AN INTRODUCTION TO FOOD DEHYDRATION AND DRYING

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The author assumes no responsibility or liability for any problems of any manner encountered through the application of the principles discussed herein.
All "Examples" and "Case Studies" are based on generic or hypothetical cases and do not represent any specific or proprietary processes in current or past use. Such "Examples" and "Case Studies" are intended for instructional purposes only.

AN INTRODUCTION TO FOOD DEHYDRATION AND DRYING

OUTLINE

CHAPTER 1: GETTING STARTED

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ACKNOWLEDGEMENTS

AN INTRODUCTION TO FOOD DEHYDRATION AND DRYING

CHAPTER 1: GETTING STARTED

1.1 Learning Objectives

The purpose of this manual is to provide a basic understanding of dehydration and drying as it is used in the food industry and in various sectors of the agriculture industry.

In Chapter 1, we will examine the reasons for drying food, and then look at the factors influencing drying. We will conclude Chapter 1 with a discussion of the effects of drying on the product.

A difficulty that many people have in understanding drying involves the gathering and organization of information associated with their specific drying process. Chapter 2 is designed to assist you in these key activities. The approaches outlined in Chapter 2 can be applied to most areas of food processing and are not limited to drying. Construction of process flow diagrams and the "Unit Operations" concept will be introduced here. In order to illustrate this, a case study example that goes beyond just the drying of a product is included for illustrative purposes.

Once the information regarding a process has been gathered and organized in a manner that makes it clearer and easier to understand, the next step is to develop relationships between the raw materials entering the process and the finished products leaving the process. In a drying process, this generally involves a series of mathematical calculations to determine amounts of moisture removed during the time that the materials are subjected to various drying conditions. They may also involve heat calculations. It is absolutely essential that you develop a structured approach to the mathematics involved. The mathematics is usually not too complex. However, if you do not follow a logical and systematic approach to your problem solving, it is easy to become confused and ultimately frustrated. Chapter 3 has been included to introduce the "Dimensional Analysis" approach to problem solving. This is a relatively straight-forward, yet highly effective method of attacking mathematical problems that involves using numbers along with their associated units or dimensions such as kg or kg per hour, etc.

Once you feel comfortable with the organization of information from Chapter 2 and the use of Dimensional Analysis from Chapter 3, you will be ready to move on to Chapter 4 which introduces the concepts of wet basis moistures and dry basis moistures. Sample calculations and case studies are included to familiarize you with these concepts and their applications to drying process work.

After completing the "Introduction to Food Dehydration and Drying", you should:

- be familiar with the reasons why food is dried and the factors that influence food drying.

- be able to "break down" a food process into its component "unit operations".

- be able to prepare a process flow diagram for a typical food process and understand the basic functions of the unit operations involved in it.

- be able to understand and apply the "Dimensional Analysis" approach in solving food processing related problems (as well as to be able to detect calculation errors on the basis of the units or dimensions involved).

- be able to calculate (or estimate) the moisture content of a finished product based on information regarding its initial moisture content and the amount of water removed.

- be able to understand the pitfalls involved in using wet basis moisture values when working with the water content of food materials.

1.2 Background

1.2.1 Definition of "Drying"

For the purpose of this work, we will refer to "drying" as the removal of water from any material, such as a food product. This may be done by means of exposing the material to heated air in a chamber which we will call a "dryer"; or it may be accomplished through natural means such as solar drying where the sun provides the energy necessary to remove the water from a food product.

The term "dehydration" should be considered as being essentially the same as drying. Although some food scientists and food processing engineers may consider that there are subtle differences between the two terms, we will not worry about these differences here.

1.2.2 Historical Development

Drying is one of the oldest forms of food processing. Its origins most certainly pre-date recorded history. It is not hard to imagine early hunters and gatherers finding berries that had become dried on the vines. These dried berries would have possessed characteristics that were different from the fresh undried fruit, but most importantly, they would have remained edible for longer periods of time than they did in their undried form. Other forms of food may have also been dried naturally by laying them out in the sun.

With the discovery of fire, a new means of drying was available. It offered numerous advantages over sun-drying since it was more reliable, more controllable, and much more convenient. Meat could be dried over a fire and gain the added advantages of cooking and smoking.

If we come forward to the 21st Century, we can see tremendous advances have been made in all areas of food processing. Not the least of these areas is food "dehydration" or "drying". Although the drying process still basically involves the removal of water, modern drying equipment has replaced primitive open fires and scientific knowledge has added to our understanding of it. Even though sophisticated drying equipment is available in many parts of the world, sun drying, drying over an open fire, and smoking are still viable ways of drying and preserving certain foods.

In spite of all of the modern developments in the field of drying, drying still retains much of its "art". To produce high quality products which meet the demands of today's consumers, it is simply not enough to know the theoretical aspects of

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drying - one also has to know the "art" of applying this knowledge to the material being dried.

1.3   Reasons for Drying Foods

1.3.1   Spoilage Reduction

The most important reason for drying food is to prevent or reduce spoilage and thereby create a product that remains edible for a longer period of time than it would in its undried form. A suitable level of moisture is required by spoilage microorganisms in order to sustain their growth and solublize nutrients that they require. Without this moisture, microorganisms will either lie dormant or die.

One of the most commonly observed spoilage microorganisms is "mold". Colonies of mold growth often appears as "fuzzy" grey spots on the surface of a food product.

While mold is generally quite visible to the consumer, other spoilage microorganisms may not be so easy to see.

Clostridium botulinum is an earth-borne bacteria that can be found on the surfaces of vegetables and root crops etc. If allowed to grow in a food product, it can produce a toxin that has serious health implications which we know as food poisoning or "botulism". Similarly, microorganisms like Salmonella, Listeria, and *E. coli* can produce potentially deadly toxins in foods if measures are not taken to properly process and preserve the food.

By lowering the moisture content of a food product to a sufficiently low level,

additional advantages can be obtained in addition to spoilage reduction. These are discussed in the following sections.

1.3.2   Enhanced Storage-Life

Water removal can increase the duration of time over which a food remains edible. While this is essentially the same as spoilage reduction, it is worthy of mention as a reason for drying a food product. As an example, dried berries will last longer than in their fresh undried form. In many cases, water can be added back into dried products, such as the dried berries, to rehydrate them and regain many of the attributes of the initial product.

1.3.3   Changed Storage Conditions

All foods require certain conditions to prevent their spoilage. It is also desirable to preserve their taste, nutritional attributes, and other properties, such as aroma. In order to accomplish this, special storage conditions such as freezing or refrigeration may be necessary. If the food can be dried and stored at ambient or room temperature, it reduces the expense of maintaining specialized storage conditions. It also increases the potential market for a product when such storage and transportation conditions are not required.

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1.3.4 Weight Reduction

In today's world, food production areas are often far from the areas where the food will be consumed. Much of the weight of many food products is attributable to the presence of water. If water can be removed, the weight can be reduced and the cost of shipping the product can also be reduced. Often, there is a volume change associated with food drying. As water is removed, the food shrinks in size, thereby taking up less room and allowing more product to be shipped in a given volume.

Shipping water from one location to another is viewed as an undesirable and unnecessary expense. The removal of water from orange juice to create orange juice concentrate is a good example. With orange juice, the water is removed in a concentration process that is not a typical drying process. However, the example is an appropriate one to show how water removal can be used to good advantage. Removal of water to create a concentrate with 65% solids instead of the usual 9% to 10% solids in fresh squeezed orange juice reduces both the shipping weight and volume. Once the concentrate arrives at its intended destination, or is purchased by the consumer, water can be added back into it to dilute it to the desired final water content prior to consumption.

1.3.5 Increased Convenience

Many consumers want foods that are convenient. This is especially true in cases where there may not be enough time available to prepare a meal from fresh unprocessed products. Examples of this would include dehydrated potato flakes or instantized rice. The consumer may take the desired portion of dried product, mix it with boiling water, allow it to stand until the moisture is taken into the dried product, and then serve it . With recent technological advances, such products are often better in quality than similar products in their in fresh form.

Another benefit of dehydrated foods is that waste may be reduced during preparation by the consumer. In the case of dehydrated potato flakes, there is no need for the consumer to peel the potatoes and remove undesirable blemishes or "bad spots". All of the product is usable in its purchased form.

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1.3.6 Changed Properties:

Dried foods may offer different properties from their undried forms. These differences may create unique products that have applications which are quite novel compared to the original material. In addition, through drying, value may be added and new markets may be created to increase the use and commercial value of a particular raw material.

Consider the following examples:

Dried products such as raisins (from dried grapes) and prunes (from dried plums) offer taste and texture differences from their original form. Sun dried raisins are used in a different manner than grapes due to their changed properties that have resulted from water removal.

Dried apple slices can be used in combination with dried cereals to add increased taste and flavour. They also create a textural change from the cereal flakes. While the dried apples do not regain the characteristics of fresh apples when they pick up moisture from the milk, their soft chewy texture is quite appealing and pleasant to many individuals.

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1.4 Methods of Water Removal and Dehydration

We will be discussing this topic in much greater depth as we move on to the Intermediate Level material. However, in order to appreciate some of the introductory material, it would be advantageous to have some understanding of the various methods of water removal in food processing.

1.4.1 Traditional Methods

Most traditional drying methods rely on the application of heat by direct or indirect means.

In the case of direct heat application, the heat is usually brought to the product by air which has been previously heated to the desired temperature. It is the function of the heated air to evaporate moisture in a product and transport the evaporated moisture out of the dryer. Air can be heated by passing it through flames from a gas burner or similar source of heat. Air can also be heated by passing it over metal tubes through which steam is circulated. The hot air is then blown across or through the product being dried. This is a variation on the simplest example of direct heat application which would be drying something over an open fire. Many commercially available dryers are based on direct heat application.

An example of indirect heat application might be the use of a drying oven which has metal walls heated from the outside. The heat radiating from the metal oven walls then heats the air and product in the oven which in turn dries the product. This indirect heat application is generally not as efficient, nor as effective, as direct heat application.

1.4.2 Non-Traditional Methods:

Non-traditional drying methods may also be referred to as "emerging" drying technologies. As drying technologies become more advanced, we are seeing methods of water removal which are aimed at minimizing the application of heat. When drying food products that are sensitive to heat, this is especially important in order to prevent the quality of the food from being reduced.

We are also seeing methods that address energy efficiency. In these cases, the application of heat is highly controlled so as to avoid waste and apply heat in a manner that matches the needs of the product rather than simply applying excessive amounts of heat to drive off as much water as possible in the shortest possible time.

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1.5 Factors Influencing Drying

1.5.1   Introduction

For purpose of the following discussion, let us consider materials that contain water on the outside surface and distributed throughout the interior structure of the material as well.

We will divide the factors influencing drying into two basic groups: Product Attributes and Drying Equipment Attributes.

As we consider the factors that influence drying, I will attempt to give examples that relate specifically to food, but other examples will also be included for illustrative purposes. You should draw upon your experiences in everyday life to support your visualization of the concepts of drying. Even if it is something as seemingly simple as drying wet clothes, there are lessons to be learned that can be applied to more complex drying operations.

1.5.2   Product Attributes

1.5.2.1   Particle Size

Drying is a process that takes place at the surface of the material for much of the drying time. Some degree of drying may also take place just below the surface, but we generally should focus on water removal as being a surface phenomenon.

When we have large particles, it takes water at the centre of the particle more time to travel to the surface and be removed by the drying air than it would for water to reach the surface from the centre of a smaller particle. For this reason, we must adjust our drying times to account for the size of the particle.

Water travels from the interior of the product to the surface by a process known as "diffusion".   The rate of diffusion, or how much water reaches the surface in a given period of time is something that is dependent on the particle size and the structure of the material (see below).   Under normal drying conditions, there is very little that can be done to speed up the rate of diffusion and you must match your drying procedure with the particle size and type of material being dried.

If we are drying hydrated cereal grains such as rice or wheat, the more plump (i.e., bigger diameter) grains will take longer to dry than the smaller diameter grains due to the distance that the water has to travel from the inner core to reach the surface.
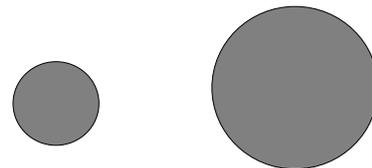
FIGURE 1-1: Particle Size Differences

As you can visualize from the two circles (or spheres) in Figure 1-1, any water at the centre of the larger particle will have further to travel to reach the surface than it would in the smaller one. This means that it will take longer for the water to reach the surface of the larger product particle and be removed.

1.5.2.2 Particle Shape

Shape is another important consideration in drying any material. Shape is also important when it comes to cooking a material and getting heat into it.

There are really only three basic shapes of objects that we have to deal with in drying. They are shown in Figure 1-2.

i. spheres   ii. cylinders

iii. flat plates or slabs
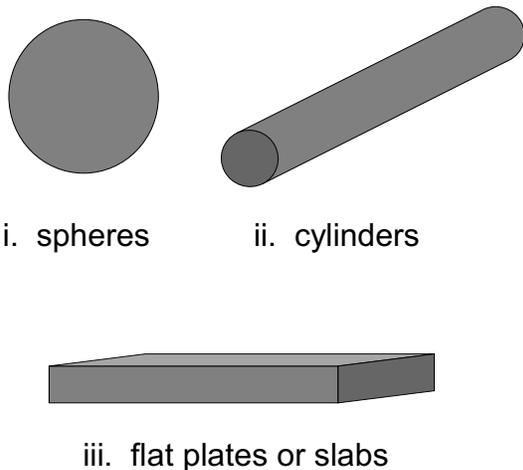
FIGURE 1-2:   Basic Shapes of Objects

Spherical objects are those that are round like a ball. Peas are spherical, as are most berries. With spherical objects, the maximum possible volume is contained within the smallest possible surface area for a given weight of material. As a result, spherical particles can be rather difficult or slow to dry. As stated above, it takes time for moisture at the interior of the sphere to diffuse to the particle surface where evaporation by the hot air or other drying medium will occur. With spherical objects, the total surface area is considered to be important in the removal of water during drying.

Cylindrical objects are long but have a circular cross-section. A carrot would be considered to be a cylinder, even though one end of it might be larger in diameter than the other end.   Wieners and sausages are cylindrical, as are cereal grains such as rice. When moisture is removed from a cylindrical material, water must diffuse from the centre of the cylinder and travel outwards along the radius to reach the surface just as it did in the case of the spherical object. The main difference between drying a spherical object and drying a cylindrical one is that the ends of the cylinder are generally not considered as being very important in the drying process.   The ends represent a relatively small fraction of the surface area for water removal when compared to the sides of the cylinder. When drying a cylindrical object, there is usually more surface area per unit weight of material than there is for a spherical object, so drying is somewhat faster with cylinders than with spheres. It should be noted that large diameter cylinders will take longer to dry than smaller diameter cylinders.

Flat plates or slabs may be thought of as looking like a flat piece of wood that has flat top and bottom surfaces and a flat surface around its edge. A steak or a piece of flat cookie dough may be considered as being slabs.   In drying, water would be lost from the top and bottom surfaces. The surfaces around the edge would play a minor role in water removal. Because the surface area of a slab is often quite large in relation to its thickness, it may be easier to dry slab-shaped objects than it would be to dry spherical or cylindrical objects.

Each of the three basic shapes has a characteristic dimension that determines the relative drying rate.   In the case of

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spherical objects, it is the radius (i.e., half of the diameter) that is important. For cylinders, it is also the radius that is most important. For flat plates or slabs, the characteristic dimension is one-half the thickness since water only has to diffuse from the centre of the slab to either the top or bottom surfaces of the slab.

If we consider an everyday example, think of drying a wet sock that is rolled up into a ball and an identical wet sock that is spread out fully. The rolled-up sock will resemble a sphere and the flat sock will look like a flat plate or slab. You probably know from experience that the sock that is spread out will dry faster than the rolled-up sock, which shows the importance of shape in influencing drying.

1.5.2.3 Composition, Structure, and Porosity

The influence of composition and structure on drying is quite pronounced. A tight, dense structure will tend to hold moisture inside the material more than a loose open structure will. Large pores penetrating throughout the interior of a product or material will allow diffusion of moisture to proceed at a faster rate than in the case where there are very few or very narrow pores.

A starchy material will hold more moisture when the starch is gelatinized and the "starch matrix" is swollen with absorbed water. A fibrous material may loose moisture more readily than a less fibrous material due to the routes available for moisture to escape from the interior to the surface.

The importance of composition, structure, and porosity should not be

underestimated. These are quite complex properties that may even change during the drying process. As water is removed, the "starch matrix" of something like hydrated rice may collapse in on itself and change the diffusional properties of the material. Temperature can also change starches from a non-gelatinized to a gelatinized form and affect the drying process.

One of the most important things to recognize here is that before purchasing a dryer to dry any product, you should do a series of thorough investigative trials using all available resources, including pilot-scale drying equipment if that is possible. You should work with dryer suppliers to determine how your product behaves throughout the drying process and leave nothing to chance.

1.5.2.4 Moisture Content

Perhaps one of the most obvious factors affecting drying is the actual moisture content of the material itself. In most drying applications, we have a final target moisture to which we want to reduce the product moisture. If the initial moisture of the starting material is high, then more moisture will have to be removed compared to cases when its moisture content is somewhat lower. This will take additional drying time which must be taken into account when establishing operating conditions for the dryer.

In setting up a dryer, the initial moisture content and amount of product being processed per unit time (e.g., kilograms or "kg" of product at a given moisture content going into a dryer each hour) are key variables to consider.

