

# Beet-Sugar Handbook

*Mosen Asadi, PhD*



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# Beet-Sugar Handbook



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# DEDICATION

**This book** is dedicated to the following five sugar-technology masters, who contributed to establish the foundation of modern beet-sugar technology:

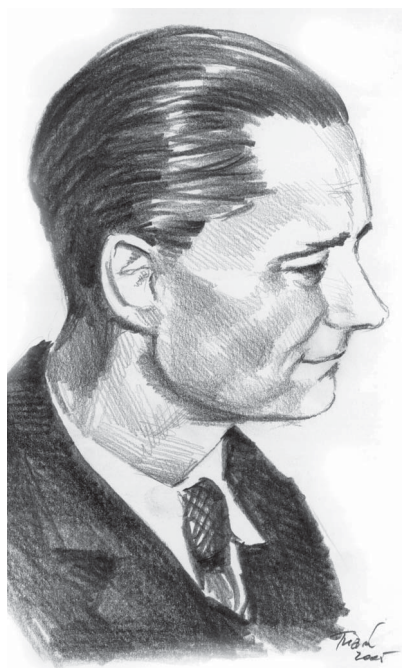
**Richard A. McGinnis** (1903–1995, from the United States) was the editor of *Beet-Sugar Technology*, a well-known sugar reference book, and the author of “Picking Table,” a sugar-related column, in the *Sugar Journal* for 17 years. Dr. McGinnis most lasting achievement was the cofounding of the Beet-Sugar Institute in Fort Collins, Colorado, in 1972 with his friend James H. Fischer. The Institute teaches beet-sugar technology in two sections: beet-end and sugar-end. Later, this institute was renamed the **McGinnis Beet-Sugar Institute** to honor him.



**Pavel M. Silin** (1887–1967, from Russia) taught sugar technology at the Moscow Institute of Food Technology. Professor Silin was the author of *Technology of Beet-Sugar Production and Refining* and an outstanding researcher on many areas in beet-sugar technology, such as the diffusion process and molasses exhaustibility. Most sugar technologists know him through the Silin number (the length in meters of 100 grams of cossettes), which is used in sugar factories to justify the quality of beet cossettes. Professor Silin's daughter, Z. A. Silina, continued in her father's footsteps at the Moscow Institute of Food Technology and conducted research on the formation and exhaustion of molasses.



**Jaroslav Dedek** (1890–1962, born in Prague, Czech Republic, and died in Belgium) is the author of a book on juice carbonation (*La Carbonate de Chaux*) and several sugar-technology articles. A master of lime-carbondioxide chemistry, he could be called the father of the juice-purification process, the heart of the beet-sugar factory. His most important accomplishment, together with his colleague Josef Vašátko, at the Czech Institute in Brno, was the progressive pre-liming process.





**Ferdinand Schneider** (1911–1984, from Germany) is the author of the German edition of *Sugar Technology* and hundreds of sugar-related articles. Professor Schneider was director of Agricultural Technology and the Sugar Industry in Braunschweig, Germany, where he taught sugar technology for many years. During his career, he trained many men and women from around the world who have PhD in sugar technology.



**Rudolf Bretschneider** (1914–1985, from Czech Republic) is the author of the Czech edition of *Sugar Technology* and a few other books. Professor Bretschneider taught sugar technology in the Department of Carbohydrates Chemistry and Technology at the Institute of Chemical Technology (ICT), Prague, Czech Republic.

The author of this book is honored to have been Professor Bretschneider's graduate student from 1976 to 1984 in the Department of Carbohydrates Chemistry and Technology at ICT.





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# PREFACE

## Life starts when we begin to help others

**This book** is a unique learning reference to cover the void existing in beet-sugar literature. For the first time, the following subjects are covered in a single book:

- Basics of beet-sugar technology
- Sugarbeet farming
- Sugarbeet processing
- Laboratory methods of analysis
- Sugar-related tables used in calculations
- Basics of science related to sugar technology

The book has 12 chapters, an appendix, 18 sugar-related tables, and a complete glossary of technical terms. To provide an easier understanding of the subjects, it is written:

- **Effectively:** Subjects are given practically with less emphasis on reference citation
- **User-friendly:** Subjects are given systematically to ease readers' understanding
- **Con conversationally:** Concepts are given informally to engage readers' interest
- **Example-presentably:** Examples are presented to clarify the equations
- **Internationally:** Measurement units are given in metric and British systems
- **Illustratively:** Technical flow diagrams improve reading ability of the reader
- **Definably:** Technical terms are defined as they are used and in a complete glossary

This book is written for the following readers:

- Beet-sugar chemists
- Beet-sugar technologists
- Sugar-technology students and instructors
- University-library audiences
- Beet-sugar researchers
- Sugarbeet farmers

Also, this book is a helpful reference for cane-sugar technologists and chemists, since some aspects of beet- and cane-sugar technology are closely related.

### **To Inexperienced Sugar Technologists**

**Mark Twain** (1835–1910) in “Life on the Mississippi” states: “To make sugar is really one of the most difficult things in the world. And to make it right is next to impossible.” Sugar technology may seem complicated but a user-friendly, systematic book written for the average technologist can make a big difference. Such a book was unavailable until now. This book gives special attention to the topics that often confuse beginners, offers many practical examples, and highlights important Notes to clarify the subjects and to fix concepts more firmly in your mind.

