INTRODUCTORY CONCEPTS IN CHEMICAL ENGINEERING

Second Edition

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Cover photo: David Gonzales

To my wife Emalyn, and our children
Estelle Diane and Williard Joshua

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Preface to the Second Edition

The first course in chemical engineering usually deals with mass and energy balance and the basic principles necessary in introducing chemical engineering. Mass and energy balance is a fundamental concept in chemical engineering and in other fields in general. Majority of the basic principles are taken up in chemistry, physics, and mathematics. The usual approach in teaching the first course in chemical engineering is to consider that every student is familiar with those princi-ples. The teacher reviews and use them in mass and energy balance problems.

A textbook for the first course should start with the basic principles to gradually build the foundation of the discipline of chemical engineering. It should present ideas in a structured manner to gradually form a strong framework. This avoids the pitfall of an author to discuss topics beyond the background and knowledge of the student. With this guide, I used the following strategy in writing this textbook:

> Regard mass and energy balance calculations (MEBC) in steady-state situation as an extension of arithmetic and algebra subjects. The problems in MEBC are viewed as verbal problems in arithmetic and algebra. Since all engineering students have more than sufficient background in these subjects, learning MEBC will be easier and teaching more efficient. Most of the relationships needed to solve the problems are principles from chemistry, physics, mathematics, chemical engineering, and other related fields. The other relationships are explic-itly stated in the problem, usually the case in arithmetic and algebra problems. Students will soon realize that many of the principles presented are the same ones they have learned before. In this manner, the perceived difficulty in studying a new subject dissipates. The textbook (and the course) is structured such that only few principles (to be used as relationships) are given in each chapter. In this manner, the students are not overloaded. By the time all the relationships are given, (towards the end of the book) students are confident in solving MEBC problems.

With the above strategy, students are properly equipped with tools in calculation. They would attack problems in MEBC as arithmetic or algebra problems more confidently. With the gradual introduction of principles and relationships, the students are able to cope with the problems getting more difficult as the number of available relationships increases.

This book resulted from my lecture notes through many years. I used the techniques and strategies I developed through “probing the paradigm of chemical engineering”, a 25-year research that I have conducted.

I extend my appreciation to the students and teachers for their comments and feedback that were useful in improving the textbook. Many thanks to the assistants and researchers (too many to mention) who helped correct and edit the manuscript.

W. I José

—Chapter 1—
Introduction

SECTION 1 WHAT IS CHEMICAL ENGINEERING?

About four decades ago, chemical engineering was defined as a field concerned with the design, construction, and operation of industrial plants where matter undergoes physical or chemical changes. Of course, the major objective was to obtain maximum profit. Today this definition only partly applies. What is missing? Nothing is mentioned about the environment. Back then, a criterion in choosing a plant location was that the plant should be near a body of water such as a river. The wastes were thrown directly to receiving waters without treatment. The environment degraded as expected. By the seventies, all countries around the world were concerned with protecting the environment. This of course came at some costs. Gradually, pollution prevention, waste management, and resource recovery became part of the manufacturing cost of a product.

Today, chemical engineering impacts society in so many ways that we cannot imagine the world devoid of commercial output of antibiotics, fertilizers, agricultural chemicals, special polymers for biomedical devices, high-strength polymer composites, and synthetic fibers and fabrics, among others. In manufacturing these commodities, the major objective is to produce them economically. An equally important concern is to protect the environment from any adverse impact. We achieve a balance in economics and environmental protection by using especially designed chemicals, materials, and equipment. Chemical engineering deals with developing this ability and implementing it on a practical scale. Chemical engineers synthesize, design, test, scale up, operate, control, and optimize processes in which materials undergo physical or chemical changes.

HISTORY OF CHEMICAL ENGINEERING [HOUGEN, 1977]

Although chemical engineering is a relatively new field, some principles and practices have been used for almost 5,000 years. The early Egyptians filtered grape juice through cloth bags. During the 16th century, saltmakers recovered salt from sea water using the heat energy supplied by the sun and the combined operations of fluid flow, evaporation, crystallization, and sedimentation.

Initially, manufacturers thought that the technology of each particular chemical industry was a special kind of knowledge distinct from the others. Chemical engineering evolved from the continuous addition and revision of techniques resulting from dynamic changes in the chemical process industries.

Chemists and engineers (mechanical and civil) undertook the fields of industrial chemistry and chemical manufacture in the 18^{th} and 19^{th} century. The term "chemical engineering" originated in the United Kingdom. George E. Davis tried to form a society for chemical engineers in England but met stern opposition. In 1888, he gave a series of 12 lectures on chemical engineering, later published as a handbook. Near the turn of the century, four universities started to offer chemical engineering in the United States. Industrial chemistry and basic engineering subjects were the bases of the first courses. The American Institute of Chemical Engineers was founded in 1908.

We could trace the development of chemical engineering through the metamorphosis of the curriculum. Since chemists and mechanical engineers were the chief personnel of industrial plants, early courses in chemical engineering were heavily based on chemistry (industrial chemistry and chemical manufacture) and engineering (machine design, surveying, hydraulics, mechanics).

In 1915, A. D. Little introduced the concept of unit operations, which was considered a major breakthrough. The basis of the concept is that many steps or physical operations in totally different industries have some similarities. Similar steps or operations could be classified into a distinct "unit operation". For example, the evaporation of water from a sugar solution was no different from the evaporation from a salt solution or from the evaporation of solvents other than water. Other unit operations that evolved were drying, heat exchange, absorption, humidification, and crystallization, among others. Soon after, a limit was reached on what could be done with unit operations. New concepts were needed.

Further scrutiny of the unit operations revealed that they could still be classified into major groups that use similar principles: fluid flow or momentum transfer, mass transfer, heat transfer, and simultaneous heat and mass transfers. The areas of momentum, heat, and mass transfers were always considered three different subjects. In 1960, the principles of momentum, mass, and heat transfer were combined to form the transport processes. This development is of major significance in chemical engineering. Through the years, the other specialized branches of chemical engineering evolved.

Essential to the unit operations are the concepts of material and energy balances. We have to account for the materials passing through all the unit equipment.

As important as the unit operations were the chemical reactions called “unit processes” or the unit chemical conversions. In this book we will refer to a unit process as unit process technology. Typical unit process technologies are oxidation, neutralization, polymerization, and calcination, among others. The equipment for these processes is the chemical reactor. Production of more desirable products and less waste or by-products (increased yields) is the major objective in carrying out a process. Chemical engineers apply the principles of chemical kinetics, which deals with the rate of chemical reactions. Equilibrium in a chemically reacting system is inevitable, hence a need for a chemical-engineering-oriented thermodynamics. This is particularly useful in considering the energy balances around a system.

As the processes and systems became more diversified and complex, the need for proper control of process variables and conditions arose. Thus, process dynamics and control emerged, which was concerned with automatic controls and instrumentation of chemical plants.

The integration of the principles above is the basis of process design. The introduction of computer technology and high speed electronic computers opened up new approaches and solutions impossible through manual computation. Gradually, exact solutions superseded empiricism. Table 1-1 gives the specialized branches of chemical engineering and their years of prominent appearances. [Hougen, 1977] Presently, more and more fields of study find applications for chemical engineering.

Since the last decade, new products and materials have come to the market mainly from biotechnology, electronics, and high performance materials industry. They are dependent on structure and design at the molecular level. The manufacturing processes require precise control of chemical composition and molecular level. [Commission, 1988)

The traditional essence of chemical engineering was carried at a *mesoscale* level -- that is, at medium level size and complexity. This is typically the unit operation equipment and chemical reactors -- and the combination of the unit operations and unit process technologies. The current researches extend to phenomena at the molecular level -- the *microscale*, and with exceedingly complex systems -- the *macroscale*.

In the future, chemical engineers will be able to manufacture specialty products in gram or kilogram scales rather than in megagram.

Table 1-1 Specialized Branches of Chemical Engineering (Hougen, 1977)

	Year of Prominent Appearance
Industrial Chemistry	1898
Unit Operations	1923
Material and Energy Balances	1926
Thermodynamics and Unit Processes	1947
Transport Phenomena and Computer Technology	1960
Interdisciplinary Technology	1965

This will require strict process control and chemical purity on a level that is not yet practical at present. Along with the traditional mesoscale and macroscale processing, the field of molecular science is required. This will result in improved process productivity, quality, efficiency, and environmental friendliness, which are keys to global competitiveness.

DUTIES AND FUNCTIONS OF A CHEMICAL ENGINEER

E. L. Brown [1936] has pointed out the general function of an engineer: "Engineering is primarily the art of applying the resources of materials and power in nature to the use and convenience of man. Engineers translate the discoveries of scientists into structures, machines, and processes." The chemical engineer performs this general function too. The traditional duties of the chemical engineer are: research and development, modeling/pilot plant operation, design, plant operation, sales and marketing, and management and administration.

Research and Development

A chemical engineer is responsible for translating a new chemical reaction into large scale production. He works in close coordination with a chemist when a reaction is promising. While the reaction is still only on a small scale, he applies chemical engineering principles to make a preliminary evaluation of the project. He tries to gear the work towards an economic venture. The chemist may think only of the technical difficulties; besides this concern, the chemical engineer also has the profitability of the project in mind.

Research is not confined to chemical reactions alone, however. The chemical engineer can always do research in improving unit operations, reaction kinetics, and process control. Transport processes, for example, are the subjects of many researches.

The chemical engineer always aims for the most efficient operation. A program for process improvement and development is not only applied at the start of a project, but is an internal and ongoing part of any project.

Modeling and Simulation

The success of a new chemical process on a commercial scale is not always assured. Thus, instead of designing the actual plant at once, chemical engineers first model and simulate processes usually using computers. This is a development stage that provides an inexpensive basis for the final design and operation of the plant and equipment. Before the advent of computers, chemical engineers first try the process on a pilot plant scale -- a scale-down model of the commercial plant.

Design

The chemical engineer works with other engineers in all phases of the design of a chemical plant. Most important is the design of chemical equipment. He applies his training in designing equipment for unit operations and unit processes.

In plant design, economics is the prime consideration and the chemical engineer has to choose the most appropriate from several possible processes. He also uses foresight in determining the market potential of the products. The plant design also includes the selection of plant site in terms of market and the raw material source.

The chemical engineer works in close coordination with other engineers in the design of process control and instrumentation, piping and electrical systems, building layout, and others. Before a final design is reached, the team of engineers makes several preliminary designs to avoid errors.

The construction of the plant may not be a major function of a chemical engineer but his presence is essential in locating flow lines, instrumentation, and auxiliaries.

Plant Operation

Once a chemical plant is constructed, the chemical engineer is responsible for its startup, efficient operation, and proper maintenance. The qualifications needed are similar to those for design but are more complex since the chemical engineer must contend with the different problems encountered such as equipment malfunction and product quality maintenance. Aside from the initial plant startup, the engineer encounters startups from time to time since a plant has to be shut down for repairs and maintenance. In everyday operation, the chemical engineer always tries to attain conditions for full production and operation in chemical reaction, product separation, and equipment performance.

Sales and Marketing

A company may manufacture a product in the most efficient way but they might not be able to sell it. They have no point in manufacturing such a product. Sales and marketing are so important that without the proper techniques, a product may not get a good share of the market. A chemical engineer can be a good salesman because of his background. He helps the customer best by giving information about the product. Moreover, his duties do not end in selling. He tries to help the customer in problems encountered in using the product as well as related products. He does this to maintain the market. A chemical engineer in general gets involved in the strategy for marketing a product.

Management and Administration

From any of the previous functions, a chemical engineer gets enough experience to qualify him for an administrative or executive position resulting from his technical background and a knowledge of total company economics. Starting from purely technical activities, he integrates all considerations for efficient company operation. Since the technological changes require broad training, many plants are developing plant superintendents and managers among their chemical engineers. An important asset of an engineer is his creativity which results from basic training in analysis and synthesis from both the school and actual job. The manager runs the plant efficiently in terms of two things - man and machine - to produce marketable products at a good profit.

