velocities) and the skin friction. Both form drag and skin friction make up the pressure drop. There is a direct relationship between heat and mass-transfer surface coefficients and skin friction. It is advantageous to have a high percentage of the total pressure drop attributable to skin friction. Because from fig 3.3, considering line A, a line of constant liquid rate and imagine that a transparent column is being used till point 1 on the curve, the pressure drop characteristics is quite similar to that of the dry packing at C. The slope of the line is about the same as that of the dry curve, but pressure drop is greater. The larger pressure drop occurs due to blocking of part of the voids by the liquid and roughening of the surfaces by waves. Observation from the packing indicates, orderly trickling of the liquid downward through the packing with no observable liquid build-up. At point 1, a change in slope occurs, leading to more increase in the pressure drop than the increase in gas velocities. This point may not show any visual change in the flow pattern or characteristics. Thus, it might be possible to obtain an increase in the quantity of liquid retained in the packed section of the column.

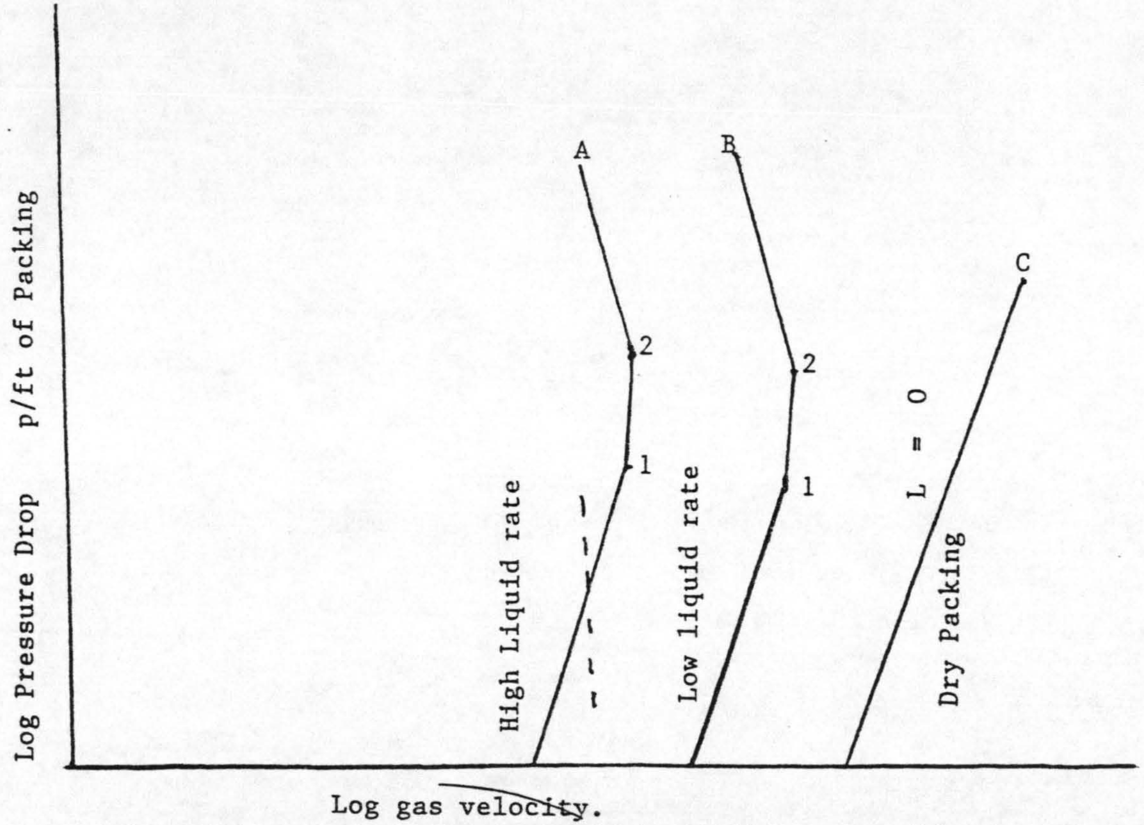


Figure 3.3: Pressure - Drop Characteristics In Packed Column.(Alan 1976)

Point 1 is called the loading point while the retained liquid is known as the hold-up and the increased dependence of the pressure drop on the gas velocity is a consequence of drag between the phases. As we exceed point 1, it's observed that there is a greater amount of liquid hold-up (Alan 1976).

A gradual filling of the packing voids with liquid is observed, as there are liquid layers at the top of the packing. Since the liquid has filled a large portion of the packing, it means the gas must bubble through it. This condition is called visual flooding. The second change in the slope of the pressure drop line occurs when the gas rate is somewhat greater than that corresponding to visual flooding. This point is more reproducible than the visual observation and is generally known as the flooding point. Here, the drag force of the gas bubbling through the liquid is quite important. Each liquid rate has it's own loading and flooding points.

The operation of packed column is not practical above the loading point. Therefore, for simplicity and safety purpose, packed column are designed using gas velocities of about 50-80 percent of flooding velocity at expected liquid rate. This normally ensures a stable operating condition for the design somewhere below loading and provides for thorough wetting of the packing surface. The flooding velocity is a function of the liquid flow-rate, the gas and liquid densities, the viscosity of the liquid and the nature of the packing. All these factors are correlated in the flooding velocities chart, Fig 3.4.

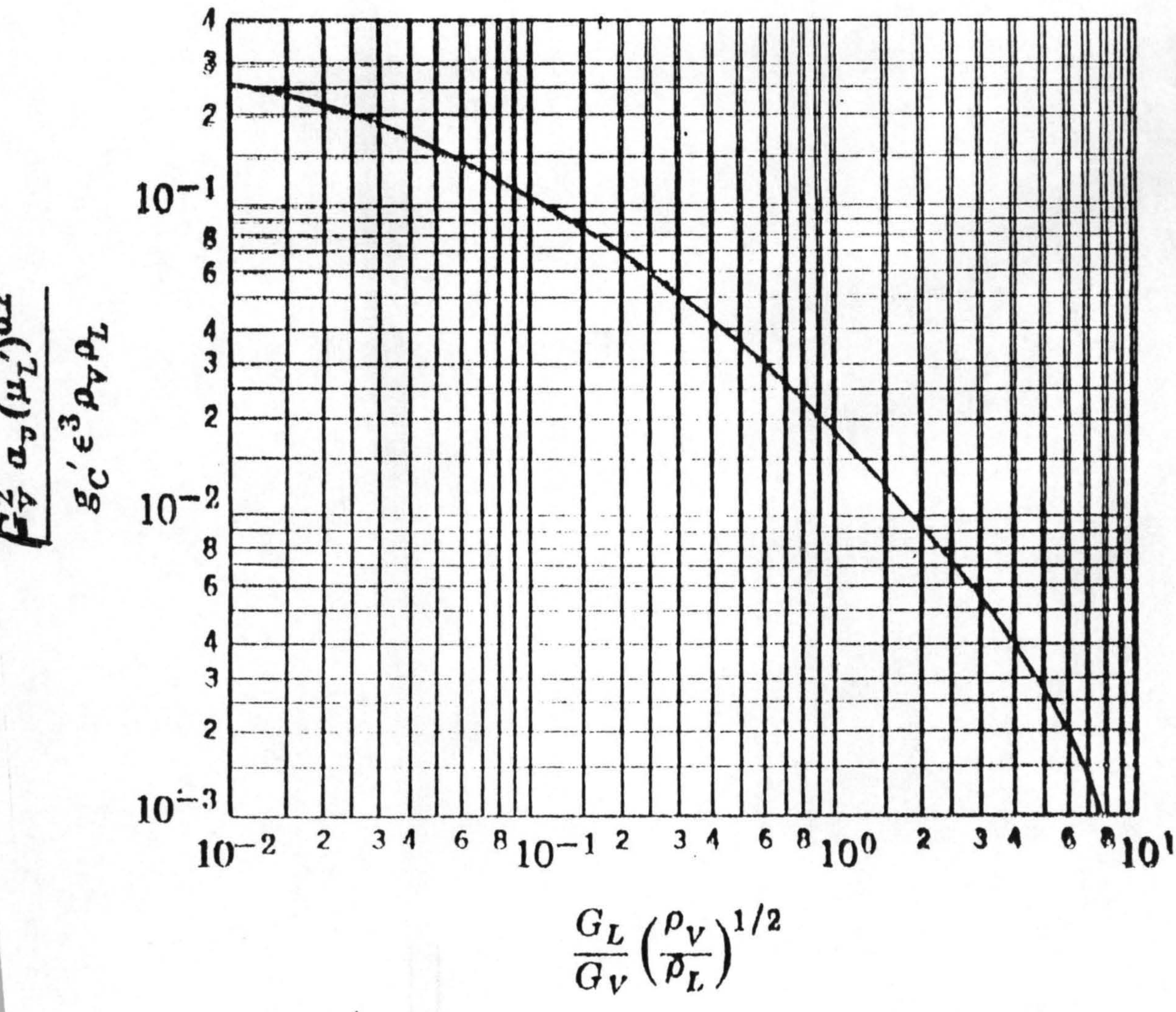


Figure 3.4: Flooding Velocity In Packed Column.

3.4 <u>Interfacial Transfer Coefficients</u>

In mass transfer, one or more components of two discrete phases are transferred between the phases. Mass transfer coefficient is a quantity describing the rate of mass transfer per unit interfacial area per unit concentration difference across the interface [Alan 1976].

The most important single factor in calculating the size of an absorption column [Coulson & Richardson 1991], is the value of the transfer coefficient or height of the transfer unit. Considering the process, the total flow rates of the gas and liquid stream will be fixed. The most suitable flow per unit area through the column must be determined. The flooding rate must not be exceeded to enable a limited gas flow and if the liquid rate is very low, there will be a serious drop in performance. The effect of flow rates of the gas and liquid on the transfer coefficients is to be examined and the influence of variables such as temperature, pressure and diffusivity are to be investigated.

Wetted-wall column has been used by a number of designers determining the importance of the various factors. It has also served as a basis from which correlations have been developed for packed column.

3.5 <u>Evaluation of transfer unit.</u>

A single transfer unit may be defined as giving an enrichment of one of the phases equal to the average driving force producing this enrichment (Alan 1976). A resistance to mass transfer exists within the fluid on each side of the interface, and the overall transfer rate of a component in a mixture depends on the sum of this resistance and total driving force.

The number of transfer unit and the height of a transfer unit may be expressed as functions of driving forces in any set of units. Although the height of a transfer unit has a single dimension of feet, it presents an advantage over the use of the many-dimensioned mass-transfer coefficient. But in reality, this is only a superficial advantage because the definition of the height of a transfer unit includes the mass- transfer coefficient, which in turn must be consistent with the units of driving force employed [Alan 1976].

The height of a transfer unit is a measure of the separation effectiveness of the particular packing for the chemical species being processed. If the rate of inter-phase mass transfer is high and the surface area for transfer is large, then the height of a transfer unit will be small. The traditional methods of assessing the capacity of column packings, involves the use of specific surface area and voidage, developed from the fact that these properties could readily be defined and measured for a packed column. The value of specific surface area and voidage enables a reasonable prediction of hydraulic performance to be made. To complete the determination of the height of a packed column, the height of a transfer unit must be evaluated, once the numbers of transfer units have been established. The height of the transfer unit can be defined in various ways corresponding to the specific expression for the number of transfer unit.

3.6 PACKED COLUMN DESIGN - ECONOMIC EFFECT

In designing industrial scale packed column, a balance must be made, between the capital cost of the column and ancillary equipment on one side as well as the running cost on the other side. Generally reducing the diameter of the column will reduce the capital cost but will increase the cost of pumping the gas through the column due to the increased pressure drop (Meyers 1992). For economic and safety reasons packed column should be designed using gas velocity of about 50 to 80 percent of the flooding velocity at the expected liquid rate (Alan 1976, Coulson & Richardson, 1991).

The design process should aim at satisfying all the necessary technological, economic and other chemical conditions. Usually, the economic requirement is that the unit operation should be performed at a low total, capital and operating cost (Meyers 1992). An optimization base design solves problems that arise from interrelated technological and economical requirements.

CHAPTER FOUR

4.0 DESIGN PROCESS

The unit operation in which soluble components of a gas mixture are dissolved in a Liquid is known as gas absorption. The inverse operation of this process, is called desorption, is employed when it is desired to transfer volatile components from a liquid mixture into a gas (Perry and Green 1997).

Absorption operations are usually carried in a vertical cylindrical column in which devices such as packing elements are placed. The gas and liquid often flow counter – currently, and the device serves as the contacting and development of interfacial surface through which mass transfer occurs.

4.1 GENERAL DESIGN PROCEDURE

To achieve gas absorption in the design of equipment, the main requirement is that the gas be brought into intimate contact with the Liquid and the effectiveness of the equipment will largely be determined by the success with which it promotes contact between two phases [Coulson and Richardson 1991].

4.2 DESIGN INFORMATION AND DATA

The procedures to be used in specifying the principal dimensions of gas absorption, involved three main steps:

4.2.1 **Data for Gas-Liquid or Vapour-Liquid equilibrium for the system:-**

The equilibrium data are critical to determine the maximum possible separation. In some cases rate-based operations are considered, but requires equilibrium knowledge at the inter-facial phase. Other data include physical properties such as viscosity, density and thermodynamic properties i.e. enthalpy (Perry and Green 1997).

4.2.2 Information on Liquid and gas capacity:- The information on the liquid and gas-handling capacity of the contacting device chosen for the particular separation problem must include pressure drop characteristics of the device in order that an optimum balance between capital cost [Column Cross Section] and energy requirements might be achieved.

4.2.3 Determination of the Required Height:-The required height of the contacting zone for the separation is used as a function of properties of the fluid mixtures and mass-transfer efficiency of the contacting device. The determination involves the series of calculation such as mass transfer unit, height of transfer units, and plate efficiencies as well as equilibrium or number of transfer units.