### **To Nonnative-English Speaking Sugar Technologists**

**To help** readers for whom English is a second language, I have used a simple writing style to provide an easier understanding of the subjects without translation to your native language. Comparably, having this book is like having a savings account at the bank; what you put in, you get out with interest. The interest is the improvement of your English within the context of familiar subjects.

### **To Sugar Scientists**

**Standard sugar terminology** (SST) does not exist for sugar technology. This often confuses the readers of sugar literature. I have tried to overcome this deficiency by choosing exact (accurate and precise) and self-defined terms (refer to Section 3 in Chapter 1), and to be consistent with the terms used in this book. Hopefully, you will find this effort to be a positive approach and will try to prepare a comprehensive SST for the sugar industry. Once a comprehensive SST is established, there will be only one exact and unified term for every concept, which can be used by people involved with the industry in all sugar-producing countries.

### **To Sugar Facility Directors**

**Hopefully**, you (directors of the sugar industry, research institutes, and university departments offering major in sugar technology) will find this book to be an effective learning tool and will offer to their employees or recommend it to their students. Investing in training is an efficient strategy for managing any industrial, research, or educational facility.

### **To Readers**

**With** hard work and help from a few individuals, I have written this handbook to help you (persons involved with the sugar industry). And it is finally your job to decide whether this is a **handbook** or a **shelfbook**. The ultimate test of success of any technical book is whether it will be taken in hand and used or placed on a shelf and forgotten.

Based on experience, some typing or technical errors may remain. However, they are now entirely my responsibility. Please send an email to my subject editor, Jonathan Rose, at [jrose@wiley.com](mailto:jrose@wiley.com) to let me know about any possible error or comment.

# ACKNOWLEDGMENTS

I want to express my thanks to Chris D. Rhoten for writing Chapter 7 and for his valuable technical comments on some specific subjects. Thanks also go to Jeffrey L. Carlson, PhD, for writing Chapter 10. Chris and Jeff work for Minn-Dak Farmers Cooperative Sugar Company in Wahpeton, North Dakota, and for years have been contributing to the educational side of our industry by teaching at the McGinnis Beet-Sugar Institute in Fort Collins, Colorado.

I would like to thank Lee Hubbell for reviewing Chapter 2 and Mathew Tucker for reviewing Chapter 4. Lee works as agricultural research manager and Mathew as quality manager for Michigan Sugar Company in Bay City, Michigan.

I am grateful to my daughter, Miriam Asadi, for reviewing subsection of First Aid in Chapter 11. Miriam is a PA practicing family medicine in Kalamazoo, Michigan.

Thanks also go to my friend R. Mirchi, PhD, from Prague for finding such a skilled Czech artist, Trešá Zost, to paint the images of sugar-technology masters (to whom this book is dedicated from copies of old duplicates).

Special thanks are extended to Robert L. Hetzler for his support throughout my career at Monitor Sugar Company. He was the president of the company during the years of my service to the company. What makes Bob a special individual is that he believes that *“if we are not part of the solutions, we are part of the problems.”*

At my publishing company John Wiley & Sons, Inc., Scientific, Technical, and Medical (STM) division, I want to thank Danielle Lacourciere (associate managing editor) and Jonathan Rose (associate editor) for doing their jobs in the best possible way.

Last but more importantly, my sincere appreciation goes to my family for being patient with me during four years when I was writing and fully concentrating on this book.

Mosen Asadi  
Henderson, Nevada  
June 2006





# BASICS OF BEET-SUGAR TECHNOLOGY

## SECTIONS

- ... 1. Sugar
- ... 2. Beet-Sugar Factory
- ... 3. Sugar Terminology
- ... 4. Sucrose Properties
- ... 5. Carbohydrates

**ABOUT THE CHAPTER** Chapter 1 gives all the basics related to beet-sugar technology and sugar functionalities that the readers of this book need to know to better understand the rest of the book.

Today, **beet-sugar technologists** (operators and problem solvers of the beet-sugar factories) and **sugar chemists** (operators and problem solvers of the sugar laboratories) need to know advanced beet-sugar technology, which is firmly rooted in the basics of science. The first and last chapters are complementary. The first chapter gives the basics of beet-sugar technology, and the last chapter gives the chemistry, mathematics, and statistics that relate to sugar technology. You may find it useful to refer to both chapters while studying the rest of the book.

**Beet-sugar technology** is the study of the production of sugar from **sugarbeet** (see the following Note) on an industrial scale. It requires a deep knowledge of two substances in sugarbeet juice:

- **Sugar** (sucrose)
- **Nonsugars** (nonsucroses)

Sugar and **nonsugars** (all soluble substances in sugarbeet juice except sugar) come to the factory in **sugarbeet** (the raw material of the beet-sugar factory). Sugar goes out as the product and nonsugars accumulate in molasses (which is a by-product of the factory). A person who has a good knowledge of sugar and nonsugars and knows how to separate them (with the highest possible efficiency) to produce sugar on an industrial scale is called a **beet-sugar technologist**.