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1.5.2.5 Surface Characteristics

Surface characteristics are important from several perspectives. First, we should consider that in many cases, such as berries, the surface is designed to retain moisture. If we want to dry berries, we have to realize that nature has intended the berry to protect the seeds to ensure that the plant reproduces. In order to keep a supply of moisture around the seed, the surface of the berry is often quite tough, or waxy, or otherwise forming a barrier to moisture loss. If we wish to dry the berry, then we must recognize this fact and take measures to overcome this barrier to moisture loss. We could slice the berries to allow the drying medium (i.e., the air) to reach the fleshy moist part of the berry. Alternately, we could rupture the skin of the berry to allow points through which the moisture could escape during drying.

If the surface of a product is quite rough and pitted, this may allow moisture to escape better than if the surface was relatively smooth.

1.5.2.6 Specific Surface Area

Specific surface area is an indication of the surface area present in a unit weight of material. It could be measured in units of square centimetres per gram or square metres per kilogram (m^2/kg), or some other appropriate set of units. Basically, it acknowledges that drying is a surface phenomenon and the more surface that is available for moisture loss, the faster the drying process can proceed.

We use this principle frequently when we are cooking food to speed the heating process. For example, when we want to boil potatoes for a meal, we usually cut large potatoes into smaller pieces so they will cook faster. The cutting process creates more surface area for the heat to penetrate than was available before the potato was cut. The cutting also reduces the distance the heat has to travel to reach the centre of the piece of potato. The same thing is true with drying. If we have smaller pieces, we have more surface area available from which the moisture can escape. In addition to this, we have the reduced thickness of the pieces which reduces the time it takes for moisture from the centre of the material to reach the surface and be evaporated by the drying air.

1.5.2.7 Specific Heat Capacity

Although we will not be using specific heat capacities in our early discussions about drying technology, it does have an effect on drying, and it should be mentioned here for the sake of completeness.

Specific heat capacity (C_p) is a measure of how much heat it takes to raise the temperature of one kilogram of a material by one Celsius degree. It is expressed in units of kilojoules per kilogram per Celsius degree (kJ / kg C°). The higher the water content of a product, the higher its specific heat capacity. Pure water has a specific heat capacity of 4.187 kJ / kg C°. Potatoes, which are approximately 78% water by weight have a specific heat capacity of 3.450 kJ / kg C°. Okra, having a moisture content of about 90% water by weight, has a specific heat capacity of 3.852 kJ / kg C°. This means that it takes more heat to raise the temperature of a given weight of okra by a certain temperature than it does to raise the

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temperature of the same weight of potatoes by the same number of degrees. Or, putting it another way, if we apply the same amount of heat to equal weights of potatoes and okra which are at the same starting temperature, the potatoes will have a higher final temperature than the okra.

The effect of specific heat capacity on drying may not be as obvious as some of the other factors discussed here. In most cases, when material is first brought into a dryer, its temperature must be raised to a certain level to enhance the drying process. When we introduce a product into the dryer, it may take longer to get products with higher specific heat capacities up to the desired temperature than it would for products with lower C_p values. This can lengthen the time required for drying. Although the effects of specific heat capacities may not always be noticeable, they should be mentioned here for due consideration.

1.5.2.8 Seasonal Variation:

Seasonal variation from one crop year to the next is a factor that often confronts food processors. Consider cereal grains such as rice. In a good crop year, the rice kernels may be large and quite plump. In a poor growing season, the kernels may be significantly smaller and not as plump. This size variation can have quite an effect on how the kernels dry. If you have your dryer set up to process rice kernels from a rather poor growing season and then change to a new shipment of rice from a very good growing season, you will probably find that the kernels have not had enough moisture removed. This is because moisture inside the kernels with the bigger diameter requires more time to

reach the surface of the kernel than it did in the smaller kernels. If your dryer is set up to give the proper drying time to the smaller kernels, the larger kernels will tend to be higher in final moisture until you make the necessary adjustments to the dryer.

1.5.2.9 Cultivar or Varietal Differences

Not all varieties of a particular agricultural commodity have identical properties. The kernel sizes of grains of rice will vary depending on whether the rice is a long-grain or short-grain variety. The characteristics of the starches may also vary between varieties of rice and other starchy foodstuffs such as cassava or potatoes. These differences will affect how water is held within the product, which will ultimately lead to differences between the drying properties of two varieties of the same plant.

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1.5.3 Drying Equipment Attributes

Just as the properties of the materials or products being dried have an impact on the overall drying process, so also do the attributes of the equipment that is being used to do the drying. We will not go into any great detail at this point, since we will be discussing various factors about dryer operation and design at a later time. However, we will introduce several of these factors at this time.

1.5.3.1 Type of Dryer:

Keep in mind that all materials have somewhat different drying characteristics that require special consideration. Drying parsley flakes is vastly different than drying corn for animal feed. Drying whey to recover its solid components is much different than sun-drying tomatoes. Drying potatoes to produce potato flakes is different than drying tobacco leaves in a kiln. The list goes on and on. The point here is that there are many types of dryers available from manufacturers to address the needs of a particular product. If you purchase a dryer to dry parsley flakes, you should not use it to dry potatoes for potato flakes. If you do use a dryer for a purpose other than for what it was designed or intended to be used, do not be surprised if it does not work properly for you and your final product is not of the quality you had hoped to obtain.

1.5.3.2 Dryer Design Features

Just as the actual type of dryer can affect the drying of a product, features that are incorporated into the design of a dryer can also have an impact. Some dryers use a moving wire mesh belt to convey product through a drying chamber. With this arrangement, particles of product are stacked up on top of each other and air is passed through the bed of material to remove moisture. To overcome the effects of surface-to-surface contact among the food particles and to create a better overall contact of the drying air and the product surface, some dryers may be equipped with a vibrating mechanism that agitates the particles of food as they travel through the dryer. As the particles of food bounce upwards and fall back down onto the vibrating surface of the dryer, they experience closer contact with the drying air than they would experience in a flat bed on a moving conveyor.

1.5.3.3 Air Temperature

Most drying applications in the food industry use hot air as the drying medium. As stated above, the air can be heated by passing it through the flames from a burner assembly much like that used in a home gas or oil-fired heating furnace. In some cases, air may be heated by passing it across electrical heating elements. Regardless of the source of the heat, the temperature of the air is a key factor in drying any material. The higher the temperature of the air, the greater its water holding capacity will be, which in turn means that its ability to remove water from a product will be greater than if cooler air was used

While it may be tempting to use the highest possible air temperature in a particular dryer, extreme caution must be exercised in this regard. First of all, some products are very sensitive to heat and their quality diminishes substantially if they are exposed to excessive temperatures. If temperatures are too high, the product may be scorched or

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toasted. A product like parsley can only be dried at temperatures in the area of 60°C for this reason. Although it may take a long time to remove the moisture from sprigs of parsley at this temperature, anything above this limit will seriously damage the quality of the dried parsley flakes.

Another potentially negative effect of excessive temperatures is something called "case hardening". If the wet material is exposed to too much heat, its outer surface may become very dry in a short period of time and create a shell or crusty layer around the material. This hardened surface will trap the moisture that was at the centre of the product and prevent it from reaching the outer surface of the particle where it normally would evaporate. Since the moisture cannot escape, it will remain inside the "case hardened" piece of material. After the case hardened product is in storage for a while, the moisture that is trapped in it will begin to create problems. Over time, the moisture can diffuse through the surface shell and condense inside the package or storage bin where it can promote mold growth etc. It can also cause the structure of the dried food particles or pieces to change over time. Often the outer shell will remain intact but the inner structure of the particle collapses in on itself due to the effects of the moisture inside it. When the consumer goes to use the product, the first thing that they notice is that the product does not function as they expected and that the texture of it has changed drastically from the normal texture. Care must be taken to apply heat at a rate that does not case harden the product - unless some degree of case hardening is actually desired.

We have discussed air as the heat delivery medium for most drying applications. However, we should not lose track of the fact that water can also be removed from food materials by other methods as well. Let's consider what happens when products are fried in hot oil. When the product containing moisture is dropped into the hot oil, the water will heat up rapidly and will be converted into a vapour or "steam". The vapour then escapes into the oil and subsequently leaves the oil and goes into the atmosphere above the oil fryer. The loss of water leaves the product with a lower moisture content and the hot oil creates a crisp or browned surface. It is the escaping water vapour which is responsible for the violent action observed when food is initially dropped into an oil fryer.

Water can also be removed using concentrated sugar solutions in a process known as "osmotic dehydration". Briefly, when food materials such as sliced fruits or berries are soaked in a concentrated sugar solution (about 60% sucrose) at an elevated temperature (50° to 60°C), moisture is drawn out of the cells of the product and into the concentrated sugar solution through "osmosis". Over time, the sugar solution becomes diluted from the water pulled out of the product being dried and measures must be taken to restore the sugar solution to its original concentration.

1.5.3.4 Retention Times:

Just as the temperature of the drying air can affect the final product quality, so too can the length of time during which the product is exposed to the hot air. We know from our experiences cooking food in our kitchen ovens that it takes less time

to cook something at a higher temperature than it does at a lower temperature. Temperature and time are inter-related in drying in basically the same way. It should take less time to dry a material at a higher temperature than it would at a lower temperature. However, there are some complicating factors.

We cannot just hit a product with as much heat as possible and expect it to dry properly. We must recognize that it takes time for moisture to travel from the centre of a food particle to the outside surface where it can be evaporated by the hot air in the dryer. We must balance the time in the dryer at a specific temperature with the ability of the moisture to diffuse out of the food material. In the case of parsley at 60°C, it takes a number of hours to dry it to the desired final moisture level. Other products may only take 20 or 30 minutes to dry under their particular set of drying conditions.

1.5.3.5   Relative Humidity

The relative humidity of air is a measure of how much moisture the air is holding compared to how much moisture it could possibly hold if it was saturated with moisture under those conditions. On a hot humid summer day, the air temperature around us might be 30°C and the relative humidity could be 90%. This means that the air is holding 90% of the maximum amount that it could possibly hold at that temperature. Its ability to pick up water through evaporation would be much less than if we had air at 30°C with a relative humidity of 20% or 30%. If we try to dry a material with air that already contains a high moisture content, we will not be able to remove as much water as we could with

air containing a lower moisture content.

If we take the 90% relative humidity air at 30°C and heat it to 60°C, its relative humidity would be about 20% since the hotter the air, the more moisture it can hold. This is one very important reason for heating air in any drying application.

Anyone who is involved in food drying should own and use a device for measuring relative humidity (RH). These RH meters are a valuable tool in monitoring the moisture content of air entering a dryer and exhaust air leaving a dryer. In the "Advanced Drying Course", we will examine the topic of "psychrometrics" which allows for the estimation of the properties of air at various temperatures and moisture contents. The relative humidity and temperature of the air are essential pieces of information in this procedure.

1.5.3.6   Volumetric Air Flowrate

Volumetric air flowrates are a measure of the amount of air delivered into the drying chamber of a dryer in any given time period, and are expressed in units of volume per unit time (e.g., cubic metres per minute or cubic feet per second, etc.). They can be controlled by adjusting the fan speeds on the dryer to deliver more or less air volume in a given period of time. Volumetric air flowrates are an alternate way of delivering more heat to the dryer. In many dryers, you can either increase the temperature of the air to introduce more heat; or you can increase the volume of air passing through the dryer; or you can do a combination of both.

Adjusting the volumetric air flowrate is particularly useful when dealing with

materials that are heat sensitive. If we consider the parsley example once again; we may need more heat to dry a load of parsley, but we cannot increase the temperature due to potential heat damage to the parsley. By increasing the volume of air we blow through the dryer, we could accomplish much the same thing and increase the drying capacity of the dryer.

1.5.3.7   Linear Air Velocity

The linear velocity of the air is directly linked to the volumetric air flowrate. It is the speed at which the air is moving through the dryer, and would be expressed in metres per second, or feet per second, or some other similar units of speed.

Since most dryers have fixed dimensions (i.e., the size of the dryer does not change), the cross-sectional area of the dryer is constant. If you increase the volume of air being blown through the dryer, its linear velocity (i.e., speed) will increase proportionately. If you decrease the volumetric flowrate of the air, its speed will decrease.

The main effect of linear air velocity in a dryer is that if it becomes too great, it may have sufficient force to lift pieces of the material being dried and blow them around inside the dryer. Not only can this result in lost product being blown right out of the dryer, but it can result in uneven drying. If the material is spread in a bed of uniform thickness across the drying surface, the air can blow holes in this bed of material. The holes in the bed then become paths of low resistance to the air as it attempts to reach the outlet or exhaust vents of the dryer. Product

around these holes may become overly dried while product at other locations in the dryer is not sufficiently dried.

1.5.3.8   Air Flow Patterns

We will deal with this topic in more detail in a future module. However, it should be mentioned at this point that it is extremely important to have the airflow as uniform as possible in a dryer. Sometimes, we may want the air to flow upwards through the product, or downwards through the product. In other applications, we may want the air to flow across the top surface of the product.

Dryer design is the major contributing factor to how the air is delivered to the product being dried.

1.5.3.9   Seasonal and Daily Variations

Earlier, we mentioned how seasonal variations in an agricultural commodity such as cereal grains can influence their drying. We can also notice variations in how well a dryer performs from one season to the next. In Canada, we have some large swings in temperature between the winter and summer months. In January and February, when our climate tends to be most severe, it is possible to have days when the temperature is as low as - 40°C (or even lower). During the summer months of July and August, temperatures can rise to above 30°C.

When air is brought into a dryer, the burners heat it to the desired temperature before the air goes into the drying chamber. Cold winter air takes more heat to raise it to the proper temperature than

does warmer summer air. In cases where the dryer is always operating with the burners turned to their maximum capacity, it may not be possible for the burners to heat the cold winter air to the same temperature as they could during the summer when the air is warmer.

Humidity of the air is another factor to consider. Because the air is colder in winter, it does not contain as much moisture as the humid warm summer air. While this humidity change may not create any major differences in how well a dryer functions during the summer or winter months, it does have an impact of what is called the "**equilibrium moisture content**" of the product.

All food products contain some level of moisture. Even dried wheat, or rice, or other cereal grains contain about 10% water by weight. If we were to completely dry these materials so that they contained absolutely no moisture and expose them to the ambient air (i.e., the air around them), they would start to pick up moisture. They would continue to pick up moisture until there was a balance or equilibrium between their water content and the water content of the air around them. Even if the product was packaged in a container that allowed some degree of air passage, there would be an equilibrium relationship established between the product and the air.

In winter, when the moisture content of the air is lower than in the summer, the equilibrium moisture content of most dried products is lower than it would be in the more humid summer air. Food processors may need to take the equilibrium moisture content into account when setting their drying specifications throughout the year.

Just as there can be seasonal variations in drying, there can also be daily or diurnal changes. I have seen instances when product coming off the discharge end of a dryer has picked up measurable amounts of moisture from the air. To illustrate this point, consider the following situation. On a hot summer afternoon, the operators of a drying facility had all available windows open. Since there were screens on the windows, this was not a problem in terms of insects or foreign material getting into the product. Everything went well during the day and the moisture of the product coming out of the dryer was exactly on target. However, late at night, the operator on the midnight shift frequently saw that the finished product moisture increased to the point where the product moisture was at the upper end of its allowable range. This happened even though nothing in the actual drying process had changed since the afternoon. The problem then became one of identifying the source of this moisture increase.

The reason for the moisture increase in this case was attributed to the air coming through the screened windows. During the day, the air was warm enough that it did not pose a problem. When the air cooled at night, its water holding ability was reduced. The cool moist air coming in contact with the warm dry product created a situation whereby the moisture from the air was taken in by the product, which raised the moisture content of the product. By closing the windows early in the evening, the problem was eliminated.

1.6 Effects of Drying on Products

1.6.1 Introduction

In an ideal world, drying would have no negative impact on the final product whatsoever. We all know that this is not an ideal world and as a result, we must do whatever we can to minimize the negative effects of drying on the various quality aspects of the product.

In cases where we prepare a dehydrated food product that is rehydrated before eating, the quality attributes of the rehydrated food are expected to be as close to that of the original product as possible. In some cases, the dried product may even be expected to have improved attribute when compared to the initial material. An example of this could be instant mashed potato flakes. The consumer may feel that for the price of the product, not only should they be more convenient, but the resultant mashed potatoes should be lighter or fluffier, or creamier than the mashed potatoes prepared from whole potatoes at home. Not only that, they should be free from any black marks and the like that may be found in home-cooked potatoes.

The following is a brief summary of a number of negative factors that may be introduced into a food product if drying is not properly conducted:

1.6.2 Nutritional Degradation

Vitamins that are present in food products may be unstable and susceptible to heat damage. Overheating due to excessive temperatures or prolonged exposure to heat during drying can cause this problem.

1.6.3 Loss of Structural Integrity:

On occasion, improper drying can create stresses in the structure of a material that can have serious negative results.

Consider the example of a starch-based cereal grain that is placed in boiling water to "cook" it. When heated sufficiently, the starch can gelatinize to form a rather soft and pliable material. It also expands in water and the water can be taken into the starch network or matrix. Once the starch-based cereal grain is "cooked", it may be necessary to dry it. As the water leaves the inner regions of the cereal grain, the starch matrix may shrink back towards its original size, or it may stay in its expanded state. Once it is dried and cooled, the gelatinized starch changes from a soft, pliable material to a hard glassy or brittle material. If the drying and cooling have been done rapidly, the glassy starch may be under considerable stress. Over time, these stresses may cause the dried product to break apart or shatter.

1.6.4 Reduction in Functionality

"Functionality" is a term used to describe the fact that various components in a food system have a role to perform. For example, ungelatinized starch may be present in a food (e.g., corn or potato starch). If ungelatinized starch enters a dryer, it may become gelatinized if the temperature of the material exceeds the gelatinization temperature of the starch. Typically, potato starch gelatinizes at a temperature of around 60°C.