The designer of gas absorption column is required to determine the best solvent to be used. In the selection of solvent when choice is a possible, liquid with high solubility for the solute is preferred. This is because high solubility reduces the amount of solvent to be circulated (Perry & Green 1997). Low cost solvent should be used, since the exit gas normally leaves the column saturated with the solvent. A solvent is suitable when it is nonflammable, non-corrosive, nonvolatile, non-foaming, non-viscous, inexpensive and most especially stable. The solubility values determine the liquid rate necessary for complete or economic solute recovery and are essential in design. The three forms of equilibrium data are:

Solubility data can be expressed either as solubility in weight or mole percent or pure component vapour pressures or equilibrium distribution coefficient. The minimum possible liquid rate is readily calculated from the composition of the entering gas and the solubility of the solute in the exit liquor, when saturation is assumed. It is necessary to estimate the temperature of the exit liquid which is based on heat of solution of the gas. Head of solution is the quantity of heat released or absorbed when 1 gram or 1 mole of substance is dissolved in a large volume of solvent. Subject to economic consideration the operating pressure is the pressure at which the absorber will operate.

The packed column are chosen for very corrosive materials, for liquids that foam badly and for either small or large diameter columns involving very low allowable pressure drops. The designer should note the following:

1. Select the type and size of packing
2. Determine the diameter (Capacity) to handle the liquid and vapour flow – rates.
3. Determine the column height required for a specified separation.
4. Select and design the column internal features; Packing support, liquid distributor, redistributors.

4.3 Types of Packing and Characteristic

The Principal requirements for packing are as follows:

1. It must promote uniform vapour gas flow across the column cross-section. And a good wetting, characteristics.
2. It must provide a large surface area; a high interfacial area between the gas and liquid.
3. It should have a low bulk density, in order to avoid support problems.
4. It must have an open structure i.e. low resistance to gas flow.
5. It should be relatively inexpensive.

Although many types and shapes of packing have been developed to satisfy these requirements. They can be divided into two broad classes.

1. Packing with a regular geometry such as stacked rings, grids and proprietary structure packings.

2. Random packing:- Saddles and proprietary shapes, which are dumped into the column and take up a random arrangement.

Grids have an open structure and are used for high gas rates, where low-pressure drop is essential, e.g. cooling towers.

Random packings and structured packing elements are more commonly used in the process industries.

We have different type of packing rings some of which will be discussed here.

Raschig Rings: - The oldest and are still in use.

Pall Rings:- Are essentially or actually Raschig rings in which openings have been made by folding strips of the surface into the ring. This improves the liquid distribution characteristic and increases the free area.

Berl Saddles:- The berl saddles were developed to give improved liquid distribution compared with the Raschig rings.

Intalox Saddle:- In consideration, this can be regarded as an improved type of Berl Saddle. Their shape makes them easier to manufacture, than Berl Saddle.

Hypac And Supper Intalox Saddle:- We can regard this as the improved types of pall rings and Intalox Saddle respectively.

Rings and Saddle can be found in a variety of materials, such as ceramics, metals, plastics and carbon metal. Plastics (Polypropylene) rings are more effective or efficient than ceramic rings as it is possible to make the wall thinner.

Raschig rings are cheaper per unit volume than pall rings or saddles but less efficient. Where the column operation is likely to be unstable ceramic packing should not be used since it can be broken easily. The best choice should be metal rings. But for corrosive liquids, ceramic packing will be first choice. Note that ceramic packing are unstable for use with strong alkalies. Plastic packings are attacked by some organic solvents, and can only be required at moderate temperature. Generally, the choice of material normally depends on the nature of the fluids and the operating temperature (Perry and Green 1997).

4.3.1 Packing Size:- In considering packing size, small sizes are appreciably more expensive than larger sizes. Above 50mm, the lower cost per cubic meter dose not normally compensate for the lower mass transfer efficiency and cause the use of too large a size in a small column resulting in poor liquid distribution. But the largest size of packing that is suitable for the size of column should be considered. This should be up to 50mm for difficult separations, requiring many stages such as the separation of isotopes. Also in the case of high vacuum distillation, and for column revamps (that is to increase capacity and reduce reflux ratio requirement), Structural Packing should be used. It is mostly used in distillation but can be used in absorption when high efficiency and low-pressure drop are needed. (Alan 1976).

The Optimum Solvent Rate: (Colburn 1939) has suggested that the optimum value for the term MGm/Lm will be between 0.7 to 0.8, for dilute mixtures/concentrations (6) the optimum solvent rate Lm can be given by

$$L_m = \frac{MG_m}{(MG_m / L_m)} \qquad 4.1$$

4.4 Packed Column Height: When the concentration of the solute gas is small, say less than 10 percent, the flow of gas and liquid will be essentially constant throughout the column and the height of packing required Z is given by

$$Z = \frac{G_M}{K_G a p} \int_{y_2}^{Y_1} \frac{dy}{Y - Ye} \qquad 4.2$$

OR

$$Z = \frac{L_M}{K_L\, a\, C_t} \int_{x_2}^{X_1} \frac{dx}{x_e - x} \qquad 4.3$$

For the overall gas-phase mass transfer coefficient K_L and the liquid composition. It is convenient to write equations (4.2) and (4.3) in terms of Transfer units (HTU) for design purposes. The group in-front of the integral sign, which has units of length is the height of a transfer unit. Equations 4.2 and 4.3 is broken down in equations 4.6 – 4.10.

Hence

$$Z = H_{OG} N_{OG} \qquad \text{\_\_\_\_\_\_\_\_\_\_} \quad 4.4$$

OR

$$Z = H_{OL} N_{OL} \qquad \text{\_\_\_\_\_\_\_\_\_\_} \quad 4.5$$

Where, the Height of the overall gas-phase transfer unit (H_{OG}) is given by

$$H_{OG} = \frac{Gm}{K_G \, ap} \qquad \text{\_\_\_\_\_\_\_\_\_\_} \quad 4.6$$

Where,

G_M = Molar gas flow- rate per unit cross-sectional area, $Kmol/m^2s$,

L_M = Molar Liquid flow-rate per unit cross-sectional area, $Kmol/m^2s$,

P = The Column operating Pressure, atm or bar,

C_t = Total molar concentration, $Kmol/m^3$ = e_l/molecular weight of solvent,

a = Interfacial surface areas per unit volume m^2/m^3,

K_L = Liquid – phase mass transfer coefficient, $Kmol/m^2s$ ($kmol/m^3s$) = m/s,

K_G =Gas-phase mass transfer coefficient, $Kmol/m^2s$ atm or $Kmol/m^2s$ bar,

H_L = Height of a liquid – phase transfer unit, m, (ft),

H_G = Height of a gas-phase transfer unit, M, (ft),

X_e = The concentration in the Liquid that would be in equilibrium with the gas concentration at any point.

Y_e= The concentration in the gas that would be in equilibrium with the liquid concentration at any point,

x_1 and x_2 = The mol fractions of the solute in the liquid at the bottom and top of the column, respectively.

Y_1 and Y_2 = The mol fractions of the solute in the gas at the bottom and top of the column, respectively,

~~Z~~ = Height of the column ft or m.

Number of overall gas-phase transfer unit

$$N_{OG} = \int_{Y2}^{y1} \frac{dy}{Y-Y_2} \qquad 4.7$$

The Height of the overall Liquid-Phase transfer unit is given by

$$H_{OL} = \frac{L_m}{K_x\, a\, C_t} \qquad 4.8$$

Number of overall Liquid-Phase transfer unit is given by

$$N_{OL} = \int_{X2}^{x1} \frac{dx}{x_e - x} \qquad 4.9$$

NOTE:- The number of overall gas-phase transfer unit is often more conveniently expressed in terms of the partial pressure of the solute gas. (Coulson and Richardson 1993). This is given by

$$N_{OG} = \int_{p1}^{p2} \frac{dp}{P-P_e} \qquad 4.10$$

The relationship between the overall height of a transfer unit and the individual film transfer units H_L and H_G which are based on the concentration driving force across the Liquid and gas films (Alan 1976) is given by

$$H_{OG} = H_G + m \frac{G_m}{L_m} H_L \quad \text{———} \quad 4.11$$

OR

$$H_{OL} = H_L + \frac{L_m}{MG_m} H_G \quad \text{———} \quad 4.12$$

For dilute systems, where the operating and equilibrium lines are straight, then the number of transfer units is given by

$$N_{OG} = \frac{Y_1 - Y_2}{\Delta ylm} \quad \text{———} \quad 4.13$$

Where, Δylm is the Log mean driving force given by

$$Ylm = \frac{\Delta y_1 - \Delta Y_2}{I_n(\Delta y_1/\Delta y_2)} \quad \text{———} \quad 4.14$$

$$\Delta y_1 = Y_1 - Y_e \quad \text{———} \quad 4.15$$

$$\Delta y_2 = y_2 - y_e \quad \text{———} \quad 4.16$$

When the equilibrium curve and operating lines can be taken as straight and the solvent feed essentially solute free, the number of transfer units is given by

$$NOG = \frac{1}{1-(MG_m/L_m)} I_n \left[\left(1-\frac{MG_m}{L_m}\right) \frac{Y1}{Y_2} + \frac{MG_m}{L_m} \right] \quad \text{———} \quad 4.17$$

Colburn (1939) suggested that the optimum value for the term MG_m/L_m should lie between 0.7 to 0.8.

The over all driving forces or driving forces through a single resistance may be employed to evaluate the number of transfer units required for a given enrichment based on the fact that the number of transfer unit is the same as the area under the curve. This allows Simpson's rule to be applied in obtaining the number of transfer units. Therefore,

$$N_{OG} = A \approx S/3 \ \{(F + L) + 4E + 2R\} \qquad 4.18$$

Where,

S = Width of each strip

F + L = Sum of the first and last co-ordinates

4E = 4 multiply by the sum of the even numbered co-ordinates

2R = 2 multiply by the sum of the remaining odd numbered co-ordinates.

It is essential to note that each ordinate is used only once (Stroad 1987).

4.4.1 Prediction of the Height of the Transfer Unit (HTU)

This is a satisfactory method for predicting the height of a transfer unit. In practice the value for particular packing will depend not only on the physical properties and flow-rates of the gas and liquid, but also on the uniformity of the liquid distribution throughout the column, which is dependent on the column height and diameter.

The correlation for predicting the height of a transfer unit and the mass-transfer coefficients, are;-

(1) Cornell's method

(2) Onda's Method

(3) Sherwood & Holloway experimental correlation

Following the Sherwood & Holloway Experimental Correlation the use of flooding velocity chart in figure 3.4 was interpolated using rational interpolation method in relating the pressure drop & superficial gas mass velocity as been used in the problem statement.

4.4.2 Using Rational Interpolation for the Flooding Velocity Chart.

This process, call Rational Interpolation, utilizes a ratio of polynomials to express an approximation to the data. Before deriving the appropriate equations for implementing rational approximation, we should know that ordinary polynomials are useful for approximation in a broad context. [e.g. Taylor's theorem, polynomials interpolation, orthogonal polynomial]. If we consider the use of the basic arithmetic operations to generalize polynomial approximation, we see that the operations of addition, subtraction, and multiplication of polynomials all leads to new polynomials, such that nothing different is produced. On the other hand, division of polynomials does not produce a polynomial, thus this operation does indeed give a new kind of function. Rational functions include polynomials as a special case, corresponding to the situation where the denominator polynomial is just unity. Common asymptotic behavior corresponds to the dependent variable approaching zero, a constant, or a bounded oscillation; such behavior cannot be well-described by an ordinary polynomial, which necessarily has an unbounded asymptotic behavior. However rational functions can mimic such trend quite well. Also functions with zero denominator (poles at certain point) can be represented by rational function but not by a polynomial.

Considering the details of rational interpolation. The advantages of rational approximation are that it often affords a better approximation than we can achieve otherwise, including estimation of derivatives and integrals, it gives a single relatively simple equation for the approximation; and it is often more useful than other approximations for extrapolation beyond the range of the data.

The standard rotation we shall use for a rational approximation is as follows:

$$Y(x) = \frac{P_0+P_1x+P_2x^2+ P_3x^3+\ldots\ldots +P_ax^a}{1+q_1x + q_2 x^2 + q_3x^3 +\ldots q_bx^b}$$

To obtain an equation for the unknowns P_i & q_i , by convention, we take the leading term of the denominator to be unity. This process produces the following system of linear algebraic equations when cross-multiplication takes place in the above equation and it require that the resulting equation be satisfied for each of the data pairs (X_1, Y_i)

$Y_i = P_o+X_i P_1+X_i^2 P_2+X_i^3 P_3...+X_i^a P_a-X_iY_iq_1 - X_i^2 Y_i q_2-X_i^3Y_iq_{i3} ...X_i^bY_iq_b$

For the n data pairs we determine the n unknowns, i.e. P_o, P_1,P_2, P_3 ... P_a, q_1,q_2,q_3... q_b Note that in general we must have n= a+1+b. Hence, as we take more terms in the denominator, we must have fewer in the numerator, and vice versa. When we use different (a,b) combinations for a fixed n, the P_i,Q_i coefficients will change. For this case 15 point was chosen from the flooding velocity chart where a=7 [P_o-P_7] and b=7 [q_1-q_7].

Using this points from flooding velocity chart ranging from 0.01 to 8.0 for x-axis and 0.001 to 0.25 on the y-co-ordinate. We can now interpolate the chart. The calculation involved is given in appendix A

4.5 **Design problem and it's Solution**

Gas mixture containing 6.0 percent $S0_2$ and 94.0 percent dry air from a sulfur burner is to be scrubbed with fresh water in a tower packed with 1- in Rashing rings to remove the $S0_2$ in such a way that the exist gas will contain no more than 0.1 mole percent $S0_2$. The tower must treat 1000.1b/hr of gas and is to be designed using 50 percent of flooding velocity, The water flow is to be twice the minimum required to achieve this separation in a tower of infinite height. Operating conditions will be isothermal at 30^oc and 1 atom pressure. Determine the required tower diameter and height the liquid- phase Schmidt number may be taken as 570.

Solution

The equilibrum Line must be obtained first, this is done by using the equilibrum data at 30^oC, since the operating conditions will be isothermal at that temperature. Equilibrium data is presented in Table 4.1.