**Beet** and **cane** are almost similar in sugar content (beet typically contains 18% and cane about 15%), but are dissimilar in the amount of nonsugars (beet juice contains about 2.5% and cane juice about 5%) and fiber (beet contains about 5% and cane about 10%). The composition differences require different methods to produce sugar from beet or cane. The differences in farming, composition, and processing of these crops are sufficient to justify two separate industries:

- Beet-sugar industry
- Cane-sugar industry

During the last century, both industries have grown considerably. World sugar production has increased from approximately 10 million tons in 1900 to about 150 million tons in 2005.

The beet-sugar industry plays an important role in the economy of beet-sugar-producing countries, which employ large numbers of people to grow sugarbeet, to produce sugar, and to support sugar-related areas such as sales, service, and research. For example, about 77000 U.S. jobs depend on beet-sugar industry. The United States produces about 30 million tons of beet/year on 0.6 million ha (1.5 million acres) of land, processes in 23 factories, and produces about 4 million tons of sugar. (There are over 500 beet-sugar factories in the world.)

About 40% of the world's sugar production is from beet, and 60% is from cane. The climates of most sugar-producing countries are suitable for growing either beet (in moderately cold areas) or cane (in tropical areas). In only a few countries (United States, Iran, Spain, Egypt, and Pakistan), the growing conditions are suitable for both crops.

Sugar from sugarbeet is produced in about 50 countries worldwide, in North America (United States and Canada), South America (Chile), Asian, North Africa (Morocco and Egypt) countries, and most of Europe.

Sugar technologists often use an old statement regarding a sugar factory's **goal**: "*The sugar factory does not make sugar; it separates nonsugars.*" But this is only half a picture because today's beet-sugar factory cannot survive if it doesn't aim for the following:

- To produce sugar with the highest efficiency
- To produce molasses with the lowest possible purity
- To be responsive to the natural environment with its wastes

**Molasses desugaring by chromatographic (MDC) process** has been accepted over the last two decades by the beet-sugar industry, mainly in the United States, as an efficient cost/return, environmentally safe technology. The MDC process (discussed in Chapter 8) can recover up to 90% of the sugar in molasses. A factory using the MDC process can increase the yield of **granulated-refined (GR) sugar** from about 80% to about 90%. This greatly improves the factory's efficiency and income, making the beet industry more secure in the market.

#### NOTE

- ▶ Although in English-language dictionaries the term **sugar beet** is two words, some sugar technologists connect the words and use simply **sugarbeet**. This trend is followed in this book as well. The terms *sugarbeet* and *beet* are used interchangeably. Furthermore, European sugar technologists and beet growers use these terms in their singular forms (for example, % on beet), while their American counterparts use them in plural forms (e.g., % on beets). In this book, primarily their singular forms are used. For sake of comparison, we, for example, say, "some farmers grow corn," but never say, "some farmers grow corns."



Sugar (table sugar or granulated-refined sugar) in its market-quality form is white and crystalline (granulated) with a pleasantly sweet taste. It is used in the kitchen, as an ingredient in sugar-added food products (e.g., soft drinks and confectioneries), and in production of nonfood products (e.g., detergents and ethanol). Sugar is considered:

- One of the world's purest food products (99.95% sucrose; water is the main remainder)
- One of the most natural foods used by humans for centuries without proven health risk
- One of the most purified organic compounds in the world
- One of the lowest priced food products

**Beet sugar** (sugar made from sugarbeet), **cane sugar** (sugar made from sugarcane), and **refined sugar** (sugar made from raw sugar) are similar in shape, taste, and other chemical and physical properties. Both beet and cane sugar (refers to their granulated refined form) that we use in cooking are pure **sucrose** with 99.95% purity, so the old belief of placing a higher value on one of them is not true. Sugar producers are not required to mention the source of the sugar on the label, so both are used interchangeably in households and in sugar-added food products.

Even experienced people find it almost impossible to recognize whether a sugar is made from sugarbeet or sugarcane. Advanced laboratory instruments and techniques are required to find the difference in beet and cane sugar by the content of **carbon isotope ratio**, which is the ratio of  $C^{13}$  (reads carbon 13) to  $C^{12}$ . This ratio is about 25% in beet sugar and 11% in cane sugar (Bubnik et al. 1995). Another differential marker is based on the raffinose content in these sugars (to a much higher extent in cane sugar) determined by chromatographic method (Eggleston 2005).

In some countries, liquid sugars (discussed in Section 20 of Chapter 3) are used by some food industries because they do not have to dissolve granulated-refined (GR) sugar before use. In a few countries (for example, the United States, Canada, and Japan), high fructose corn syrup (HFCS) has captured the liquid-sugar market because of its similarities in properties to liquid sugars and its lower production cost. HFCS is mainly used in carbonated beverage industries.

Although worldwide sugar is in a close competition with the sugar substitutes (discussed later in this section), it still has a larger market share in the sweetener industry (more than 70% of the world sweetener market belongs to sugar).

Even though sugar can be used as **added sugar** (sugar as a food additive in sugar-containing food products) in almost all food products, its properties are not entirely suitable for production of certain food products. For example, in some food products (like in fruit gums) liquid sugar may re-crystallize after the products are produced if the concentration of sugar syrup used in these products is high (more than 75%).

Before we get to other properties of sugar and basic subjects related to sugar technology, however, you might be interested briefly in knowing about the history of sugar production.