Once it has gelatinized, the starch behaves much differently than it did before gelatinization.   Ungelatinized

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starch is not soluble in water; but gelatinized starch is able to take up water and swell into a rather wet pasty mass. When compressed, the starch gel may release much of this moisture. Care must be taken to dry ungelatinized starchy materials at temperatures below their gelatinization temperatures if functionality of the starch is a concern.

1.6.5   Flavour and Aroma Changes

Flavour changes imparted by drying may be desirable or undesirable depending upon the end use of the dried product. During drying, heating may create a toasted flavour in the product along with the associated toasted aroma.

The development of caramel flavours can be attributed to non-enzymatic browning through the Maillard Reaction where reducing sugars in the product react with amino acids.

Other flavours and aromas may also develop, depending upon the nature of the material being dried and the drying conditions used.

1.6.6   Colour Changes

In the previous section, we mentioned the development of caramel flavours through the Maillard Reaction. This non-enzymatic browning also produces a characteristic brown colour (hence the name). This is particularly evident in the production of maple syrup from the sap of North American sugar maple trees. In the traditional process, sugars in the tree sap are concentrated from an original level of less than 2% by weight to over 65% by weight. In the original process, water was removed by boiling the sap in open kettles over a fire. This prolonged heating caused the syrup to turn brown and develop desirable flavours.

Some colour changes can be quite undesirable, however. If a white product is being dried, it may become "toasted" and have a light brown colour which consumers find objectionable.

1.6.7   Case Hardening

We have already mentioned case hardening under the heading of "Air Temperature" earlier in this module. It is being repeated here to re-emphasize the negative impact that drying can have on a product if it is not done properly.

Case hardening is a term that refers to the development of a hard shell or crust around the outside of the food particles being dried. It is caused by excessive drying of the surface of the food particle and creates a shell that prevents moisture from being removed from the interior portions of the food particle.

In normal drying, moisture is removed by evaporation from the surface of the food particles after which moisture from the inner portions of the particle travels to the particle surface where it, in turn, is evaporated. If the surface moisture is removed too rapidly, the surface may become overly dry and form a hard layer that prevents any more moisture from reaching the surface. Since the interior moisture cannot be removed during the drying process, it will be trapped inside the particle where it will remain when the product is packaged. Once in the package, this moisture will slowly and gradually come to the food particle

surface where it may promote the growth of mold. Occasionally, the moisture may soften the shell, or create internal stresses which cause the particle to collapse in on itself or to break apart.

1.6.8 Leaching of Soluble Constituents

During the drying process, water from the interior portion of the food particles or pieces travels to the surface where it is evaporated by the hot air inside the dryer. This water may contain dissolved nutrients that it leaves on the food surface when it evaporates. These nutrients are still present on the food surface at the time it is packaged, but if the food has to be rehydrated by soaking it in water or boiling it in water, the nutrients may be solubilized by the water and removed from the food. The nutrients are then not available for the person consuming the cooked food.

1.7 General Questions

Question 1:

Prepare a list of dried or dehydrated foods food in your local food store or market. (Try to find at least ten).

Question 2:

Prepare a list of dehydrated products which your industry uses as ingredients in further processing steps.

Question 3:

Prepare a list of products in your region which are suitable for dehydration or drying.

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AN INTRODUCTION TO FOOD DEHYDRATION AND DRYING

CHAPTER 2:   ORGANIZING INFORMATION

2.1   Introduction

Typically, in the food processing industry, we gather information about how a process is operating over a period of time. We do moisture tests on the material entering a dryer and on the finished product leaving the dryer. Values of variables such as temperatures, air velocities, and retention times are generally recorded at regular intervals over the course of a drying run.

In any process, it is not sufficient to simply have information of this nature stored away - we must be able to use it to understand the manner in which the process is functioning. Being able to effectively organize the information that is gathered is a challenge that often faces the food processor.

Many food processes appear quite complex at first glance. When viewed in its entirety, it may be difficult to know what is happening throughout the process. Trying to deal with the entire process at one time is probably the most common mistake that people make. When we eat a meal, we do not try to put all of the food in our mouth at the same time and swallow it in one gulp. Rather, we cut our food into smaller bite-sized pieces that are easier to chew and easier to digest. If we do this with our food, then why not use the same approach in dealing with an industrial food process? The "unit operation" approach will allow us to do just that.

2.2   The "Unit Operation" Approach

Most food processes consist of a series of individual steps arranged in a particular sequence to convert starting raw materials to the desired finished product.

A complete food process may cover a great deal of floor space in a manufacturing plant. Many processes occupy several floors in the plant and involve large pieces of equipment linked together by conveyors, pumps, and other associated hardware.

In the example presented here, we will go beyond considering only drying. We will look at a much larger process to illustrate the unit operation concept.

If we were to consider a hypothetical cereal process where raw grain is brought to a manufacturing site and made into a formed finished product, we could divide the overall process into a series of individual steps. The output from one step would become the input for the next step and so on. We could then view each one of these steps on an individual basis to simplify our treatment of the total process. Normally, each step would be focussed upon an individual piece of equipment, or an individual task which can be referred to as a "unit operation".

In the hypothetical cereal process, the grain might be conveyed into the plant and screened to remove foreign material like stones, etc. The bran layer could be removed from the grain by a milling

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operation and separated from the kernel in the same operation. From here, the bran may go to a secondary process, but our concern is for the kernels of milled grain.

The milled grain kernels could then be ground into flour which could be blended with other ingredients, including water, in the barrel of a large extruder. After grinding, the flour should be screened to remove excessively large particles. These large particles can be sent back to the grinding operation to be broken down to a smaller size. While in the extruder, the ingredients are thoroughly mixed and heated either by the addition of steam, or by the mechanical energy within the extruder. Heating in the extruder "cooks" the mixture of ingredients and creates a cooked dough that is passed through a "die" at the discharge end of the extruder barrel. The "die" creates a long continuous rope-like piece of finished product in the appropriate cross-sectional shape that can then be cut to the desired length by rotating knife blades positioned at the discharge end of the extruder barrel. As it leaves the high pressure inside the extruder barrel, the product may expand to give a puffed product.

The shaped cereal in our process then travels on a conveyor belt into a "coating reel" where a flavoured syrup is sprayed onto it. After it leaves the coating reel, the cereal enters a small dryer to reduce the moisture of the surface coating. It then is screened to remove any small fragments or large clusters of cereal pieces. Following packaging, the final cereal product is warehoused prior to distribution to various retail outlets where it is sold to consumers.

A rambling account of the process as described in the previous paragraphs is somewhat confusing and hides a great deal of information concerning the process and the equipment involved. A far more satisfactory approach to describing a process is through the use of a flow chart or "process flow diagram".

Flow charting begins by listing all the steps involved, such as:

1. Raw material receiving
2. Screening of grain
3. Milling of grain
4. Grinding
5. Screening
6. Blending of ingredients
7. Heating / Cooking
8. Shaping and Cutting
9. Coating
10. Drying
11. Cooling
12. Screening
13. Packaging
14. Warehousing and Distribution

The majority of the steps listed above involve specific pieces of equipment for each specialized task. These are usually considered as large components made up of a number of smaller components. A mill would be a good example of a "unit operation" in our hypothetical process. Essentially, it has one function in the process - to remove bran from the grain. The extruder, by comparison, is one piece of physical equipment that may be considered to embody several unit operations such as blending of ingredients, heating and cooking, and shaping and cutting. Various people will have their own opinions on how to treat the extruder in a process flow diagram. However, the main thing is to understand how the overall process is functioning.

Many food process engineers like the names of each unit operation to end in "er" or "or" whenever possible. Examples of this in our hypothetical cereal process would be "blender", "cooker", "dryer", "cooler", etc. A personal preference of mine is to have the labels for each unit operation end in "ing" to indicate its specific function. This is why you see such labels as "screening", "cooking", and "drying" in the list of processing steps.

In our example of the "unit operations" approach, we might be tempted to view the dryer as a single unit operation. Its primary purpose is to remove water from the product, as was done after the coating operation in our process. It may also toast the product as well. Some dryer manufacturers include a cooling zone in their dryers; and you may want to consider cooling as a separate unit operation, as was done in our process here. However, you can use your own discretion on how you want to address this in many cases. In the initial stages, you might not be overly concerned about the dryer's individual parts, unless you were to be doing an in-depth dryer study. On these occasions, you will have to break the dryer down into a series of smaller steps within that unit operation to explain what is happening in the drying process itself.

You also need to realize that coupled with physical pieces of equipment there are frequently "reactions" that are occurring within them. These may be physical or chemical in nature (or a combination of both). There are generally two basic factors controlling the "reactions" within a process, namely, temperature and time. Coupled with temperature and time can be other factors such as moisture content, etc. We will not worry about

these factors here.

2.3   Process Flow Diagrams

2.3.1   What is a Process Flow Diagram?

Having defined the steps involved in the process, we can now prepare a process flow diagram or schematic diagram to communicate the information more effectively than we could by a few pages of written text. Figure 2-1 is a process flow diagram of our hypothetical cereal process which includes the fourteen steps listed above in our description of the process. Several of these steps have been combined into one block or "box" which appears as the "extruder" in Figure 2-1. If you wish, you can also include some of the actual processing conditions on the process flow diagram, but that has not been done here, in the interest of clarity.

In dealings that you might have with any process (even non-food processes), the first thing you should always try to do is to break down the overall process into its individual unit operations or component steps. This is the first step to being able to resolve difficulties and address problems.

Notice in Figure 2-1 that cooling has been treated as a separate step from drying. In many industrial processes, the target moisture is specified after cooling rather than after the drying step. This is due to the fact that in cooling, there is often a change in moisture from that at the end of the drying step. Very warm product can pick up moisture from humid ambient air which is prevalent in the summer months; or it can lose moisture when cooled with