TABLE 4.1 Equilibrium Data at 30°c

PsO_2 mm Hg	0.6	1.7	4.7	8.1	11.8	19.7	36.0	52.0	79.0
C. grams sO_2 portion grains of water	0.02	0.05	0.10	0.15	0.20	0.30	0.50	0.70	1.00
Density of solution 1b/cu ft.	62.16	62.17	62.19	62.21	62.22	62.25	62.32	63.38	62.47

The above equilibrium data are converted to fractional units. In that case.

$$Y = \frac{PsO_2}{760} \quad \text{And}$$

$$X = \frac{\frac{0.18\,c}{64}}{1 + \frac{0.18}{64}c} = \frac{\frac{\%\,M_{wt}\text{ of solvent} \times C}{M_{wt}\text{of solute gas}}}{1 + \frac{\%\,M_{wt}\text{ of solvent}}{M_{wt}\text{ of solute gas}} \times c} \qquad 4.27$$

$$Y_1 = \frac{0.6}{760} = 0.000789 \simeq 0.00079.$$

$$Y_2 = \frac{1.7}{760} = 0.0002236 \simeq 0.000224$$

$$Y_3 = \frac{4.7}{760} = 0.00618 \simeq 0.0062$$

$$Y_4 = \frac{8.1}{760} = 0.010657 \simeq 0.010657$$

$$Y_5 = \frac{11.8}{760} = 0.015526 \simeq 0.0155$$

$$Y_6 = \frac{19.7}{760} = 0.02592 \simeq 0.0259$$

$$Y_7 = \frac{36.0}{760} = 0.04736 \simeq 0.0474$$

$$Y_8 = \frac{52.0}{760} = 0.06842 \simeq 0.0684$$

$$Y_9 = \frac{79.0}{760} = 0.10395 \simeq 0.104$$

$$X_1 = \frac{\frac{0.18/64\ C}{64}}{1 + \frac{0.18C}{64}} = \frac{0.0028125\ (0.02)}{1+0.0028125\ (0.02)} = 0.0000563$$

$$X_2 = \frac{0.0028125\ (0.05)}{1+0.0028125\ (0.05)} = \frac{0.000140625}{1+0.000140625} = 0.000141$$

$$X_3 = \frac{0.0028125\ (0.10)}{1+0.0028125(0.10)} = \frac{0.00028125}{1+0.00028125} = 0.000281$$

$$X_4 = \frac{0.0028125(0.15)}{1+0.0028125(0.15)} = \frac{0.000421875}{1+0.000421875} = 0.000422$$

$X_5 = \frac{0.0028125(0.20)}{1+0.0028125(0.20)} = \frac{0.0005625}{1+0.0005625} = 0.000562$

$X_6 = \frac{0.0028125(0.30)}{1+0.0028125(0.30)} = \frac{0.00084375}{1+0.00084375} = 0.000843$

$X_7 = \frac{0.0028125(0.50)}{1+0.0028125(0.50)} = \frac{0.00140625}{1+0.00140625} = 0.00140$

$X_8 = \frac{0.0028125(0.70)}{1+0.0028125(0.70)} = \frac{0.0019675}{1+0.00196875} = 0.00197$

$X_9 = \frac{0.0028125(1.00)}{1+0.0028125(1.00)} = \frac{0.0028125}{1+0.0028125} = 0.00281$

Table 4.2: Equilibrium Data obtained at 30°c (x 10^{-3})

Y	0.79	0.224	6.2	10.7	15.5	25.9	47.4	68.4	104
X	0.565	0.141	0.281	0.422	0.562	0.843	1.40	1.97	2.81

Table 4.3: Operating line data at 30°c **(X10^{-3})**

Y	60	50	40	30	20	10	1.00
X	0.872	0.716	0.564	0.420	0.270	0.130	-0.00022 ~ 0

It is quite evident that the phase- flow rates are not constant throughout the column so to plot the operating line, we write a material balance from the tower bottom to any point within the tower. Or

$V_1y_1 + L_x = Vy + L_1 X_1$ ---------- 4.28

This Equation may be rewritten in terms of the non-diffusing component where

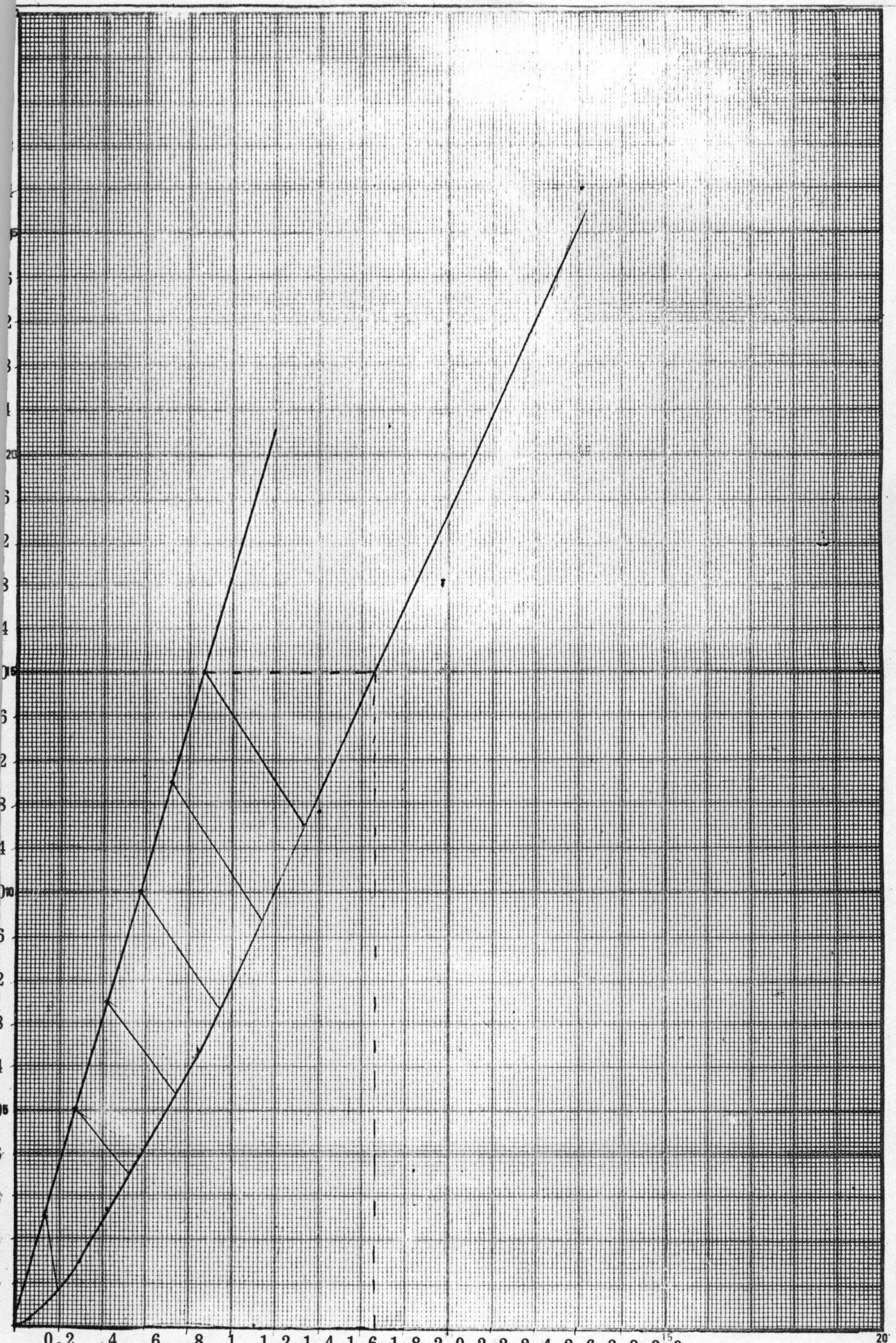


Figure 4.1 Operating - Eguilibrium Line Graph

$$V_i = V_1 (1-y_1) \text{ ------------ } \quad 4.29$$

And

$$L_i = L_1 \ (1-X_1) \text{ ------------ } \quad 4.30$$

V_1 Conversion to moles since we have SO_2 and Air we have

$$V_1 = \frac{1000}{(0.06x64)+ (0.94x29)} = \frac{1000}{3.84+ 27.26}$$

$$V_1 = \frac{1000}{31.1} = 32.15 \text{ Ib moles/hr of total gas flow}$$

Therefore, from equation 4.29

$$V_i = V_1 \ (1 - Y_1)$$

$$V_i = 32.15 (1\text{-}0.06)$$

$$= 32.15 \ (0.94)$$

$$V_i = \underline{30.2 \text{ Ib moles/hr } So_2 \text{ - free gas}}$$

The minimum water rate must be calculated before the material balance can be completed, the concentration of the gas leaving the column is given $Y_2 = 0.001$ and the concentration of the liquid entering will be $X_2 = 0$. Then considering the operating line equation, the minimum liquid flow rate can be obtained.

$$V^1 \frac{[y_2 \ - y_1]}{(1\text{-}Y_2\text{- }1\text{-}Y_1)} = L^1 \frac{[\underline{X}_2 \ - \ \underline{X}_1]}{(1\text{-}X_2 \text{-}1\text{-}X_1)} \text{ \_\_\_\_\_\_\_\_\_\_ } 4.31$$

$$30.2 \ \frac{[0.001}{[1\text{-} 0.001} - \frac{0.06 \ ]}{1\text{-} 0.06]} = L^1 \frac{[\ 0}{[1\text{-}0} - \frac{0.00174 \ ]}{1\text{-} 0.00174]}$$

Since, $Y_1 = 0.06$, $Y_2 = 0.001$ and $X_2 = 0$, the minimum liquid flow L^1 will correspond to a line through (X_2, Y_2) and (X_1,Y_1) because the equilibrium line is concave towards the operating line. From Figure 4.1

Y_1 = 0.06 the corresponding X_1 value is X_1 = 0.00174

$$30.2 \left[\frac{0.001}{0.999} - \frac{0.n06}{0.94}\right] = L^1 \left[0 - \frac{0.00174}{0.99826}\right]$$

30.2 [0.001001001 - 0.063829787] = L^1 [-0.001743032]

- 1.89742344 = L^1 [-0.001743032]

$$L^1 = \frac{-1.897429344}{-0.001743032}$$

$L^1{}_{min}$ = 1088.58 = 1088 1bmoles/hr SO_2 free water.

Since the water flow-rate is to be twice the minimum required to achieve the separation in a column of infinite height. Then for a design water rate which is twice the minimum water rate we have

$L^1 = 2 \times L^1 min$

= 2x1088 = 2176 1b moles/hr

The design flow rate of L^1 = 2176 1b moles/hr can now be used in the equation for the operating line to determine the exist – liquid composition.

$$30.2 \left[\frac{0.001}{0.999} - \frac{0.06}{0.94}\right] = 2176 \frac{[0 - x_1]}{[1 - x_1]}$$

$$-1.897429344 = \frac{-2176 \quad x_1}{(1 - x_1)}$$

$-1.897429344 + 1.897429344X_1 = -2176X_1$

$-1.897429344 = (-2176 - 1.897429344)\ X_1$

$$X_1 = \frac{-1.897429344}{-2177.897429}$$

$X_1 = \underline{0.000871}$

All terminal compositions and flow-rates are established.

$X_1 = 0.000871$, $X_2 = 0.0$, $L^1 = 2176$ Ib moles/hr, $V^1 = 30.2$ 1b moles/hr

$Y_1 = 0.06$, $Y_2 = 0.001$

The entire operating line can be evaluated.

$$30.2\left[\frac{Y}{1-y} - \frac{0.06}{1-0.06}\right] = 2176\left[\frac{x}{1-x} - \frac{0.000871}{1-0.000871}\right]$$

Concentration of the liquid phase is dilute enough so that $(1-x) \simeq 1$,

Therefore,

$$30.2\left[\frac{Y}{1-y} - \frac{0.06}{0.94}\right] = 2176\left[X - \frac{0.000871}{0.999129}\right]$$

$$30.2\left[\frac{y}{1-y} - 0.063829787\right] = 2176\ [x - 0.000871759]$$

$$\frac{30.2y}{1-y} - 1.927659574 = [2176x - 1.896948242]$$

$$\frac{30.2y}{1-y} - 1.927659574 + 1.896948242 = 2176x$$

$$\frac{30.2}{2176}\ \frac{y}{1-y} - \frac{0.030711332}{2176} = x$$

$$x = 0.013878676 \frac{y}{1-y} - 0.000014113$$

When,

$Y = 0.06$

$$X_1 = 0.013878676 \frac{0.06}{1-0.06} - 0.000014113$$

$x_1 = 0.000885872 - 0.000014113$

$x_1 = \underline{0.000871759}$

Where $Y = 0.05$

$$X_2 = 0.013878676 \frac{(0.05)}{1-0.05} - 0.000014113$$

$X_2 = \underline{0.000716}$

$Y = 0.04$

$$X_3 = 0.013878676 \frac{(0.04)}{1-0.04} - 0.000014113$$

$X_3 = \underline{0.000564164}$

$Y = 0.03$

$$X_4 = 0.013878676 \frac{(0.03)}{1-0.03} - 0.000014113$$

$X_4 = \underline{0.000415124}$

$Y = 0.02$

$$X_5 = 0.013878676 \frac{(0.02)}{1-0.02} - 0.000014113$$

$X_5 = \underline{0.000269125}$

When Y = 0.01

$$X_6 = \frac{0.013878676\ (0.01)}{(1 - 0.01)} - 0.000014113$$

X_6 = 0.000126075

Y = 0.001

$$X_7 = \frac{0.01387\,8676\ (0.001)}{(1 - 0.01)} - 0.000014113$$

X_7 = -0.00000022

X_7 will be neglected because it is very small and is a negative value. Or approximated to zero.

It is necessary to calculate the mass-transfer coefficients for both phases, No assumption can be made concerning the controlling phase, to obtain this values requires knowledge of mass velocities of both phases. Since both phase velocities are quantities, which normally appear in the correlations, but only the mass rates of flow are known, hence, it is necessary to determine the area of the tower. The flooding velocities will be obtained from the chart. First, the total flow-rates must be determined.

V_1 = 1000 Ib/hr = 32.15 Ib moles/hr

The SO_2 entering and leaving the column can be calculated by converting the V_1 back to Ib/hr.

The SO_2 entering and leaving the column can be calculated by converting the V_1 back to Ib /hr.

SO_2 entering = 32.15 x 0.06 x 64

= 123.456 Ib/hr

SO_2 leaving = $\frac{0.001}{0.999}$ 30.2 x 64

= 1.935 Ib/hr

Hence, SO_2 absorbed by water will be

123.456 – 1.93 = 121.5 1b/hr.