JOBS CHEMICAL ENGINEERS HOLD

Chemical engineers do not always hold jobs described above. Surveys indicate that many of them have jobs that are not engineering in nature but which make use of their chemical engineering background. A chemical engineer may question his status but he should not worry. He can carry out any job because his chemical engineering training prepared him. He is versatile and flexible. There should be no remorse but instead pride in being able to carry out a job of a different nature. In financial management, a chemical engineer uses his knowledge to reinforce his performance in this field. He is better than his non-chemical engineering counterpart because he understands the technical aspects and seamlessly includes them in his analysis. Some chemical engineers are in the government and directly help in the development of their country. Many chemical engineers become successful entrepreneurs. While research is a duty of the chemical engineer, some chemical engineers have used invention, creativity, and innovation as passports to success. A chemical engineer can easily adapt to the intricacies of technology transfer. By studying technology intelligence, they can easily take advantage of the fact that only about 5% of a technology is secret.

A chemical engineer can take a second course (such as the other engineering professions, medicine, dentistry, microbiology, agriculture, or practically any course) and be good at it provided his interest is keen. If possible, he should take advanced studies in his second degree. The emerging fields such as biotechnology, material science, nanotechnology, DNA computation, and surface science, among others, are fields that can easily capture his interest. The arts, humanities, and social sciences are fields some chemical engineers enter.

A listing and description of successful chemical engineers in different jobs would be an interesting compilation.

THE CHEMICAL ENGINEER AND THE ENVIRONMENT

Human activities cause environmental degradation in the form of global warming, acid rain, thinning of the ozone layer, defoliation, desert formation, soil and water pollution, and marine pollution. These environmental problems are interrelated and cannot be addressed singularly. Multidisciplinary approach is necessary. Everyone must not only recognize his role in solving problems directly concerning his field but he must also realize that some environmental problems require expertise from other disciplines. Chemical engineers are flexible. As expected, they can help in the solution of the problems.

The relationship between engineering and the environment was accelerated by the United States National Environment Protection Act of 1969 and the requirement for environmental impact assessment. Initially, the industries adapted the “end-of-pipe” treatment of wastes. This meant added expense to the manufacturing cost that ultimately affected the profit margin. Methods to avert treatment costs led to concepts that include pollution prevention and waste minimization, cleaner production, life cycle analysis, and redesign of plants for higher process efficiency, among others. Ultimately, we expect the development of new highly efficient processes with minimal waste emission.

While the problems concerning the environment require concerted effort of people from different disciplines, the chemical engineer has advantage over other professionals because he is flexible and versatile. As the field concerning the environment is broad and some aspects require specialization such as in the design of waste treatment plants, a background in pollution prevention and waste minimization is most useful to the chemical engineer.

POLLUTION PREVENTION

Pollution prevention is a combination of reuse, recovery, and minimization of waste sources. To start a pollution prevention program is to realize that reducing waste does not only concern the environment, but also gives economic advantage in production. The goal is to minimize unwanted impact to the environment and at the same time, to lower the production cost. We can see the compatibility of pollution prevention with the definition of chemical engineering given earlier.

Instituting a pollution prevention plan is one of the surest ways to improve productivity. This instills a new culture and pride in attaining set goals. More profits, less environmental problems, and increased employee morale are the major incentives that can be achieved by companies.

While pollution prevention is good business, there are other support rationales for its implementation. According to Nemerow (1995), these are mainly concerned with economics and include the following: reduced waste disposal costs (because less waste is produced), reduced raw materials costs (because manufacturing processes more efficiently use and reuse these materials), reduced damage costs (because lawsuits and insurance charges are eliminated), and improved public relations (because both the local and national public image of the industry is elevated as a result of environmental improvement). In addition, the paperwork associated with national, regional, and local permitting regulations is greatly reduced, providing savings of both time and money.

GLOBALIZATION

Today, we talk of the world as a “global village”. Distance and language barriers are rapidly diminishing. We can communicate instantaneously and travel faster. This emerging concept of the entire globe as a single entity is what we refer to as “globalization”. While this idea applies to almost any aspect, the term globalization commonly relates to world economics -- defined as the process of creating an integrated worldwide financial market. During the last three decades, companies have felt the pressure to build their plants and sell their products in many countries aside from their home base. They have to think in global terms in order to be successful. The chemical engineers in common with other engineers should now have a global perspective.

MASS BALANCE CALCULATIONS

The primary topic in the first course in chemical engineering is mass and energy balance. Chemical engineering work essentially starts with a mass balance. Chemical engineers need it in their professional practice. Thus, you must study the methods and techniques in mass balance calculations. For a student to be confident in carrying out such calculations, he must have a good background in mathematics, chemistry, and physics, as well as a practical knowledge of the properties of various materials. The second chapter presents a review of some necessary fundamentals.

The basis of mass balance calculations is the law of conservation of mass: Mass cannot be created nor destroyed in an ordinary chemical reaction, and just converted from one form to another. In the presence of nuclear reaction, the law is limited because matter is converted to energy. For a chemical engineer, the mass balance is the accounting for materials entering and leaving the process, whether or not a chemical reaction occurs.

My strategy in teaching mass and energy balance calculations (MEBC)

This dual application of MEBC – in an introductory course and an application in higher chemical engineering – has affected how we teach mass and energy balances. I analyzed the situation and adopted an appropriate strategy. When I first taught mass and energy balance calculations, I prepared my lecture notes with a course syllabus based on the textbooks I used during my undergraduate education. I arranged the topics based on what I believed was the logical way of teaching: start with the simplest theories and gradually add the necessary relationships so the students are not overwhelmed. My students did not perceive the change in the degree of difficulty of the topics as the course progressed.

Let us recall our algebra courses in high school and college. Think also about those courses that used arithmetical solutions. Some of the verbal problems we solved then dealt with mixing (for example, mixing 10% acid solution with 30% acid solution), compounding (given a formula, finding the quantities of components necessary), simple processes (manufacturing low-fat milk from regular milk), etc. We consider them examples from real life. We were able to solve those verbal problems (with the help of our teachers). It may surprise you to know that those problems are mass balance problems. Even without any chemical engineering background, you have solved mass balance problems. You may have used an algebraic or arithmetical solution or a combination of both. In this book, we will use the same technique -- we consider this subject an extension of algebra and arithmetic courses. We need to study the appropriate relationships necessary in calculations. This book is so structured that only a few relationships are given in each chapter so that students will be able to handle the load.

The following is the mass balance equation:

$$\sum \text{mass inputs} = \sum \text{mass outputs} + \text{accumulation} \qquad (1\text{-}1)$$

Anything that enters a process must come out at some point. If a liquid mass enters an empty container, some mass accumulates initially, and the outgoing mass is zero. Eventually, the liquid overflows from the container, and the accumulation becomes zero. If the accumulation is zero,

$$\sum \text{mass inputs} = \sum \text{mass outputs} \qquad (1\text{-}2)$$

If the mass output is larger than the mass input, then depletion (or negative accumulation) occurs. We usually set up the mass balance around a process (a single equipment unit or system consisting of several components). Figure 1.1 shows this schematically.

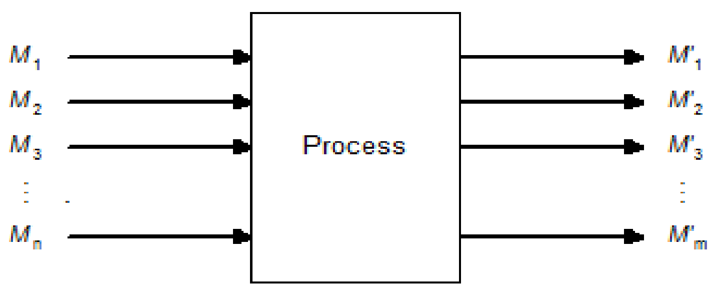

Figure 1–1 Mass inputs and outputs in a process.

This meant added expense to the manufacturing cost that ultimately affected the profit margin. Methods to avert treatment costs led to concepts that include pollution prevention and waste minimization, cleaner production, life cycle analysis, and redesign of plants for higher process efficiency, among others. Ultimately, we expect the development of new highly efficient processes with minimal waste emission.

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The mass balance equation corresponding to Figure 1-1 is

$$M_1 + M_2 + M_3 + +\ldots M_n = M'_1 + M'_2 + M'_3 + +\ldots M'_m \quad (1\text{-}3)$$

where

$M_1, M_2, M_3 \ldots M_n$ = masses of input streams 1, 2, 3, … n, respectively
$M'_1, M'_2, M'_3 \ldots M'_m$ = masses of output streams 1, 2, 3, … m, respectively

Equation (1-3) is an algebraic equation with several mass quantities, which may be known or unknown. We know we need the same number of equations, as many unknowns exist. The more unknowns there are, the more difficult it is to solve the simultaneous equations.

In setting up a mass balance, we should know the domain boundaries in which we set up a mass balance equation. What we consider could be a single piece of equipment, a section of equipment, a whole plant, or a section of a plant. We can draw an imaginary boundary using a broken line.
Let us consider a simple example. Water is flowing through a pipe. Fig. 1-2 represents a section of the pipe..

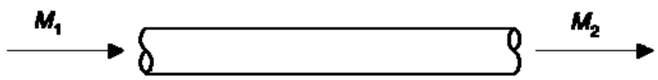


Figure 1–2 Mass input and output in a pipe section.

The mass balance equation is

$$M_1 = M_2 + \text{Accumulation} \quad (1\text{-}4)$$

Since water is flowing for some time, the accumulation is zero (the pipe section is full of water).

$$M_1 = M_2 \quad (1\text{-}5)$$

Now, let us say that a leak is present at a point in the pipe, and some water is lost. Figure 1-3 shows this, with M_L as the water that leaks out.

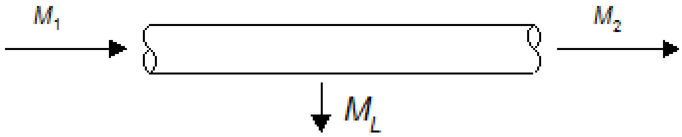


Figure 1-3 Mass balance in a pipe section with a leak.

In this case,

$$M_1 = M_2 + M_L \qquad (1\text{-}6)$$

We have a single equation. If again M_1 = 10,000 liters,

$$10{,}000 = M_2 + M_L \qquad (1\text{-}7)$$

We have two unknowns, M_2 and M_L. From algebra we know that we need another equation to solve for the two unknown quantities. Physically, we can collect the leakage (if the leak is in the form of droplets that can be collected). We can then solve for M_2. If M_L is 1 liter, then M_2 = 10,000 - 1 = 9,999 liters. Installing a water meter to determine M_2 is a possibility. M_L can then be solved. However the meter may not be sensitive enough to give the true value of M_L.

In chemical engineering, not all unknowns are measurable physically. Sometimes we have to estimate them indirectly using previously known methods or techniques. For example the tracer technique is used to determine the amount of leakage. We tie the amount to the flow of a known amount of injected material that can easily be tracked such as a radioactive compound.

The example discussed above involves the loss of 1 kg of process water to the environment. What is the impact? The cost of the lost water is negligible. Since the water is clean, it will not have an adverse effect on the environment. Plant and animal life forms would welcome it. How about if the temperature is higher, say 60°C? In this case, some plants and animals will be affected because of the high temperature and will definitely have an impact.

Suppose the piping system transports another liquid like for example, benzene. In a similar manner, we set up a mass balance equation in the system under consideration.

Now let us consider the impact of benzene if a small amount is released to the environment. The cost would be several times that of water. This is still negligible and a company would not even look at it. How about its impact to the environment? If we look at the specifications of benzene we see the following:

> "melting point 5.4°C, boiling point 80°C. Insoluble with water, miscible with organic solvents...vapor inhalation may cause depression of the bone marrow, convulsions, and paralysis..." [ ]

Well from the data, would you allow benzene to contaminate the environment? Of course not. Benzene is a carcinogen. In one instance, a bottled mineral water company discovered that its underground source of mineral water was contaminated with benzene. You can just imagine the impact of this phenomenon. Thousands of the bottled product had to be recalled. It meant the loss of a large amount of business. This may have been the fault of another company that inadvertently released the benzene contaminant.

If a company contaminates the environment, the owners are liable to many litigations that could cost the company large sums of money. Moreover, the negative publicity can affect product sales. Recently the sales of Coca-cola in Europe decreased when several thousand batches of the canned softdrink were contaminated with a toxic chemical. Likewise, dairy products from Belgium suffered rejection when they were found to be contaminated with dioxin.