## BRIEF HISTORY OF SUGAR PRODUCTION

**Sugarcane** cultivation and the technique of sugar production began in India probably around 2000 BC and moved to Persia (now Iran) around AD 600. In Persia, the technique was improved; milk was used as the purifying agent; and the filtered syrup was crystallized. Then

the Persians invented a cone-shaped clay mold for the production of **cone sugar** (loafsugar). The mold had a small dripping hole in the middle of its bottom so that the syrup around the crystals slowly drips from the mold. The crystals were then left to dry for few days. (Similar cone-sugar molds made of sheet metal are still used in some countries.)

In AD 800, sugarcane cultivation spread from Persia to Egypt, Syria, and as far as Morocco and Spain. By the fourteenth century, Egypt was Europe's main supplier, via the port of Alexandria, of sugar made from sugarcane.

Sugar became popular in tea in Britain by the end of the seventeenth century. In those days, sugar was available in large cone shapes that had to be broken first into large pieces with a cast-iron pincer and then into regular cube size with a little chopper.

**Sugarbeet** cultivation on a research scale began in 1747 when Andreas Marggraf (a German chemist) discovered sugar in sugarbeet varieties (Bruhns 1997). Later, Franz Achard (Marggraf's student) in Germany and Ya. S. Esipov in Russia were simultaneously engaged in the cultivation of sugarbeet varieties. They also continued independently with research on the processing of sugar from sugarbeet in industrial scale. The first beet-sugar factory was built in Cunern (in Germany) in 1802 by Achard and in Alyabevo (in Russia), shortly thereafter. Beet-sugar technology developed rapidly, resulting in more than 400 beet-sugar factories in European countries by 1830 (including several factories in France by the order of Napoleon Bonaparte).

The first U.S. beet-sugar factory was built in Northampton, Massachusetts, in 1838. The first two successful U.S. beet factories were built in 1870 by Dyer family in Alvarado, California, and in 1880 by Claus Spreckels in Watsonville, California. The third successful factory was built in 1890 by the Oxnard brothers in Grand Island, Nebraska (Richard 2003).

During the industrial revolution between the late eighteenth and mid-nineteenth centuries, sugar technologists had always been the models for other industries by developing new technologies and equipment.

## FUNCTIONALITIES OF SUGAR

People like sugar for its sweetness. But the sweetness is only one of the **functionalities** (the factors improving the characteristics of other products) of sugar. Following are some of sugar's other functionalities:

- Improves the taste of food products
- Improves the flavor of food products
- Improves the sparkle in candy products
- Improves the shelf life of food products
- Improves the bulking property of food products
- Improves the color and texture of baked products
- Improves the preserving property of food products
- Improves the texture (mouth-feel) of food products
- Improves the foam in egg white in meringue products
- Improves the release of pectin of fruits in jam products
- Improves the heating rate of food products in the microwave
- Improves the flavor and color of food products by caramelization

- Decreases the freezing point of frozen-food products such as ice cream
- Increases the activity of yeast fermentation and the rising of baking products
- Increases the boiling-point (*BP*), allowing faster cooking at higher temperatures

**NOTES**

- ▶ Low **water activity** in sucrose-containing food products is responsible for the **freezing point depression (FPD)** in these products. Without sugar, ice cream would freeze rock hard and would be difficult to eat.
- ▶ Low water activity in sucrose-containing solutions helps sugar factories by slowing rust-formation action in containers relative to containers containing just water. Generally, corrosion happens when iron reacts with oxygen in air and in water. Comparably, there are fewer free oxygen molecules in a sugar factory's juices than in water. This is the reason for less rusting activity of the factory's containers. But the headspaces of tanks and vessels not covered in the solution may suffer corrosion due to the release of volatile organic compounds (VOC) from the solution.

**SWEETNESS OF SUGAR**

Sweet, salty, sour, and bitter are recognized in sensory science as basic taste feeling. Beginning in infancy, humans develop a taste for sweetness. Sweetness is sensed on the tongue and recognized by the **taste receptors** located mainly at the tip of the tongue. The receptors transfer the sweet taste through the central nervous system to the brain, which compares the sweetening power of a sweetener. The **sweetening power** depends on the following:

- Solubility of sweetener's molecules in the mouth (in water)
- Number of hydroxyl groups (OH) presence in sweetener's molecule
- Intensity of penetration of the sweetener's molecules to taste receptors
- Intensity of chemical bonding between sweetener's molecules and taste receptors

According to the **theory of sweetness**, (developed by U.S. scientist, Lamont Kier), there must be a **chemical bond** (see Glossary) between the molecules of the sweetener and the receptor to feel the sweetness. The bonds are ionic (see Chapter 12 for **ionic bonds**) between the hydroxyl group (OH) of the sweetener's molecules and the nitrogen (N) of the protein molecules in the receptor (*the better the sweet molecules fulfill the bonding requirements, the better the receptor detects the sweetness*). Sucrose, glucose, fructose, and several more compounds meet these requirements.