Fresh water entering = 2176 x 18 = 39168 Ib/hr

Therefore, total liquid leaving will be

39168 + 121.5

G_L = 39289.5 Ib/hr

Assume the density of the gas stream to be essentially that of air at 1 atm and 30°c

Recall that, 1 kmol occupies 22.41 m^3 atm & O°c, 30+273 = 303k - Temperature

ℓ_v = 29/359 x 273/303

ℓ_v = 0.0727 Ib/cu ft

See appendix D_1 for Density of Water

995.62kg	Ib	$(0.3048)^3$ m^3
m^3	0.454kg	ft^3

$$\frac{995.62\ (0.3048)3\ \times 1}{0.454 \times 13} = \frac{28.19282}{0.454}$$

$= \underline{62.1\ Ib/cu\ ft}$

$\frac{G_L}{G_V}\sqrt{\frac{\ell_V}{\ell_L}} = \frac{39289}{1000}\ \frac{0.0727}{62.1}$ [At flooding, the x ordinate superficial gas mass velocity Of the flooding vel. Chart is $= \underline{1.3443}$]

$= 39.289\sqrt{0.001171} = 39.289\ (0.0342)$

$= \underline{1.3443}$

With this ordinate & 1.3443 as abscissa (superficial gas mass velocity) the pressure drop for the packing is estimated from the flooding velocity chart.

As $0.0152 = \frac{F_V^2\ a_V\ (\mu^I_L)^{0.2}}{g_c\ \epsilon^3\ \ell_V \ell_L}$ = Pressure drop

$\frac{G_L}{G_V}\sqrt{\frac{\ell_V}{\ell_L}} = 1.3443$

From the Chart

$$\frac{F_V^2\ a_V\ (\mu^I_L)^{0.2}}{g_c\ \epsilon^3\ \ell_V \ell_L} = 0.0152$$

From the physical characteristics of dry commercial packings it is given that 1in ceramic Raschig ring percent void (E) = 73%,

$g_c = 4.17 \times 10^8$ ft – Ib/Ibf hr^2 and specific surface $\underline{a_V}$ = 58 sqft/cuft.

$F_v^2 (58)\ (1.0)^{0.2} / 4.17x\ 10^8 (0.73)3\ (0.0727)\ (62.1) = 0.0152$

$F_v^2 (58)\ (1.)^{0.2} = 732370169.2 \times 0.0152$

$F_v^2 (58)\ (1) = 11132026.57$

$F_v^2 = 11132026.57/58$

$F_v = \sqrt{191931.4926} = 438.099866 \approx 438.$

$F_v \approx$ 438 Ib/hr sq ft

From the problem, the specifications are to use 50% of flooding velocity/ies.

Thus, $F_v = 0.5 \times 438 =$ 219 Ib/hr/sq ft

As the gas flow at the bottom of the column is greatest, but the area will be based on this flow rate or

$S = v/F_v = 1000/219 =$ 4.57 sq ft

Considering the column diameter, let a = S

$a = S = \pi r^2 = \pi D^2/4$

$4S = \pi D^2$

$D^2 = 4S/\pi$

$D = \sqrt{4S/\pi}$

$\Rightarrow D = \sqrt{4\ (4.57)\ /\ 3.14159} = 2.412ft$

Consequently,

$F_v = 219$ Ib/hr sq ft

$\Rightarrow F_L = 2176\ (18)$ Ib/hr/4.57 sq ft $= 39168/4.57$

$F_L = 8570.6$ Ib/hr sq ft

Liquid Phase

Considering the above quantities, values of H_G, H_L or K_ya, K_xa can be determined.

$H_L = \beta \ (F_L/\mu_L)^n \ (N_{sc})^{1/2}$ ———— 4.32

Since L is essentially constant through the column, the mass transfer coefficient (K_xa) can be deduced from the definition

$H_L = L/K_xaS$ ———— 4.33

First let obtain the value of the H_L from equation (4.32)

Sherwood & Holloway experimental correlation for absorption and desorption data, for cases where the liquid phase was the dominant resistance it's given for various packing materials. For (Rasching Ring 1in) See Appendix table C_2 for the constant values.

β =0.01, n = 0.22, N_{sc} = Schmidt Number for the liquid = 570

μ_L = Liquid viscosity 1b/ft hr = 2.42

$H_L = 0.01 \ (8570/2.42)^{0.22} \ (570)^{1/2} = 0.01(3541.3223)^{0.22} \ (570)^{1/2}$

$H_L = 0.01 \ (6.036934) \ (23.875) = 1.44 ft.$

From definition,

$H_L = L = 1.44 = L/K_xas$

$K_xa = L/H_LS = 2176/1.44) \ (4.57) = 330.6$

K_xa = 331 Ib moles/hr cu ft Δx

Gas phase

The extensive Ammonia – water data have been used to give a useful correlation for the gas phase since its correlation are not as established as those of the liquid phase. The translation of the data to other systems is not easily accomplished by use of the mass transfer coefficient Therefore, an empirical equation of the form is given,

$K_ya = b (f_v)^p (f_L)^r$ ______4.34

Where, b, p and r are constant dependent upon the specific flow rates and geometry of the packing used in the operation as shown in Appendix table B_3.

b = 0.036

p = 0.77

r = 0.20

Thus,

$k_ya = 0.036 (219)^{0.77} (8570)^{0.20}$

$= 0.036(63.41) (6.1178)$

$\Rightarrow K_ya$ = 13.96 Ib moles/hr cuft Δ_y

The Height of the Column

To obtain the interfacial compositions require the knowledge of the ratio of phase resistance, which should be known.

Ratio = - k_xa/ K_ya _______ 4.35

Ratio = 331/13.96 = -23.7

Considering several positions along the operating line the bulk conditions- to – interfacial – conditions relationships are found by plotting tie line of slope of equation (4.35) and reading interfacial compositions from the equilibrium curve. In this problem, (1- y) In and (1–y) are approximately equal and will not be taken into consideration.

Table 4.4 Interfacial composition for number of transfer unit

Y	Yi	Yi-Y	1/yi-y
0.06	0.05071	-0.00929	-107.64
0.05	0.04084	-0.00916	-109.17
0.04	0.031	-0.009	-111.11
0.03	0.02085	-000915	-109.289
0.02	0.01085	-0.00915	-109.289
0.01	0.00141	-0.00859	-116.41
0.001	0.000	-0.001	-1000

Using Simpson's Rule, the number of transfer unit can be obtained from

N_{OG} = A $\simeq$ S/3 {[F + L] + 4E + 2R } __________ 4.36

S = width of each strip.

F + L = sum of the first and last co – ordinates

4E = 4 multiply by the sum of the even numbered coordinates

2R = 2 multiply by the sum of the remaining odd numbered co – ordinates.

Note that each ordinate is used only once [Straud 1987]

$S = 0.01$

$\Rightarrow N_{OG} = A \simeq 0.01/3 \ (1107.64 + 1339.476 + 440.798)$

$\simeq 0.01 \ (2887.914$

$A = N_{OG} = 9.63$

$(1\text{-}y)\ I_m$ at the bottom $= 0.94$

$(I - y)\ I_m$ at the top $= 1 - 0\ .001 = 0.099$

An average of these two quantities $= 0.999 + 0.94/2 = 0.97$

And also an average V of $32.15 + 30.2/2 = 31.175$

$\Rightarrow V_{ar} = 31.2$

It can be use to obtain the height of the transfer unit H_{OG}

$H_{OG} = V_{ar}/K_y a_s\ (1\text{-}y)I_m$ ____________4.37

$H_{OG} = 31.2/(13.96)(4.57)(0.97) = 31.2/61.883$

$\Rightarrow H_{OG} = \underline{0.504\ ft} = \underline{0.154m}$

The height of the transfer column (Z) is determined by multiplying the number of transfer units by the height of a transfer unit.

$Z = H_G N_G = H_{OG} N_{OG} = H_L N_L = H_{OL} N_{OL}$ ________4.38

$Z = 0.504 \times 9.63 = 4.854 = 1.48m$

$\Rightarrow Z = \underline{5\ ft} = \underline{1.52m}$

4.6 CAD METHODOLOGY

The procedure used in the design of the absorption column makes use of tables, equations and graphs in calculating the various design parameters. This procedure is coded in Basic Language.

The procedure used for the source code is shown in figure 4.2

The Source Code For The Module

The source code consists of the files, CAD GAS. Bas, CAD Dat.1 Bas and CAD Dat2. Bas. The SO_2. Bas is the CAD Program source code, with instructions and information appearing at each stage of execution.

The CAD Dat1. bas and CAD Dat2.bas are the databank where most of the physical properties of the components are stored.

Program Run

The sequence of steps needed to run the program is as follows.

1. Load the CAD GAS. Bas and press [F5] to run the program. A table of choice appears.
2. Select Solute Gas from the list on the screen.
3. Select appropriate Solvent from the list on the screen.

NOTE: That the sample Design problem SO_2 should be selected for the solute gas and Water for the solvent.

4. Select choice from the main menu.
   1. Enter Data from keyboard.
   2. Load Data from file
   3. Compute Diameter
   4. Compute Height
   5. Display Result
   6. Quit.

5. If choice **I** is selected, the user will enter the necessary parameters for the required problem. These parameters are: (a) Inlet percentage of Solute gas (b) Percentage of dry air (c) amount of gas, (d) The rate of flooding velocity etc.

Enter the operating temperature and pressure, Density of Liquid, Schimidt number, Rate of Water flow.

Enter the pressure of Solute gas (i) and Solute gas per 100g of water (i).

If choice 2 is chosen (which is done for the sample problem) the necessary data is obtained from the stored data from the program.

The program asks the user: If it is a new set of data, then the user answer Yes (Y), otherwise the response is No (N).

The program states: Data successfully loaded press any key to continue.

Choice 3 and 4 calculates the diameter and height of the column.

Choice 5 displays the complete output from the module. If the results are satisfactory proceed to choice 6 which terminates the execution of the program.

If the results are not satisfactory, then the user can proceed to choice 1,2,3 or 4 to modify the specified parameters.

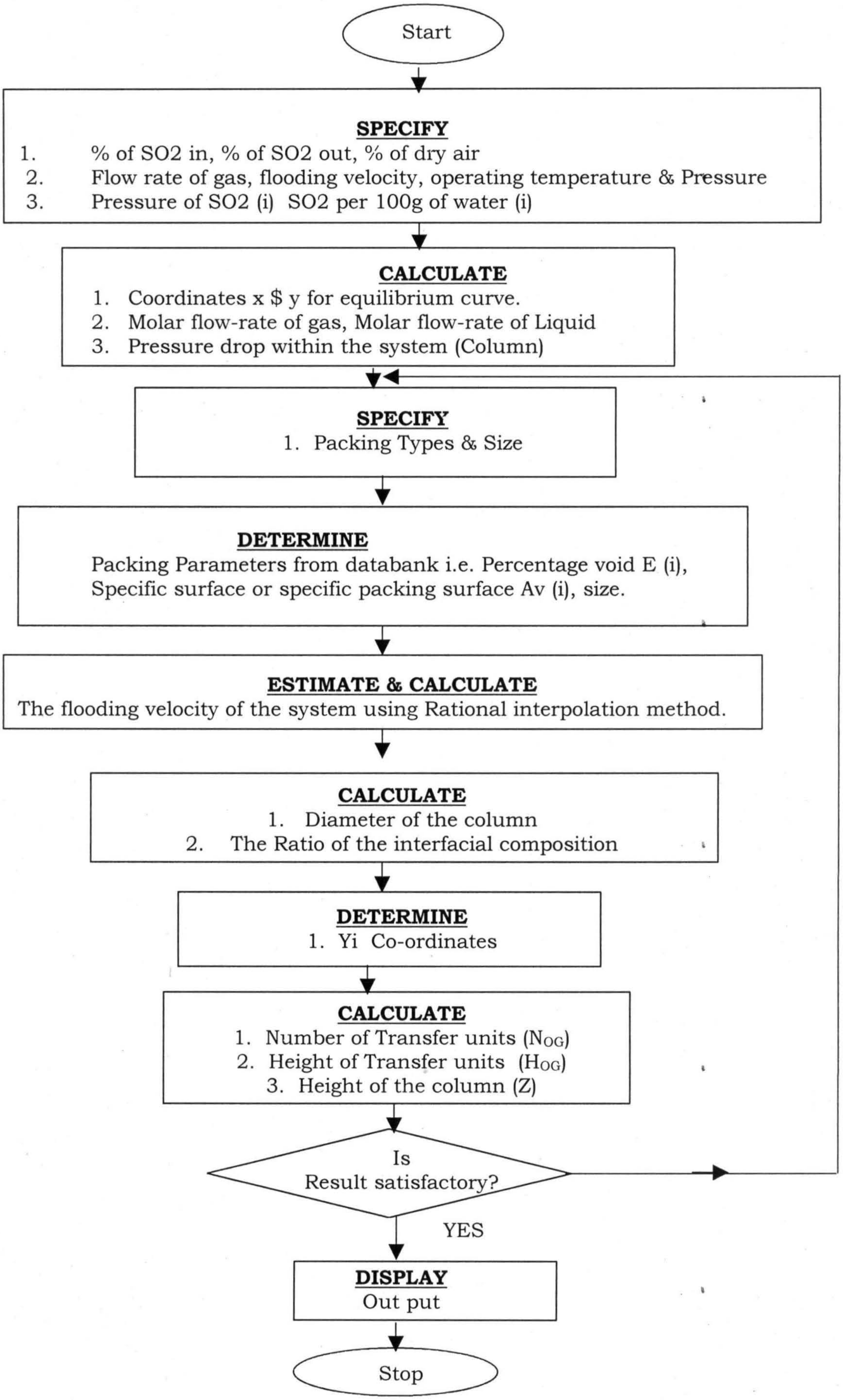


Fig. 4.2 Flow Chart of Procedure for the Source Code

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

The results obtained from manual and CAD module are shown in table 5.1 while those obtained by varying certain parameters of the sample problem are shown in Tables 5.2 to 5.4 .