Example 1-1

900 kg of cement is available to prepare a concrete mixture. The ratio cement :sand:gravel is 1:2:4. The water to cement ratio to be used is 0.4. How much gravel, sand, and water is needed? How much concrete mixture can be prepared from the available quantity of cement?

Given: 900 kg of cement
cement:sand:gravel = 1:2:4
water:cement = 0.4

Required: kg of concrete prepared

Basis: 900 kg of cement

Solution: Arithmetic method using ratio and proportion

cement available = 900 kg

cement:sand = 1:2

900/sand = 1/2 sand = 1800 kg

sand/gravel = 1/4 gravel = 3600 kg

sand/water = 0.4 water = 360 kg

concrete prepared = 900 + 1800 + 3600 + 360 = 6660 kg

Example 1-2

Water flows through a pipe that branches to three smaller pipes. The first pipe allows water to flow two times greater than the second pipe and 1.5 times that of the third pipe. If 50 m^3 flows through the main pipe, how much water flows through each of the branched pipes?

Given: 50 m^3 water flows through the main pipe and splits to a branch of three pipes. The flow rate in pipe 1 is twice that in pipe 2. The flow rate in pipe 1 is 1.5 times that of pipe 3.

Required: Amount of water that flows through each branch.

Solution: Algebraic method

Basis: 50 m^3 of water flowing through the main pipe

Let x = be the volume of water flowing through pipe 1
y = the volume water flowing through pipe 2
z = volume of water flowing through pipe 3

Water balance:

water flowing through the main pipe = water flowing through pipe 1 + water flowing through pipe 2 + water flowing through pipe 3

$$50 = x + y + z \quad \text{(a)}$$

$$y = x/2 \quad \text{(b)}$$

$$z = x/1.5 \quad \text{(c)}$$

Substituting Equation b and Equation c in Equation a,

$$50 = x + x/2 + x/1.5$$

Solving for x and substituting the values for y and z,

x = 50/2.167 = 23.08 m^3, water flowing through pipe 1

$y = x/2$ = 11.54 m^3, water flowing through pipe 2

$z = x/1.5$ = 15.38 m^3, water flowing through pipe 3

We used three unknowns in solving the problem. We could even simplify the algebraic solution by using only one unknown such as x and then expressing the unknown quantities in terms of x at once. Hence,

Let x = the volume of water flowing through pipe 1

$x/2$ = the volume water flowing through pipe 2

$x/1.5$ = the volume of water flowing through pipe 3

In this case we have only one unknown. Implicitly, we used some arithmetic in getting the unknown quantities. This solution is therefore a combination of arithmetic and algebraic method. We will use this technique later on.

CALCULATION TECHNIQUES

It may seem that the technique boils down to setting up and solving a system of simultaneous algebraic equations, or analyzing and applying arithmetic. This is not the case in actual practice. Finding all the equations, the constants, measurable quantities, etc., may not be possible. The data may be lacking (such as in designing a process) or more are available than necessary (as in plant operation). In this book however, we start from principles taken up in mathematics, physics and chemistry. We then apply *chemical-engineering-oriented* calculations.

While all the calculations can be performed in a computer, the student still has to go through the suggested methods to solidify his background.

Mass balance is indispensable in every phase of chemical engineering work, such as in the design, construction, and operation of industrial plants. Most chemical engineers perform mass balance calculations in their job. They use the same techniques that beginning chemical engineering students study. The only difference is that they know how to find the data necessary for calculations. They use their knowledge of chemical engineering.

A chemical engineer who designs a process has to find all the data necessary, which are usually lacking. He has to use empirical, theoretical, or experimental data. He can make assumptions based on his experience or previous knowledge.

A chemical engineer who operates a plant gathers data and finds out he has more data than is necessary. He has to decide which ones to use and use the rest to check for consistency. His problem is how to make use of the extraneous data he has collected in the process. A beginning chemical engineer with minimal background will be given most of the data as well as some techniques. Practicing chemical engineers and students both use the same techniques in solving mass and energy balance problems.

SECTION 3 UNIT OPERATIONS AND EQUIPMENT

The discussion in books on mass and energy balance calculations sometimes puts pressure on the students to cope with new information. This includes the unit operations and the respective equipment. Mass balance calculations are usually carried around unit operations or the corresponding equipment. A beginning student may not totally understand the function and the operation of an equipment if inadequate information or explanation is provided by the author who is familiar with the entire chemical engineering knowledge. We are aware that the beginning student is building his understanding of the profession and in a way still requires careful guidance regarding some concepts. This is because the discussion on some principles still lies in years ahead in his schooling.

This section introduces the student to the various unit operations -- with the underlying principles in a qualitative manner accompanied by the corresponding equipment. We need this in the study of mass and energy balances involved in an equipment or a combination of different equipment. The detailed theoretical treatment of these operations is covered in books on unit operations.

The unit operations provided the original basis for classifying various physical operations in chemical process plants. Now these operations are grouped under the different transport processes: heat transfer, mass transfer, mass and heat transfers, and momentum transfer. The rest is classified in a special group.

UNIT OPERATIONS OF HEAT TRANSFER

We encounter heat transmission in many chemical engineering operations. Whenever a temperature difference exists, the transfer of heat occurs. Heat travels from a hot area or volume to a cold one until the two temperatures become equal. In a plant we want to maximize the heat transfer rate and minimize heat losses at the lowest possible cost. The equipment for heat transfer is the heat exchanger. The heat energy of a hot fluid is usually transferred to a cold one without direct contact. Several types of heat exchange equipment are available. The design and the name depend on the application. Some examples of heat transfer equipment are direct heaters, steam generators, furnaces, preheaters, shell-and-tube heat exchangers, coolers, evaporators, and condensers. In energy conservation, heat transfer is important in salvaging heat energy using equipment such as exchangers, recuperators, and regenerators.

Double-Pipe Heat Exchanger

The simplest type of heat exchange equipment is the double-pipe heat exchanger. (See Figure 1-4a.) It consists of two concentric pipes. One fluid flows inside the inner pipe while the other in the annulus. The flow may either be parallel or countercurrent. If a difference in temperature exists between the two fluids, the transfer of heat from the hot to the cold fluid occurs. This heat exchanger is normally applicable for experimental or small-scale operations

Shell-and-Tube Heat Exchanger

This equipment is like the double pipe heat exchanger and is the most common type of industrial heat exchanger. Several tubes are placed inside a large tube known as the shell to increase the heat transfer area. (See Figure 1-4b.) One fluid flows inside the tubes (the tube side) and the other fluid, outside of the tubes (the shell side). It can easily be assembled and disassembled for quick cleaning and repairs. Some heat exchangers have special names, depending on their functions. Some examples are reboilers (function: to boil a liquid), vaporizers (one fluid heats up the other fluid until it vaporizes), and condensers (a cold fluid absorbs heat from the vapor that subsequently condenses).

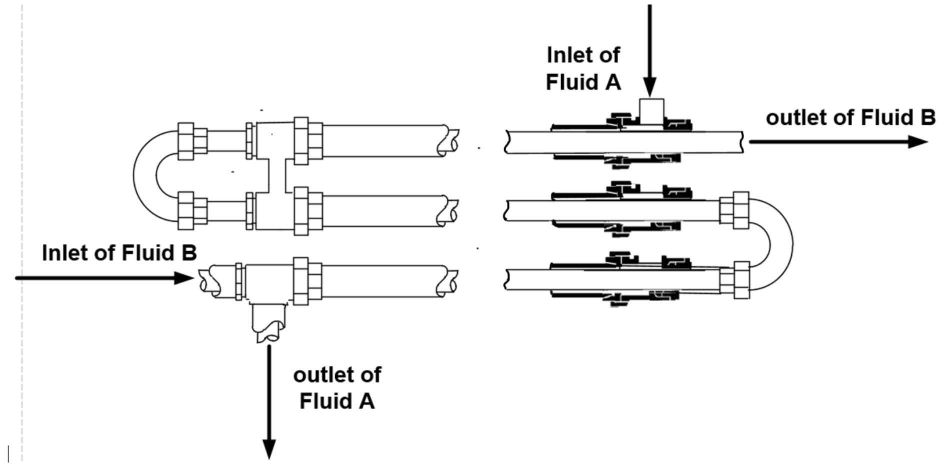


Figure 1–4a Double pipe heat exchanger

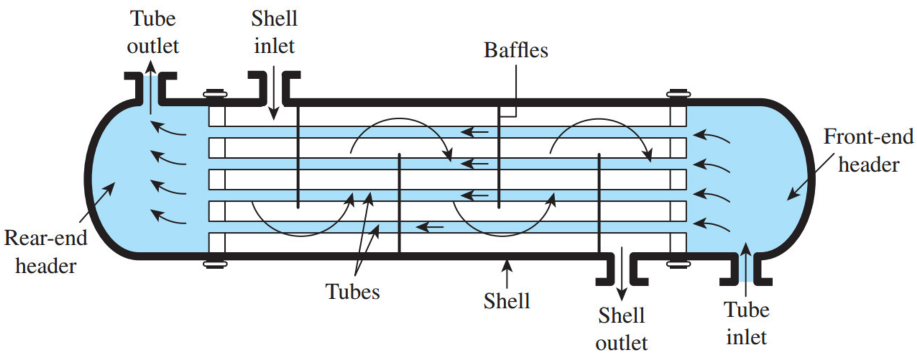


Figure 1–4b. Shell-and-tube heat exchanger (Reproduced with permission from https://www.thomasnet.com/articles/process-equipment/shell-and-tube-heat-exchangers/

UNIT OPERATIONS OF MASS TRANSFER

Most physical separations are based on differences in density or sizes of particles. Instead, mass transfer operations depend on concentration differences between two phases. A component transfers from a phase where its concentration is higher to a phase where its concentration is lower. For example, water transfers from a wet cloth to a dry cloth until both cloths have the same water content. Place a raisin in a glass of water. The water will diffuse into the raisin. The concentration difference can be in terms of solubility or vapor pressure differences and involves the diffusion of components. In the production of chemicals from raw materials, the direct product from the reaction oftentimes contains impurities in the form of unreacted reactants, by-products, and other contaminants. The most suitable processes for separation and purification are the mass transfer operations. Distillation, extraction or leaching, absorption and desorption, adsorption, and ion-exchange are some examples of these operations.

Distillation

When a solution containing a volatile component is heated, the composition of the vapor is different from the composition of the liquid that remains. The vapor is richer in the more volatile component. Condense this vapor, then heat again. The resulting vapor will be even richer in the volatile component. Repeat the process until you get a pure substance. This is the principle used in distillation. The equipment is the distillation column. *See Figure 1-5.*

The plate at the bottom is the reboiler where heat (usually from steam) is applied to boil the solution. The vapor from this solution in turn heats and boils the solution in the next higher plate. The resulting vapor, likewise, boils the liquid in the next plate, and so on.