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        ┌─────────────────────────┐
        │  Raw Material Receiving  │
        └─────────────────────────┘
                    │
                    ▼
        ┌─────────────────────────┐
        │    Screening of Grain    │ ──────► Foreign Material
        └─────────────────────────┘
                    │
                    ▼
        ┌─────────────────────────┐
        │     Milling of Grain     │ ──────► Bran
        └─────────────────────────┘
                    │
                    ▼
        ┌─────────────────────────┐
        │     Grinding  (flour)    │ ◄──┐
        └─────────────────────────┘    │ Oversized
                    │                   │ Particles
                    ▼                   │
        ┌─────────────────────────┐    │
        │    Screening of Flour    │ ───┘
        └─────────────────────────┘
```
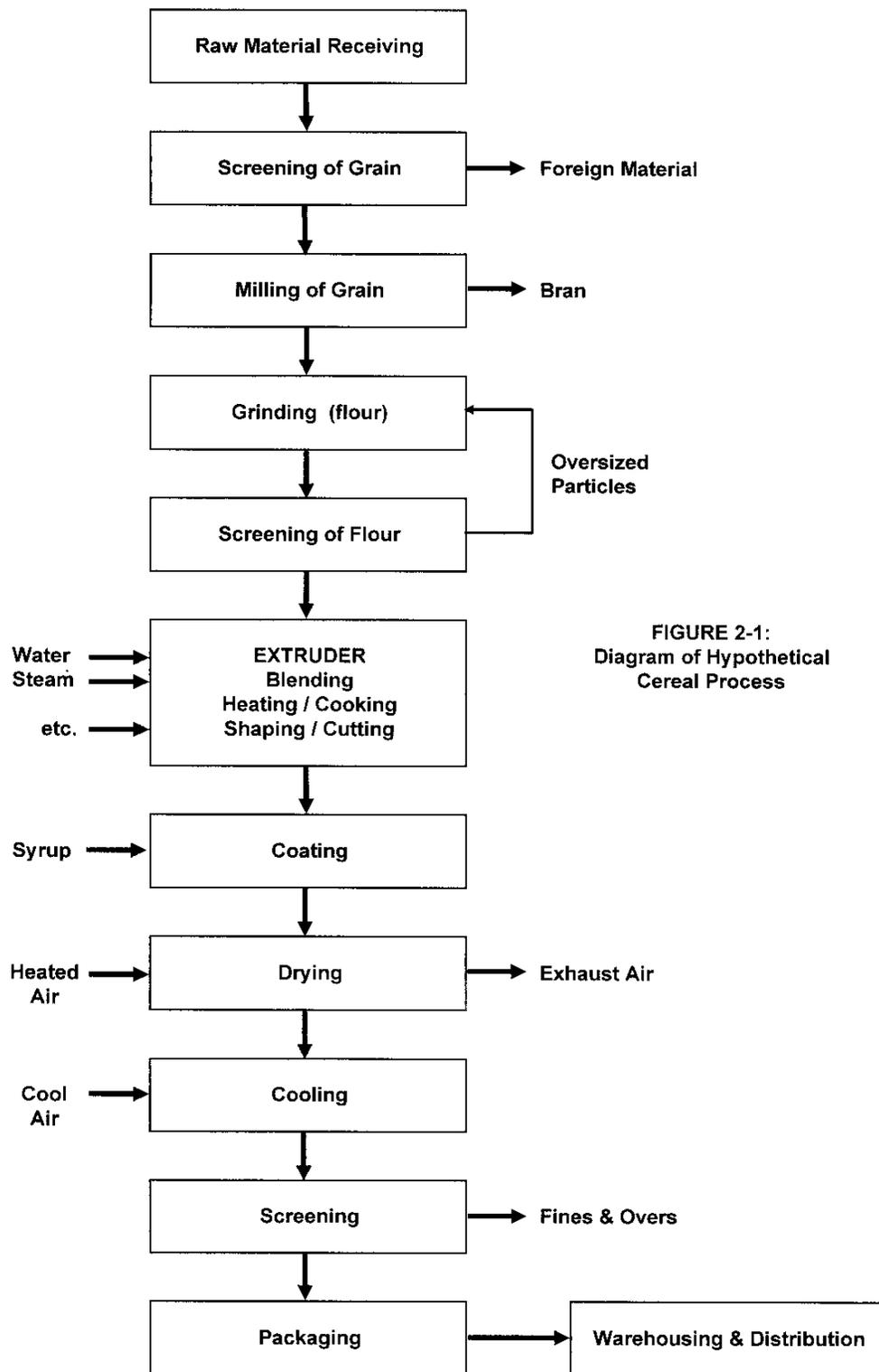
FIGURE 2-1:
Diagram of Hypothetical
Cereal Process

Water ──►
Steam ──►   EXTRUDER
            Blending
            Heating / Cooking
etc. ──►   Shaping / Cutting

Syrup ──►   Coating

Heated ──► Drying ──► Exhaust Air
Air

Cool ──►   Cooling
Air

            Screening ──► Fines & Overs

            Packaging ──► Warehousing & Distribution

cold dry air which we experience in the winter months. The moisture must be determined after all these effects have been taken into account. Most processing facilities express the moisture content on a "wet basis" which we will cover in Chapter 4.

In a time of conservation, many of the streams leaving the process (e.g., the dryer exhaust air) would be recycled within the process to reduce energy consumption and waste. Heat recovery methods allow heat from process waste streams to be used to warm incoming water or air. The bran, "fines", and "overs" (i.e., pieces of product too small or too large to be acceptable) would also be used in secondary processes, or products such as petfood. A process flow diagram allows you to identify potentially useful "waste" streams.

Hopefully, you can now see how the process flow diagram in Figure 2-1 has been a great aid in reducing the confusion of having to deal with the entire process as one single item.

2.3.2 Preparing a Process Flow Diagram

Now that you have seen a process flow diagram and are familiar with its appearance and basic construction, we will step back and review the procedures for preparing them.

Setting up a process flow diagram, or "PFD" is usually not excessively difficult, but it is normally something that cannot be done in just one attempt. It often requires several revisions and modifications before an acceptable diagram is obtained.

The best way to start a process flow diagram is to go out into the processing facility with a pad of paper and a pencil or pen to sketch out the process and write down the various processing steps. At this stage, you should not be concerned about how "pretty" you diagram looks - you simply want to gather as much relevant information about the process sequence as possible.

Having gathered the preliminary information about the process, the second step is to construct an initial draft of the PFD. You can draw a series of rough boxes representing the unit operations on a sheet of paper and link them with arrows to show the product flow. Additional inputs and outputs can also be included by sketching in arrows entering and leaving the unit operations. At this stage, you are free to add or delete items from your draft diagram.

Once you are satisfied that the draft PFD represents the process as well as possible, you should take the diagram back into the processing facility and verify that all flows and pieces of equipment are

correct. If temperatures and flowrates etc. appear on your diagram, you should confirm that all values are valid. You may also wish to review your process flow diagram with someone who is familiar with the process, such as the process operator, to check that you have represented the process in an appropriate manner. Any corrections or modifications should be made directly on the draft copy of the diagram.

When all necessary modifications have been made to the draft copy of the process flow diagram, it can then be drawn in its final form using a computer program or drawn carefully by hand. A proper title should be included with the diagram along with the date. The date will serve as a useful future reference and reduce confusion as to when the arrangement of the process was as it has been drawn. It is also a good idea to legibly sign or print your name on the process flow diagram.

Some people like to have several versions of process flow diagrams for the same process. One diagram may show only the unit operations and product flows, along with major input and output flows. A second PFD may show values of key operating parameters such as temperatures, retention times, and flowrates in addition to the previously mentioned items. Other PFD's may be used to show process waste streams, or utility inputs such as steam, heat, electricity, and so on. Each PFD can be used to address the needs of a particular group of individuals with whom you may be discussing the process.

It should be recognized that two individuals may not have identical process flow diagrams for the same

process. You and a colleague may have somewhat differing views on how to represent the process. If the differences are small, they may be considered to be insignificant. As long as the essential elements of the process are captured and clearly and accurately conveyed to the viewer, the process flow diagram will have served its intended purpose. However, it is a good idea to discuss the differences between two differing PFD's of the same process with your colleague. In this way, an agreement can generally be reached on how the process should be represented before producing two differing final versions of the diagram.

2.4 Tables and Graphs

Planning is important to the successful completion of any activity. Careful planning should take place before any actual physical work is begun. The more complex the project is, the more thorough and detailed the planning needs to be.

Data gathering is often one of the first steps in assessing how a process is operating or in evaluating the effects of a change in operating conditions on the overall process and finished product. Once you have decided upon the observations to be taken and the frequency of them (e.g., one every 15 or 30 minutes or once every hour, etc.), you then need to organize the actual data gathering process. Often, the best way to do this is by means of a "table" that you prepare on paper.

For illustrative purposes, let's consider the example of drying a small sample of sliced carrots in a laboratory dryer. The weight of the carrots can be monitored by means of a scale or balance mounted on

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top of the dryer and linked by a number of suspension rods to the rack supporting the carrots inside the dryer. It is decided to record the weight of the carrots every fifteen minutes for seven hours to follow the drying process. Table 2-1 shows the type of table that would be set up prior to the drying run to record the information.

Table 2-1:   Table for Data Gathering from Drying Test

Material: Date: Test Number: Starting Time: Air Temperature: Additional Information:	
Time (minutes)	Weight (grams)
0	
15	
30	
45	
60	
75	
90	
105	
120	
etc.	

Only the first 120 minutes (2 hours) of the table have been shown here.   There would be additional rows for times in fifteen minute increments to 420 minutes (seven hours) in the full table.   Other columns could be added if observations regarding such things as temperatures were desired.

The initial weight of the carrots would be inserted as the weight at time t = 0 minutes. When the test is started, timing would begin using a stop-watch or other appropriate means of following the time that has passed. Every 15 minutes, the weight of the carrots would be recorded.

Table 2-2 shows the weights gathered for the seven hour drying run in our example. Information regarding the date of the drying run and some of the particulars associated with it have been included for future reference.

The data presented in Table 2-2 provide a starting point from which we can make observations in an attempt to develop trends in the drying process, as will be done in the subsequent drying course material. However, a series of numbers on a page is not very informative without some further manipulation.

Most people tend to be "visual". They can appreciate information in a visual format much better than they can when it is presented in a purely numerical format. This is one reason why it is often a good idea to prepare a graph from the data gathered during an experiment. Graphs also aid in developing mathematical relationships as we will see in the "Intermediate" drying course.

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Table 2-2: Table for Data Gathering from Drying Test

Material:	Carrots
Date:	March 1, 20__
Test Number:	Carrots - 1A
Starting Time:	8:47 am
Air Temperature:	50° C
Air Flowrate:	0.2 m / second
Additional Info:	0.4 cm thick circular slices

Time (minutes)	Weight (grams)
0	201
15	192
30	182
45	172
60	163
75	153
90	144
105	135
120	126
135	117
150	19
165	102
180	93
195	87
210	80
225	73
240	68
255	62
270	57
285	53
300	49
215	46
330	42
345	40
360	37
375	35
390	33
405	31
420	30

Figure 2-2 shows a plot or graph of "Weight versus Time" for the carrot slices dried in the test run.

When preparing a graph, "time" is considered to be the "independent variable". In our case, the weight of the carrot slices would be considered to be the "dependent variable", since the weight of the material depends on the time for which it is exposed to the drying conditions. The independent variable, in this case "time", is always placed on the horizontal axis of a graph. The time axis advances from a lower value on the left to a higher value on the right. The dependent variable, in this case the weight of the carrot slices, is placed on the vertical axis of the graph, as shown in Figure 2-2.

The scale of each axis should be chosen to provide a clear view of the data being

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plotted. Choosing the incorrect scale may squash your data into one portion of the graph or spread it out so widely that it doesn't all fit on the same page. In either case, you will not be able to make any meaningful observations from the graph you have drawn. Not only do you have to select the minimum and values for each axis, but you must also decide upon the size of the divisions or increments for each axis.

In Figure 2-2, the range of values for the "time axis" was selected to cover the length of time of the drying run and leave a small amount of extra time at the end so that the curve did not touch the right side of the graph. An appropriate interval might be 15 minutes, or thirty minutes, or one hour. To comfortably fit the labels on the time axis, one hour (i.e., sixty minutes) was chosen as the major increment with a minor increment of thirty minutes. Only the major intervals have been labelled. In Figure 2-2, it is easy to tell the shorter fifteen minute time intervals by "interpolation", or reading between the thirty minute divisions. Using a time range of 0 to 480 minutes with major time intervals of 60 minutes and minor time intervals of 30 minutes gives a reasonable scale for time in Figure 2-2.

The "weight axis" scale spans the initial weight of the carrots (i.e., 201 grams) and the final weight of the carrots (i.e., 30 grams). Extending the weight axis to 250 grams gives some space above where the actual data curve begins. Using major weight intervals of 50 grams each with minor intervals of 10 grams provides a suitable weight axis.

FIGURE 2-2: DRYING OF CARROT SLICES
WEIGHT vs TIME
(March 1, 20__)
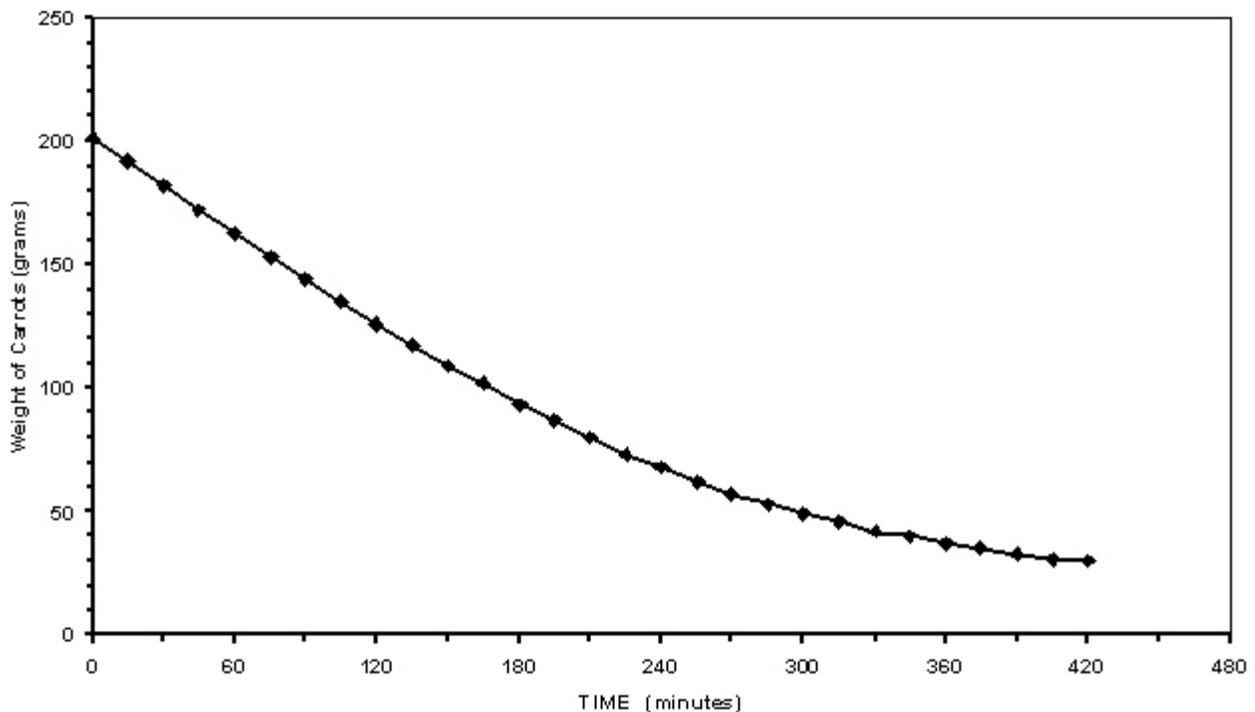
Whenever possible, or whenever reasonable, the origin (i.e., zero values) should be shown on a graph. However, there are occasions when this is not appropriate due to the large values of numbers that may not approach the zero values. For example, we may have 3,500 grams of starting material and dry it for a short time. The final weight might be 3,000 grams. In preparing a graph of this information, it would be more suitable to have a weight range starting at 2,800 grams going to a weight of 3,600 grams while using weight increments of 50 grams or 100 grams. Including 0 grams on this graph would lead to a graph with the observed data squeezed up near the top in a very narrow band where no trends could be observed. When preparing graphs, you need to use your discretion as to the range and scale of each axis.

Now that Figure 2-2 has been prepared, it can be seen that the rate at which water is removed (i.e., the change in weight of the carrots over time) is not uniform. The slope of the curve is greater from the start of the run until about 180 minutes into the run than it is after about 180 minutes.

We can also see that there is a levelling off of the weight of the carrots around 420 minutes into the run. These trends were not as evident from the raw data collected and displayed in Table 2-2. Details regarding the handling and interpretation of drying data will be discussed in the Intermediate drying course.

2.5 Organization in Problem Solving

2.5.1 The Need for Organization

There are times when you may be called upon to solve mathematical problems associated with a certain process. Regardless of how complicated or straight-forward the problem appears to be, it should be approached in a structured and disciplined manner. Using a logical sequence of problem-solving steps will enhance the probability of success and reduce the likelihood of errors in the problem solution.

Use of an orderly approach with explanatory statements as to what assumptions were made, and why a specific mathematical relationship was established, are highly beneficial when reviewing material that has been put into a file for several years and is then re-examined. A good way to view your mathematical solutions to problems is to consider if you would be able to understand what you have done in reviewing your notes five years later. If you are confused with your mathematical solutions now, then you will definitely be more confused if you have to refer back to them at a later date. You should also consider that others may have to read and understand the work that you have done without the benefit of your assistance.

Many food processing workers literally scribble out solutions to problems on scraps of paper which are then dropped into a file folder. Such notes are essentially useless at a later date since they lack any form of logic and often don't even have a date on them to tell when the work was done. This is the type of thing that we want to avoid, and it is for this

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reason that Chapter 2 is included in this study manual.

In order to demonstrate how to approach problems in a disciplined and organized manner, several examples using mass balances will be used.

2.5.2 Mass Balances

Mass balances are used by processors of most products on a routine basis. Mass balances rely on the fact that the total mass of materials coming out of a process must equal the total mass of materials entering a process. This is the case for most food processes once they are set up and running continuously (i.e., operating under steady-state conditions) and generally holds true unless there is an accumulation of material or some other similar non-steady state event inside the process. When a process is being started up or being shut down, mass balances will not apply. Therefore, when a process is operating under steady-state conditions, we can say:

Total Mass Entering the Process = Total Mass Leaving the Process

Example Problem #1:

If 100 kg of wet material enters a dryer and 70 kg of water are removed during the drying process, how much product can be expected to be leaving the dryer?

Since there is no indication that any material is lost in the drying process and nothing is being retained in the dryer, there will be 30 kg of product leaving the dryer.

This answer was obtained by recognizing that the total mass leaving the dryer must be equal to the total mass of material entering the dryer. Therefore:

100 kg entering dryer = 70 kg water leaving dryer + X kg leaving dryer

Where X kg is the weight of the product leaving the dryer. In this case, X = 30 kg.

Most people tend to be "visual" in their approach to problem solving. This means that it is often useful to draw a diagram to show what is happening in a process and to organize the available information. By using a diagram, it is often apparent what information is lacking, or what relationships exist among the various processing streams. While it is certainly not difficult to visualize what is happening in the example mass balance we are considering here, not all problems are as easy nor as clear to follow. It is a good idea to use a systematic approach to problem solving while working on examples such as these so that when more difficult problems are encountered, you have developed the necessary skills to solve them.

In looking back at the mass balance example, we can begin by drawing a "diagram". This does not have to be anything fancy or detailed. A simple "box" with arrows going into it to show the process inputs and arrows coming out of it to represent the process outputs is all that is really necessary. As shown in Figure 2-3, 100 kg of raw materials are entering the dryer while 70 kg of water is leaving the dryer. The arrow for the product stream has yet to be quantified, but it is easy to visualize that the total of

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FIGURE 2-3:
Diagram for Example Problem #1