5.1: RESULT FOR MANUAL CALCULATION AND CAD MODULE

Table 5.1 Results from manual calculation & CAD Module

Methods	Pressure Drop	Diameter (m)	No. of transfer unit NoG	Height of Transfer unit HoG (m)	Height of the Column (m)
CAD Results	0.0140	0.75	9.69	0.15	1.49
Manual Results	0.0152	0.74	9.63	0.16	1.48

TABLE 5.2 Shows results obtained from CAD Program module using sample design problem with two different types of packing 1in at operating temperature of 30°C

TABLE 5.2 CAD RESULT COMPARING TWO DIFFERENT TYPES OF PACKING.

Packing		Absorption Column obtained	
Types	**Size (in)**	**Diameter (m)**	**Height (m)**
Ceramic Raschig Ring	1	0.75	1.49
Berl Saddle	1	0.84	1.48

TABLE 5.3 Shows results obtained from CAD Program using the design problem with two types of 1in at specified temperature of 40°c .

Table 5.3 CAD RESULTS AT 40^{o}C SPECIFIED TEMPERATURE

Packing		Absorption Column obtained		
Types	Size (in)	Temperature (°C)	Diameter (m)	Height (m)
Ceramic Rasching Ring	1	40	0.75	1.49
Berl Saddle	1	40	0.84	1.48

TABLE: 5.4 Shows the result of CAD module program with lower percentage of the flooding velocity comparing with the design sample problem.

TABLE 5.4 CAD RESULT WITH 50% FLOODING VELOCITY & 80% FLOODING VELOCITY.

Packing Types & Size	% Flooding Velocity	Column Diameter (m)	Column Height (m)
Ceramic Raschig Ring	50	0.75	1.49
Ceramic Raschig 1in	80	0.59	1.01

Table 5.5: The Summary of CAD Results, Manual Results And Result from Textbook

TABLE 5.5: COMPARING CAD RESULTS MANUAL RESULTS & TEXTBOOK RESULTS

Methods	Pressure Drop from the Chat	Diameter (m)	No of transfer unit NoG	Height of transfer Unit HoG (m)	Height of Column (m)
CAD Result	0.014	0.75	9.69	0.15	1.49
Manual Result	0.015	0.74	9.63	0.16	1.54
Textbook Result	0.015	0.74	14.30	0.16	2.28

5.2 **Discussion of Results:**

A lot of work have been done in Computer Aided Design Module on Gas Absorption Column using different type of methods (Salako 2001) and host of others using Onda's method, but none of them has done any work using the sherwood and Holloway Correlation in calculating the mass transfer coefficients of gas and liquid phases K_ya & K_xa respectively.

This work uses the flooding velocity chart in fig 3.4, which correlates the liquid and vapour flow-rates, system physical properties and packing characteristics with the mass flow-rate per unit cross - sectional area with line of constant pressure drop. This chart was then used to obtain the number of transfer unit by applying Simpson's Rule and using on interpolation method.

The results in Table 5.1 shows that there is a reasonable agreement between the CAD module results compared with that of manual or hand calculation. The small difference, observed in the interpolated value from the flooding velocity chart, diameter of the column, the number of transfer unit and the height of the column is due to round -off values in manual calculation.

Table 5.2, shows the result when ceramic Raschig Rings and Berl Saddles of the same size were used. Results for ceramic Raschig Ring show that a taller but smaller diameter column were obtained. This is because "the gas flow-rate per unit cross sectional area is inversely proportional to the column area. Therefore, as the packing factor decreases the gas flow - rate per unit area increases hence the column area and the column diameter decreases. For the same fact, the column height increases". This trend is also observed in Table 5.3. Table 5.2 and 5.3 give the design result of operating temperature $30^{0}C$ and $40^{0}C$ respectively. The results show, that increase in temperature result in increase in diameter but a reduction in the height of the column. This could be attributed to the effect of temperature on the physical properties such as density, viscosity, surface tension, diffisivity etc. For example, the density of a liquid (Water) decrease with increase in temperature and since the liquid density is proportional to the height of transfer unit, the density of the liquid is low at higher temperature. Hence, the height of the column increases.

Table 5.4, shows the result when percentage of flooding velocity was increased. This led to reduction in both height and diameter of the column, since the capacity of the column is determined by its cross – sectional area which depends on the flooding velocity.

Table 5.5, shows the summary of the results of CAD module, Manual calculation and Results from Text–book. There are some slight discrepancies when the number of transfer unit, diameter, and the height of the column obtained from CAD results were compared with that of the sample problem from textbook. The slight difference in this case is due to the techniques used in graphical integration of equilibrium – operating line data on xy – co-ordinates.

The importance of computer work against manual work includes:

- Accuracy:- The need for a high degreed of accuracy is satisfied by the computer and its consistency can be relied upon.
- Volume:– The computer is particularly suited to handling large amounts of data.
- Speed:– Computers work at phenomenal speeds. This combined with their ability to communicate with other systems, even those at remote locations, enables them to respond very quickly to given situations.
- Complexity:- The computer can perform the most complex calculation. As long as the application can be programmed then the computer can provide the answers required.
- Common data:– One item of data on a computer system may be involved in several different procedures, or accessed, updated or inspected by a number of different users.. In manual systems date is often accessible to a limited number of people for particular purposes. This can hinder the work of others who need access at the data.
- Repetitiveness:– Processing cycles that repeat themselves over and over again are ideally suited to computers. Once programmed the computer happily goes on and on automatically performing as many cycles as required.

CHAPTER SIX

6.0 CONCLUSION.

CAD module was developed for the design of a gas absorption column. It employed sherwood and Holloway experimentally correlated absorption data for cases where the liquid phase was the dominant resistance. The module can be run by supplying specifications, data banks for physical property data such as values of the constants for the correlation, density of the Liquid, Percentage voids and specific surface etc., are also incorporated for running the program.

The module allows easy variation of temperature, types of packings and product specifications, to obtain optimal design.

6.1 **RECOMMENDATION**

The project work may be extended to:

- The Cad of absorber involving different solutes and solvents.
- CAD module where chemical reactions are involved in the absorption processes.
- CAD Module to handle the absorption processes where the solvent is not – solute free before it is introduced into the column.
- The Nigerian University Commission should introduce more courses in the development of computer software in the engineering profession to improve design specification and reduce cost.

6.2 REFERENCES

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APPENDIX A

A_1: Equations For Rational Interpolation

n = a+1+b=15

a= 7 and b =7

$\Rightarrow$ n = 7+1+7=15

$$y = \frac{p_0 + p_{1x} + p_2x^2 + p_3x^3 + p_4x^4 + p_5x^5 + p_6x^6 + p_7x^7}{1 + q_1x + q_2x^2 + q_3x^3 + q_4x^4 + q_5x^5 + p_6x^6 + q_7x^7}$$

$$y\left[1 + q_1x + q_2x^2 + q_3x^3 + q_4x^4 + q_5x^5 + q_6x^6 + q_7x^7\right] = p_0 + p_{1x}$$
$$+ p_2x^2 + p_3x^3 + p_4x^4 + p_5x^5 + p_6x^6 + p_7x^7$$

1. Where x = 0.01 and y= 0.25

   $0.25+0.0025q_1 + 2.5\text{x}10^{-5}\, q_2 + 2.5\text{x}10^{-7}\, q_3 + 2\text{x}10^{-9}\, q_4$
   $+ 2.5\text{x}10^{-11}\, q_5 + 2.5\text{x}10^{-13}\, q_6 + 2.5\text{x}10^{-15}\, q_7 = p_0+0.01\, p_1 + 0.0001\, p_2$
   $+ 0.000001\, p_3 + 0.00000001\, p_4 + 1\text{x}10^{-10}\, p_5 + 1\text{x}10^{-12}\, p_6 + 1\text{x}10^{-14}\, p_7$

2. Where x= 0.02 and y=0.22

   $0.22 + 0.0044q_1+0.000088q_2 + 1.76\text{x}10^{-6}\, q_3+3.5\text{x}10^{-8}\, q_4$
   $+7.04\text{x}10^{-10}\, q_5+1.408\text{x}10^{-11}q_6+ 2.816\text{x}10^{-13}\, q_7= p_0+0.02\, p_1 +$
   $0.0004\, p_2+0.000008\, p_3 +0.00000016\, p_4+3.0\text{x}10^{-9}\, p_5$
   $+ 6.4\text{x}10^{-11}\, p_6+1.28\text{x}10^{-12}\, p_7$

3. Where x = 0.04 and y = 0.18

   $0.18 + 7.2\text{x}10^{-8}\, q_1+2.88\text{x}10^{-4}\, q_2 +1.152\text{x}10^{-5}\, q_3+4.6\text{x}10^{-7}\, q_4$
   $+ 1.8\text{x}10^{-8}\, q_5+ 7.3728 \text{ x } 10^{-10}\, q_6 + 2.94912\text{x}10^{-11}\, q_7 = p_0+0.04\, p_1$
   $+ 1.6 \text{ x } 10^{-3}\, p_2 + 6.4\text{x}10^{-5}\, p_3+2.56\text{x}10^{-6}\, p_4+1.02\text{x}10^{-7}\, p_5+4\text{x}10^{-9}\, p_6$
   $+ 1.6384\text{x}10^{-10}\, p_7$

4. Where x = 0.06 and y = 0.15

   $0.15 + 0.009\, q_1 + 5.4\text{x}10^{-4}\, q_2 + 3.24\text{x}10^{-5}\, q_3+1.944\text{x}10^{-6}\, q_4$
   $+ 1.16\text{x}10^{-7}\, q_5+6\text{x}10^{-10}\, q_6 + 4.199\text{x}10^{-10}\, q_7 = p_0 + 0.06\, p_1+0.0036\, p_2$
   $+0.000216\, p_3+2\text{x}10^{9}\, p_4 + 7.77\text{x}10^{-7}\, p_5+4.6\text{x}10^{-8}\, p_6+2\text{x}10^{-9}\, p_7$

5. Where x = 0.08 and y = 0.13

$0.13 + 0.0104\ q_1 + 8.32 \times 10^{-4}\ q_2 + 6.656x10^{-5}\ q_3 + 5.324x10^{-6}\ q_4$
$+ 4.25x10^{-7}\ q_5 + 3.4x10^{-8}\ q_6 + 2x10^{-9}\ q_7 = p_0 + 0.008\ p_1 + 6.4x10^{-3}\ p_2$
$+ 5.12x10^{-4}\ p_3 + 4.096x10^{-5}\ p_4 + 3.276x10^{-6}\ p_5 + 2.62x10^{-7}\ p_6 + 2x10^{-8}\ p_7.$

6. Where x = 0.1 and y = 0.087

$0.87 + 0.0087\ q_1 + 8.7x10^{-4}\ q_2 + 8.7x10^{-5}\ q_3 + 8.710^{-6}\ q_4$
$+8.7x10^{-7}\ q_5 + 8.7x10^{-8}\ q_6 + 8x10^{-9}\ q_7 = p_0 + 0.1\ p_1 + 0.01\ p_2$
$+0.001\ p_3 + 0.0001\ p_4 + 0.00001\ p_5 + 0.000001\ p_6 + 0.0000001\ p_7$

7. Where x = 0.2 and y = 0.069

$0.069 + 0.0138\ q_1 + 0.00276\ q_2 + 0.000552\ q_3 + 0.000104\ q_4$
$+ 2.208x10^{-5}\ q_5 + 4.416x10^{-6}\ q_6 + 8.83x10^{-7}\ q_7 = p_0 + 0.2\ p_1$
$+ 0.04\ p_2 + 0.008\ p_3 + 0.0016\ p_4 + 3.2x10^{-4}\ p_5 + 2x10^{-8}\ p_6$
$+1.28x10^{-5}\ p_7.$

8. Where x = 0.4 and y = 0.042

$0.042 + 0.0168\ q_1 + 0.00672\ q_2 + 0.002688\ q_3 + 0.0010752\ q_2$
$+ 4.3008\ x10^{-4}\ q_5 + 1.72032x10^{-4}\ q_6 + 6.8812\ x10^{-5}\ q_7\ p_0 + 0.4\ p_1$
$+ 0.16\ p_2 + 0.064\ p_3 + 0.0256\ p_4 + 0.01024\ p_5 + 0.004096\ p_6$
$+ 0.0016384\ p_7.$

9. Where x = 0.6 and y = 0.030

$0.030 + 0.018\ q_1 + 0.0108\ q_2 + 0.00648\ q_3 + 0.003888\ q_4$
$+ 0.0023328\ q_5 + 0.00139968\ q_6 + 0.000839808\ q_7 = p0 + 0.6\ p_1$
$+ 0.36\ p_2 + 0.216\ p_3 + 0.1296\ p_4 + 0.07776\ p_5 + 0.046656\ p_6$
$+ 0.0279936\ p_7$

10. Where x = 0.8 and y = 0.023

$0.023 + 0.01814\ q_1 + 0.01472\ q_2 + 0.011776\ q_2 + 0.011451041\ q_4$
$+ 7.53664x10^{-3}\ q_5 + 0.06029312\ q_6 + 4.823449x10^{-3}\ q_7 = p_0$
$+ 0.8p_1 + 0.64\ p_2 + 0.512\ p_3 + 0.409\ p_4 + 0.32768\ p_5$

$+ 0.262144\ p_6 + 0.054975581\ p_7$

11. Where X=1.0 and y=0.018

    $0.018+0.018q_1+0.018q_2+0.018q_3+0.018q_4+0.018q_5+0.018q_6+0.08q_7=P_0+P_1+P_2+P_3+P_4+P_5+P_6+P_7.$

12. Where X=2.0 and y=0.009

    $0.00q+0.018q_1+0.36q_2+0.072q_3+0.144q_4+0.288q_5+0.576q_6+1.152q_7=P_0+2P_1+4P_2+8P_3+16P_4+32P_5+64P_6+128P_7.$

13. Where X=4.0 and y=0.004

    $0.004+0.016q_1+0.064q_2+0.256q_3=1.024q_4+4.096q_5+16.384q_6+65.536q_7=P_0+4P_1+16P_2+64P_3+256P_4+1024P_5+4096P_6+16384P_7.$

14. Where X=6.0 and y=0.0019

    $0.0019+0.0114q_1+0.0684q_2+0.4104q_3+2.4624q_4+14.7744q_5+88.6464q_6+531.8784q_7=P_0+6P_1+36P_2+216P_3+1296P_4+7776P_5+46656P_6+279936P_7.$

15. Where X=8.0 and y=0.001

    $0.001+0.008q_1+0.0684q_2+0.4104q_3+4.096q_4+32.768q_5+262.144q_6+2097.152q_7=P_0+8P_1+64P_2+512P_3+4096P_4+32768P_5+262144P_6+2097152P_7.$