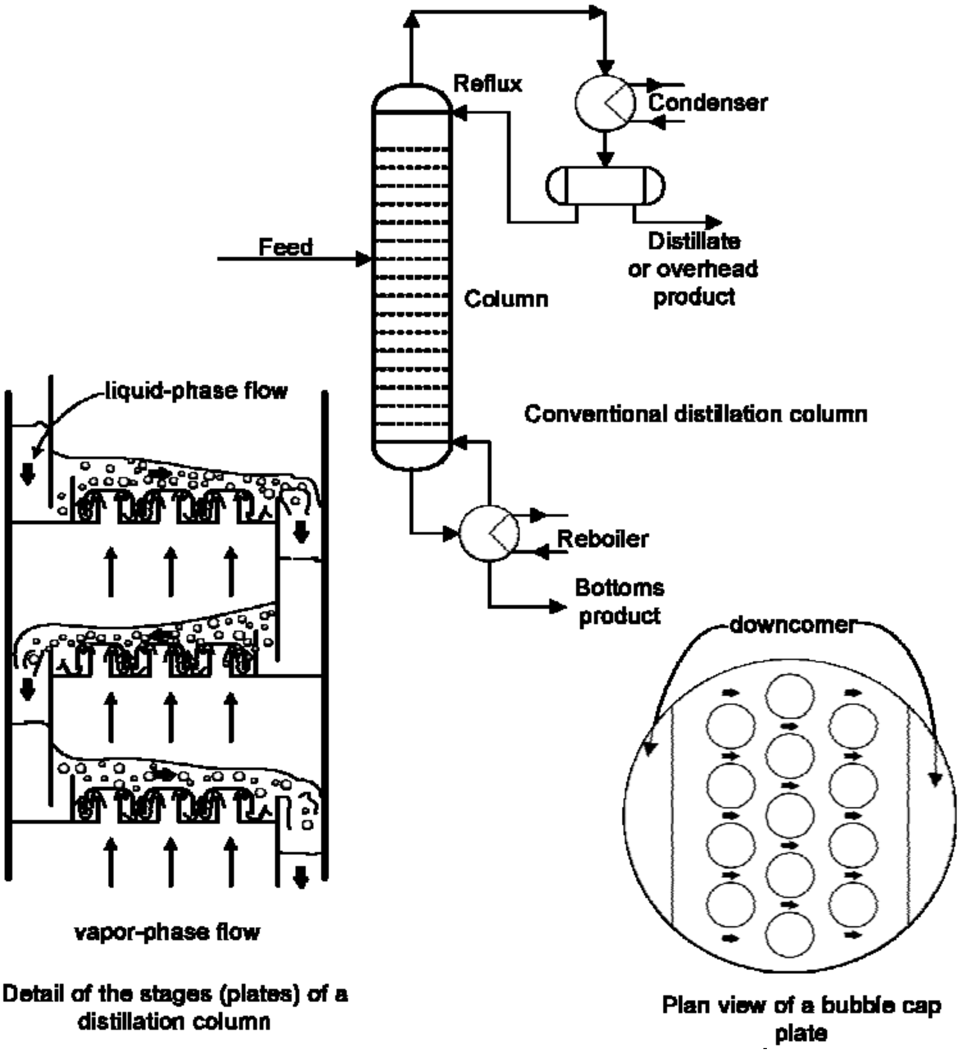


Figure 1-5 Equipment for distillation. (Reproduced with permission from Brown et al., 1950.)

Since the vapor contains more of the volatile component than the corresponding liquid, the vapor mixture becomes richer in the volatile component as it ascends from plate to plate. In a similar manner, the liquid flowing down the column, becomes richer of the less volatile component. The product withdrawn at the top, is the *distillate*, while from the bottom plate, the *bottoms*. Side products can be withdrawn from any other plate. The column operates continuously with fresh feed input near the middle of the column. Complex liquid mixtures composed of several components of different volatilities can be separated into suitable fractions by withdrawing the products from different plates in a distillation column. Petroleum or crude oil is processed in this manner. Different fractions withdrawn from the top downwards are LPG, gasoline, naphtha, kerosene, diesel fuel, fuel oil, lubricating oil, and others. Each of these fractions is still composed of several components which can be further separated in another distillation column. Alcohol from fermentation is recovered by distillation. Oxygen and nitrogen are separated from liquefied air also by distillation. Vacuum flash distillation is a one-stage distillation process where a liquid mixture is subjected to vacuum at a specified temperature and pressure. A vapor mixture with a composition different from that of the liquid results. The vapor and the liquid portions are obtained as the products.

Absorption and Desorption

In gas absorption, a constituent of a gas mixture is removed by contacting with a liquid. Ammonia in an air-ammonia mixture, when

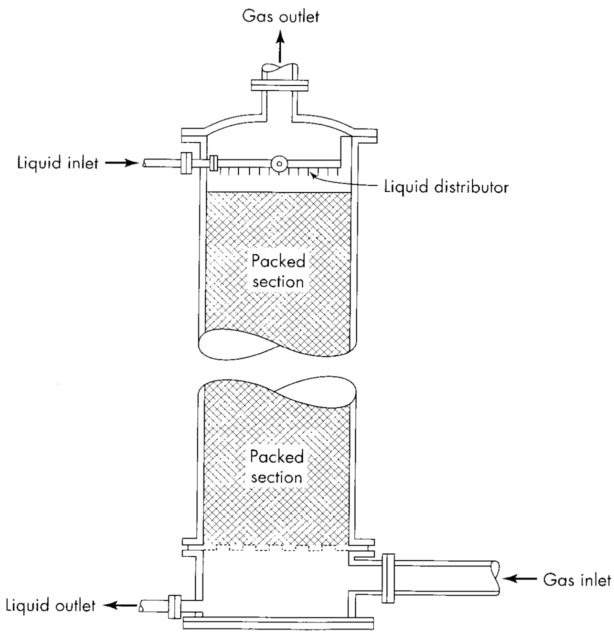


Figure 1-6 A packed tower, an equipment for absorption and desorption. (Reprinted from W. L. McCabe, J. C. Smith, and P. Harriot, Unit Operations of Chemical Engineering 6th Edition, ©2001, Boston, McGraw-Hill, p. 547. With permission from McGraw-Hill Book Co.

placed in contact with liquid water, will transfer to the liquid. In desorption (also known as stripping), the opposite happens. Here, the component of a liquid phase transfers to the gas phase. The benzene in a benzene-oil mixture is recovered by treating the mixture with steam. The benzene transfers to the steam. Upon cooling, the benzene separates easily from the steam. For more efficient transfer, the equipment should provide a large surface of contact between the gas and the liquid phases. The equipment is the packed tower. *See Figure 1-6.* It consists of a vertical cylinder filled with a packing material. *See Figure 1-7.* The packing material wetted by the liquid provides the necessary contact surface. Some typical packing materials are stoneware shapes, wood slats, broken rocks, and coke. Chemical stoneware finds applications when the fluids treated are corrosive.

To operate the tower, the liquid phase is distributed evenly at the top of the tower while the gas is fed at the bottom. Contact between phases occurs as they flow countercurrently.

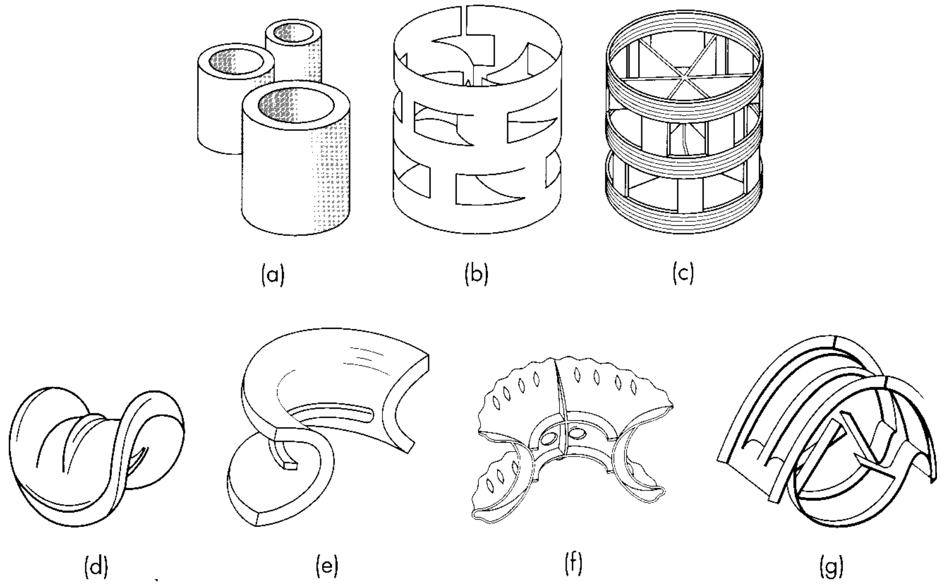


Figure 1-7 Common tower packings: (a) Raschig rings; (b) metal Pall ring; (c) plastic Pall ring; (d) Berl saddle; (e) ceramic Intalox saddle; (f) plastic Super Intalox saddle; (g) metal Intalox saddle. Reprinted from W. L. McCabe, J. C. Smith, and P. Harriot, Unit Operations of Chemical Engineering 6th Edition, ©2001, Boston, McGraw-Hill, p. 548. With permission from McGraw-Hill Book Co.

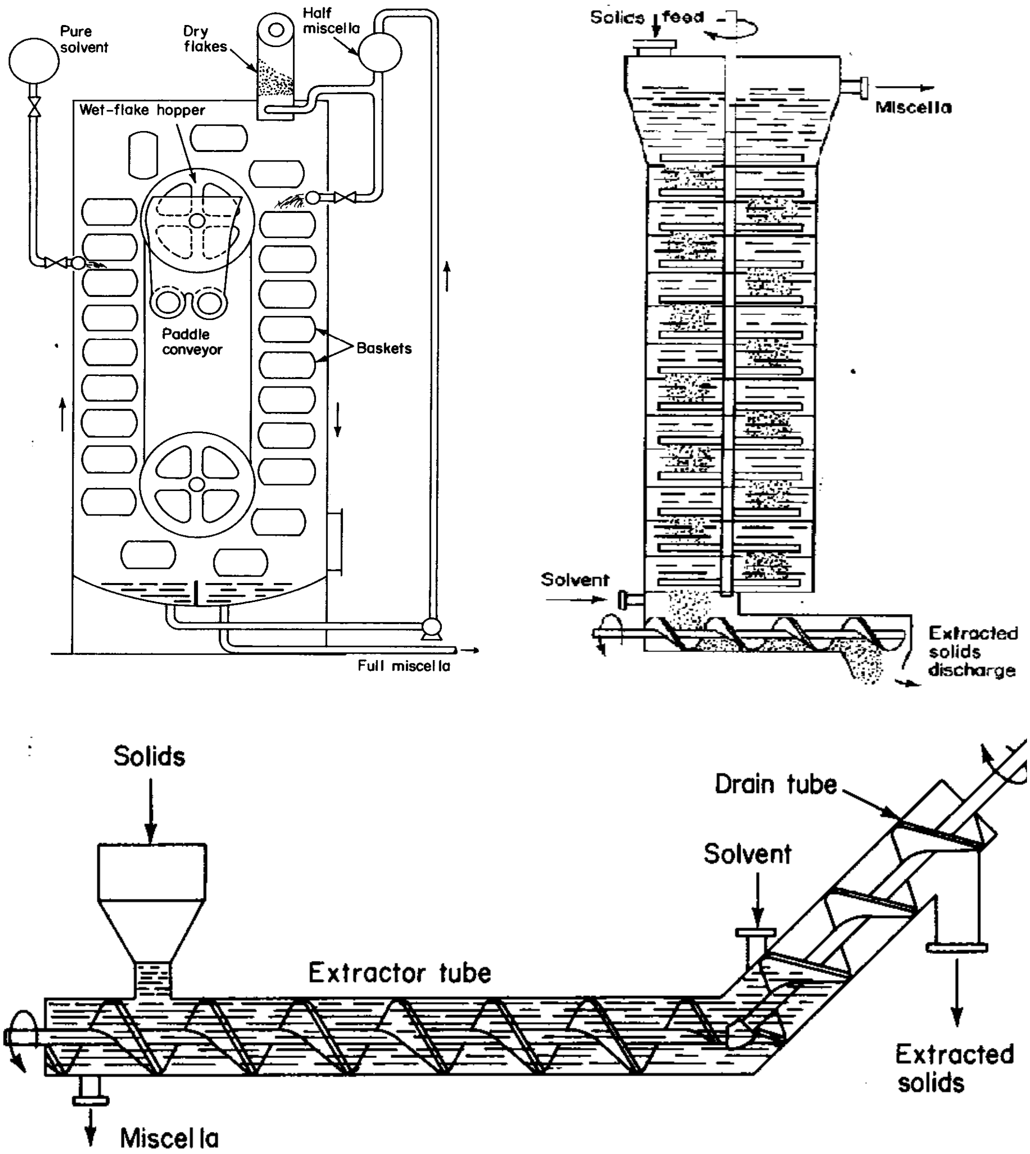


Figure 1-8 Some equipment in solid-liquid extraction. (Reproduced with permission from Brown et al., 1950)

Solid-Liquid Extraction

The valuable component (solute) in a solid, (e.g., oil in copra), can be separated by soaking the solid in a solvent (e.g., hexane) where the solute is soluble and allowing the solute to diffuse out. This is the unit operation of solid-liquid extraction. Some of the other terms equivalent to solid-liquid extraction are washing, leaching, lixiviation, elution, elutriation, diffusion, percolation, decoction, decantation, infusion, maceration, digestion, steeping, and dissolution. These terms mean the transfer of the soluble material from the solids to the solvent.

