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HANDBOOK SERIES

The Coffee Brewing Handbook

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SECOND EDITION

THE COFFEE BREWING HANDBOOK

A Systematic Guide to Coffee Preparation

By

Ted R. Lingle

Second Edition

Specialty Coffee Association of America
Long Beach, California

Founded in 1982, the Specialty Coffee Association of America (SCAA) is the world's largest non-profit trade association representing the coffee industry. With more than 2,000 member companies from the United States and nations throughout the world, SCAA's mission is to foster coffee excellence and consumption through education and information exchange. This mission is undertaken both for and with the help of the Association's membership, including coffee growers, exporters, importers, roasters, and retailers, as well as food-service professionals and representatives of allied industries.

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ABOUT THE AUTHOR

Ted R. Lingle was born and raised in Southern California. He graduated from the United States Military Academy in 1966, receiving a Bachelor of Science degree. He completed four years on active duty in the U.S. Army, serving in both Germany and Vietnam. In 1978 he received a Masters degree in Business Administration from Woodbury University in Los Angeles.

During the first twenty years of his coffee career, Mr. Lingle was Vice President of Marketing for Lingle Bros. Coffee, Inc., a business started by his grandfather in 1920 in Los Angeles. During this period he directed the company's sales programs for the food service, office coffee service, and specialty coffee market segments. His principle responsibilities included establishing quality standards for the company's products and conducting training programs for both company personnel and customers. In addition, Mr. Lingle represented the company on various coffee industry boards and committees.

Mr. Lingle served as a member of the National Coffee Association's Out-of-Home Market Committee from 1974 to 1990. He served on the Board of Directors of the National Coffee Service Association and was elected an honorary member in 1990. He was one of the founding Co-Chairmen of the Specialty Coffee Association of America.

In 1975, Mr. Lingle pioneered the development of the coffee Conductivity Meter, an electronic instrument used for the measurement of soluble solids in the coffee beverage. This was the first new method for assessing beverage quality since the coffee hydrometer, which was created in 1955. In designing the coffee Conductivity Meter, Mr. Lingle conducted extensive studies that developed the data base relating conductivity to brew strength and to beverage temperature that allowed for electronic calibration of the instrument.

Mr. Lingle played a key role in the formation and growth of the Coffee Development Group (CDG), a U.S. agency of the International Coffee Organization. He was the first chairman of both the Foodservice Education Task Force and the College Campus Task Force. He served on CDG's Board of Directors and as its Chairman in 1985-86.

In 1985, Mr. Lingle wrote the *Coffee Cupper's Handbook* to explain the science and chemistry behind the techniques used in coffee cupping. Coffee cupping is the traditional means for professional coffee tasters to make sensory evaluations of the coffee beans they select for their blends. The *Coffee Cupper's Handbook* deals with the basics of flavor chemistry and how the aroma, taste, and body of the coffee beverage relate to chemical make up, type and intensity of the components, and temperature and cooling of the various flavor compounds found in coffee.

In 1991, Mr. Lingle was appointed Executive Director of the Specialty Coffee Association of America. As the first full-time staff member of SCAA, he helped guide the Association's activities during its remarkable growth from 350 members in 1991 to over 2,400 members in 1995. During this period the Association established a number of technical standards that advance quality guidelines in all facets of coffee, from seed to cup.

In 1995, Mr. Lingle wrote the *Coffee Brewing Handbook* to promote excellence in beverage preparation. This work is a compendium of the various scientific studies on coffee brewing conducted by the coffee industry during the past fifty years, beginning with the important research of Dr. Ernest Lockhart, who served as the Scientific Director for the Coffee Brewing Center from 1952 to 1964. The book focuses on the science that supports the industry's standards and recommendations for good brewing practices.

In 1998 he was awarded the National Medal of Merit by the Federation of Coffee Growers of Colombia for his scientific efforts to improve quality. In 2004 he was awarded the Oren Flor del Café award from the National Association of Coffee Growers of Guatemala for his work in promoting sales of coffee based on denomination of origin. In 2007, he was awarded the Bwana Kahawa Lifetime Achievement award by the Eastern Africa Fine Coffee Association for his efforts to assist the coffee growers in East Africa increase the value and volume of coffee sales to the specialty coffee industry. In 2009, he was given the Lifetime Achievement Award by the Specialty Coffee Association of America.