Multiplying the 15 points by 10,000, we have the following

1. $2500 = 10000P_0 + 100P_1 + P_2 + 0.01P_3 + 0.0001P_4 + 0.000001P_5 + 0.00000001P_6\ 1x10^{-10}P_7 - 25q_5 - 0.00000000296 - 2.5x\ 10^{-11}\ q_7.$

2. $2200 = 10000P_0 + 200P_1 + 4P_2 + 0.08P_3 + 0.0016P_4 + 0.00003P_5 + 6.4x10^{-7}P_6 + 1.2x10^{-8}q_4 - 7.04x10^{-6}q_5 - 1.4x10^{-7}q_6 - 2x10^{-9}q_7.$

3. $1800 = 10000P_0 + 400P_1 + 16P_2 + 0.64P_3 + 2.56x10^{-2}P_4 + 1.02x10^{-3}P_5 + 4x10^{-5}P_6 + 1.638x10^{-6}P_7 - 72q_1 - 2.88q_2 - 0.1152P_3 - 0.0046q_4 - 1.8\ x10^{-4}q_5 - 7.372x10^{-6}q_6 - 2.94x10^{-7}.$

4. $1500 = 10000P_0 + 600P_1 + 36P_2 + 2.16p_3 + 2x10^{-5}P_4 + 7.77x10^{-3}P_5 + 4.6x10^{-4}P_6 + 2x10^{-5}P_7 - 90P_1 - 5.4q_2 - 0.324q_3 - 0.01944q_4 - 1.16x10^{-3}q_5 - 6x10^{-5}q_6 - 4.199x10^{-6}q_7$

5. $1300 = 10000P_0 + 800P_1 + 64P_2 + 2.62x10^{-3}P_3 + 0.4096P_4 - 0.03276P_5 + 2.62x10^{-3}P_6 + 2x10^{-4}P_7 - 1.0816q_1 - 8.32q_2 - 0.6656q_3 - 0.5324q_4 - 4.25x10^{-3}q_5 - 3.4x10^{-4} q_6 - 2x10^{-5}q_7$.

6. $870 = 10000P_0 + 2000P_1\ 100P_2 + 10P_3 + P_4 + 0.1P_5 + 0.01P_6 + 0.001P_7 - 87q_1 - 8.7q_2 - 0.87q_3\ 0.087q_4 - 0.0087q_5 - 8.7 x10^{-4}q_6 - 8x10^{-5}q_7$.

7. $690 = 10000P_0 + 2000P_1 + 400P_2 + 80P_3 + 16P_4 + 3.2P_5 + 2x10^{-4}P_6 + 0.128P_7 - 138q_1 - 27.6q_2 - 5.52q_3 - 1.104q_4 - 0.2203q_5 - 4.416x10^{-2}q_6 - 8.83x10^{-3}q_7$.

8. $420 = 10000P_0 + 4000P_1 + 1600P_2 + 640P_3 + 256P_4 + 102.4P_5 + 40.96P_6 + 16.384P_7 - 168q_1 - 67.2q_2 - 26.88q_3 - 10.752q_4 - 4.3008q_5 - 1.72032q_6 - 0.39808q_7$.

9. $300 = 10000P_0 + 6000P_1 + 3600P_2 + 2160P_3 + 1296P_4 + 777.6P_5 + 466.56P_6 + 279.936P_7 + 180q_1 - 108q_2 - 64.8q_3 - 38.88q_4 - 23.328q_5 - 13.9968q_6\ 8.39808q_7$.

10. $230 = 10000P_0 + 800P_1 + 6400P_2 + 5120P_3 + 4096P_4 + 3276.8P_5 + 2621.24P_6 + 549.755P_7 - 184q_1 - 147.2q_2 - 117.76q_3 - 144.51041q_4 - 75.3664q_5 - 602.9312q_6 - 48.235449q_7$.

11. $180 = 10000P_0 + 10000P_1 + 10000P_2 + 10000P_3 + 10000P_4 + 10000P_5 + 10000P_6 + 10000P_7 - 180q_1 - 180q_2 - 180q_3 - 180q_4 - 180q_5 - 180q_6 - 180q_7$.

12. $90 = 10000P_0 + 20000P_1 + 40000P_2 + 80000P_3 + 160000P_4 + 320000P_5 + 640000P_6 + 1280000P_7 - 180q_1 - 360q_2 - 720q_3 - 1440q_4 - 2880q_5 - 5760q_6 - 11520q_7$.

13. $40 = 10000P_0 + 40000P_1 + 160000P_2 + 640000P_3 + 2560000P_4 + 10240000P_5 + 40960000P_6 + 163840000P_7 - 160q_1 - 640q_2 - 2560q_3 - 10240q_4 - 40960q_5 - 163840q_6 - 655360q_7$.

14. $19 = 10000P_0 + 60000P_1 + 360000P_2 + 2160000P_3 + 12960000P_4$ $77760000P_5 + 466560000P_6 + 2799360000P_7 - 114q_1 - 6184q_2 - 4104q_3 - 24614q_4 - 147744q_5 - 886464q_6 - 5318784q_7$.

15. $10 = 10000P_0 + 80000P_1 + 6400000P_2 + 5120000P_3 + 40960000P_4 + 327680000P_5 + 2621440000P_6 + 2.097152x10^{10}P_7 - 80q_1 - 640q_2 - 5120q_3 - 40960q_4 - 327680q_5 - 2612440q_6 - 2.097152x10^{10}q_7$.

The equations for the 15 points as given above and the matrix for obtaining the unknowns using n by n matrix which is included in the qbasic program in Appendix B.