Solid-liquid extraction finds application in the recovery of oil from oil seeds, fish oil from fish livers, copper from oxidized copper ore, etc., using suitable solvents. Extraction involves two major steps: (1) contact of the solvent with the solid to effect a transfer of the solute to the solvent, and (2) separation of the solute from the solution. The transfer of the solute from the solids to the solvent occurs by diffusion and takes some time. A recovery of 85% is considered economical.

An open tank extraction unit is the simplest equipment for extraction. After the solids are placed in the tanks, the solvent is pumped in until the solids are soaked. Contact is allowed until most of the solute is dissolved. The liquid is then drained from the bottom. The solute is recovered by evaporating off the solvent which is condensed and recycled. In practice, several extractors in series are used which allows more efficient operation. The extracted solids from one extraction unit (known as a stage) is sent to the next stage where it is treated again. In extraction, the raffinate or the underflow refers to the extracted solids, while, the extract phase or the overflow, to the solution containing the solute. Some equipment are shown in Figure 1-8.

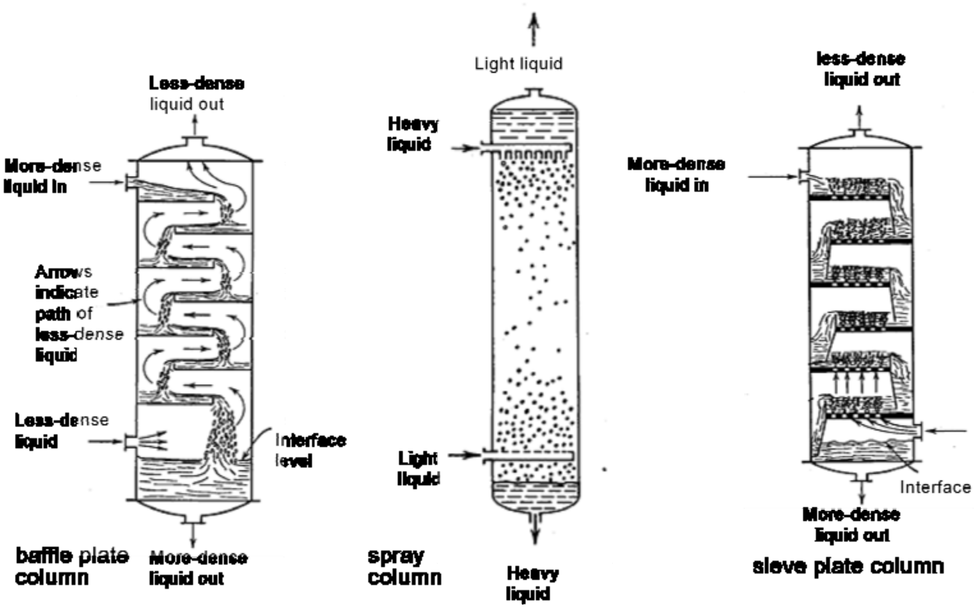


Figure 1-9 Some equipment for liquid-liquid extraction. (Reproduced with permission from Brown et al., 1950)

Liquid-Liquid Extraction

This is a unit operation in which a solute dissolved in a liquid phase is transferred to another liquid phase. Ideally, the two liquids should not be miscible. Otherwise, the two fluids mix and no separation takes place. Two major steps comprise the process: (1) the intimate contacting of the two phases, and (2) the separation of the two phases.

An example is in the recovery of the acetic acid from acetic acid and water solution. The separation of these two substances using distillation is quite difficult. Instead, a solvent such as isopropyl ether can extract the acetic acid. When isopropyl ether comes in contact with the solution, most of the acetic acid transfers to the ether layer. We can easily separate the acetic acid in the isopropyl ether by distillation.

Liquid-liquid extraction is widely used in lubricating oil processing, vegetable oil technology, plastics manufacture, and recovery of penicillin, among others.

The equipment for liquid-liquid extraction provides maximum contact between two phases. Some of these are the spray column, the packed column, the plate column, the sieve plate column, and the bubble cap column. See Figure 1-9. The spray column consists of a cylindrical vessel and spray nozzles at the top and at the bottom. The nozzles at the top spray the dense fluid while at the bottom, the light fluid. Intimate contact between small droplets of the two fluids results. The packed column on the other hand, contains packing materials that allows contact between phases. The plate column consists of a series of perforated plates. The dense fluid is drawn out at the bottom by gravity while the lighter fluid, at the top.

Adsorption

Adsorption is a unit operation in which a component of a fluid mixture adheres to the surface of the solid (called the adsorbent), resulting in a change of composition in the fluid mixture. The adsorbed substance could be an impurity (such as odor or color) or a substance to be recovered (such as acetone). Activated carbon is an example of an adsorbent used to remove undesired color, odor, or other impurities from fluids. Other examples are Fuller's earth (used in refining oils, fats, and waxes), acid-treated clays (used in refining petroleum fractions), bone char or bone black (used in sugar refining), alumina (used in drying air, gases, and liquids), and silica gel (used in drying and purification of gases).

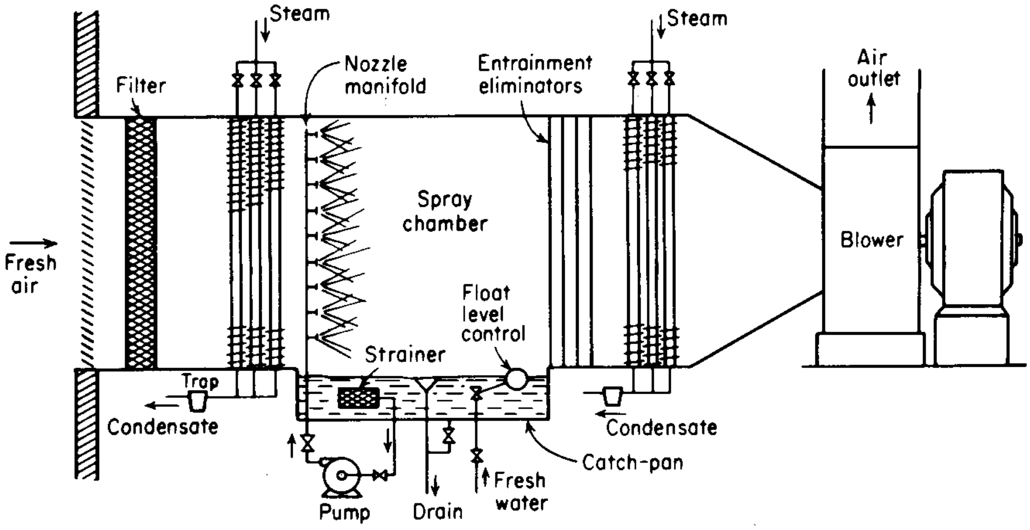
Adsorbents have large surface-to-volume ratio and preferential affinity for specific substances. The equipment for adsorption consists of a bed of adsorbents arranged to provide intimate contact with the fluid for treatment. The spent adsorbent is regenerated and used for many cycles.

SIMULTANEOUS HEAT AND MASS TRANSFERS

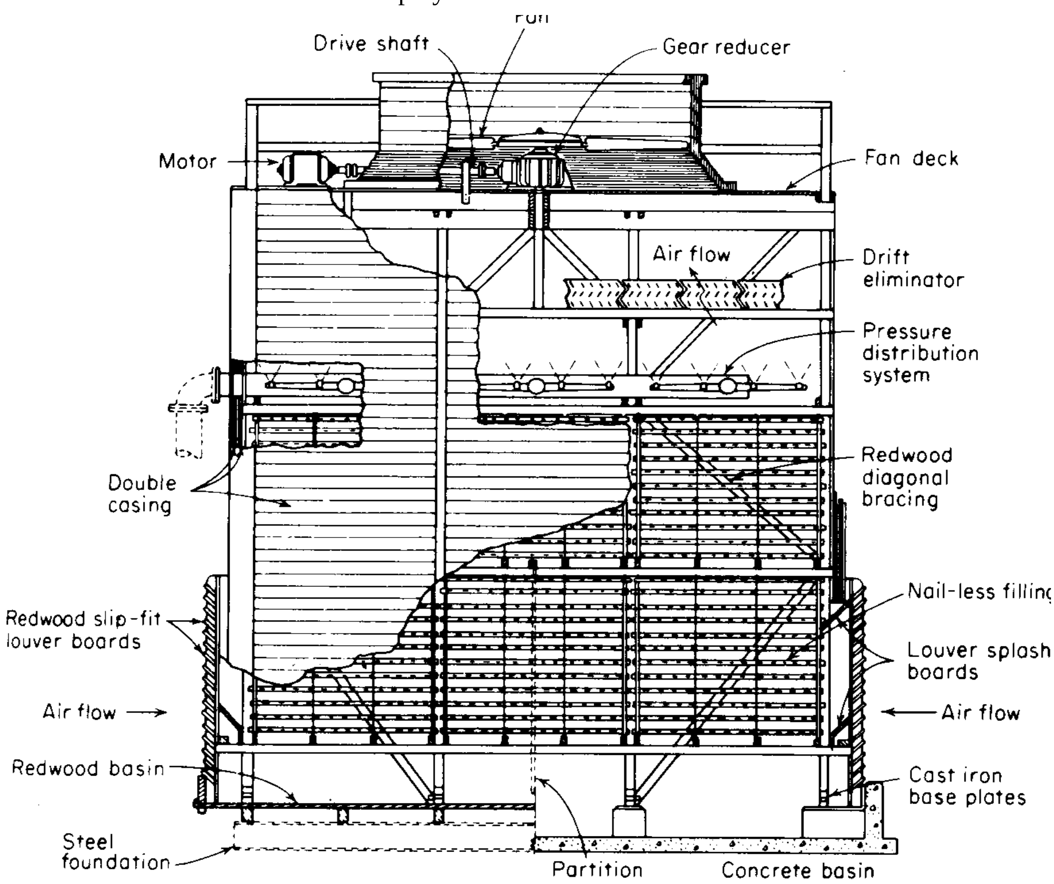
This is a group of unit operations where mass and heat transfers occur at the same time. When a gas phase component becomes liquid, latent heat evolves. Changing from the liquid phase to the gas phase, requires heat. In the unit operations of evaporation, crystallization, drying, humidification, and dehumidification, heat and mass transfers are equally important.

Humidification

Humidity is the amount of moisture in the air. Humidification is the addition of water to air to increase its humidity. As the water



Spray chamber



Induced Draft Cooling Tower

Figure 1-10 Equipment for humidification and dehumidification. (Reproduced with permission from Treybal, 1980).

evaporates, the remaining liquid water provides the latent heat of vaporization. This results in the cooling of the residual liquid water. Humidification therefore serves two purposes: increasing the humidity of the air and cooling of the liquid water. An example of a humidification equipment is the spray chamber. *See Figure 1-10.* Spray nozzles distribute the liquid droplets to the air stream. This is usually applicable for small-scale operations. Another equipment used to cool water is the spray pond. Nozzles spray the water into the air and the evaporation of some of the water cools the remaining water. For large-scale cooling, cooling towers are the appropriate equipment. The cooling tower is usually of wood construction. It consists of several wood -slat decks. A distributor dispenses liquid evenly at the top of the tower. The liquid flows down countercurrent to the air fed at the bottom. The cooled water flows out at the bottom. A simpler way to increase the humidity of air or any gas is by plain injection of steam.

The term humidification originally referred to air-water system, but it also applies to systems involving other gases and liquids.

Dehumidification

Dehumidification (the opposite of humidification) is the process of condensing out the water vapor from the air to decrease its humidity. The cooling tower, an equipment for humidification can also be used for dehumidification. By using a liquid with a temperature lower than that of the wet bulb temperature of the entering gas, some of the water vapor in the air will condense out.

Dehumidification is important in air conditioning where the chiller is the corresponding equipment. The chiller cools a vapor-gas mixture and condenses out some of the water vapor. By using the same principle, dehumidification finds application in the recovery of solvents such as benzene, methanol, acetone, and carbon disulfide, among others.