Sucrose (sugar) is the **standard reference** in sensory tests comparing the sweetness of other sweeteners (sugar is assigned a value of 1.0). The following list provides the approximate sweetening power of several natural and artificial sweeteners relative to sucrose, tested under the same conditions (concentration, temperature, and pH) and equal amounts. Remember that in addition to the concentration, temperature, and **pH** (measure of acidity and basicity) of the solution, the presence of other ingredients (e.g., salt) also affects the level of sweetness.

Sucrose	1.0
Glucose	0.7
Fructose	1.0
HFCS*	1.0

Invert sugar	1.2
Acesulfame	150
Aspartame	180
Saccharin	300
Sucralose	600

\* High-fructose corn syrup

As you can see, some sweeteners (mainly artificial sweeteners) are sweeter than sucrose. For example, sucralose (see Notes) is an artificial sweetener, which is 600 times sweeter than sucrose. Sucralose (its brand name is Splenda) is a chlorinated compound, and its molecules correspond to those of sucrose, but three of its hydroxyl groups are replaced by chlorine (Cl), which creates an artificial taste compared with natural sugar.

### NOTES

- ♦ The high sweetness of sucralose was discovered when a researcher misunderstood a supervisor's request to *test* a new chlorinated compound, and instead *tasted* it.
- ♦ The word *ose* in sucralose does not include it in the natural sugar group.

## METABOLISM OF SUGAR IN THE HUMAN BODY

**Sucrose** is a simple carbohydrate with a fast metabolism (digestibility characteristic). In the digestive system, an **enzyme** called **sucrase** (see the following Notes) converts the sucrose to glucose and fructose.



In the liver, the fructose is converted to its **isomer** (compounds with the same chemical formula but different structures), **glucose** (known as **blood sugar**), to be used in the blood as the source of energy. Blood carries oxygen (O<sub>2</sub>), absorbed from the air by inhalation, to the various cells of the body. The cells oxidize the glucose by combining it with the oxygen. The **oxidation** (simply, reaction of a substance with oxygen) of glucose produces considerable amounts of energy:



This reaction is an **exothermic reaction** (energy-releasing reaction), releasing 2800 kJ (669 kcal) energy per mole of C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> (or 669/180 = 3.7 kcal/g). (The value 180 is the glucose molecular mass.) The released energy enters the bloodstream to be used as the source of energy. This is a fast reaction, so it is used when a fast response to energy deficiency is needed. In hospitals, the glucose solution is injected directly into a patient's vein to restore the blood glucose level. We also know that athletes drink sweet beverages before sporting events.

In the body, all carbohydrates (sugars, starches, and dietary fibers) eventually convert to glucose to produce energy. The energy required to perform individual functions by the body is much less than the energy produced by glucose conversion. In our body, about half of the energy produced by glucose conversion is used to do activities. The remainder of the energy is released as heat to maintain the body's temperature. In addition, part of glucose is converted to **glycogen** (a polysaccharide) and stored in the liver and muscles to be used later. When the body needs energy, glycogen is broken down again into glucose to maintain blood glucose level.

The normal range of glucose in an adult's blood is between 70 to 100 mg per 100 mL (0.07 to 0.10%).

**Diabetes** is a disease in which the body either does not produce **insulin** (a hormone that regulates glucose level in the blood) or does not use it properly to allow glucose (blood sugar) to be converted to energy. So the extra glucose builds up in the blood causing a high glucose level, known as a high blood-sugar level.

#### NOTES

- ▶ Although the term **diabetes** applies to the high level of glucose (as the product of all carbohydrates in the body), sucrose (sugar) is the only carbohydrate that gets the blame for diabetes, and just because of the generality of the word “sugar” in peoples’ minds.
- ▶ The competitors of the sugar industry try to make sugar a label-unfriendly ingredient and mislead people that consumption of sugar (sucrose) is the cause of diseases such as diabetes, heart problems, and hyperactivity in children, but with no accepted scientific proof. A connection with some diseases exists but by way of the overconsumption of daily caloric intake, which creates obesity. The majority of our daily caloric intake comes from other sources (fats, proteins, and starches) than sugar. So far, scientists have confirmed no health risks related to a moderate use of sugar.
- ▶ In enzyme chemistry, the names of enzymes often end with *ase* and often describe the compound on which an enzyme works. For example, the enzyme sucrase hydrolyzes sucrose.

## CALORIC VALUE OF SUGAR

A **calorie** (cal) is the amount of energy required to raise the temperature of 1 g of water 1°C (actually from 15 to 16°C). The **kilocalorie** (kcal, Cal or Calorie with capital C), equivalent to 1000 cal, is used as the **dietary** (food) **calorie**, which expresses the nutritional value of food products. (Note: Most of the time calorie [cal] is simply referred to as a Calorie or **caloric value**.)

The **servicing size** (the base for reporting each food) of sugar is *one teaspoon (4g)*, which contains 16 Calories (16kcal) or 66 kilojoule (**kJ**, joule rhymes with *tool*) of nutritional energy. In the United States, the FDA requires that the serving size be expressed in both common household terms and metric units (e.g., one teaspoon, 4g). For detailed calculations of the amount of calories of sucrose, refer to the Sucrose Specific Enthalpy subsection in Section 4 of this chapter.