Appendix B

LIST OF COMPUTER PROGRAM AND ITS RESULTS

```
DECLARE FUNCTION Finden! (mtemp!)
DECLARE FUNCTION Interpo! (x!)
'** UTEBOR MICHEAL MANASSEH EMEKE
'** M.ENG/SEET/1999/2000/436
'** CHEMICAL ENGINEERING DEPARTMENT, F.U.T. MINNA
DECLARE SUB Calcuyii (num, Tyis(), pts1(), rats)
DECLARE SUB clrscr ()
DECLARE FUNCTION getmax! (vec!(), num!)
DECLARE SUB borders (x1!, y1!, x2!, y2!)
DECLARE SUB joinpts (num!, pts1(), xcheck, ycheck)
DIM pts(50, 2), x(20), y(20), Tx(20), Ty(20), Tysend(20)
DIM e(14), Av(14), comp$(14)
clrscr
no = 9
flag = 0
fflag = 0
cho$ = "0"
DO UNTIL VAL(cho$) = 6
cho$ = "0"
   clrscr
   LOCATE 7, 20: PRINT "1. Enter New set of Data "
   LOCATE 9, 20: PRINT "2. Load Saved Data from Disk "
   LOCATE 11, 20: PRINT "3. Compute Diameter "
   LOCATE 13, 20: PRINT "4. Compute Height "
   LOCATE 15, 20: PRINT "5. Display Output File"
   LOCATE 17, 20: PRINT "6. Quit "
 DO UNTIL VAL(cho$) > 0 AND VAL(cho$) <= 6
   LOCATE 19, 20: INPUT "Select Option (1..6) : "; cho$
 LOOP
SELECT CASE VAL(cho$)
 CASE 1
      GOSUB dataentry
 CASE 2
      GOSUB readdata
 CASE 3
      GOSUB computed
 CASE 4
      GOSUB computeh
 CASE 5
      GOSUB Listrpt
END SELECT
LOOP
END

dataentry:
flag = 1
clrscr
INPUT "Enter Percentage of SO2 in  : "; so2in
INPUT "Enter Percentage of SO2 out : "; so2out
INPUT "Enter Step of Increment     : "; nstep
INPUT "Enter Percentage of dry air : "; dryair
INPUT "Enter Amount of Gas         : "; Amtgas
INPUT "Enter Flooding Velocity     : "; fvel
INPUT "Enter Operating Temperature : "; Optemp
INPUT "Enter Operating Pressure    : "; Oppres
INPUT "Enter Schimidt Number       : "; Nsc
INPUT "Enter Rate of Water Flow    : "; Wrate
PRINT
```

```
FOR i = 1 TO no
  INPUT "Enter Pressure of SO2        : "; PSo2(i)
  INPUT "Enter SO2 per 100g of Water : "; C(i)
  INPUT "Enter Density of Solution   : "; Densol(i)
  y(i) = PSo2(i) / 760
  x(i) = .0028125# * C(i) / (1 + (.0028125# * C(i)))
NEXT i
 PRINT "Do you wish to write data to File (Y/N) : "
 ans$ = ""
 DO UNTIL ans$ = "Y" OR ans$ = "N"
    ans$ = INPUT$(1)
 LOOP
 IF UCASE$(ans$) = "Y" THEN
    GOSUB writedata
 END IF
RETURN

writedata:
OPEN "so2.dat" FOR OUTPUT AS #1
WRITE #1, so2in
WRITE #1, so2out
WRITE #1, nstep
WRITE #1, dryair
WRITE #1, Amtgas
WRITE #1, fvel
WRITE #1, Optemp
WRITE #1, Oppres
WRITE #1, Denliq
WRITE #1, Nsc
WRITE #1, Wrate
FOR i = 1 TO no
WRITE #1, PSo2(i)
WRITE #1, C(i)
WRITE #1, Densol(i)
  y(i) = PSo2(i) / 760
  x(i) = .0028125# * C(i) / (1 + (.0028125# * C(i)))
WRITE #1, y(i)
WRITE #1, x(i)
NEXT i
CLOSE #1
RETURN

readdata:
flag = 1
clrscr
OPEN "so2.dat" FOR INPUT AS #2
INPUT #2, so2in
INPUT #2, so2out
INPUT #2, nstep
INPUT #2, dryair
INPUT #2, Amtgas
INPUT #2, fvel
INPUT #2, Optemp
INPUT #2, Oppres
INPUT #2, Denliq
INPUT #2, Nsc
INPUT #2, Wrate
```

```
FOR i = 1 TO no
INPUT #2, PSo2(i)
INPUT #2, C(i)
INPUT #2, Densol(i)
  y(i) = PSo2(i) / 760
  x(i) = .0028125# * C(i) / (1 + (.0028125# * C(i)))
INPUT #2, y(i)
INPUT #2, x(i)
NEXT i
CLOSE #2
PRINT "Data Successfully Read from File. Press any Key": Press$ = INPUT$(1)
RETURN

computed:
clrscr
IF flag <> 1 THEN
   PRINT "You must Select 1 or 2 before you can Compute Diameter": Press$ =
INPUT$(1)
   RETURN
END IF
OPEN "so2.out" FOR OUTPUT AS #2
maxx = getmax(x(), no)
maxy = getmax(y(), no)
FOR i = 1 TO no
    pts(i, 1) = 40 + (600 * x(i) / maxx)
    pts(i, 2) = 300 - (300 * y(i) / maxy)
NEXT i
y1 = so2in / 100
y2 = so2out / 100
V1 = Amtgas / ((y1 * 64) + (dryair / 100 * 29))
V1prime = V1 * (1 - y1)
x2 = 0


yget = y1
    ysend = 300 - (300 * yget / maxy)

SCREEN 9
borders 40, 0, 640, 300
LOCATE 1, 1: PRINT USING ".####"; maxy
LOCATE 22, 4: PRINT "0"
LOCATE 23, 76: PRINT USING ".####"; maxx
joinpts no, pts(), xsend, ysend
LINE (xsend, 300)-(xsend, ysend)
LINE (40, ysend)-(xsend, ysend)
xget = (xsend - 40) * maxx / 600
x1 = xget
LOCATE 2, 10: PRINT "Value of Y = "; yget
LOCATE 4, 10: PRINT "Value of X = "; xget
a$ = INPUT$(1)
SCREEN 2: SCREEN 0
Ly = (y2 / (1 - y2)) - (y1 / (1 - y1))
Lpri = (V1prime * Ly) / ((x2 / (1 - x2)) - (x1 / (1 - x1)))
Lprime = Wrate * Lpri
x1 = (V1prime * Ly / Lprime) / (V1prime * Ly / Lprime - 1)

i = 0
```

```
FOR yy = y1 TO 0 STEP -nstep
    i = i + 1
    Ty(i) = yy
    a = V1prime * ((Ty(i) / (1 - Ty(i))) - (y1 / (1 - y1))) / Lprime
    B = x1 / (1 - x1)
    Tx(i) = (a + B) / (1 - (a + B))
    PRINT "y = "; Ty(i): PRINT "x = "; Tx(i)
NEXT yy
Ty(i) = y2
no2 = i
Vin = V1 * y1 * 64
Vout = (y2 / (1 - y2)) * V1prime * 64
Abso2 = Vin - Vout
Freshw = Lprime * 18
gv = Amtgas
gl = Freshw + Abso2
ktemp = Optemp + 273
ev = (29 / 359) * (273 / ktemp)
el = (Denliq * (.3048 ^ 3)) / .454
PresDrop = (gl / gv) * ((ev / el) ^ .5)

'************Calculate fv here
clrscr
chol$ = "0"
DO UNTIL VAL(chol$) <> 0
chol$ = "0"
   clrscr
   LOCATE 7, 8: PRINT "1. Ceramic Rasching (1/4)      2. Ceramic Rasching (1/2)
"
   LOCATE 9, 8: PRINT "3. Ceramic Rasching (1)        4. Ceramic Rasching (2) "
   LOCATE 11, 8: PRINT "5. Berl Saddle (1/4)          6. Berl Saddle (1/2)    "
   LOCATE 13, 8: PRINT "7. Berl Saddle (1)             8. Berl Saddle (2)     "
   LOCATE 15, 8: PRINT "9. Pall Rings (1)             10. Pall Rings (2)      "
   LOCATE 17, 7: PRINT "11. Cyclohelix & Spiral (3.25) 12. Cyclohelix & Spiral
(4)"
   LOCATE 19, 7: PRINT "13. Cyclohelix & Spiral (6)    14. Exit  "
 DO UNTIL VAL(chol$) > 0 AND VAL(chol$) <= 14
   LOCATE 21, 20: INPUT "Select Option (1..14) : "; chol$
 LOOP
 ii = VAL(chol$)
 IF ii <> 14 THEN
 OPEN "databk1.dat" FOR INPUT AS #1
 FOR i = 1 TO 13
     INPUT #1, e(i)
     INPUT #1, Av(i)
     'input #1,
     'input #1,
 NEXT i
 CLOSE #1
 END IF
LOOP

clrscr
PRINT
INPUT "Enter value from Flooding Velocity Graph : "; valgrh
```

```
gc = 417000000
ul = 1!
e(ii) = e(ii) / 100
fv = ((gc * (e(ii) ^ 3) * ev * el * valgrh) / (Av(ii) * (ul ^ .2))) ^ .5
ufv = fvel / 100 * fv
s = gv / ufv
pie = 3.141592654#
d = ((4 * s) / pie) ^ .5
fl = Lprime * 18 / s
GOSUB printout0
RETURN

computeh:
GOSUB computed
clrscr
cho2$ = "0"
DO UNTIL VAL(cho2$) <> 0
cho2$ = "0"
   clrscr
   LOCATE 7, 8: PRINT "1. Raschig Rings (0.5) "
   LOCATE 8, 8: PRINT "2. Raschig Rings (1) "
   LOCATE 9, 8: PRINT "3. Raschig Rings (1.5) "
   LOCATE 10, 8: PRINT "4. Raschig Rings (2)  "
   LOCATE 11, 8: PRINT "5. Berl Saddles (0.5) "
   LOCATE 12, 8: PRINT "6. Berl Saddles (1)  "
   LOCATE 13, 8: PRINT "7. Berl Saddles (1.5)"
   LOCATE 14, 8: PRINT "8. Spiral Rings  (3)  "
   LOCATE 15, 8: PRINT "9. Exit  "
 DO UNTIL VAL(cho2$) > 0 AND VAL(cho2$) <= 9
   LOCATE 19, 20: INPUT "Select Option (1..9) : "; cho2$
 LOOP
 jj = VAL(cho2$)
 IF jj <> 9 THEN
 OPEN "databk2.dat" FOR INPUT AS #1
 FOR i = 1 TO 8
     INPUT #1, be(i)
     INPUT #1, om(i)
 NEXT i
 CLOSE #1
 END IF
 LOOP

'************Calculate Hl here
Hl = be(jj) * ((fl / d) ^ om(jj)) * (Nsc ^ .5)
Kxa = Lprime / (Hl * s)
Kya = .036 * (ufv ^ .77) * (fl ^ .2)
ratio = Kxa / Kya

SCREEN 9
maxx = getmax(x(), no)
maxy = getmax(y(), no)
FOR i = 1 TO no
    pts(i, 1) = 40 + (600 * x(i) / maxx)
    pts(i, 2) = 300 - (300 * y(i) / maxy)
NEXT i
borders 40, 0, 640, 300
LOCATE 1, 1: PRINT USING ".####"; maxy
```

```
LOCATE 22, 4: PRINT "0"
LOCATE 23, 76: PRINT USING ".####"; maxx
joinpts no, pts(), xsend, ysend

maxx = getmax(Tx(), no2)
maxy = getmax(Ty(), no2)
FOR i = 1 TO no2
    ptts(i, 1) = 40 + (600 * Tx(i) / maxx)
    ptts(i, 2) = 300 - (300 * Ty(i) / maxy)
    Tysend(i) = 0
NEXT i

joinpts no2, ptts(), xsend, ysend

Calcuyii no2, Tysend(), ptts(), ratio

FOR l = 1 TO no2
IF Tysend(l) = 0 THEN Tyi(l) = 0 ELSE Tyi(l) = (300 - Tysend(l)) * maxy / 300
NEXT l
'LOCATE 2, 10: PRINT "Value of Y = "; yget
'LOCATE 4, 10: PRINT "Value of X = "; xget
a$ = INPUT$(1)
SCREEN 2: SCREEN 0

GOSUB Printout1
CLOSE #2
RETURN


printout0:
PRINT #2, "EQUILIBRIUM DATA AT"; Optemp; "(Degrees Centigrade)"
PRINT #2, "****************************************************"
PRINT #2,
PRINT #2, "Pressure    C grams/100 grams   Density of        y         x"
PRINT #2, " of So2     of water                Solution    "
PRINT #2, "-----------------------------------------------------------------"
FOR i = 1 TO no
   PRINT #2, USING "##.###"; TAB(2); PSo2(i);
   PRINT #2, USING "##.###"; TAB(18); C(i);
   PRINT #2, USING "##.###"; TAB(35); Densol(i);
   PRINT #2, USING "##.###"; TAB(48); y(i);
   PRINT #2, USING "##.#######"; TAB(58); x(i)
NEXT i
PRINT #2,
PRINT #2, "Molar Flow Rate of Gas/Vapour Phase (lb moles/hr) : "; V1prime
PRINT #2, "Molar Flow Rate of Liquid Phase (lb moles/hr) : "; Lprime
PRINT #2, "Flow Rate of Liquid (lb/hr)                    : "; gl
PRINT #2, "Flow Rate of Solute gas (lb/hr)                : "; gv
PRINT #2, "Mass Velocity of Vapour (lb/hr sq ft)          : "; fv
PRINT #2, "Diameter of the Column  (ft)                   : "; d
PRINT #2, "Mass Transfer Co-efficient (Liquid)            : "; Kxa
PRINT #2, "Mass Transfer Co-efficient (Gas)               : "; Kya
PRINT #2,
RETURN

Printout1:
PRINT #2, "EQUILIBRIUM DATA AT"; Optemp; "(Degrees Centigrade)"
```

```
PRINT #2, "****************************************************"
PRINT #2,
PRINT #2, "Pressure    C grams/100 grams   Density of        y         x"
PRINT #2, " of So2     of water              Solution    "
PRINT #2, "-----------------------------------------------------------------"
FOR i = 1 TO no
   PRINT #2, USING "##.###"; TAB(2); PSo2(i);
   PRINT #2, USING "##.###"; TAB(18); C(i);
   PRINT #2, USING "##.###"; TAB(35); Densol(i);
   PRINT #2, USING "##.###"; TAB(48); y(i);
   PRINT #2, USING "##.#######"; TAB(58); x(i)
NEXT i
PRINT #2,
PRINT #2, "Molar Flow Rate of Gas/Vapour Phase (lb moles/hr) : "; V1prime
PRINT #2, "Molar Flow Rate of Liquid Phase (lb moles/hr) : "; Lprime
PRINT #2, "Flow Rate of Liquid (lb/hr)                   : "; gl
PRINT #2, "Flow Rate of Solute gas (lb/hr)               : "; gv
PRINT #2, "Mass Velocity of Vapour (lb/hr sq ft)         : "; fv
PRINT #2, "Diameter of the Column  (ft)                  : "; d
PRINT #2, "Mass Transfer Co-efficient (Liquid)           : "; Kxa
PRINT #2, "Mass Transfer Co-efficient (Gas)              : "; Kya
PRINT #2,
PRINT #2,
PRINT #2, "NUMBER OF TRANSFER UNIT IN GAS PHASE"
PRINT #2, "************************************"
PRINT #2,
PRINT #2, "S/No      Y          Yi         Yi - Y       1/(Yi - Y)"
PRINT #2, "-----------------------------------------------------"
FOR i = 1 TO no2
   TTy(i) = Tyi(i) - Ty(i)
   TTyi(i) = 0
   IF TTy(i) <> 0 THEN TTyi(i) = 1 / TTy(i)
   PRINT #2, USING "##"; TAB(2); i;
   PRINT #2, USING "##.###"; TAB(8); Ty(i);
   PRINT #2, USING "##.######"; TAB(17); Tyi(i);
   PRINT #2, USING "##.#######"; TAB(28); TTy(i);
   PRINT #2, USING "####.####"; TAB(45); TTyi(i)
   TTyi(i) = ABS(TTyi(i))
NEXT i
FplusL = TTyi(1) + TTyi(no2)
Even = 0
FOR i = 2 TO no2 - 1 STEP 2
  Even = Even + TTyi(i)
NEXT i
Odd = 0
FOR i = 1 TO no2 - 1 STEP 2
  Odd = Odd + TTyi(i)
NEXT i
Area = nstep / 3 * (FplusL + (4 * Even) + (2 * Odd))
Avey = ((1 - Ty(1)) + (1 - Ty(no2))) / 2
Avev = (V1 + V1prime) / 2
Height = Area * (Avev / (Kya * s * Avey))
PRINT #2,
PRINT #2, "Number of Transfer Unit at Gas Phase : "; Area
PRINT #2, "Height of the Tower                  : "; Height

RETURN
```

```
Listrpt:
OPEN "SO2.OUT" FOR INPUT AS #1
i = 0
clrscr
DO WHILE NOT EOF(1)
   i = i + 1
   INPUT #1, ALINE$
   PRINT ALINE$
   IF i > 15 THEN
      PRINT
      PRINT "Press anykey to continue scrolling"
      i = 0
      SLEEP
      clrscr
   END IF
LOOP
PRINT
PRINT "End of file (press anykey)"
SLEEP
CLOSE #1
RETURN

SUB borders (x1, y1, x2, y2)
   LINE (0, 0)-(639, 320), 2, B
   LINE (x1, y1)-(x1, y2), 15
   LINE (x1, y2)-(x2, y2), 15
END SUB

SUB Calcuyii (num, Tyis(), pts1(), rats)
pi = 3.142
k = 0
   FOR i = 1 TO num
       x = pts1(i, 1)
       y = pts1(i, 2)
       rad = 90 / rats
       FOR j = 1 TO 20
       IF POINT(x + (j * rad), y + j) = 15 OR POINT(x + INT(j * rad), y + j) =
15 THEN
         k = k + 1
         Tyis(k) = y + j
         SLEEP 2
         EXIT FOR
       END IF
       NEXT j
       LINE (x, y)-(x + 20 * rad, y + 20), 2
   NEXT i
END SUB

SUB clrscr
    CLS
    LOCATE 1, 20: PRINT "*****************************************"
    LOCATE 2, 20: PRINT "**      Computer Aided Design on      **"
    LOCATE 3, 20: PRINT "**        Gas Absorption Column       **"
    LOCATE 4, 20: PRINT "*****************************************"
    LOCATE 5, 20: PRINT
END SUB
```

```
FUNCTION getmax (vec(), num)
  gmax = vec(1)
  FOR i = 1 TO num
      IF gmax < vec(i) THEN gmax = vec(i)
  NEXT i
  getmax = gmax
END FUNCTION

SUB joinpts (num, pts1(), xcheck, ycheck)
   FOR i = 1 TO num
       x = pts1(i, 1)
       y = pts1(i, 2)
       SLEEP 1
       CIRCLE (x, y), 3, 15
       PAINT (x, y), 15, 15
   NEXT i
   FOR i = 1 TO num - 1
       LINE (pts1(i, 1), pts1(i, 2))-(pts1(i + 1, 1), pts1(i + 1, 2)), 15
   NEXT i
   FOR i = 41 TO 600
       IF POINT(i, ycheck) = 15 THEN xcheck = i
   NEXT i
END SUB
```

CAD RESULT USING BERL SADDLE 1in FOR THE SAMPLE DESIGN PROGRAM

PARAMETERS USED:
Berl Saddle (1 in.) where e = .69 Av = 76
where b = .0085 p = .75 r = .4

Percentage of SO2 in	:	6	Percentage of SO2 out	:	.1
Percentage of dry air	:	94	Amount of Gas	:	1000
Flooding Velocity	:	50	Operating Temperature	:	30
Operating Pressure	:	1	Density of Liquid Stream	:	995.62
Schimidt Number	:	570	Rate of Water Flow	:	2

EQUILIBRIUM DATA AT 30 (Degrees Centigrade)
****

Pressure of So2	C grams/100 grams of water	Density of Solution	y	x
0.600	0.020	62.160	0.001	0.0000562
1.700	0.050	62.170	0.002	0.0001406
4.700	0.100	62.190	0.006	0.0002812
8.100	0.150	62.210	0.011	0.0004217
11.800	0.200	62.220	0.016	0.0005622
19.700	0.300	62.250	0.026	0.0008430
36.000	0.500	62.320	0.047	0.0014043
52.000	0.700	62.380	0.068	0.0019649
79.000	1.000	62.470	0.104	0.0028046

Molar Flow Rate of Gas/Vapour Phase (lb moles/hr)	:	30.22508
Molar Flow Rate of Liquid Phase (lb moles/hr)	:	2180.398
Flow Rate of Liquid (lb/hr)	:	39368.71
Flow Rate of Solute gas (lb/hr)	:	1000
Interpolated Value From Flooding Velocity Graph	:	1.400926E-02
Mass Velocity of Vapour (lb/hr sq ft)	:	337.8279
Diameter of the Column (ft)	:	2.745505

Mass Transfer Co-efficient (Liquid)	:	296.2704
Mass Transfer Co-efficient (Gas)	:	13.4511

NUMBER OF TRANSFER UNIT IN GAS PHASE
****

S/No	Y	Yi	Yi - Y	1/(Yi - Y)
1	0.060	0.038800	-0.0212000	-47.1698
2	0.050	0.018600	-0.0314000	-31.8471
3	0.040	0.008600	-0.0314000	-31.8471
4	0.030	0.000000	-0.0300000	-33.3333
5	0.020	0.000000	-0.0200000	-50.0000
6	0.010	0.000000	-0.0100000	-100.0000
7	0.001	0.000000	-0.0010000	-999.9999

Height of the Transfer Unit	:	.4039907
Number of Transfer Unit at Gas Phase	:	6.553085
Height of the Tower	:	2.647386

CAD RESULT USES CERAMIC RASCHING RING 1in AT SPECIFIED TEMPERATURE 40°C

PARAMETERS USED:
Raschig Rings (1 in.) where e = .73 Av = 58
where b = .036 p = .77 r = .2

Percentage of SO2 in	: 6	Percentage of SO2 out	: .1
Percentage of dry air	: 94	Amount of Gas	: 1000
Flooding Velocity	: 50	Operating Temperature	: 40
Operating Pressure	: 1	Density of Liquid Stream	: 992.16
Schimidt Number	: 570	Rate of Water Flow	: 2