Evaporation

Evaporation is a unit operation where part of the solvent in a solution is vaporized to concentrate the solution. Either the concentrated solution or the evaporated solvent is the desired product. The most common heating medium is steam delivered through heating coils, tubes, or jackets. In some instances, hot gas may be injected directly. For smaller units, electric heaters are common.

The standard equipment uses vertical or horizontal tubes with steam as the heating medium. *See Figure 1-11.* The evaporated solvent from a unit can be used as the heating medium in the next unit. The process is known as "multi-effect" evaporation, where a unit is an "effect".

Some examples of mixtures separated by evaporation are sugar-water solution, NaCl-water solution, glycerine-water solution, etc. For heat sensitive substances, the operation is carried out under vacuum. In the production of salt, water is evaporated from sea water by solar energy.

Crystallization

Crystallization is a unit operation in which a solution is brought to a concentration where it cannot hold all the soluble component (the "solute") in solution. We can attain this condition by cooling a hot

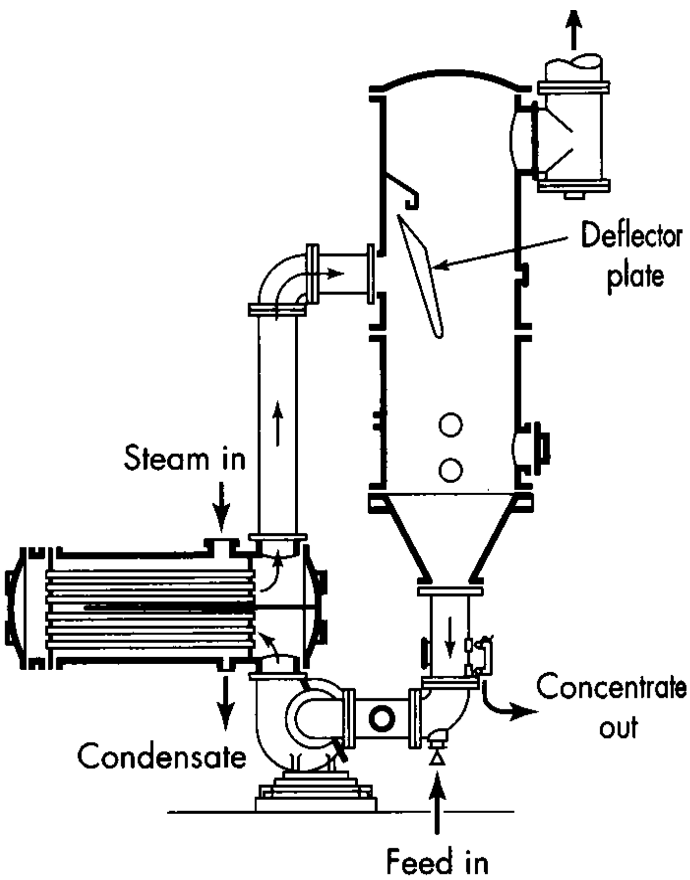


Figure 1-11 Typical evaporator. Reprinted from W. L. McCabe, J. C. Smith, and P. Harriot, Unit Operations of Chemical Engineering 6th Edition, ©2001, Boston, McGraw-Hill, p. 476. With permission from McGraw-Hill Book Co.

solution and/or by evaporating some of the solvent. Crystallization can take place either by addition of a solvent, or by evaporation, or by simple cooling of the solution. The solute precipitates out as crystals. These crystals separate out as pure substance. The impurities left in solution may adhere to the crystals. Washing of the crystals is necessary to obtain a purer product. The simplest type of equipment is a tank where natural cooling and evaporation occurs. Usually, the crystallizer is integral with an evaporator. The Swenson-Walker crystallizer is provided with a cooling system. The vacuum crystallizer removes part of the solvent by evaporation under vacuum, with the crystals precipitating out of solution. *See Figure 1-12.*

Drying

Drying involves the removal of water or another liquid from a solid, slurry, or liquid by vaporization. Hence, the definition of drying is not clear-cut from that of evaporation. Drying is the operation that usually follows evaporation, crystallization, or filtration for the final removal of water.

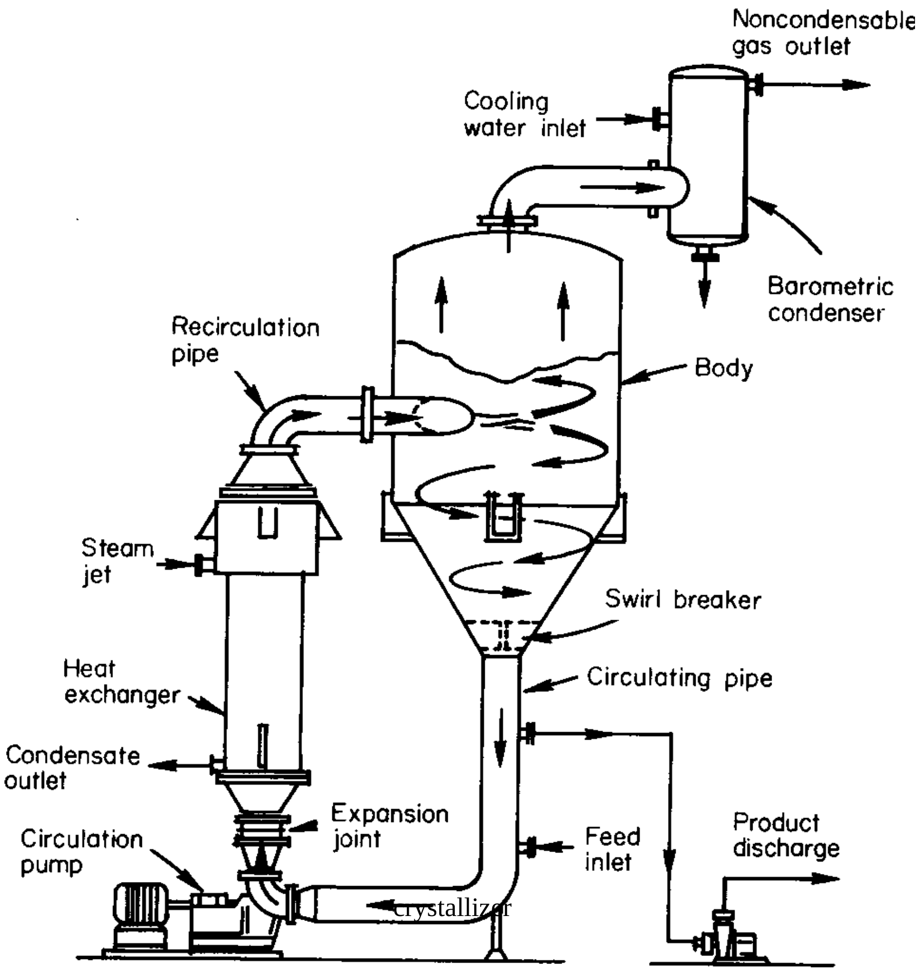


Figure 1-12 A typical crystallizer. (Reproduced with permission from Brown , et. al., 1950)

In drying, a gas medium picks up the vaporized liquid from the solid. By raising the temperature and/or lowering the humidity of the gas medium, we can enhance its drying capacity. In such cases a heater and a dehumidifier are integral with a drier.

The design of drying equipment depends on the type of materials handled. Different types of materials such as sheets, granules, pastes, sludge, slurries, caking crystals, or solutions require specific drier designs. The operation of experimental or small-scale driers are usually carried out in a batchwise manner. The tray drier in *Figure 1-13*, is an example of a batch drier. For continuous operation, tunnel and rotary driers find application. For materials in solution, drum driers or spray driers are preferable. For heat sensitive materials, vacuum operation is required.

MOMENTUM TRANSFER

In a process plant, materials are constantly flowing. This involves transfer of momentum. Processes that involve momentum transfer

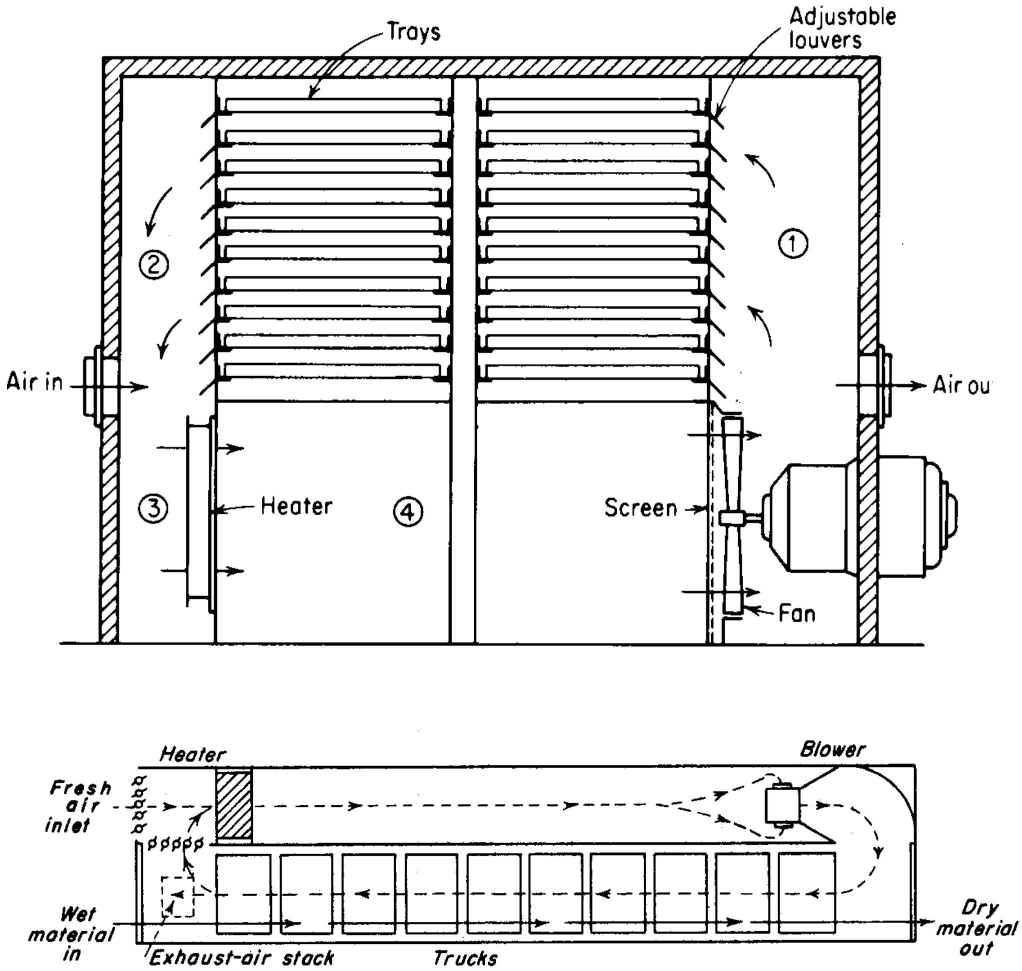


Figure 1-13 Some typical driers. (Reproduced with permission from Treybal, 1980.)

require study of material and energy relationships. Flow of fluids requires application of fluid mechanics. Fluid handling, filtration, and fluidization are some unit operations that involve momentum transfer.

Fluid Flow and Handling

The transportation and movement of fluids in a process is the unit operation of fluid flow. The equipment consist of the fluid movers (pumps, compressors, blowers) and conduits (normally pipes and fittings). Pumps, compressors, and blowers provide energy to move fluids through the process equipment. The types of pumps are many and depend on the nature of materials handled. Materials flow through pipes and fittings. Mild steel is the common material of construction but stainless steel, nickel, plastics, rubber, ceramics, brass, copper, concrete, and glass, among others, find application when they can resist corrosion from fluids being handled. The fittings (which join the pipes) are either threaded, bell-and-spigot, flanged, or welded connections.

Valves control the flow while different flow measuring devices indicate the flowrate.