An equation, the “4-4-9 equation” is used to calculate the caloric value of food products. To find the amount of calories in a food product, the following are determined:

- Amount of fat in the product
- Amount of protein
- Amount of water
- Amount of ash
- Total of above

$$\text{Amount of carbohydrate} = \text{Actual weight} - \text{Total of above}$$

$$\text{Calories} = (\text{g carbohydrate} \times 4) + (\text{g protein} \times 4) + (\text{g fat} \times 9)$$

The 4-4-9 equation is based on:



Carbohydrates	4 Calories/g
Proteins	4 Calories/g
Fats	9 Calories/g

Human caloric requirements depend on:

- Age
- Body size
- Metabolic rate
- Physical activity

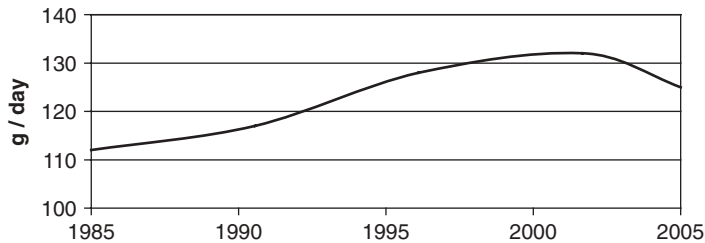
A rough estimate of a minimum caloric intake to maintain body activity is about 1 Cal/kg.h (1 Cal per each kg of body mass per hour). Average daily human caloric intake varies with age:

About 700 Calories for a 3-year-old baby

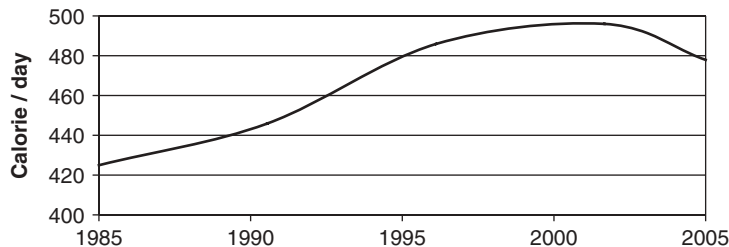
About 1500 Calories for a 25-year-old woman

About 2000 Calories for a 25-year-old man

The FDA determines the daily food intake based on 2000 Calories. The **average daily intake** (ADI) of all sweeteners in the United States in 2005 was about 125 g per day, mainly used in sweetening drinks. This equates to 480 Calories, or about 25% of the **daily calorie intake** (based on 2000 Calories per day). Figures 1.1 and 1.2 show the daily sweetener consumption and calorie intake from sweeteners in the United States from 1985 to 2005 (USDA 2005).



**Figure 1.1** Daily sweetener consumption in the United States since 1985



**Figure 1.2** Daily calorie intake from sweeteners in the United States since 1985

**NOTES**

- ▶ Sugar is a luxury food in some less developed countries, where people are short of calories (an unfortunate fact), while in developed countries some people try to consume less sugar because of its calories.
- ▶ World per-capita sugar consumption increased from about 220 Calories/day in 1985 to 280 in 2005. This equates to about 55g/day (20kg/year) in 1985 and 70g (25kg/year) in 2005.

**CRYSTAL SIZE OF SUGAR**

**Sugar factories** in different countries produce sugar of certain crystal sizes, depending on the habits of the household and commercial use. In general, household consumers in the United States prefer fine sugar, those in Europe prefer medium-size sugar, and those in Asia, Africa, and the Far East prefer coarse sugar.

The size of sugar crystals is expressed by the **mean aperture** (*MA*). The *MA* is the average crystal size of the sugar, expressed as the size of the screen in millimeter (mm) or in micrometer ( $\mu\text{m}$ ) on which 50% of the sugar sample stays and 50% passes through. Besides the crystal size, the **uniformity** (distribution) of the crystals is also important. The uniformity of the sugar is expressed by its **coefficient of variation** (*CV*). (For more information on *MA* and *CV*, see Chapter 4.) Standard crystal sizes are as follows:

- Extra-fine sugar with an *MA* of about 200 $\mu\text{m}$  (0.2mm)
- Fine sugar with an *MA* of about 300 $\mu\text{m}$
- Medium-size sugar with an *MA* of about 500 $\mu\text{m}$
- Coarse sugar with an *MA* of about 1000 $\mu\text{m}$
- Extra-coarse sugar with an *MA* above 1000 $\mu\text{m}$

For example, the baking industry uses extra-fine sugar because it mixes well during processing (due to its high surface area) and produces dough with higher rising property, and finely baked products with better quality (finer texture and less crumbs).

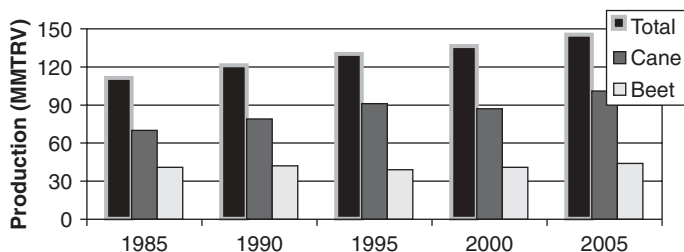
In most countries, fine and medium-size sugars are usually the standard, and extra-fine, coarse, and extra-coarse sugars are considered **specialty sugars** (see Section 20 in Chapter 3), for which customers pay a premium.