In 2006 after 15 years of service to SCAA, Mr. Lingle retired from his position as Executive Director of SCAA to become the new Executive Director of the Coffee Quality Institute (CQI), a non-profit foundation established by SCAA in 1996.

FOREWORD

I wrote the *Coffee Brewing Handbook* as a companion piece to the *Coffee Cupper's Handbook*. You don't need to spend a lot of time at the cupping table to realize that most coffee brewers do not bring out the full potential of coffee's flavor, particularly for truly fine specialty coffees.

Coffee brewing creates the illusion of being a simple process. In fact, it is a very complex interaction of many variables, all of which must be tightly regulated if the resulting brew is to become a delicious beverage. This handbook presents the science behind the craft of controlling the variables to achieve your desired result.

The *Coffee Brewing Handbook* represents the lessons learned over a 20-year period of identifying, understanding, and resolving coffee brewing problems encountered in the foodservices industry. It is based on the initial work of Dr. E.E. Lockhart, compiled while he served as Scientific Director of the Coffee Brewing Institute. It also draws heavily on the research conducted by Michael Sivetz and presented in his book, *Coffee Technology*.

Like most technical manuals, the handbook was greatly improved by the individuals who so generously reviewed the initial manuscript and made numerous important and constructive criticisms. It would particularly like to thank John Adinolfi, John Heuman, Michael Sivetz, and Carl Staub for their assistance. I would also like to thank my editor, Sandy Sabo, for taking my often confusing and tangled technical jargon and turning it into readable and understandable prose.

It has been said that the human mind creeps up on the secrets of Mother Nature through a series of small guesses, which is sometimes known as the scientific method. I hope you well enjoy using the *Coffee Brewing Handbook* as your guide in attempting to unravel the mystery and science of coffee brewing.

Ted R. Lingle
January 15, 1996

INTRODUCTION

The first organized, scientific study of the coffee beverage in the United States began in 1952 with the formation of the Coffee Brewing Institute Inc., an entity of both the National Coffee Association and the Pan American Coffee Bureau. Dr. E.E. Lockhart, a professor of food science at Massachusetts Institute of Technology, became the institute's first Scientific Director. From 1952 until 1964, Dr. Lockhart collected, organized, and interpreted a wide range of scientific data on coffee. He conducted some of the most advanced coffee research of the time, and his personal leadership brought science, agriculture, and industry together in understanding the complex nature of coffee's flavor.

As Dr. Lockhart wrote in May 1957, "The acceptability of this beverage, like that of all other products enjoying wide distribution, depends upon a harmonious interaction of many factors which, taken together, comprise its history. A few of these factors are controlled by nature, but for the most part, both agriculture and industry are responsible for acceptability. How well they are able to take care of their obligation can be directly related to the extent of their experience. As is well known, experience can be developed through trial and error into an industrial art, or though research rigorously organized into an industrial science. **In the case of coffee, agriculture and industry have fostered an art.** Only recently, as the age of the commodity is reckoned, have they recognized the need for an organized scientific attack on the variety of unsolved problems with which they are confronted."

Dr. Lockhart was responsible for conducting most of the technical and scientific programs of the Coffee Brewing Institute and publishing the results. He also developed the concept of relating the intensity of coffee's flavor, the solubles concentration, to its acceptability. With a few simple analytical tools of physical chemistry, he was able to develop a model for acceptability that remains valid today. Virtually all of what the industry knew about its product during the 1950s and early 1960s was the result of Dr. Lockhart's research.

It may not be entirely a coincidence that the highest point of coffee consumption in the United States was attained in 1962 during the peak of the Coffee Brewing Institute's influence. At the time, coffee was still regarded as an inexpensive commodity and the entire industry was focused on improving all aspects of its acceptability for the consumer. Following the close of the Institute, the industry began to shift its focus to meet the intense price competition developing in the commercial trade; most scientific research was refocused on maintaining acceptability while using lower grades and obtaining higher yields.