Filtration

Filtration is a unit operation in which a fluid with solids particles passes through a filter medium. The fluid flows through but the filter medium retains the particles that could not pass through its pores. In filtration, we call the deposited solid the "filter cake" while the separated liquid, the "filtrate". For flow to occur, a driving force is necessary. This force can be gravity, positive pressure, vacuum, or centrifugal force. This is also a basis of classifying filtration equipment. For example, the gravity filter consists of a tank filled with sand filters. The feed is at the top. The liquid drains at the bottom while the solid remains entrapped within the filter medium. Periodic backwashing cleans the filter medium. The plate -and-frame filter press as shown in *Figure 1-14*, consists of alternating

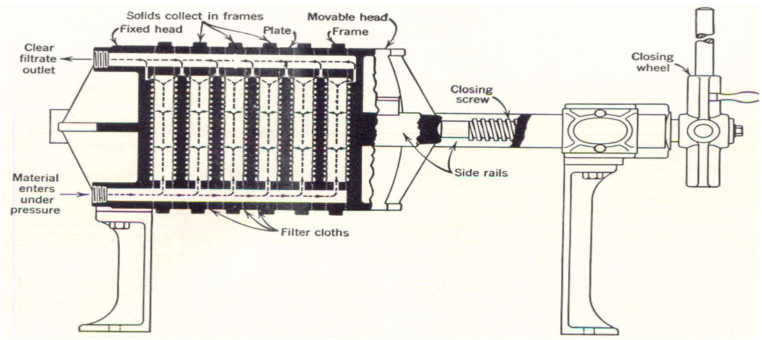


Figure 1-14a . Plate and frame filter press, (Courtesy T. Shriver and Company.)

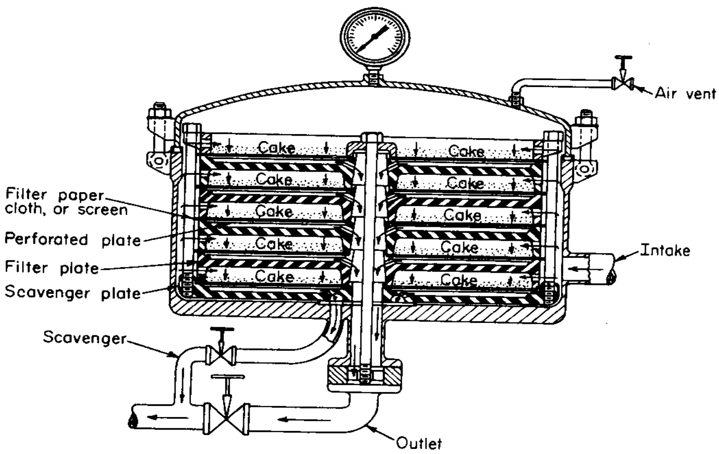


Figure 1-14 b Horizontal plate filter. (Courtesy Sparkler Mfg. Company.)

frame and plate with cloth as the filter medium. With a positive pressure supplied by a pump, the solids remain as a cake bounded by the cloth filters. The leaf filter, on the other hand, needs vacuum. We immerse the "leaf" in the material to be filtered. We apply vacuum within the "leaf" and the solids deposit outside the leaf while the applied vacuum sucks the liquid. The drum filter operates continuously and needs vacuum. With part of a rotating drum immersed in the fluid, the solids deposits on the drum. A knife scrapes the filter cake on the drum.

Fluidization

Fluidization refers to the movement of solid particles in a packed bed when a fluid passes through the bed. The particles move up and down and the bed appears to expand. The expanded bed height depends on the fluid velocity. We can increase the velocity to a point that the solid particles flow with the fluid. Whether as expanded bed or flowing with the fluid, the solid particles are "fluidized". With water as the medium, we can transport sand. Fluidization with air is a means of transporting grain materials. A pump or blower supplies the energy.

OTHER UNIT OPERATIONS

This section considers some of the unit operations that are not included in the first four groups.

Centrifugation is a unit operation that separates solids from liquids, or liquids from other liquids by centrifugal force. The equipment, batch or continuous, involves rotation at a high speed to cause the separation of phases. Butterfat can be separated from whole milk by using a centrifuge. *See Figure 1-15.*

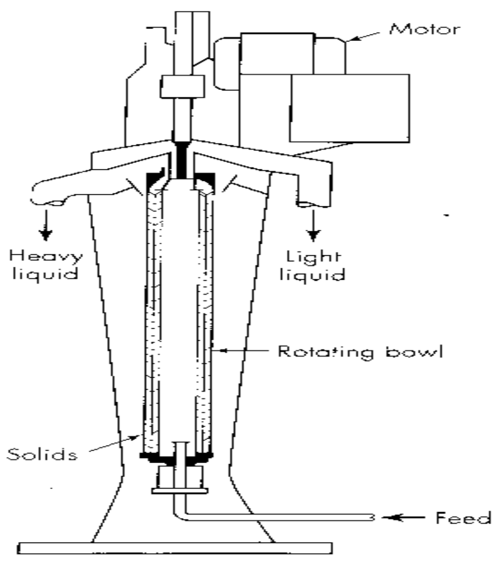


Figure 1-15 A tubular centrifuge. Reprinted from W. L. McCabe, J. C. Smith, and P. Harriot, Unit Operations of Chemical Engineering 6th Edition, ©2001, Boston, McGraw-Hill, p. 1049. With permission from McGraw-Hill Book Co.

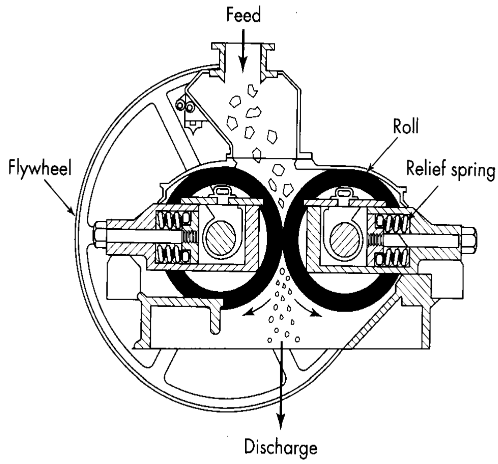


Figure 1-16 A crusher. Reprinted from W. L. McCabe, J. C. Smith, and P. Harriot, Unit Operations of Chemical Engineering 6th Edition, ©2001, Boston, McGraw-Hill, p. 972. With permission from McGraw-Hill Book Co.

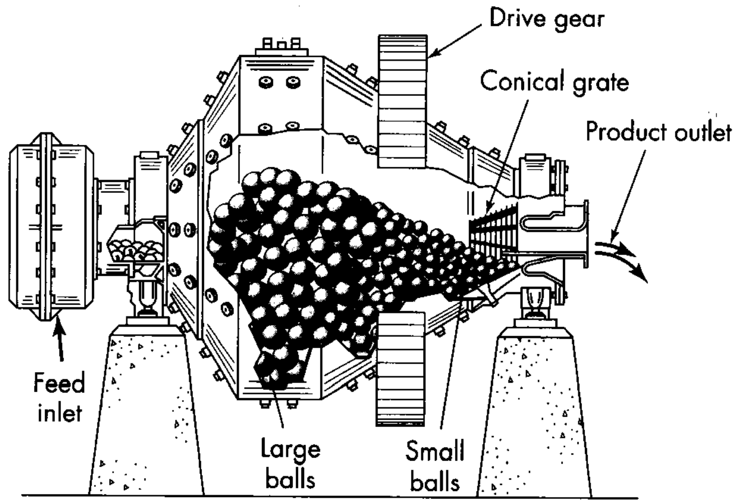


Figure 1-17 A ballmill. Reprinted from W. L. McCabe, J. C. Smith, and P. Harriot, Unit Operations of Chemical Engineering 6th Edition, ©2001, Boston, McGraw-Hill, p. 976. With permission from McGraw-Hill Book Co.

Size reduction involves subdividing solids by application of force to fracture or shatter large masses. Examples are crushers for coarse size reduction and grinders and pulverizers for intermediate and fine size reduction. The type of equipment depends on the properties of materials to be treated. Rocks or gravel require high impact force to break them up. A hammer-like component of a crusher delivers such effect. *See Figures 1-16 and 1-17.* A wood chipper requires a shearing force like that effected by a knife.

Screening is the separation of solid particles into different sizes by passage through several screens with different sizes of openings. Each screen retains the particles that cannot pass through its opening. The size fraction depends on the size of the opening of the screen. A standard set of sieves with known openings determines the size distribution of a mixture of particles of different diameters.

Mixing and agitation is a method for combining liquids, solids, and gases to form intimate mixtures or to maintain intimate contact between the components. The equipment consist of a tank provided with propellers run by motors. See Figure 1-18. Agitators are used to *agitate* liquids or simply mix solutions so they are also called *mixers*. The type of impeller used qualifies the agitator such as turbine, propeller, anchor, scraper, or ribbon shape. For non-viscous liquid such as water, a turbine or a propeller is used. For thick liquids, an anchor or a ribbon type is used.

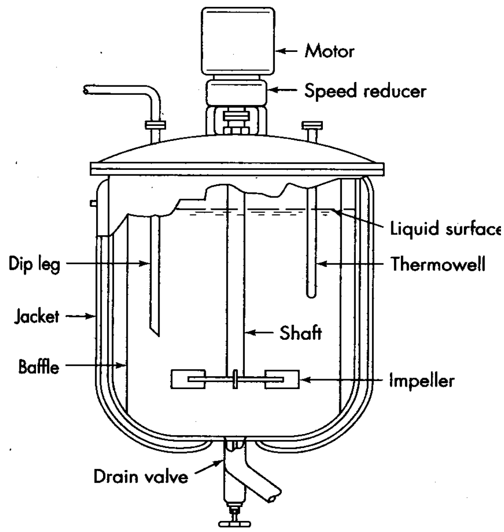


Figure 1-18 An agitator. Reprinted from W. L. McCabe, J. C. Smith, and P. Harriot, Unit Operations of Chemical Engineering 6th Edition, ©2001, Boston, McGraw-Hill, p. 239. With permission from McGraw-Hill Book Co.

Flotation is a unit operation where solids separate by floating to the surface of a fluid. Air is the common flotation agent. Solids that readily take air bubbles on the surface float and separate from those without adhering air bubbles. *See Figure 1-19.*

Sedimentation involves the separation of a suspension of fine solids in a liquid by gravity settling. The fine particles settle to form a denser slurry. Clear fluid issue out from the top. The operation is either batch or continuous. Waste treatment plants use large sedimentation tanks operated continuously. The solids settle at the bottom and an arm continuously scrapes it. The clarified solution overflows at the top. *See Figure 1-20.*

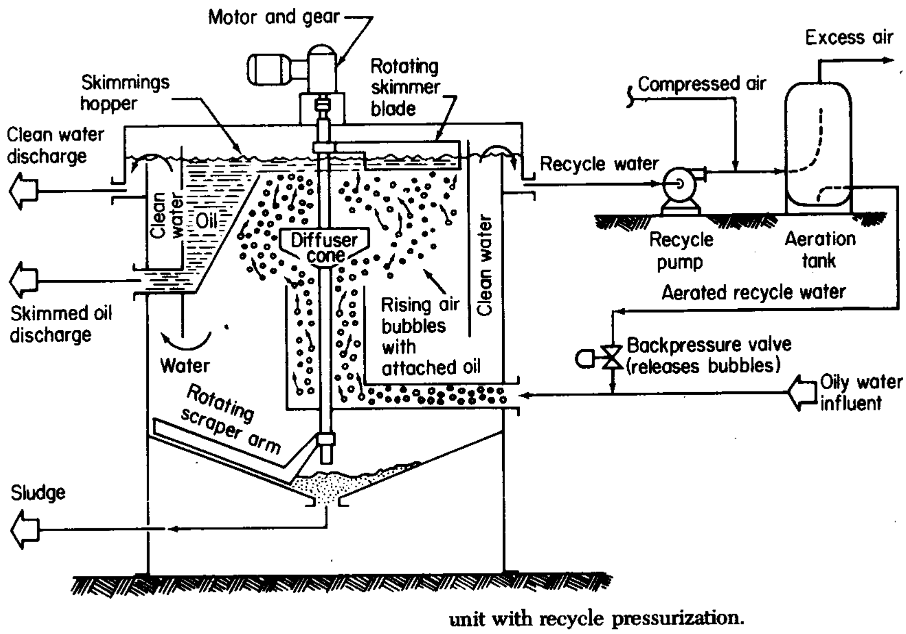


Figure 1-19 A flotation equipment. Reproduced with permission from (Schweitzer, p. 4-129)

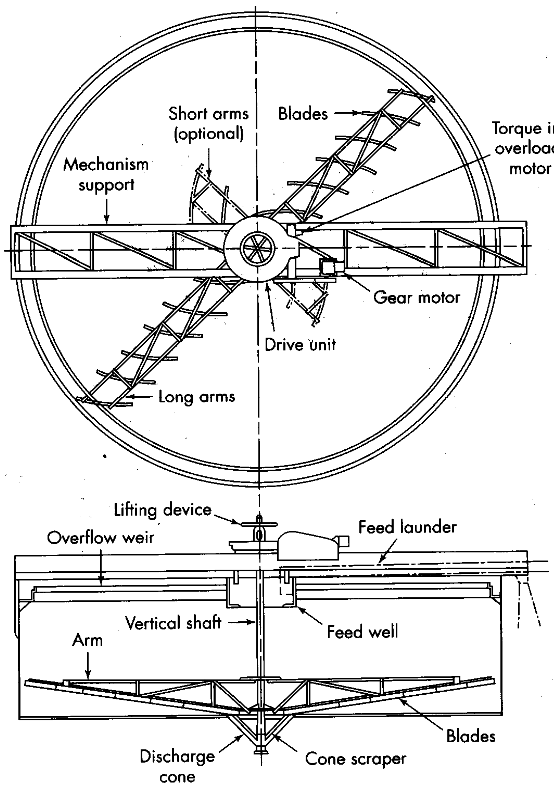


Figure 1-20 A clarifier separates suspended solids by settling due to gravity. Continued on page 33.