**PRODUCTION AND CONSUMPTION OF SUGAR**

World sugar production (from beet and cane) in 2005 was 149.5 million **metric tons raw value** (MTRV) and consumption was 150.5 MTRV. (Sugar production and consumption is usually expressed in raw sugar equivalent MTRV.) World sugar consumption has grown by 3% annually since 1985, and the world production has kept up with this increase in demand for sugar. Figure 1.3 shows world sugar production since 1985.

The 25 member countries of the **European Union** (EU-25) are the world's third-largest sugar producers (after Brazil and India) with about 16 million tons sugar production and the second-largest exporter of sugar (after Brazil) with about 6 million tons sugar export. Twenty-one countries of the EU-25 are sugarbeet-growing countries.

In the United States in 2005, the sugar production from sugarbeet was about 4 million tons raw value and from cane was 3.9 million tons. The U.S. production from sugarbeet has



**Figure 1.3** World sugar production

been essentially around 4 million tons since 1990. What has changed is that fewer factories are producing sugar (there were 36 beet factories in the United States in 1990 and 23 in 2005).

In recent years, world sugar **consumption** has increased almost yearly, to about 25 kg (55 lb) per capita per year in 2005. This includes household consumption and added sugar (sugar as a food additive in sugar-containing food products such as beverages and confectioneries). Household consumption accounts for almost one-third of the total consumption. It is estimated that the world consumption per capita will be 30 kg (66 lb) in 2010. Nevertheless, sugar consumption has decreased in some countries. For example, in the United States, the per capita intake has decreased from 29 kg (64 lb) in 1990 to 28 kg (61 lb) or about 77 g/day in 2005.

The following list shows the sugar production and consumption (capita intake) in 2005 in three countries with the highest sugar production in the world.

	Production (M tons)	Consumption (kg/capita)
Brazil	28.2	60
India	19.1	19
EU	16.7	42
World	149.5	25

#### NOTES

- ▶ The United States and India combined consume 46 million tons of sugar a year, making them the largest consumers of sugar in the world. This equates to 30% of the world's consumption. China is next, with about 10 million tons consumption a year. Consumption in China is projected to increase to 15 million tons in 2010 (Bouvier 2005).
- ▶ U.S. per capita consumption of sweeteners is almost 3 times higher than India and 10 times higher than China.
- ▶ In the world sugar market, the base (raw sugar with 96% sucrose) is used for expressing sugar production as raw value (*RV*). Usually granulated-refined (*GR*) sugar and liquid-sugar value are converted to raw value based on the percentage of sugar content (*S*), measured by polarimeter (called polarimetric sugar or *pol*) by using the following formula:

$$RV = 100 \times [(1.07 - (100 - S) \times 0.0175)] \quad (1.1)$$

**EXAMPLE 1**

Given: 100 kg raw sugar with 97.7% sugar content  
 Calculate:  $RV$

$$RV = 100 \times [(1.07 - (100 - 97.7) \times 0.0175)] = 103.0 \text{ kg}$$

This means that the sugar refinery makes *about* 100 kg of granulated-refined sugar from processing 103 kg of this raw sugar. Refer to Example 2 in Chapter 9 for more information.

**PRODUCTION COSTS OF SUGAR**

Sugar is produced from two different raw materials: **sugarbeet** and **sugarcane**, which are grown in different geographical areas with different production costs. The production costs of sugar consist of the following:

- **Labor costs:** Wages, benefits, and health insurance
- **Raw material costs:** Sugarbeet or sugarcane growing costs
- **Processing costs:** Fuel, chemicals, maintenance, and other related costs

These costs are different depending on which raw material is used. Most importantly, in the cane-sugar factories, **bagasse** (desugared-fibrous residue left after milling sugarcane) is used as fuel in boilers for the production of steam. (In some cases, cane factories even produce energy surplus, which is sold to public system.) The desugared-fibrous residue left after sugarbeet processing, called **pulp**, cannot burn properly, so beet-sugar factories do not have a suitable by-product to use as source of energy for boilers. In addition, the production costs of sugarbeet and sugarcane in the field is different. Such dissimilarities create a considerable difference in production costs of sugar from sugarbeet and sugarcane in the field as well as at the factory levels. But there is no difference in sugar price when it gets to the market, since both crops produce the same product.

Although transportation costs are incurred in cane-sugar production, because cane raw sugar is usually produced in a cane factory and then refined to granulated-refined (GR) sugar at a sugar refinery, the *production costs of cane sugar are lower than that of beet sugar*. Investigations have indicated that the **weighted average** (the average that gives points to the priorities—here, the average that gives points to countries with higher production) of world production costs, at both the field and the factory levels, is substantially lower (by about 60%) in favor of cane-sugar producers (Kingsman 2002).

The difference in production costs puts a great challenge on beet-sugar producers to be *highly efficient*. Some countries have met this challenge. For example, despite high labor and environmental protection costs, the U.S. beet-sugar producers have among the world's lowest production costs (despite high labor costs) because of high efficiency and the use of the **molasses desugaring by chromatographic (MDC) process**. Chile is another low-cost producer of beet sugar. Ukraine (with about 100 beet-sugar factories) is the highest cost producer, well above the average world production cost. In cane-sugar production, Brazil, Australia, and South Africa produce sugar below the average world production cost (Kingsman 2002).