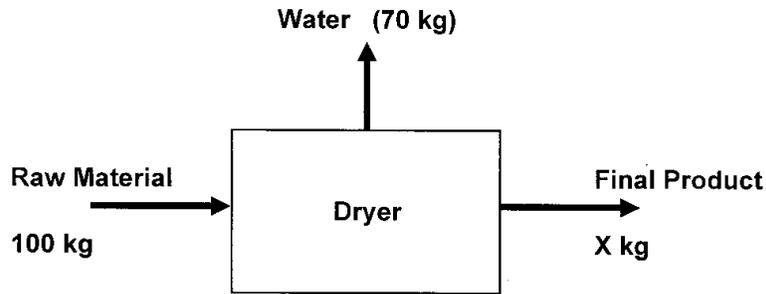
the 70 kg water arrow and the product stream leaving the dryer must total the 100 kg of material entering the dryer.

Solving for X gives a product weight of 30 kg, as stated above.

While it may be tempting to say that a problem of this nature is too simple to bother drawing a diagram to solve, please use this as an opportunity to develop your problem solving skills so that you will not be frustrated when it comes to working with more difficult problems.

Example Problem #2:

73 kg per hour of ingredient "A", 26 kg per hour of ingredient "B", and 37 kg per hour of ingredient "C" are mixed in a device that feeds into a drying process. During the drying process, 32 kg per hour of water are removed and 102.5 kg per hour of finished product are obtained. It is suspected that some small pieces of powdery material are being carried out of the dryer along with the air used in drying. How much material is lost each hour in the drying process?

The first step in solving this problem is to organize the information using a simple diagram. As shown in Figure 2-4, two "boxes" can be used to represent the mixing and drying operations. The three arrows entering the mixing operation indicate the three ingredients that are being blended together to give the mixer output of 136 kg per hour.

The mixer output of 136 kg per hour then becomes the input to the dryer. Heated air is the only other input into the dryer and it is shown without any values since it is not an essential part of the mass balance being done on the material. There are four streams leaving the dryer. The first stream is the exhaust air, which again has not been quantified. The second stream is the water loss of 32 kg per hour, and the third stream is the product at 102.5 kg per hour. The amount of material lost in the air leaving the dryer is shown as the fourth stream leaving the dryer. It has been separated from the other streams to assist in simplifying the solution to the problem.

Solving for X gives a loss of 1.5 kg/hour.

FIGURE 2-4:
Diagram for Example Problem #2

"B"   26 kg / h

"A"

73 kg / h

Mixing Vessel

"C"

37 kg / h

Total = A + B + C

Heated Air

Drying Chamber

Exhaust Air

Water   32 kg / h

Product
102.5 kg / h

Losses
X kg / h
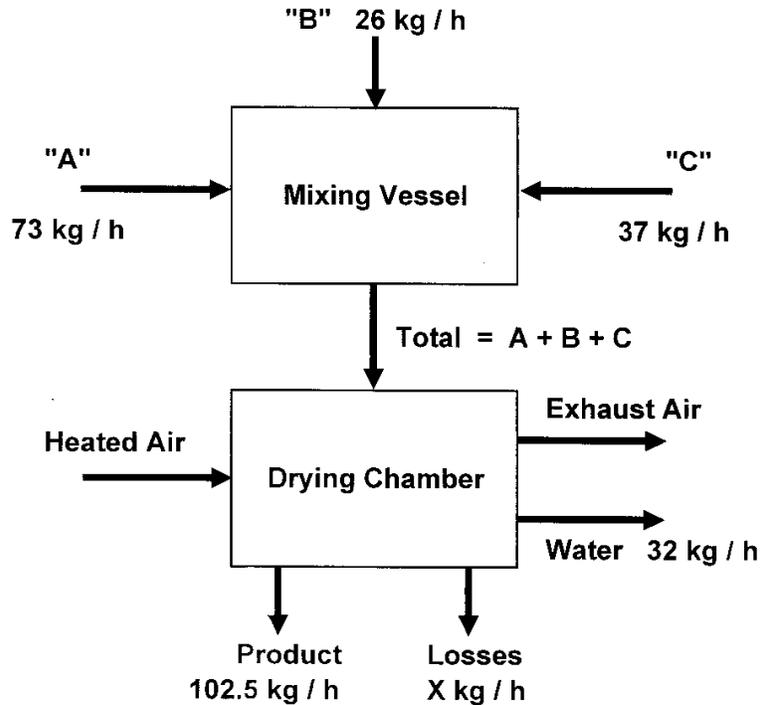
2.6 Practice Problems

Question 1:

Prepare a process flow diagram of a suitable process within your food processing facility. Include the basic unit operations, major inputs and outputs, and indicate the values of a number of key variables in the process. Retain all you work, including your rough work, so that you can see how your process flow diagram has evolved with each successive step in your design.

If you do not have access to an operating food process, or if your process information is considered confidential in nature, visit a website such as that of the "Institute of Food Technologists" (IFT) and use an example of a process that appears there. You may use any process for any material you wish, as long as there are multiple processing steps involving a variety of unit operations.

Discuss your process flow diagram with someone knowledgeable with the process you have chosen, and gather his or her feedback. Incorporate this feedback into a revised PFD if necessary.

Question 2:

Prepare a process flow diagram to describe the process for preparing a

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favourite food in your home. It may be something like preparing rice where you have a number of steps involved from the time the rice is harvested until it is cooked and consumed. Discuss your process flow diagram with someone knowledgeable in food processing and gather his or her feedback. Incorporate this feedback into a revised PFD if necessary.

Question 3:

From a newspaper, or other appropriate source, collect the high and low temperature readings for a fourteen day period in your area. Prepare a graph of temperature versus time (i.e., the date) with curves for both the daily maximum and daily minimum temperatures on the same graph. Use different symbols to mark the maximum and minimum temperatures. Join the data points for the maximum temperatures with a solid line and use a dashed line to join the minimum temperature points.

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AN INTRODUCTION TO FOOD DEHYDRATION AND DRYING

CHAPTER 3: DIMENSIONAL ANALYSIS APPROACH TO PROBLEM SOLVING

3.1 Introduction

Nearly all food processing applications involve some degree of mathematics to fully understand the actions taking place within a particular unit operation. The complexity of the mathematics can range from almost trivial to extremely difficult. As stated in Chapter 2, an organized disciplined approach should be taken in all problem solving activities. This gives you a better understanding of the components of the problem and reduces the chances of error.

The following steps may be helpful in solving problems:

i. draw a sketch or "picture" of what is taking place.
ii. label all known values and identify the "unknowns".
iii. establish initial mathematical relationships.
iv. refine the relationships to define the "unknowns".
v. use these relationships to characterize or "model" the process.

The primary focus of this chapter is on helping you address steps iii and iv, and to help you avoid making unnecessary errors in calculations as you proceed through your problem solving sequences.

3.2 Conversion Factors

While most countries of the world have officially embraced the metric system of measurement (or SI, "Systeme Internationale" units of measurement), the United States has maintained its links to what used to be called the "British" or "Stirling" system of measurement. There may be times that you are called upon to convert from one system of measurement to the other. In this case, a set of conversion factors is required to assist you in doing the conversion calculations. In addition, doing conversions such as these is an effective way of demonstrating a problem solving technique referred to as "Dimensional Analysis".

A list of basic conversion factors for length, mass, volume, and temperature appears below. Conversion factors for time have also been included for completeness. To avoid confusion, conversions for various pressure units, viscosity units, and other more complicated quantities have not been included. They will be introduced in the appropriate courses when needed.

While it is not necessary to commit these values to memory, learning certain conversion factors such as "2.54 cm equal one inch" may prove beneficial.

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Length:

1 inch = 2.54 cm

1 foot = 12 inches = 30.48 cm

1 yard = 3 feet
        = 36 inches
        = 91.44 cm
        = 0.9144 metres

1 mile = 5,280 feet
        = 1.609 kilometres

1 metre = 100 cm

1 metre = 1,000 mm

1 kilometre = 1,000 metres

Mass / Weight:

1 kilogram (kg) = 1,000 grams
              = 2.20462 pounds (lb)

1 pound (lb) = 16 ounces (oz)
            = 453.6 grams

1 ounce (oz) = 28.35 grams

1 metric tonne = 1,000 kg

1 ton = 2,000 pounds

Volume:

1 mL = 1 cm^3

1 litre = 1,000 millilitres (mL)
          = 1,000 cubic centimetres

1 cubic metre = 1,000 litres

1 U.S. gallon = 3.785 litres

1 Imperial gallon = 4.546 litres

Temperature Conversions:

Celsius to Fahrenheit:
      F = (C * 1.8) + 32

Fahrenheit to Celsius:
      C = (F - 32) / 1.8

Celsius to Kelvin:
      K = C + 273.15

A temperature difference of one degree on the Celsius scale is equal to a temperature difference of one degree on the Kelvin scale.

Time:

1 minute = 60 seconds

60 minutes = 1 hour

24 hours = 1 day

365 days = 1 year (if not a "leap year")

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3.3 Dimensional Analysis:

A common sources of error in problem solving is confusion in how to handle the data that you have been given. You may not know whether to multiply two numbers or divide them. If you have to divide two numbers, you may not know which number goes on top (i.e., in the numerator) and which goes into the denominator (i.e., the bottom) of a fraction. Dimensional analysis virtually eliminates this problem, yet very few people seem to use it.

Very simply put, dimensional analysis involves putting units or "dimensions" with all numbers used in a mathematical equation.

Example 1:

In a simple example, we may have to convert 4.5 feet to the equivalent number of centimetres. Knowing that there are 12 inches in a foot, and 2.54 centimetres in an inch is essential to solving this problem.

There are several ways to go about solving this example, but we will convert the feet to inches first, and then convert the inches to centimetres.

Number of inches = 4.5 ft x $\dfrac{12 \text{ in}}{\text{ft}}$

= 54 inches (Eq'n 1)

Number of cm = 54 inches x $\dfrac{2.54 \text{ cm}}{\text{inch}}$

= 137.16 cm   (Eq'n 2)

In equation 1, the units of feet in the denominator cancel the units of feet in the numerator to leave you with inches as your resultant dimension. This is what you want, so you're halfway to solving the problem. You then multiply 4.5 by 12 to get the numerical part of your answer. In equation 2, the inches in the denominator cancel the inches in the numerator and you are left with centimetres as your final dimension, so you've done the appropriate mathematical operations. Multiplying 54 by 2.54 will give the final numerical portion of the answer.

The example can be handled in one step:

Number of cm =

$$4.5 \text{ ft} \ \text{x} \ \dfrac{12 \text{ in}}{\text{ft}} \ \text{x} \ \dfrac{2.54 \text{ cm}}{\text{in}}$$

= 137.16 cm   (Eq'n 3)

For more complex problems (there aren't many simpler than this example), a better method of writing the mathematical equations is to use a horizontal line and a series of vertical lines. Terms above the horizontal line get multiplied by each other. Terms below the line get divided into those above the line. For example, equation 3 can be rewritten as:

Number of centimetres =

$$\dfrac{4.5 \text{ ft} \ | \ 12 \text{ in} \ | \ 2.54 \text{ cm}}{| \ \text{ft} \ | \ \text{in}}$$

= 137.16 cm   (Eq'n 4)

The starting value should be positioned as the first entry on the calculation line and then you can work from there to obtain the desired conversion.

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Example 2:

Knowing that there are 16 ounces (oz) in a pound (lb); 453.59 grams in a pound; and 1,000 g in a kilogram, convert 250 ounces to kilograms.

Number of kilograms =

$$\frac{250 \text{ oz} \mid \quad \text{lb} \quad \mid 453.59 \text{ g} \mid \quad \text{kg}}{\mid 16 \text{ oz} \mid \quad \text{lb} \quad \mid 1000 \text{ g}}$$

= 7.09 kg   (Eq'n 5)

You can see how the appropriate units cancel each other to leave only kilograms. "Ounces" (i.e."oz") above the line cancel with "ounces" below the line. "Pounds" (i.e., "lb") above the live cancel with "pounds" below the line. "Grams" (i.e., "g") above the line cancel with "grams" below the line. This leaves "kilograms" (i.e., "kg") as the final dimension for the calculation, which is what we are required to find. The numbers above the line are then multiplied together and the numbers below the line can also be multiplied together. The numbers below the line are then divided into the numbers above the line to get the final numerical value.

Example 3:

Let's suppose we get "mixed up" in how to do the conversion from Example 2 and go about things in the **wrong way**. Instead of dividing by 16 ounces per pound, we erroneously multiply by 16 ounces per pound. Here is what happens.

Number of kilograms =

$$\frac{250 \text{ oz} \mid 16 \text{ oz} \mid 453.59 \text{ g} \mid \quad \text{kg}}{\mid \quad \text{lb} \quad \mid \quad \text{lb} \quad \mid 1000 \text{ g}}$$

= 1,814.36 oz^2 kg/lb^2 (Eq'n 6)

If the size of the number doesn't tip you off that your answer is wrong, the units certainly should. There is no such thing as a "pound squared", or an "ounce squared"; and even if there were, you were setting out to determine the number of kilograms, so you know you've made an error in your conversion.

You should try to develop an appreciation of size and orders of magnitude in different units of measurement. We use SI Units for teaching and scientific purposes because of their inherent advantages. However, the "industrial world" uses a variety of measurement units depending on the type of monitoring device they have and also on the basis of "that's how we've always done it". You may see temperatures measured in both Celsius and Fahrenheit; or weights measured in both pounds and kilograms, in the same processing plant. The situation is even worse when it comes to pressure measurements, but that is a place where we will not go here.

So, even though we are trying to convert to SI Units, the "real world" is not as quick to respond as we would like.

3.4 Sample Calculations

In this section, we will switch from the format of two columns per page to a single column. In this way, the calculations will be easier to show and follow.

<u>Example 1</u>:

Problem Statement:

Convert a speed of "500 furlongs per fortnight" to "cm per second".

> Note: These are legitimate units of measurement. However, they do not fit within the SI guidelines.
>
> A furlong is a unit of measurement for distance used in horse-racing that is equivalent to one-eighth of a mile. Therefore, 1 furlong = 1/8 mile = 0.125 miles
>
> A fortnight is an old English term referring to a two-week period of time.

Solution:

The approach will be to convert "furlongs" to "centimetres" first and then convert "fortnights" to "seconds".

$$\frac{500 \text{ furlongs}}{\text{fortnight}} \left| \frac{0.125 \text{ miles}}{1 \text{ furlong}} \right| \frac{5{,}280 \text{ ft}}{\text{mile}} \left| \frac{12 \text{ inches}}{\text{foot}} \right| \frac{2.54 \text{ cm}}{\text{inch}}$$

500 furlongs =

per fortnight

$$\times \frac{1 \text{ fortnight}}{14 \text{ days}} \left| \frac{1 \text{ day}}{24 \text{ hours}} \right| \frac{1 \text{ hour}}{60 \text{ minutes}} \left| \frac{1 \text{ minute}}{60 \text{ seconds}} \right|$$

= 8.3154 cm / sec

Therefore: 500 furlongs / fortnight ≈ 8.32 cm / sec.

(Note: The mathematical treatment above had to be broken into two parts since it would not fit across the page on a single line.)


Example #2:

Problem Statement:

Calculate the volume of a tank that is 2.0 m tall and has an interior diameter of 80 cm. Express the volume to the nearest tenth of a litre.

Solution:

Begin by drawing a diagram of the tank and labelling it with the appropriate dimensions as shown in Figure 3-1. Even though this may be a relatively straight-forward problem, it is important to develop good problem solving techniques, which is the purpose of this exercise.

Figure 3-1: Diagram of Tank

Height = 2.0 m

d = 80 cm
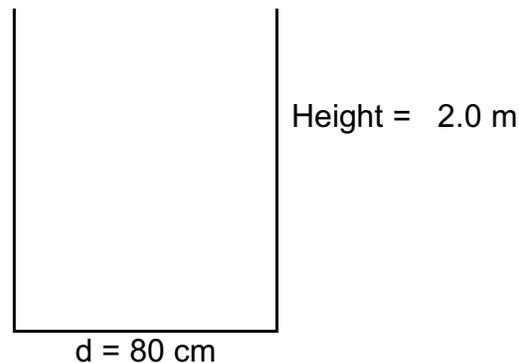
The volume of a cylinder is given by the formula:

$$\text{Volume} = \pi r^2 h = \frac{\pi d^2 h}{4}$$

where: π = 3.14159 (constant used in equations involving circles)
   r = radius of the cylinder (radius = one-half the diameter)
   d = diameter of the cylinder
   h = height of cylinder (or length of cylinder)

The first thing to do is to plan the approach to this problem. Since the final answer is required to be in "litres", it would be most efficient to calculate the volume of the cylinder based on its dimensions in centimetres. The resulting volume would then be in cubic centimetres which can easily be converted to litres on the basis that there are 1,000 cm^3 per litre.

The height of the tank is 2 metres which is equal to 200 cm.

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$$\text{Volume} \quad = \quad \frac{\pi\, d^2\, h}{4} \quad = \quad \frac{3.14159}{4} \left|\, \frac{80\ \text{cm}}{}\, \right|\, \frac{80\ \text{cm}}{}\, \left|\, \frac{200\ \text{cm}}{}\, \right|$$

$$= \quad 1{,}005{,}309\ \text{cm}^3$$

$$\text{Volume in litres} \quad = \quad \frac{1{,}005{,}309\ \text{cm}^3}{} \left|\, \frac{\text{litre}}{1{,}000\ \text{cm}^3}\, \right|$$

$$= \quad 1{,}005.3\ \text{litres}$$

Therefore, the volume of the tank is 1,005.3 litres
(to the nearest tenth of a litre as required).

In the calculation of the tank volume, the "80 cm" diameter appears twice to show that the diameter must be squared as part of the calculation.

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<u>Example #3</u>:

Problem Statement:

A food processing establishment is renovating its production facility. It intends to put new sanitary tiles on the floors and new washable panels on the walls of the "wet" processing area. The room is 48 feet long by 36 feet wide and the ceiling is twelve feet high. The floor tiles are 9 inches square (i.e., nine inches by nine inches in size) and the wall panels that are available are four feet by twelve feet in size. If we do not worry about openings for doors and windows in the walls and drains etc. in the floor, how many floor tiles and wall panels would be required for this job?

Solution:

This is probably one of the few times when it is easier to work in units of feet and inches than it is to work with their metric equivalents. The room is twelve feet high which is the height of a wall panel, and the panels are four feet wide which is a convenient dimension considering the length and width of the room.

Calculation of wall panels:

Draw a diagram of the room and determine what steps you need to take to solve the problem. A simple rectangle as shown in Figure 3-2 is sufficient for this problem.

Figure 3-2: Top View of "Wet" Processing Area

36 feet

48 feet

Height = 12 feet
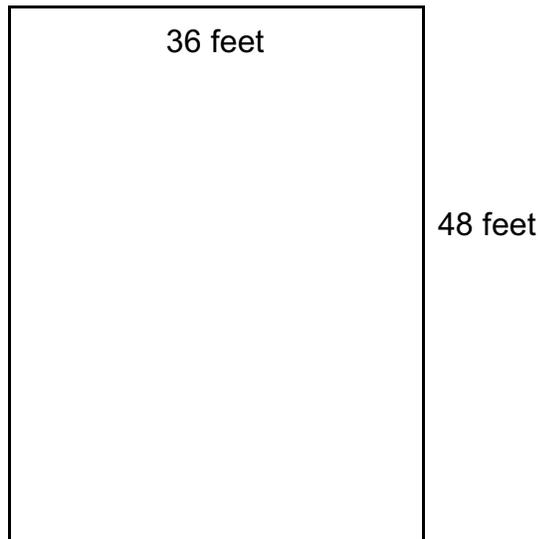
As stated above, this problem is suited to using feet as the dimension of choice.

The perimeter of the room (i.e., the distance around the outside of the room) is equal to 168 feet (i.e., 48 feet + 36 feet + 48 feet + 36 feet = 168 feet).