EQUILIBRIUM DATA AT 40 (Degrees Centigrade)
****

Pressure of So2	C grams/100 grams of water	Density of Solution	y	x
0.600	0.020	62.160	0.001	0.0000562
1.700	0.050	62.170	0.002	0.0001406
4.700	0.100	62.190	0.006	0.0002812
8.100	0.150	62.210	0.011	0.0004217
11.800	0.200	62.220	0.016	0.0005622
19.700	0.300	62.250	0.026	0.0008430
36.000	0.500	62.320	0.047	0.0014043
52.000	0.700	62.380	0.068	0.0019649
79.000	1.000	62.470	0.104	0.0028046

Molar Flow Rate of Gas/Vapour Phase (lb moles/hr) : 30.22508
Molar Flow Rate of Liquid Phase (lb moles/hr) : 2180.398
Flow Rate of Liquid (lb/hr) : 39368.71
Flow Rate of Solute gas (lb/hr) : 1000
Interpolated Value From Flooding Velocity Graph : 1.423801E-02
Mass Velocity of Vapour (lb/hr sq ft) : 416.6864
Diameter of the Column (ft) : 2.472096

Mass Transfer Co-efficient (Liquid) : 319.9506
Mass Transfer Co-efficient (Gas) : 13.31313

NUMBER OF TRANSFER UNIT IN GAS PHASE
****

S/No	Y	Yi	Yi - Y	1/(Yi - Y)
1	0.060	0.049800	-0.0102000	-98.0392
2	0.050	0.039800	-0.0102000	-98.0392
3	0.040	0.029800	-0.0102000	-98.0392
4	0.030	0.019800	-0.0102000	-98.0392
5	0.020	0.009800	-0.0102000	-98.0392
6	0.010	0.000800	-0.0092000	-108.6956
7	0.001	0.000000	-0.0010000	-999.9999

Height of the Transfer Unit : .5034575
Number of Transfer Unit at Gas Phase : 9.684569
Height of the Tower : 4.875769

CAD RESULT USING BERL SADDLE 1in AT SPECIFIED TEMPERATURE OF 40°

PARAMETERS USED:
Berl Saddle (1 in.) where e = .69 Av = 76
where b = .0085 p = .75 r = .4

Percentage of SO2 in	: 6	Percentage of SO2 out	: .1
Percentage of dry air	: 94	Amount of Gas	: 1000
Flooding Velocity	: 50	Operating Temperature	: 40
Operating Pressure	: 1	Density of Liquid Stream	: 992.16
Schimidt Number	: 570	Rate of Water Flow	: 2

EQUILIBRIUM DATA AT 40 (Degrees Centigrade)
****

Pressure of So2	C grams/100 grams of water	Density of Solution	y	x
0.600	0.020	62.160	0.001	0.0000562
1.700	0.050	62.170	0.002	0.0001406
4.700	0.100	62.190	0.006	0.0002812
8.100	0.150	62.210	0.011	0.0004217
11.800	0.200	62.220	0.016	0.0005622
19.700	0.300	62.250	0.026	0.0008430
36.000	0.500	62.320	0.047	0.0014043
52.000	0.700	62.380	0.068	0.0019649
79.000	1.000	62.470	0.104	0.0028046

Molar Flow Rate of Gas/Vapour Phase (lb moles/hr)	: 30.22508
Molar Flow Rate of Liquid Phase (lb moles/hr)	: 2180.398
Flow Rate of Liquid (lb/hr)	: 39368.71
Flow Rate of Solute gas (lb/hr)	: 1000
Interpolated Value From Flooding Velocity Graph	: 1.423801E-02
Mass Velocity of Vapour (lb/hr sq ft)	: 334.5075
Diameter of the Column (ft)	: 2.759098

Mass Transfer Co-efficient (Liquid)	: 294.5779
Mass Transfer Co-efficient (Gas)	: 13.29917

NUMBER OF TRANSFER UNIT IN GAS PHASE
****

S/No	Y	Yi	Yi - Y	1/(Yi - Y)
1	0.060	0.038800	-0.0212000	-47.1698
2	0.050	0.018600	-0.0314000	-31.8471
3	0.040	0.008600	-0.0314000	-31.8471
4	0.030	0.000000	-0.0300000	-33.3333
5	0.020	0.000000	-0.0200000	-50.0000
6	0.010	0.000000	-0.0100000	-100.0000
7	0.001	0.000000	-0.0010000	-999.9999

Height of the Transfer Unit	: .4045897
Number of Transfer Unit at Gas Phase	: 6.553085
Height of the Tower	: 2.651311

CAD RESULT USING 80% FLOODING VELOCITY OF THE SAMPLE PROGRAM

PARAMETERS USED:
Raschig Rings (1 in.) where e = .73 Av = 58
where b = .036 p = .77 r = .2

Percentage of SO2 in	: 6	Percentage of SO2 out	: .1
Percentage of dry air	: 94	Amount of Gas	: 1000
Flooding Velocity	: 80	Operating Temperature	: 30
Operating Pressure	: 1	Density of Liquid Stream	: 995.62
Schimidt Number	: 570	Rate of Water Flow	: 2

EQUILIBRIUM DATA AT 30 (Degrees Centigrade)
****

Pressure of So2	C grams/100 grams of water	Density of Solution	y	x
0.600	0.020	62.160	0.001	0.0000562
1.700	0.050	62.170	0.002	0.0001406
4.700	0.100	62.190	0.006	0.0002812
8.100	0.150	62.210	0.011	0.0004217
11.800	0.200	62.220	0.016	0.0005622
19.700	0.300	62.250	0.026	0.0008430
36.000	0.500	62.320	0.047	0.0014043
52.000	0.700	62.380	0.068	0.0019649
79.000	1.000	62.470	0.104	0.0028046

Molar Flow Rate of Gas/Vapour Phase (lb moles/hr) : 30.22508
Molar Flow Rate of Liquid Phase (lb moles/hr) : 2180.398
Flow Rate of Liquid (lb/hr) : 39368.71
Flow Rate of Solute gas (lb/hr) : 1000
Interpolated Value From Flooding Velocity Graph : 1.400926E-02
Mass Velocity of Vapour (lb/hr sq ft) : 420.8226
Diameter of the Column (ft) : 1.944735

Mass Transfer Co-efficient (Liquid) : 441.2832
Mass Transfer Co-efficient (Gas) : 21.20496

NUMBER OF TRANSFER UNIT IN GAS PHASE
****

S/No	Y	Yi	Yi - Y	1/(Yi - Y)
1	0.060	0.038800	-0.0212000	-47.1698
2	0.050	0.018600	-0.0314000	-31.8471
3	0.040	0.000000	-0.0400000	-25.0000
4	0.030	0.000000	-0.0300000	-33.3333
5	0.020	0.000000	-0.0200000	-50.0000
6	0.010	0.000000	-0.0100000	-100.0000
7	0.001	0.000000	-0.0010000	-999.9999

Height of the Transfer Unit : .5107579
Number of Transfer Unit at Gas Phase : 6.507438
Height of the Tower : 3.323725

RESULTS OF CAD MODULE FOR THE SAMPLE DESIGN PROBLEM

PARAMETERS USED:

Raschig Rings (1 in.) where e = .73 Av = 58
where b = .036 p = .77 r = .2

Percentage of SO2 in	:	6	Percentage of SO2 out	:	.1
Percentage of dry air	:	94	Amount of Gas	:	1000
Flooding Velocity	:	50	Operating Temperature	:	30
Operating Pressure	:	1	Density of Liquid Stream	:	995.62
Schimidt Number	:	570	Rate of Water Flow	:	2

EQUILIBRIUM DATA AT 30 (Degrees Centigrade)
****

Pressure of So2	C grams/100 grams of water	Density of Solution	y	x
0.600	0.020	62.160	0.001	0.0000562
1.700	0.050	62.170	0.002	0.0001406
4.700	0.100	62.190	0.006	0.0002812
8.100	0.150	62.210	0.011	0.0004217
11.800	0.200	62.220	0.016	0.0005622
19.700	0.300	62.250	0.026	0.0008430
36.000	0.500	62.320	0.047	0.0014043
52.000	0.700	62.380	0.068	0.0019649
79.000	1.000	62.470	0.104	0.0028046

Molar Flow Rate of Gas/Vapour Phase (lb moles/hr)	:	30.22508
Molar Flow Rate of Liquid Phase (lb moles/hr)	:	2180.398
Flow Rate of Liquid (lb/hr)	:	39368.71
Flow Rate of Solute gas (lb/hr)	:	1000
Interpolated Value From Flooding Velocity Graph	:	1.400926E-02
Mass Velocity of Vapour (lb/hr sq ft)	:	420.8226
Diameter of the Column (ft)	:	2.459917

Mass Transfer Co-efficient (Liquid)	:	322.075
Mass Transfer Co-efficient (Gas)	:	13.44129

NUMBER OF TRANSFER UNIT IN GAS PHASE
****

S/No	Y	Yi	Yi - Y	1/(Yi - Y)
1	0.060	0.049800	-0.0102000	-98.0392
2	0.050	0.039800	-0.0102000	-98.0392
3	0.040	0.029800	-0.0102000	-98.0392
4	0.030	0.019800	-0.0102000	-98.0392
5	0.020	0.009800	-0.0102000	-98.0392
6	0.010	0.000800	-0.0092000	-108.6956
7	0.001	0.000000	-0.0010000	-999.9999

Height of the Transfer Unit	:	.5036067
Number of Transfer Unit at Gas Phase	:	9.684569
Height of the Tower	:	4.877214

Appendix C

Table C_1: Physical Characteristic of Dry Commercial packings

Packing & Size (In)	% Voids (E)	Specific Surface (av)
Ceramic Raschig Rings		
½	63	111
1	73	58
1½	73.5	43
2	74	28
Berl Saddle		
1	69	76

Table C_2: Values of Constants for Equation 4.32

Types of Packing Size (In)	β	N
Ceramic Raschig Rings		
½	0.00357	0.35
1	0.01	0.22
1½	0.0111	0.22
Berl Saddle		
1	0.00588	0.28

Table C_3: Ammonia – Air Water Absorption Data Constant

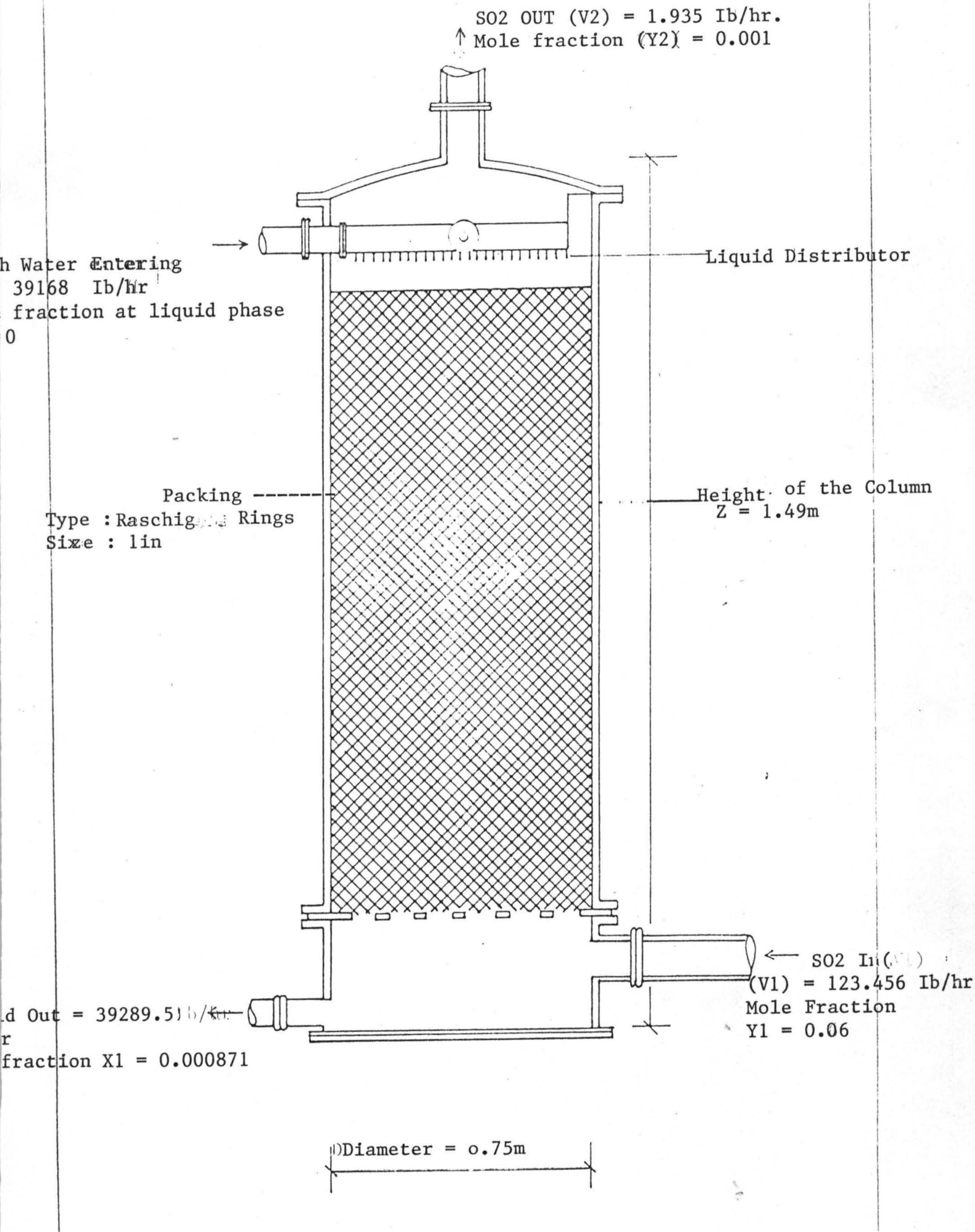
Types of Packing Size (In)	b	p	r
Ceramic Raschig Ring			
½	0.0065	0.90	0.39
1	0.036	0.77	0.20
1½	0.0142	0.72	0.38
2	0.048	0.88	0.09
Berl Saddle			
1	0.0085	0.75	0.40

Appendix D

Table D_1: Density of Water

Temperature (°C)	Density ev. (Kg/m²)
0	999.80
5	999.90
10	999.70
15	999.00
20	998.20
25	997.01
30	995.62
35	994.04
40	992.16
45	990.20
50	988.14
55	985.22
60	983.28

APPENDIX E



: Diagram of the design Gas Absorption Column