Raw material costs account for a large part of total production costs. Factories pay farmers for tons of delivered sugarbeet. In many countries, the *sucrose content* also affects the price of the sugarbeet delivered to the processor. High-sucrose and low-nonsucrose content are the most important factors affecting the quality of the sugarbeet. Sugarbeet production costs in the field

vary considerably among countries. In 2000, the production cost of sugarbeet in the United States ranged from \$15.40 to more than \$60.00 per ton, with the average of \$37.30 (USDA 2004). (Note: The production costs are higher in western parts of the United States because of the cost of irrigation.)

## SUGAR ECONOMY

From 1990 until late 2004, the sugar industry experienced a decrease in sugar prices. During this period, sometimes the price of sugar fell even below production costs, considerably affecting the profitability of sugar companies. Flat or declining sugar prices in those years led to problems in some producing countries where rising production costs were not offset by profit.

The main reasons for the decrease in sugar prices in those years are the following:

- Barrier international sugar regulations on price stabilization
- Changes in sugar tariffs in different countries
- Competition with sugar substitutes in some countries
- Dependability of the market on world sugar surplus and stock
- Reliability of the market on the regulation of duty-free import quotas
- Decrease in governments buying sugar during buyer shortages (Pack 2003)
- Reliability of the market on Brazil as the world's primary sugar producer and exporter and Brazil's interest in lowering the world price of sugar due to the devaluation of its currency (Chavanes 2003)

In addition, the world price of sugar depends on oil price. Furthermore, it also depends on weather, economic and political stability of the individual countries and their desire to produce sugar.

Since early 2005, the world price of sugar has started to rise, reaching an increase of 35% by the end of that year. It is expected that sugar price will keep its rising trend during 2006, reaching a quartercentury high. Besides the increase in oil price and its connection to sugar price, the other main reasons for the price rise of sugar are the following:

- Brazil has started to use more of its crop to produce ethanol due to recent high oil price
- World consumption has increased (from about 146M tons in 2004 to about 150Mt in 2005)
- World stocks of sugar have recently dropped (from about 35Mt in 2004 to about 31 Mt in 2005), e.g., U.S. stock-to-use ratio in 2004 was about 18.8% and dropped to 12.8% in 2005

Despite fall and rise in sugar prices since 1990, production costs of sugar have increased steadily during this time because of the following reasons:

- Increase in oil price
- Increase in labor cost
- Increase in equipment cost
- Increase in barriers in environmental policies
- Decrease in funds for factory maintenance and improvement
- Decrease in national subsidies (sugar-price support and loan programs by some governments)

Knowing that sugar is a politically involved commodity and governments can never satisfy all involved parties, the primary responsibility of the sugar industry is to produce sugar at the lowest cost possible. To do so, the industry has decided to move toward the following three main goals:

- Improve the type of management and ownership of sugar companies
- Use new cost-effective technologies and cost-saving measures
- Adapt to national and international sugar regulations

On the side of improvement in the type of management and ownership, the beet-sugar industry has initiated important policies during the last two decades to become more competitive. Among other plans, the two most successful policies instituted by the industry are the following:

- Managing sugar companies as cooperatives
- Merging sugar companies

**Cooperative sugar companies** (simply, co-ops) were established in the United States to manage the production facilities more efficiently. Beet-sugar co-ops are owned by growers and are performing considerably well. In the United States, the first beet-sugar co-op was formed in 1899 in California. In 1973, the first large beet-sugar company of this type was formed when sugarbeet growers purchased the American Crystal Sugar Company in North Dakota. This trend continued with three new factories built in North Dakota and Minnesota. In 1997, sugarbeet growers started to negotiate over the financial assets of the Amalgamated Sugar Company and succeeded later to purchase the company. In 2002, the Michigan Sugar Company (with four sugar factories) was bought by sugarbeet farmers. In late 2004, the Monitor Sugar Company (with one large factory) was the latest company bought by local beet growers and merged into the Michigan Sugar Company.

In the United States in 2005, all 9 beet-sugar companies (with 23 factories) were co-ops, accounting for 100% of the total processing capacity (165000t/day in all factories).

In Europe, co-ops are also increasing in popularity. Today, growers are the main shareholders of some larger European sugar companies. For example, in 2005, growers held 56% of the shares of Südzucker in Germany.

The major advantages of co-ops compared with privately owned or investor-type companies are as follows:

- **Increased efficiency and profitability:** In a co-op operation, owners (beet growers) are interested in the efficiency of the factory as well as in the improvement of the quality of the sugarbeet. (Co-ops have been more successful than privately owned companies in producing quality sugarbeet.) Growers in charge of both important operations can increase profits to shareholders. In other words, the profit goes to the growers in a co-op, but it is shared among growers and the processor in a privately owned company.
- **Tax advantages:** The sugar factory does not produce a profit and thus pays no taxes based on U.S. tax regulations. All profits from the business are passed on to the growers except those used to pay debts or to make capital improvements to maintain or raise plant efficiency and capacity. Growers pay taxes on their income, but the processing facility is converted to a cost-saving center in the overall production of the sugar. As a result, the grower receives the maximum levels of income possible from sugarbeet production. Capital invest-