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Number of wall panels   = $\dfrac{\text{perimeter of room}}{\text{width of each wall panel}}$

$$= \quad \dfrac{168 \text{ feet}}{} \; \Big| \; \dfrac{\text{wall panel}}{4 \text{ feet}}$$

= 42 wall panels

There are also other approaches to solving this problem that work equally as well. For example, you could say that it takes 12 panels to cover each 48 foot wall and 9 panels to cover each 36 foot wall. This would give you a total of 42 panels.

Calculation of floor tiles:

Each floor tile is 9 inches by 9 inches. Convert this size to feet.

9 inches = $\dfrac{9 \text{ inches}}{} \; \Big| \; \dfrac{\text{foot}}{12 \text{ inches}}$ = 0.75 feet

Area of the room = length x width = 48 feet x 36 feet = 1,728 ft^2

Area per floor tile = length x width = 0.75 feet x 0.75 feet = 0.5625 ft^2

Tiles required = $\dfrac{\text{area of room}}{\text{area per floor tile}}$ = $\dfrac{1728 \text{ ft}^2}{} \; \Big| \; \dfrac{\text{tile}}{0.5625 \text{ ft}^2}$ = 3,072 tiles

Therefore, we would need 42 pieces of wall panelling and 3,072 floor tiles for this job.

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3.5 Practice Problems (with answers)

Use the "dimensional analysis" approach to answer the following questions. Be sure to show all of the steps involved in your solutions in order to develop good problem solving skills. Draw diagrams to assist you whenever they seem appropriate.

Question 1:

Calculate the capacity of a rectangular trough (with straight vertical sides) that is 3 feet - 9 inches long by 1 foot - 6 inches wide by 15 inches deep. Express your answer to the nearest tenth of a litre. (Converting the dimensions to centimetres as a first step will assist greatly in solving this problem)

Answer: 199.1 litres

Question 2:

An industrial dryer is set up to remove 6,500 pounds of water every hour. How many kg of water and how many metric tonnes of water will it remove in an eight hour production shift?

Answer: 23,587 kg or 23.59 tonnes
               per eight-hour shift.

Question 3:

Many chemicals are sold in 55 U.S. gallon drums. What is the capacity in litres?

Answer: 208.2 litres

Question 4:

A dryer has two drying chambers each with its own temperature setting. Zone 1 is set to run with air at a temperature of 250°F and Zone 2 is set to run at 180°F. What are these temperatures in degrees Celsius?

Answer: Zone 1 = 121°C
               Zone 2 = 82°C

Question 5:

Air is entering a drying chamber at a speed of 4.2 miles per hour. Convert this speed to cm per second and metres per second.

Answer: 187.8 cm / second
               1.88 m / second

Question 6:

A recipe calls for 4 ounces of sugar in 1.3 Imperial gallons of water. Convert this mixing ratio to grams of sugar per litre of water.

Answer: 19.22 grams / litre

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Question 7:

How many seconds are in one year?
(Not a "leap year").

Answer: 31,536,000 seconds

Question 8:

The speedometer in a car reads 65 miles
per hour. How fast is this in kilometres
per hour and metres per second?

Answer: 104.59 km / hour
                   29.05 m / second

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AN INTRODUCTION TO FOOD DEHYDRATION AND DRYING

CHAPTER 4: WET AND DRY BASIS MOISTURE

4.1 Definitions of Wet and Dry Basis Moistures

There are two ways in which the moisture content of a food product may be expressed.

The more frequently used method is to state the water content on a "wet" basis, which may be defined by the following equation:

Wet Basis Moisture =

$$\frac{\text{Weight of Water}}{\text{Total Weight of Wet Material}} \times 100\%$$

= % Moisture (wet basis)

A less commonly used method of describing the moisture content of a product is one that is based on the weight of the dry material contained in the product. This "dry" basis moisture may be defined as being:

Dry Basis Moisture =

$$\frac{\text{Weight of Water}}{\text{Weight of Dry Material}}$$

= g water / g dry solids

Although wet basis moistures are the most frequently used methods of expressing the amount of water present in a material, they can also be somewhat misleading and confusing if they are not used in the proper manner.

It should be noted that **wet basis moistures** are expressed with water as a fraction of the total weight of the material present. As more water is added, the total weight of the material increases, as does the weight of the water. This means that the numerator (i.e., top) and denominator (i.e., bottom) of the fraction defining wet basis moisture are both changing as water is added or removed from a mixture. There is **no constant basis** in this definition, so you cannot compare two wet basis moistures directly.

Several practice problems (with answers provided) will be used to illustrate a number of points regarding water removal from products, plus water addition to products. As we will also see in the "Case Study" at the end of this chapter, the difference of 5% moisture between two products with moisture levels of 80% and 85% wet basis moistures is significantly different from a 5% moisture difference between two products having moisture levels of 10% and 15% wet basis moistures, which is a mistake commonly made by workers involved in drying products.

Dry basis moistures are not as commonly used in defining target moisture values. However, they do **have a constant basis** which allows you to compare two dry basis moistures directly. For example, a product containing 0.70 g water per g dry product contains twice the amount of water present in a product containing 0.35 g water per g dry product.

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The graph of "Wet Basis vs Dry Basis Moisture" shown as Figure 4-1 illustrates how wet basis and dry basis moisture values are related.

FIGURE 4-1:
Wet Basis Moisture vs Dry Basis Moisture

Percent Moisture (Wet Basis) (y-axis: 0% to 100%)
Grams of Water per Gram of Dry Solids (x-axis: 0 to 7)
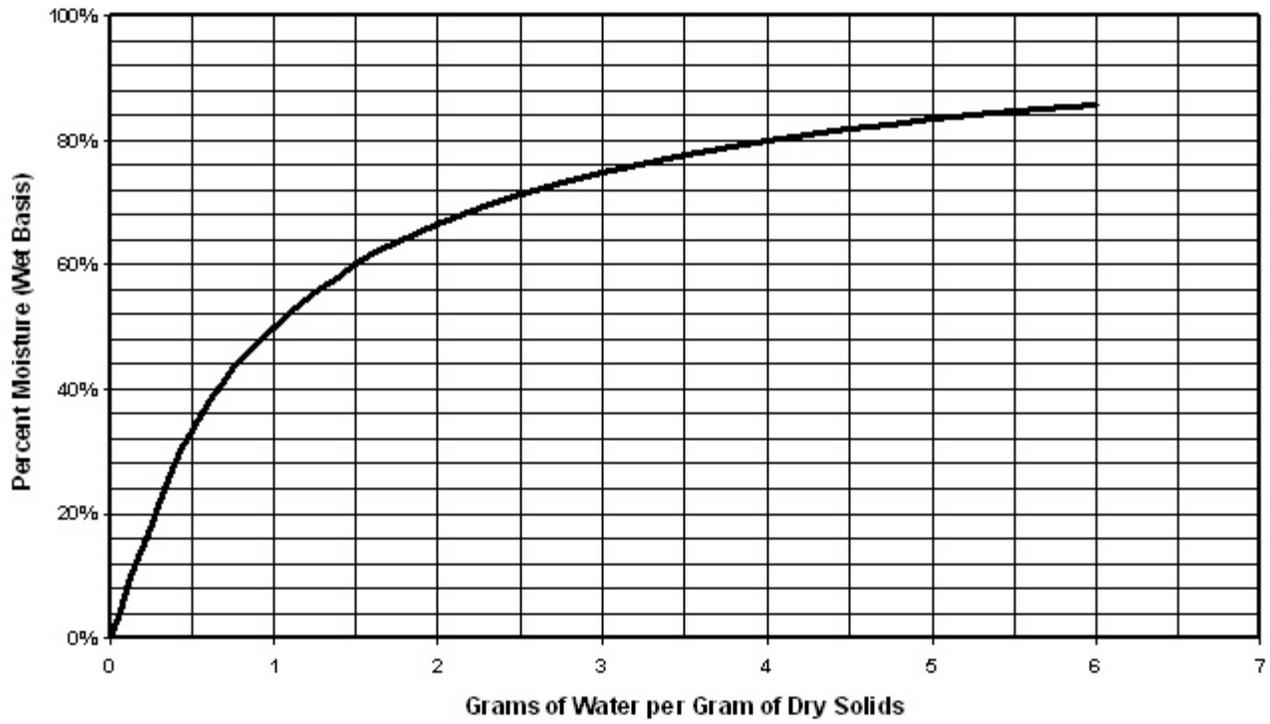
To demonstrate how misleading it can be to express moistures on a wet basis, consider the modified version of the "Wet Basis vs Dry Basis Moisture" graph shown in Figure 4-2.

FIGURE 4-2:
Wet Basis Moisture vs Dry Basis Moisture
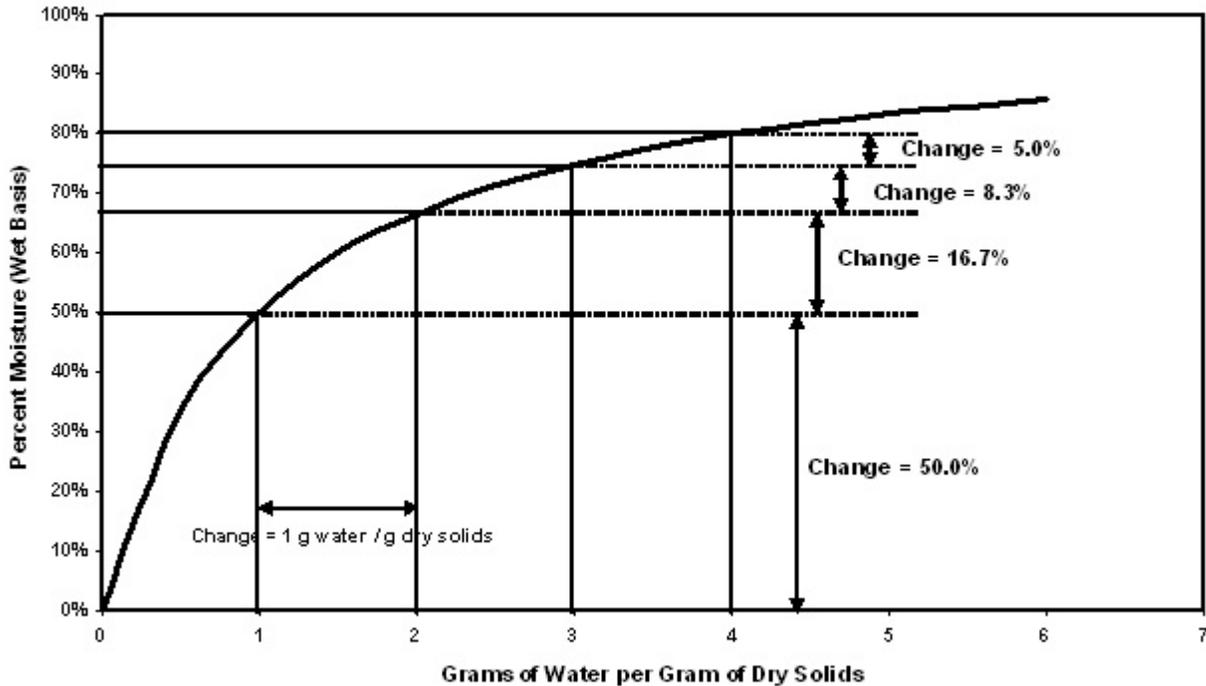
In Figure 4-2, vertical lines have been drawn at intervals of 1 gram of water per gram of dry solids (i.e., at 1.0, 2.0, 3.0, and 4.0 grams of water per gram of dry solids). At the point where these vertical lines contact the curve of "wet basis vs dry basis moistures", lines have been drawn horizontally across to the wet basis moisture axis.

Let us consider a four step process of adding moisture to some dry solids.

Step 1:   If we start with a totally dry or "bone dry" solid containing absolutely no water (i.e., 0.0 grams of water per gram of dry solids) and add 1.0 gram of water, we will have a dry basis moisture of 1.0 g water per g dry solids. On the wet basis moisture axis, this corresponds to going from 0% to 50% wet basis moisture. So, an initial addition of 1 gram of water to 1 gram of dry solids gives a 50.0% change in the wet basis moisture.

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Step 2: We will now take the product from Step 1 with 1.0 gram of water per gram of dry solids (or 50% wet basis moisture) and add another gram of water to it, we now have 2.0 g water per g dry solids as a dry basis moisture. Looking at Figure 4-2, a dry basis moisture of 2.0 g water per g dry solids corresponds to a wet basis moisture of 66.7%. Even though we added 1.0 gram of water to the material in Step 2, just as we did in Step 1, the wet basis moisture only increased by 16.7% (i.e., from 50% to 66.7%) compared to an increase of 50% wet basis moisture for the same amount of water being added in Step 1.

Step 3: Next, we will take the product from Step 2 with 2.0 grams of water per gram of dry solids (or 66.7% wet basis moisture) and add another gram of water to it. We now have 3.0 g water per g dry solids as a dry basis moisture. Again, looking at Figure 4-2, we can see that a dry basis moisture of 3.0 g water per g dry solids corresponds to a wet basis moisture of 75.0%. This addition of 1.0 gram of water to the material in Step 3 gave us an increase in the wet basis moisture of only 8.3% (i.e., from 66.7% to 75.0%). Compare this to an increase of 50% wet basis moisture for the same amount of water being added in Step 1, and a 16.7% increase in Step 2.

Step 4: In our final step, we will take the product from Step 3 with 3.0 grams of water per gram of dry solids (or 75.0% wet basis moisture) and add another gram of water to it. Now, we have 4.0 g water per g dry solids as a dry basis moisture. Once again, by looking at Figure 4-2, we can see that a dry basis moisture of 4.0 g water per g dry solids corresponds to a wet basis moisture of 80.0%. This addition of 1.0 gram of water

to the material in Step 3 gave us an increase in the wet basis moisture of only 5.0% (i.e., from 75.0% to 80.0%). Compare this to an increase of 50% wet basis moisture for the same amount of water being added in Step 1, and a 16.7% increase in Step 2, and an 8.3% increase in Step 3.

Hopefully, you can now see that when we add uniform amounts of water to a material, the wet basis moisture does not change by uniform amounts. This is due to the fact that wet basis moistures are based on the total weight of the material including the water that is added. For this reason, we do not have a constant basis on which to base the comparison of the moisture content of two materials. This means that when we do any calculations of water content using wet basis moistures, we must convert them to a dry basis before we can do any meaningful comparisons.

It is now an appropriate time to show how to convert from wet basis to dry basis moistures and from dry basis to wet basis moistures.

For the detailed calculations presented below, we will change the format of the text. By not having two columns per page, the calculations may be shown somewhat more clearly than when two columns are used.

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4.2   Wet and Dry Basis Moisture Conversions

4.2.1   Wet Basis Moisture Sample Calculations

Convert the following wet basis moistures to dry basis moistures:

Example 1:   74% wet basis moisture   (typically the moisture content of yams)
Example 2:   93% wet basis moisture   (typically the moisture content of tomatoes)
Example 3:   11% wet basis moisture   (typically the moisture content of dried beans)
Example 4:   95% wet basis moisture   (typically the moisture content of lettuce)

Recall the definition of dry basis moisture:

$$\text{Dry Basis Moisture} = \frac{\text{Weight of Water}}{\text{Weight of Dry Solids}}$$

Example 1:   For 74% wet basis moisture: (Convert to dry basis moisture)

Since no initial weight of product is given, start by considering 100 kg of starting material.

Convert the wet basis moisture from a percent to a decimal fraction. 74% will become 0.74 for our calculations.

$$\text{Weight of water} = \frac{100 \text{ kg material} \mid 0.74 \text{ kg water}}{\mid \text{kg starting material}}$$

$$= 74 \text{ kg water}$$

Weight of solids   =   100 kg starting material - 74 kg water

$$= 26 \text{ kg solids}$$

$$\text{Dry Basis Moisture} = \frac{74 \text{ kg water}}{26 \text{ kg solids}} = 2.85 \text{ kg water / kg dry solids}$$

Or: 2.85 g water / g dry solids etc.

Therefore, a product like yams with a wet basis moisture of 74% would have a dry basis moisture of 2.85 kg water / kg dry solids, or 2.85 g water / g dry solids. (Note that the weight units can vary except whatever units are used for the water should be used for the solids to maintain a consistent comparison).

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Example 2:   For 93% wet basis moisture: (Convert to dry basis moisture)

As in Example 1, consider 100 kg of starting material

Weight of water = $\underline{\text{100 kg material } | \quad \text{0.93 kg water}}$
                                           | kg starting material

= 93 kg water

Weight of solids   =   100 kg starting material - 93 kg water

= 7.0 kg solids

Dry Basis Moisture   = $\dfrac{\text{93 kg water}}{\text{7 kg solids}}$ =   13.3 kg water / kg dry solids

Or: 13.3 g water / g dry solids etc.

Therefore, a product like tomatoes with a wet basis moisture of 93% would have a dry basis moisture of 13.3 kg water / kg dry solids, or 13.3 g water / g dry solids.

Example 3:   For 11% wet basis moisture: (Convert to dry basis moisture)

As in Example 1, consider 100 kg of starting material

Weight of water = $\underline{\text{100 kg material } | \quad \text{0.11 kg water}}$
                                           | kg starting material

= 11 kg water

Weight of solids   =   100 kg starting material - 11 kg water

= 89 kg solids

Dry Basis Moisture   = $\dfrac{\text{11 kg water}}{\text{89 kg solids}}$ =   0.124 kg water / kg dry solids

Or: 0.124 g water / g dry solids etc.

Therefore, a product like dried beans with a wet basis moisture of 11% would have a dry basis moisture of 0.124 kg water / kg dry solids, or 0.124 g water / g dry solids.

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Example 4:   For 95% wet basis moisture: (Convert to dry basis moisture)

As in Example 1, consider 100 kg of starting material

Weight of water = $\dfrac{100 \text{ kg material} \mid 0.95 \text{ kg water}}{\mid \text{ kg starting material}}$

=   95 kg water

Weight of solids =   100 kg starting material - 95 kg water

=   5.0 kg solids

Dry Basis Moisture = $\dfrac{95 \text{ kg water}}{5 \text{ kg solids}}$ =   19.0 kg water / kg dry solids

Or: 19.0 g water / g dry solids etc.

Therefore, a product like lettuce with a wet basis moisture of 95% would have a dry basis moisture of 19.0 kg water / kg dry solids, or 19.0 g water / g dry solids. This is truly an incredible amount of water per unit weight of dry solids!

Compare this to tomatoes with a wet basis moisture of 93% which contain 13.3 grams of water per gram of dry solids. At these moisture levels, a difference of 5.7 grams of water per gram of dry solids causes a difference of only 2% in the wet basis moisture.

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4.2.2 Dry Basis Moisture Sample Calculations

Convert the following dry basis moistures to wet basis moistures:

Example 1:   3.6 kg water / kg dry solids
Example 2:   4.7 grams of water per gram of dry solids
Example 3:   0.075 grams of water per gram of dry solids

Recall the definition of wet basis moisture:

$$\text{Wet Basis Moisture} = \frac{\text{Weight of Water}}{\text{Total Weight of Material}} \times 100\%$$

Example 1:   3.6 kg water / kg dry solids: (Convert to wet basis moisture)

Note that this is actually a dry basis moisture.

As a starting position, consider 1 kg of solids, and work from there.

Water contained in 1 kg dry solids   = 3.6 kg water

Total weight with added water   =   1.0 kg solids + 3.6 kg water

= 4.6 kg total weight

$$\text{Percent wet basis moisture} = \frac{3.6 \text{ kg water}}{4.6 \text{ kg total weight}} \times 100\%$$

= 78.26 %

Therefore, the wet basis moisture is approximately 78.3%

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Example 2:   4.7 grams of water per gram of dry solids: (Convert to dry basis moisture)

To begin this conversion process, consider 1 gram of solids.

Water contained in 1 g dry solids   = 4.7 g water

Total weight with added water   =   1.0 g solids + 4.7 g water

=   5.7 g total weight

Percent wet basis moisture   = $\dfrac{\text{4.7 g water}}{\text{5.7 g total weight}}$ X   100%

=   82.46 %

Therefore, the wet basis moisture is approximately 82.5%

Example 3:   0.075 grams of water per gram of dry solids: (Convert to dry basis moisture)

As we did in Example 2, to begin this conversion process, consider 1 gram of solids.

Water contained in 1 g dry solids   = 0.075 g water

Total weight with added water   =   1.0 g solids + 0.075 g water

=   1.075 g total weight

Percent wet basis moisture   = $\dfrac{\text{0.075 g water}}{\text{1.075 g total weight}}$ X   100%

=   6.98 %

Therefore, the wet basis moisture is approximately 7.0%

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4.2.3 Additional Wet Basis Moisture Calculations

Often we are required to determine the wet basis moisture of materials from information other than the dry basis moisture.

When working with liquid products such as sugar solutions, we are frequently told the solids content of the solution as a percentage of the total weight (i.e., % solids), or in units of "degrees Brix". "Degrees Brix" (or ° Brix) have nothing at all to do with temperature. "Degrees Brix" is just another way of expressing the percent solids, usually sugar, in a solution. A 65° Brix sucrose solution would contain 65% by weight sucrose and the remaining 35% would be water.

In other cases, we may be required to calculate the moisture content on a wet basis of a mixture prepared by blending a solid material of known moisture with some additional water. Although we may not often think of liquid solutions in terms of drying, the principles and calculations involved are quite similar.

For illustrative purposes, let us consider the following examples for which we are to calculate the wet basis moistures:

Example 1: 38° Brix sucrose solution   (Convert to wet basis moisture)

Example 2: 250 g water + 630 g powdered material with no moisture
(Convert to wet basis moisture)

Example 3: 55 kg water + 30 kg powdered material with 15% moisture (wet basis)
(Convert to wet basis moisture)

Example 1: 38° Brix solution: (Convert to wet basis moisture)

Note   As stated above, "Brix" is an indication of the percent solids by weight present in a solution. The solids are usually sugars.

A 38° Brix solution will contain 38% solids by weight. We will express this percentage as a decimal fraction (i.e., 0.38) in our calculations.