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PROBLEMS

1-1 How does the profession of chemical engineering differ from that of chemistry? Of physics? Of mathematics?

1-2 Interview some chemical engineers you know. Ask them if they feel versatile and how does this affect their work and profession.

1-3 Identify chemical engineers that are known locally and their contribution to the Philippines.

1-4 Identify internationally known chemical engineers and their breakthroughs.

1-5 Identify some chemical process industries within your city or town.

1-6 Cite additional fields where you believe chemical engineering will be increasingly important.

1-7 What characteristic of the chemical engineer is necessary in globalization?

1-8 A batch of 180 m^3 of wastewater contains 5% oil by volume. An oil sepa rator is used to recover the oil. If the separator is 98% efficient, how much oil is recovered?

1-9 A building has a common water meter and a cistern for the households. In the last month, tenant #1 consumed 50 m^3; tenant #2, 45.5 m^3; tenant #3, 63.3 m^3; tenant # 4, 39 m^3; and tenant #5, 65 m^3. If the reading of the main meter for that month is 300 m^3, how much is the leakage?

1-10 Biomass materials normally contain an average of 50% lignin, 30% cellu lose, and 20% hemicellulose. How many grams of each component does 20 kilograms of the biomass contain?

1-11 We want to mix coconut oil with corn oil at a ratio of 2:1 (by mass). How many grams of each is necessary to prepare 4.5 kg mixture?

1-12 To make a low fat milk containing 1% butterfat, how much butterfat must be removed from 8,000 liters of milk containing 5.1% butterfat?

1-13 An alloy contains 90% (by mass) of gold while another contains 20%. How many grams of each alloy should be combined to produce an alloy con taining 60% gold?

1-14 A laboratory maintains 35% (by mass) hydrochloric acid and 10% (by mass) hydrochloric acid solutions. The process needs 400 kg 15% solu tion. How many kg each of 35% and 10% acid solutions are needed?

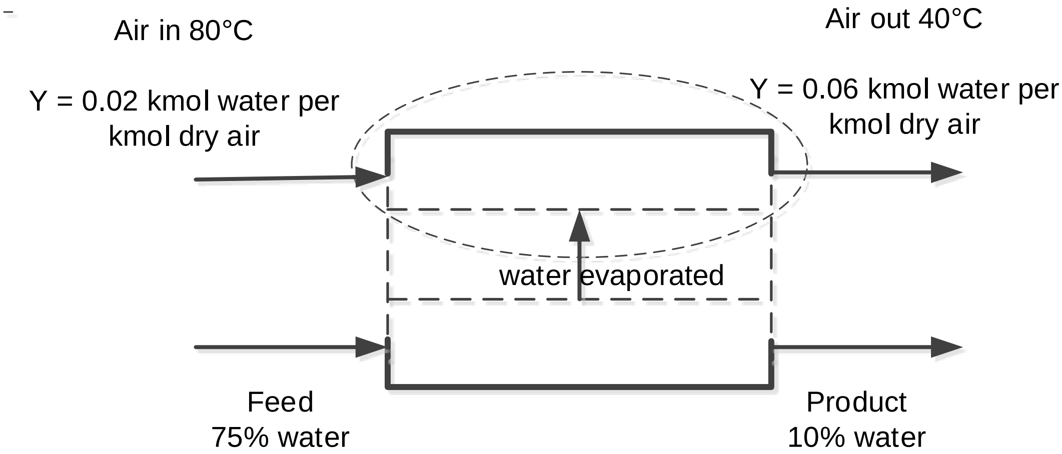
1-15 A 200-gram mixture of salt and sugar contains 50% of each. How many grams of sugar must be added to the mixture to produce a mixture con taining 60% sugar? A glycerin-water solution contains 60% glycerin (by mass). How much water must be removed from the solution to produce a 90% glycerin?

INDEX

Solution to the problem in the inside back cover.

A drier handles a wet material containing 75% water and dries it to 10% water. The air used is at 80°C and contains 0.02 kmol water per kmol dry air. The outgoing air is at 40° and contains 0.06 kmol water per kmol dry air. If the product rate is 100 kg/h, what is the volumetric flowrate of the outgoing air in m^3/min?

Given:



We get the ratio of water to the bone-dry-solids (BDS) in the feed and in the product.

In the feed this ratio is 75 kg water per 25 kg BDS, while in the product, 10 kg water 90 per kg BDS. The difference of the two quantities is (75/25 – 10/90) with a unit, kg water evaporated per kg BDS. Similarly, we apply this to the air stream. The difference between the two humidities, (Y_{out} - Y_{in}) has a unit, kmol water picked up per kmol dry air.

Volumetric flow rate of gas out =

$$100 \times \frac{\text{kg prod}}{\text{h}} \times \frac{25 \text{ kg BDS}}{100 \text{ kg prod}} \times \left(\frac{75}{25} - \frac{10}{90}\right) \times \frac{\text{kg water evaporated}}{\text{kg BDS}} \times \frac{1 \text{ kmol water}}{18 \text{ kg water}}$$

$$\times \frac{\text{kmol dry air}}{(0.06 - 0.02) \text{ kmol water picked up}} \times \frac{(1 + 0.06) \text{ kmol humid air}}{1 \text{ kmol dry air}} \times \frac{22.4 \text{ m}^3}{\text{kmol}}$$

$$\times \frac{(40 + 273)}{273} \times \frac{1 \text{ h}}{60 \text{ min}}$$

= 45.5 m^3/min

Atomic Numbers and Atomic Masses

Element	Symbol	Atomic number	Atomic mass	Element	Symbol	Atomic number	Atomic mass
Actinium	Ac	89	227.03	Mercury	Hg	80	200.59
Aluminum	Al	13	26.98	Molybdenum	Mo	42	95.94
Americium	Am	95	243	Neodymium	Nd	60	144.24
Antimony	Sb	51	121.75	Neon	Ne	10	20.18
Argon	Ar	18	39.95	Neptunium	Np	93	237.05
Arsenic	As	33	74.92	Nickel	Ni	28	58.70
Astatine	At	85	210	Niobium	Nb	41	92.91
Barium	Ba	56	137.33	Nitrogen	N	7	14.01
Berkelium	Bk	97	247	Nobelium	No	102	259
Beryllium	Be	4	9.01	Osmium	Os	76	190.2
Bismuth	Bi	83	208.98	Oxygen	O	8	16.00
Boron	B	5	10.81	Palladium	Pd	46	106.4
Bromine	Br	35	79.90	Phosphorus	P	15	30.97
Cadmium	Cd	48	112.41	Platinum	Pt	78	195.09
Calcium	Ca	20	40.08	Plutonium	Pu	94	244
Californium	Cf	98	251	Polonium	Po	84	209
Carbon	C	6	12.01	Potassium	K	19	39.09
Cerium	Ce	58	140.12	Praseodymium	Pr	59	140.91
Cesium	Cs	55	132.90	Promethium	Pm	61	145
Chlorine	C1	17	35.45	Protactinium	Pa	91	231.04
Chromium	Cr	24	51.99	Radium	Ra	88	226.03
Cobalt	Co	27	58.93	Radon	Rn	86	222
Copper	Cu	29	63.55	Rhenium	Re	75	186.2
Curium	Cm	96	247	Rhodium	Rh	45	102.91
Dysprosium	Dy	66	162.50	Rubidium	Rb	37	85.45
Einsteinium	Es	99	254	Ruthenium	Ru	44	101.07
Erbium	Er	68	167.26	Samarium	Sm	62	150.4
Europium	Eu	63	151.96	Scandium	Sc	21	44.96
Fermium	Fm	100	257	Selenium	Se	34	78.96
Fluorine	F	9	19.00	Silicon	Si	14	28.09
Francium	Fr	87	223	Silver	Ag	47	107.89
Gadolinium	Gd	64	157.25	Sodium	Na	11	22.99
Gallium	Ga	31	69.72	Strontium	Sr	38	87.62
Germanium	Ge	32	72.59	Sulfur	S	16	32.06
Gold	Au	79	196.97	Tantalum	Ta	73	180.95
Hafnium	Hf	72	178.49	Technetium	Tc	43	97
Helium	He	2	4.00	Tellurium	Te	52	127.60
Holmium	Ho	67	164.93	Terbium	Tb	65	158.93
Hydrogen	H	1	1.01	Thallium	TI	81	204.37
Indium	In	49	114.82	Thorium	Th	90	232.04
Iodine	I	53	126.90	Thulium	Tm	69	168.93
Iridium	Ir	77	192.22	Tin	Sn	50	118.69
Iron	Fe	26	55.85	Titanium	T1	22	47.90
Krypton	Kr	36	83.80	Tungsten	W	74	183.85
Lanthanum	La	57	138.91	Uranium	U	92	238.03
Lawrencium	Lr	103	260	Vanadium	V	23	50.94
Lead	Pb	82	207.2	Xenon	Xe	54	131.30
Lithium	Li	3	6.94	Ytterbium	Yb	70	173.04
Lutetium	Lu	71	174.97	Yttrium	Y	39	88.91
Magnesium	Mg	12	24.31	Zinc	Zn	30	65.38
Manganese	Mn	25	54.94	Zirconium	Zr	40	91.22
Mendelevium	Md	101	258				

A practical approach to teaching the first course
In chemical engineering

INTRODUCTORY CONCEPTS IN CHEMICAL ENGINEERING

This textbook is designed for students with only a background (general education) in chemistry, physics, arithmetic, and algebra. Thus, this book is for anyone who wants a simple background of the chemical engineering discipline (e.g. elementary chemical engineering).

Drawing on 40 years of teaching and professional experience W. I. Jose takes you step-by-step learning the basics of mass and energy balance calculations, starting with a revelation that you have solve some mass problems in high school arithmetic or algebra subjects without any background in chemical engineering. Principles and relationships are gradually introduced so that the increasing difficulty is not felt at all. Computer aided solution is discouraged to keep focus on the principles so they are ingrained in the students' mind. Although some shortcut solutions are given, they are intended for student's personal use to sharpen their solving and thinking skills.

For example, solve the following problem using a one-line solution:

> A drier handles a wet material containing 75% water and dries it to 10% water. The air used is at 80°C and contains 0.02 kmol water per kmol dry air. The outgoing air is at 40° and contains 0.06 kmol water per kmol dry air. If the product input rate is 100 kg/h, what is the volumetric flowrate of the outgoing air in m^3/min?

(Shortcut solutions should be avoided when presenting work to others or in taking exams in other subjects.) If you are able to do this you will be adept in analyzing solutions to problems as many chemical engineers do. The solution is on page 344.

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