Since no initial weight of the solution is given, we will consider 100 kg as a weight for the starting solution

Weight of solids   =   100 kg solution | 0.38 kg solids
| kg solution

= 38 kg

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Weight of water = 100 kg solution - 38 kg solids = 62 kg water

% wet basis moisture = $\dfrac{62 \text{ kg water}}{100 \text{ kg solution}}$ X 100% = 62%

Or: Since 38° Brix means that the solids content is 38% by weight, the water content by weight will be:

100% - 38 % solids = 62% water

Therefore, a 38° Brix solution is 62% water on a wet basis.

Example 2: 250 g water + 630 g powdered material with no moisture
(Convert to wet basis moisture)

To calculate the wet basis moisture, we need to know the total weight of the mixture and the weight of water in it. Since there is no water present in the powder, our only source of water is the 250 grams that we add as a liquid.

Total water present = 250 g water (no water in the powdered material)

Total material in mixture = weight of water + weight of powder

= 250 g + 630 g = 880 g

Wet Basis Moisture = $\dfrac{\text{Weight of Water}}{\text{Total Weight of Material}}$ X 100%

= $\dfrac{250 \text{ g water}}{880 \text{ g total weight}}$ x 100%

= 28.41%

Therefore, the wet basis moisture of this mixture is approximately 28.4%

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Example 3: 55 kg water + 30 kg powdered material with 15% moisture (wet basis)
(Convert to wet basis moisture)

In this case, we must take into account the water that is present in the powered material as well as the water that we are adding in its liquid form.

To calculate the wet basis moisture, we need to know the total weight of the mixture and the weight of water in it. We will begin by determining how much water is present in the powdered material.

Water in 30 kg powder = weight of powder x water fraction
= 30 kg x 0.15
= 4.5 kg

Total water present = water in powdered material + water as liquid
= 4.5 kg + 55 kg
= 59.5 kg water

Total material in mixture = weight of water + weight of powder

= 55 kg + 30 kg = 85 kg

Wet Basis Moisture = $\dfrac{\text{Weight of Water}}{\text{Total Weight of Material}}$ X 100%

= $\dfrac{59.5 \text{ kg water}}{85 \text{ kg total weight}}$ x 100%

= 70.0%

Therefore, the mixture of the powder and the water has a wet basis moisture of 70.0%.

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4.2.4 Additional Dry Basis Moisture Calculations

Just as we may have to calculate wet basis moistures based on a variety of information, we also may have to do similar calculations of dry basis moistures.

For comparative purposes, we will use the same three examples as we used in the wet basis moisture calculations and we will calculate their dry basis moistures. The three examples were:

Example 1:   38° Brix sucrose solution   (Convert to wet basis moisture)

Example 2:   250 g water + 630 g powdered material with no moisture
(Convert to wet basis moisture)

Example 3:   55 kg water + 30 kg powdered material with 15% moisture (wet basis)
(Convert to wet basis moisture)

Here are the dry basis moisture calculations.

Example 1:   38° Brix sucrose solution   (Convert to wet basis moisture)

A 38° Brix solution will contain 38% solids by weight

Consider 100 kg of starting solution

Weight of solids   = $\dfrac{100 \text{ kg solution} \mid 0.38 \text{ kg solids}}{\mid \quad \text{kg solution}}$

= 38 kg

Weight of water = 100 kg solution - 38 kg solids = 62 kg water

Dry Basis Moisture = $\dfrac{\text{Weight of Water}}{\text{Weight of Dry Material}}$

= $\dfrac{62 \text{ kg water}}{38 \text{ kg solids}}$

= 1.63 kg water / kg dry solids

Therefore, a 38° Brix sugar solution has a dry basis moisture of 1.63 kg water / kg dry solids, or it could also be expressed as 1.63 g water / g dry solids.

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<u>Example 2</u>: 250 g water + 630 g powdered material with no moisture
  (Convert to wet basis moisture)

To calculate the dry basis moisture, we need to know the total weight of water and the weight of the dry solids in the mixture. We will begin by determining how much water and dry solids are present in the powdered material.

Since we are told that the powder is dry and contains no moisture,

Water in powder = 0.0 kg

Solids in powder = 630 g   (i.e., the total weight of the dry powder)

Next, we need to find the total weight of the water present in the mixture.

Total weight of water = weight of + weight of water
                           liquid water   in powder

  = 250 g + 0 g
  = 250 g

Therefore, we have 630 g solids and 250 water in the mixture

Dry basis moisture = $\dfrac{\text{weight of water}}{\text{weight of dry solids}}$

  = $\dfrac{250\text{ g water}}{630\text{ g dry solids}}$

  = 0.397 g water / g dry solids

Therefore, we have a dry basis moisture of 0.397 g water / g dry solids in our mixture.

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<u>Example 3</u>: 55 kg water + 30 kg powdered material with 15% moisture (wet basis) (Convert to wet basis moisture)

To calculate the dry basis moisture, we need to know the total weight of water and the weight of the dry solids in the mixture. We will begin by determining how much water and dry solids are present in the powdered material. (Please note that many of these calculations are repeated from the same example done to determine the wet basis moisture of this mixture)

Water in powder = $\dfrac{30 \text{ kg powder} \mid 0.15 \text{ kg water}}{\mid \text{ kg powder}}$ = 4.5 kg water

Solids in powder = 30 kg powder - 4.5 kg water = 25.5 kg solids

Or: We can calculate the weight of solids using the percentage of water present and subtracting it from 100%. In the equation below, we have converted the percents to decimal fractions.

Solids in powder = $\dfrac{30 \text{ kg powder} \mid (1.0 - 0.15) \text{ kg solids}}{\mid \text{ kg powder}}$

= 25.5 kg solids

Therefore, we have 25.5 kg solids and 4.5 kg water present in 30 kg of the powder.

Total water present = water in powdered material + water as liquid
= 4.5 kg + 55 kg
= 59.5 kg

Total dry solids present = solids in powder = 25.5 kg

Dry basis moisture = $\dfrac{\text{weight of water}}{\text{weight of dry solids}}$

= $\dfrac{59.5 \text{ kg water}}{25.5 \text{ kg solids}}$

= 2.33 kg water / kg dry solids

Therefore, the dry basis moisture of this mixture is 2.33 kg water / kg dry solids.

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4.3 Methods of Moisture Determination

4.3.1 Introduction

In the previous sections, we have looked at methods of converting from one moisture basis to another and we have done calculations of the moisture contents for several mixtures. However, we have not yet discussed how the moisture contents of various products can be determined.

If we have an apple, how do we determine its moisture content? Or, what is the moisture content of hay used to feed cattle before and after it is dried? These are questions that we need to address before we proceed too much further in our discussions of drying.

There are several ways of determining how much moisture (i.e., water) is present in a material. Water determination methods such as laboratory titrations will not be examined here. We will focus on two basic methods that a commonly used in industry. These are vacuum oven and moisture balance methods.

At the outset, it should be explained that both the vacuum oven and moisture balance methods actually measure the total amount of water and other volatile material present in the sample. Volatile compounds are those that evaporate when the sample is heated. For example, if there was water and some alcohol present in a sample, both of these would evaporate and give a weight loss to the sample. In our testing, we assume that all weight loss is due to the evaporation of water. If there was a high level of alcohol present in the sample, we would have an error in our moisture determination.

However, most food materials have such a low weight of volatile compounds other than water that we can generally assume that the total weight loss in our testing is due to the evaporation of water.

4.3.2 Moisture Balances

Moisture balances are extremely useful for determining the moisture content of various products. Many of them are highly automated and are very easy to use. However, they tend to be rather costly.

When using a moisture balance, a small sample (perhaps 5 grams) is placed on a weighing pan inside the drying chamber of the moisture balance. The moisture balance registers the weight of the initial sample at the start of the test. Once the drying chamber is closed, heat is applied to the sample by means of an infrared heating lamp. As water is evaporated, the moisture balance compares the weight of the sample being dried to its initial weight and the wet basis moisture is indicated on its display panel. When the weight of the sample no longer changes, it is assumed that all of the water has been evaporated. The moisture balance then turns off the heating lamp and displays the final wet basis moisture of the sample. Depending on the nature of the sample and its initial weight, the moisture determination test can take anywhere from a few minutes to an hour or so.

Modern moisture balances are highly reliable and are quite accurate in their moisture determinations.

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4.3.3 Vacuum Oven Method:

The vacuum oven method is considered to be the "official" method of moisture determination. Exacting standards and procedures have been developed by the Association of Official Analytical Chemists (AOAC) for moisture determination testing. Their methodology should be followed. The explanation given here of how vacuum oven moisture tests are conducted is a simplified overview of the procedure.

When conducting a vacuum oven moisture test, samples are accurately weighed in previously dried and weighed aluminum weighing pans. Weighing is generally done on sophisticated balances that are capable of weighing to one ten-thousandth of a gram. Since the weights are so accurate, special handling of the samples is explained in great detail in the testing procedures. Forceps or tweezers are always used to move and lift the weighing pans.

The product samples are then placed in a specially designed drying oven which has been previously heated to the specified drying temperature (ca. 105° C). In order to assist in the evaporation of water from the sample, a vacuum is applied to the drying oven. The samples remain in the oven for a considerable time period (16 to 24 hours). After they have been in the oven for the appropriate amount of time, the vacuum that has been drawn on the oven is released and the sample pans are removed and placed in a desiccator to cool. If the samples are left out in the room air while they are still hot, they can pick up moisture from the air and this will affect the test results.

Once cooled, each weighing pan and its

dried contents are accurately weighed. At this point, the moisture content of the samples can then be calculated. Sample calculations of several vacuum oven tests are shown below.

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4.3.4 Sample Calculations of Vacuum Oven Moisture Tests

Test 1:   A sample of an apple is tested for its moisture content.

    Weight of empty weighing pan   =   1.5052 g
    Weight of wet sample and pan   =   6.8191 g
    Weight of sample and pan after drying =   2.3536 g

Weight of initial apple sample   =   weight of wet sample   -   weight of empty pan
                                         and pan

                                 =   6.8191 g - 1.5052 g

                                 =   5.3139 g

Weight of dried apple sample   =   weight of dry sample   -   weight of empty pan
                                       and pan

                               =   2.3536 g - 1.5052 g

                               =   0.8484 g

Weight of water in sample   =   weight of wet sample   -   weight of dry sample

                            =   5.3139 g - 0.8484 g

                            =   4.4655 g

Wet Basis Moisture   = $\dfrac{\text{Weight of Water}}{\text{Total Weight of Wet Material}}$ x 100%

                     = $\dfrac{4.4655 \text{ g}}{5.3139 \text{ g}}$ X   100%

                     =   84.034%

Therefore, the moisture content of the apple would be reported as 84.03%, on a wet basis (to two decimal places).

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<u>Test 2</u>:   A sample of hay going into a hay dryer is tested for its moisture content.

Weight of empty weighing pan   = 1.5813 g
Weight of wet sample and pan   = 4.3208 g
Weight of sample and pan after drying   = 3.5072 g

Weight of initial hay sample = weight of wet sample   - weight of empty pan
                                             and pan

                              = 4.3208 g - 1.5813 g

                              = 2.7395 g

Weight of dried hay sample = weight of dry sample   - weight of empty pan
                                             and pan

                              = 3.5072 g - 1.5813 g

                              = 1.9259 g

Weight of water in sample = weight of wet sample - weight of dry sample

                              = 2.7395 g - 1.9259 g

                              = 0.8136 g

Wet Basis Moisture = $\dfrac{\text{Weight of Water}}{\text{Total Weight of Wet Material}}$ x 100%

                      = $\dfrac{0.8136 \text{ g}}{2.7395 \text{ g}}$ X 100%

                      = 29.699%

Therefore, the moisture content of the hay would be reported as 29.70%, on a wet basis (to two decimal places).

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4.3.5 Miscellaneous Drying Calculations

It is almost impossible to show all of the types of calculations that would be encountered in drying applications. There are some examples, however, that may be useful for you to see. You may wish to consider the following sample drying problems which involve the use of wet basis moisture values.

Please note that these problem solutions may look rather long and involved due to the fact that every step in the calculations has been shown and explanatory notes have been added for clarity.

4.3.5.1 Sample Problem #1

Problem Statement:

> A processor has 525 kg of fresh green peas containing 74% moisture (wet basis). How much moisture must be removed from these peas to produce a final dried pea product with 12% moisture? What would the final weight of the dried peas be?

Solution:

Before proceeding with any problem of this nature, it is a good idea to organize your information in a simple diagram. While this problem may not appear to be too difficult, developing the habit of drawing a diagram will be a definite benefit to you when it comes time to solving more difficult problems which involve much more information.

Figure 4-3 summarizes the known information and allows us to determine which values we need to calculate.

FIGURE 4-3:
Diagram for Example Problem #1

Water
(unknown weight)

Fresh Peas

525 kg
74% moisture

Dryer

Dried Peas

X kg
12% moisture

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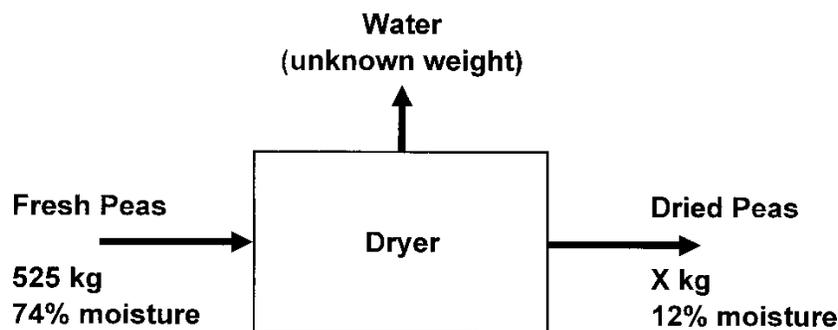
As a general rule, it is always a good idea to determine the amount of solids and the amount of water entering the drying process. We will do this first.

Weight of water in peas = weight of peas x water fraction in peas
                         = 525 kg x 0.74
                         = 388.5 kg

Weight of solids in peas = weight of peas x solids fraction in peas
                         = 525 kg x 0.26
                         = 136.5 kg

As we can see in Figure 4-3, the only thing that we know about the peas leaving the dryer is that their moisture content is 12% by weight. At this point, we know nothing about the weight of the dried peas as they leave the dryer, nor do we know how much water is removed in the process. Basically, we have two unknown quantities, but, as we shall see, they are inter-related.

In order to proceed, we need to make a simplifying assumption. Since we are not told that there are any losses of solids during the drying process, we will assume that the weight of dry solids leaving the dryer is equal to the weight of the dry solids entering the dryer. This is most frequently the case in drying. Sometimes, the drying air may carry solids out of the dryer; but if this is the case, you will have to determine the solids loss before you can proceed with your calculations.

Weight of solids leaving dryer = weight of solids entering dryer = 136.5 kg

The moisture content of the peas leaving the dryer is 12%. This means that of the total weight of dried peas leaving the dryer, 88% is solids (i.e., 100% - % water).

Since we do not know the weight of the peas leaving the dryer, we will let this weight be X kg.

Weight of peas leaving dryer = X kg

Since 88% of this weight is solids and the solids weigh 136.5 kg, we can say:

0.88 X = 136.5 kg

Solving for X: X = $\underline{136.5\ kg}$ = 155.1 kg
                              0.88

This means that we have 155.1 kg of dried peas leaving the dryer.

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Weight of water   =   weight of dried peas   -   weight of solids in peas
 in dried peas
                   =   155.1 kg   -   136.5 kg
                   =   18.6 kg

Weight of water removed   =   weight of water in peas   -   weight of water in peas
                                entering dryer   leaving dryer

                          =   388.5 kg   -   18.6 kg

                          =   369.9 kg

Therefore, 369.9 kg of water must be removed from the peas in the dryer and you
would get 155.1 kg of dried peas from the process.

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4.3.5.2 Sample Problem #2

Problem Statement:

A processor has 25 kg of dried onion flakes containing 11% moisture (wet basis). How much water must be added to these onions to rehydrate them and raise their moisture content to 85% moisture? What would the final weight of the onions be?

Although this is not a drying process, the problem does illustrate how to work with wet basis moistures when you are adding water to a material. For that reason, it is included here.

Solution:

Once again, we will start by drawing a diagram of the process (see Figure 4-4).

FIGURE 4-4:
Diagram for Example Problem #2
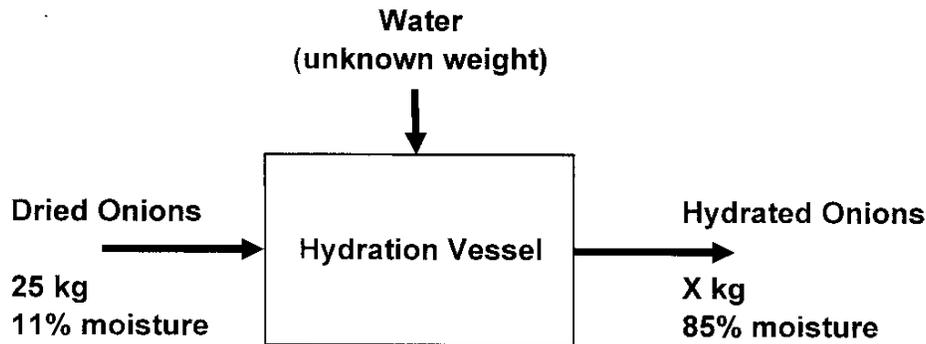
We will begin by determining the weight of water and solids in the onion flakes at the start of the process. Since the onion flakes contain 11% moisture, they will contain 89% solids.

Weight of water in flakes = weight of flakes x water fraction in flakes
= 25 kg x 0.11
= 2.75 kg

Weight of solids in flakes = weight of flakes x solids fraction in flakes
= 25 kg x 0.89
= 22.25 kg

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We know nothing about the rehydrated onions except that there final moisture content is 85% by weight. However, since we are just adding water to the onion flakes, it would be safe to assume that no dry material is lost in this process. By making this assumption, we can say:

Weight of onion solids   =   Weight of onion solids   =   22.25 kg
 after water is added   before water is added

If we let the total weight of the onion flakes after the water is added be X kg, we can say that 85% of the total weight is water and 15% of the total weight is dry solids.

Expressing this as a mathematical equation gives us the following:

$$0.15\,X = 22.25 \text{ kg}$$

Solving for X: $X = \dfrac{22.25 \text{ kg}}{0.15} = 148.33 \text{ kg}$

 Water present in   =   weight of rehydrated   -   weight of dry solids
 rehydrated onions   onions   in rehydrated onion

                    =   148.33 kg - 22.25 kg

                    =   126.08 kg

Water added to dried onion flakes   =   water at end - water at start

                              =   126.08 kg - 2.75 kg

                              =   123.33 kg

Therefore, the processor must add 123.33 kg of water to the dried onion flakes. The final weight of the rehydrated onion flakes will be 148.33 kg.

You could also take the final weight of the hydrated onion flakes (148.33 kg) minus the initial weight of the dried onion flakes (25.0 kg) to get the weight of water added (123.33 kg).

Please note that in these two sample problems, the key step is the assumption that no solids are lost in the process. Although this is generally true, there may be exceptions. As already stated, if there is a loss of solids, you must identify the size of this loss before you can proceed with any calculations.

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4.4 Case Study: Effects of Feed Moisture on Finished Product Moisture

Background:

This case study is based on actual experiences that I have had in dealing with operators of drying processes. I have changed all of the details in this case study to create a fictitious process. However, this example is highly relevant to drying processes and should not be dismissed too lightly.

Case Study Scenario:

You are the food process engineer for a fictitious company which has a drying operation that produces dried carrot cubes for use in dehydrated soup mixes. The small pieces of diced carrot entering the dryer at the start of a production run have a moisture content of 86% as expressed on a wet basis.

At the start of a drying run, the process operator carefully adjusts the dryer conditions so as to obtain a finished product moisture of 11%. After a few hours, the supply of diced carrots starts to run low and the operator requests an additional load of carrot cubes for her dryer.

When the new load of carrots arrives, it has a moisture content of 88%. The new batch of carrot cubes is sent through the dryer with identical operating conditions to the initial batch of carrots.

When you hear about the change to the new batch of carrot cubes, you go to the drying area and discuss the production with the dryer operator. The operator tells you that she expects the moisture of the second batch of dried carrots to be about 13% moisture. You disagree, but the operator says you're wrong and will not change the operating conditions of the dryer. Her reasoning is that the first batch went in at 86% moisture and came out at 11% moisture; so if the moisture of the incoming carrots is increased by two percent, the moisture of the dried carrots should also increase by two percent. A 13% moisture would still be acceptable, so no adjustments need to be made to the dryer.

When you check back later to see how well the second batch of carrots has been processed, the operator is standing there shaking her head in disbelief. The moisture content is well above the expected 13%. The operator cannot figure it out and looks to you for an explanation.

The feed-rate of the carrots is 175 kg of raw carrot cubes per hour in both cases.

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Questions:

Is the operator correct in keeping the dryer conditions the same, even though added moisture is coming through? (Or is there a big surprise in store?)

What is the weight of finished product produced on an hourly basis?

What would you predict the final product moisture to be if conditions were to be left unchanged?

Solution:

Step 1:   Always draw a picture before proceeding (see Figure 4-5). This will help identify the variables of interest and will organize the data for solving the problem.

FIGURE 4-5:
Starting Conditions for Case Study

Water
(unknown weight)

Fresh Carrots   Dried Carrots

                            Dryer

175 kg   X kg
86% moisture   11% moisture
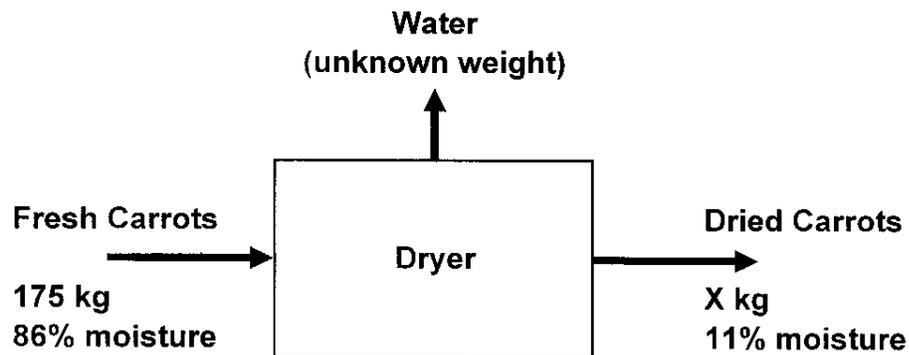
Step 2:   Determine the amount of water and solids present in the carrots wherever possible in the drying operation. You can then do a "mass balance" to follow where the water and solids go in the process.

Initial Feed: 175 kg / hour of material at 86% moisture (wet basis)

Water in carrots = 175 kg / hour x 0.86 = 150.5 kg / hour

Solids in carrots = 175 kg / hour x (1.0 - 0.86) = 24.5 kg / hour

Or: Solids = 175 kg / hour - 150.5 kg / hour = 24.5 kg / hour

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Initial Product: The dried product moisture is 11% (wet basis), which means that the dried product will have a solids content of 89% by weight

Solids leaving dryer = 24.5 kg / hour (assuming no losses)

Let weight of dried product = X kg / hour

$$0.89 \, X \;=\; 24.5 \text{ kg / hour}$$

$$X \;=\; \frac{24.5 \text{ kg / hour}}{0.89} \;=\; 27.53 \text{ kg / hour}$$

Water in dried product = weight of product - solids in product
                                      = 27.53 kg / hour - 24.50 kg / hour
                                      = 3.03 kg / hour

Therefore, 3.03 kg of water and 24.50 kg of solids would be in the finished product produced leaving the dryer each hour.

27.53 kg of finished product would be produced.

Water removed in = Water in carrots   -   Water in carrots
    dryer   going into dryer   coming out of dryer

                = 150.5 kg / hour - 3.03 kg / hour

                = 147.47 kg / hour

This means that the dryer is set up to remove 147.47 kg of water from the carrot cubes every hour.

Step 3:   Calculate the water and solids in the new carrot cubes entering the dryer after the moisture content has changed.

New Feed: 175 kg / hour of material at 88% moisture (wet basis)

Water in carrots = 175 kg / hour x 0.88 = 154.0 kg / hour

Solids in carrots = 175 kg / hour x (1.0 - 0.88) = 21.0 kg / hour

   Or: Solids = 175 kg / hour - 154.0 kg / hour = 21.0 kg / hour

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Step 4: Calculate the amount of water leaving the dryer after the moisture content of the feed has increased.

From Step 2, we know that the dryer is capable of removing a certain amount of water under its current operating set-up. This amount is 147.47 kg / hour.

Weight of water in carrots = Weight of water in carrots - Weight of water
leaving the dryer   entering dryer   removed in dryer

= 154.0 kg / hour - 147.47 kg / hour

= 6.53 kg / hour

Step 5: Calculate how the weight of the dried carrot cubes leaving the dryer

Weight of carrots = Weight of dry solids in carrots + Weight of water in carrots
leaving dryer   leaving dryer   leaving dryer

= 21.0 kg / hour + 6.53 kg / hour   (from steps 3 and 4)

= 27.53 kg / hour

Step 6: Calculate the wet basis moisture of the finished product.

From Step 4, there are 6.53 kg/hr of water leaving the dryer in the product.

From Step 5, we know that 27.53 kg/hr of dried carrot cubes leave the dryer.

$$\text{Wet basis moisture} = \frac{\text{Water in Product}}{\text{Total Product Weight}} \times 100\%$$

$$= \frac{6.53 \text{ kg/hr}}{27.53 \text{ kg/hr}} \times 100\%$$

$$= 23.72\%$$

Therefore, the finished product moisture will be approximately 23.7% after the moisture content of the dryer feed material is increased from 86% to 88%.

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Summary:

Under "normal" operating conditions, 27.53 kg of product would be produced on an hourly basis with an 11% moisture content.

When the moisture content of the feed material jumps from 86% to 88%, the finished product moisture will increase from 11% to 23.7%, if no changes are made to the dryer's setpoints.

The dryer operator was in for a big surprise since 13% moisture was expected and 23.7% moisture was actually obtained.

The Moral of the Story:

Don't be lulled into a false sense of security by using "wet basis moistures" when you should be looking at dry basis moistures.

Dry basis moistures have a consistent basis of comparison. You are always expressing the moisture level on a "unit weight basis of dry material".

Wet basis moistures do not have a consistent basis of comparison. As the moisture increases, the total weight of the wet material increases. This is what causes the problems for many dryer operators.

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4.5 Practice Problems (with answers)

Some of these questions do not involve drying as a specific topic. However, they do involve calculating wet and dry basis moistures as well as determining weights of solids and water in various products. These are important factors in doing future drying problems.

Question 1:

Calculate the amount of solids in 425 kg of frozen orange juice concentrate with a water content of 59.8%.

Answer: 170.85 kg   (solids content is 40.2% by weight).

Question 2:

What is the volume of 150 kg of a sugar syrup that has a specific gravity of 1.358?

Answer: approx. 110.5 litres

Question 3:

What are the weights of solids and water in 57.2 kg of 10.5° Brix apple juice?

Answer: 6.0 kg solids and 51.2 kg water. (Remember to convert the volume to its equivalent weight as a first step).l

Question 4:

Calculate the weights of water and solids in 13.8 kg litres of 75° Brix corn syrup.

Answer: 10.35 kg solids and 3.45 kg water.

Question 5:

Calculate the percent solids and Brix of the solution that you would get by mixing the 57.2 kg of apple juice in Question 3 and the 13.8 kg of corn syrup in Question 4.

Answer: 23.0% solids which is equivalent to 23.0° Brix. (Hint: You need the total weight of solids and the total weight of the final solution for this answer. You have already calculated the necessary values in questions 3 and 4).

Question 6:

What are the solids and water content of 150 kg of grape juice having 13.5% solids?

Answer: 20.25 kg of solids and 129.75 kg of water.

Question 7:

If 17.5 kg of dry granular sugar was added to the grape juice in Question 6, what would the percent solids become?

Answer: 22.5% solids. (Remember that the percent solids would be the total weight of the solids divided by the total weight of the solution times 100%).

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Question 8:

Calculate the wet basis moisture and dry basis moisture of mangoes having 19% solids.

Answer: 81% wet basis moisture and 4.26 grams of water per gram of dry solids.

Question 9:

What is the wet basis moisture (i.e., % water) of a product if 25 kg of it contains 3.75 kg of solids?

Answer: 85% moisture

Question 10:

What is the dry basis moisture of papayas containing 91% moisture on a wet basis?

Answer: 10.1 grams of water per gram of dry solids (or 10.1 kg of water per kg of dry solids).

Question 11:

We start with 18 kg of ripe tomatoes containing 93% water by weight. If we remove 15 kg of water by sun-drying, what is the final wet basis moisture?

Answer: 58% (You will have to find the water and solids at the start. Then subtract the water removed. This will give you the water left after drying. The final weight of the dried tomatoes will be the weight of the water after drying plus the weight of the solids. Normally, no solids will be lost during drying.)

Question 12:

How much water must be removed from 50 kg of lima beans with a moisture content of 67% to get a final moisture of 11%? What would the weight of the dried lima beans be?

Answer: 31.46 kg of water must be removed and 18.54 kg of dried lima beans would be obtained. (The trick here is to find the final weight of the product. Let it be X kg. Remember that the weight of the solids at the start of the drying equals the weight of solids after drying. You should find that you have 2.04 kg of water in the dried lima beans which you can subtract from the initial water content to get the amount of water removed).

Question 13:

a. Calculate the amount of water that must be removed from 250 kg of lima beans with an initial moisture content of 68% (wet basis) to reach a final moisture content of 48% moisture (wet basis).

Answer: 96.2 kg water removed

b. Calculate the amount of water that must be removed from 250 kg of lima beans with an initial moisture content of 68% (wet basis) to reach a final moisture content of 28% moisture (wet basis).

Answer: 138.9 kg water removed

c. Compare the answer for "Part a" where the moisture content was reduced by 20% (wet basis) to the answer for "Part b" where the moisture content of the same weight of identical product was reduced by 40%. Even though the

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reduction in wet basis moisture in "Part b" is double that in "Part a", is the amount of water removed also doubled.

Answer: No. Therefore, you should never base comparisons of water removal on the changes in wet basis moistures.

Question 14:

a. Calculate the amount of water that must be added to 100 kg of totally dry solids (i.e., bone dry solids) to reach a final moisture of 30% on a wet basis.

Answer: 42.9 kg water must be added.

b. Calculate the amount of water that must be added to 100 kg of totally dry solids (i.e., bone dry solids) to reach a final moisture of 60% on a wet basis.

Answer: 150.0 kg water must be added.

c. Compare the answer for "Part a" where the moisture content was increased by 30% (wet basis) to the answer for "Part b" where the moisture content of the same weight of identical product was increased by 60%. Even though the increase in wet basis moisture in "Part b" is double that in "Part a", is the amount of water added also doubled.

Answer: No. As stated in question 13c, you should never base comparisons of water removal on the changes in wet basis moistures.

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CHAPTER 5:   SOURCES OF INFORMATION

5.1   Introduction

The following is a list of information sources relating to food drying and food processing in general. It is not intended to be an exhaustive listing of available textbooks, etc.

The Internet / World-Wide-Web is a valuable source of information and should definitely be considered as a primary resource. Dryer manufacturers and equipment suppliers often have useful websites with details on how to contact them for further information. Due to the fact that website addresses are constantly changing while new ones appear and others may disappear, no specific website addresses are given here.

Scientific journals also offer in-depth studies of food drying. These papers are often highly specific and complex in their mathematical treatment of a particular drying phenomenon. For these reasons, scientific journal articles are not listed here.

5.2   General References:

"**Dehydration of Foods**"; Gustavo V. Barbosa-Canovas and Humberto Vega-Mercado; Chapman and Hall; New York, 1996.   (ISBN 0-412-06421-9)

"**Food Preservation and Safety - Principles and Practice**"; Shirley J. VanGarde and Margy Woodburn; Iowa State University Press, Ames, Iowa, 1994.   (ISBN 0-8138-2133-9)

"**Food Science - Fifth Edition**"; Norman N. Potter and Joseph H. Hotchkiss; Chapman and Hall; New York, 1995.   (ISBN 0-412-06451-0)

"**Food Science and Food Biotechnology**"; Gustavo F. Gutierrez-Lopez and Gustavo V. Barbosa-Canovas, editors; CRC Press; New York, 2003.   (ISBN 1-56676-892-6)

"**Food Process Engineering - Theory and Laboratory Experiments**"; Shri K. Sharma, Steven J. Mulvaney, and Syed S. H. Rizvi; Wiley-Interscience; New York, 2000.   (ISBN 0-471-32241-5)

"**Food Processing Technology: Principles and Practice**"; P.J. Fellows; Taylor and Francis, New York, 2000. (ISBN 0-8493-0887-9)

"**Fruit and Vegetable Processing**"; W Jongen; Taylor and Francis; New York, 2002.   (ISBN 0-8493-1541-7)

"**How to Dry Foods**"; Deanna DeLong; HP Books, Division of Berkley Publishing Group; New York, 1992. (ISBN 1-55788-050-6)

"**Introduction to Food Engineering - Second Edition**"; R. Paul Singh and Dennis R. Heldman; Academic Press; New York, 1993. (ISBN 0-12-646381-6)

"**Perry's Chemical Engineers' Handbook - Seventh Edition**"; Robert H. Perry and Don W. Green editors; McGraw-Hill, New York, 1997.

(ISBN 0-07-049841-5, International Edition ISBN 0-07-115448-5)

"**Principles of Food Processing**"; Dennis R. Heldman and Richard W. Hartel; Chapman and Hall, New York, 1997.   (ISBN 0-412-99451-8)