The Coffee Brewing Institute was dissolved in 1964 and immediately replaced by the Coffee Brewing Center, which was formed as a department of the Pan American Coffee Bureau. Dr. Lockhart left during this transition and was replaced by Kenneth Burgess. The Coffee Brewing Center shifted its focus to the foodservice industry and developed several programs that promoted good brewing practices in this segment of the industry, especially the Golden Cup Award program. It also offered numerous training programs for industry trade members and conducted additional consumer research. The Coffee Brewing Center employed a small field staff, and under the leadership of John Adinolfi, provided training and assistance to the large number of regional roasters selling to the foodservice trade. In addition to its own programs and publications, the Center continued to reprint most of the Coffee Brewing Institute's publications.

The Center closed at the end of 1975. For those of us lucky enough to have attended its classes or obtained its printed pamphlets, the CBC's work represented the total research material available to provide any scientific basis for understanding the complex inter-relationships of coffee cupping, roasting, and brewing. Although the research had become obsolete by the 1990s, some of it at least offered a place to start.

A reprieve from this serious lack of scientific information on coffee came from Michael Sivetz, a chemical engineer who had an extensive background in all aspects of coffee processing, thanks to a variety of job assignments that included developing, engineering, and installing soluble processing plants in Central America for a number of international companies. In 1963 he published *Coffee Processing Technology, Volumes I and II*, along with H. Elliott Foote. In 1979, together with Norman W. Desrosier, he published *Coffee Technology*. Both are excellent pieces of work, and go a long way in adding to the initial research of Dr. Lockhart.

In 1971 the Norwegian Coffee Association opened its own Coffee Brewing Center as part of the Norwegian Committee for Coffee Information. Initially, the information was aimed at the foodservice market, and a lot of work was directed toward improving the standard of coffee preparation in this market segment. Many of the guidelines issued by the Norwegian Coffee Brewing Center were based on the original studies of Dr. Lockhart while at the Coffee Brewing Institute. Many were later refined through further testing and evaluation, particularly in the area of brewing equipment evaluation.

Like its U.S. counterpart, CBC-Norway worked with industry trade members to develop standardized degrees of grinding for both the foodservice and consumer markets. Standardized package weights were also introduced into the foodservice market. Additionally, the Center developed a program for the approval of brewing equipment in both markets that resulted in significant increases in coffee consumption.

From 1987 to 1991, the International Coffee Organization (ICO) in London managed CBC-Norway. The Technical Unit of the ICO confirmed and expanded much of the Center's research and distributed it though other ICO Centers in London, Washington, and Paris. Following the collapse of the International Coffee Agreement in 1989, the ICO eventually closed all of its centers for lack of funding.

In January 1991, the board of the Norwegian Coffee Association initiated the re-establishment of the CBC. Its important tasks now include approving preparation equipment, developing and approving different degrees of grind, recommending correct brewing ratios, and providing ongoing support to the Norwegian coffee trade and equipment manufacturers to ensure they are able to offer their consumers a product of high quality.

For the most part, the recommendations of the Coffee Brewing Center in the United States (while still in operation), the Coffee Brewing Center in Norway, and the *Coffee Brewing Handbook* are identical. While there is a slight difference in converting from the metric to the foot-pound system (for example, 200ºF is actually 93.3ºC, while 94ºC is actually 201.2ºF), these differences are not significant for the range of temperatures recommended for coffee brewing as a general rule (195-205ºF versus 92-94ºC). However, standards for brewer evaluation are based on the metric system and are identical to those of the Nordic Brewing Center. Throughout the *Coffee Brewing Handbook*, metric measurements appear in italics and are intended to be equivalent to the foot-pound system measurements, as both are rounded to whole numbers.

The *Coffee Brewing Handbook* deals with coffee brewing conditions found most often in drip filtration brewers. It does not address the differences encountered in pressurized infusion methods, such as espresso preparation. This method of brewing creates a much more complex coffee beverage that requires its own analysis and text.

Coffee trade professionals who develop the skills to understand and utilize the science presented in *The Coffee Brewing Handbook* will enhance their ability to provide their customers with the very best products the coffee industry has to offer. To effectively compete with the other beverage industries in the 21st century, coffee industry members must advance their understanding of both the methods and the science of coffee brewing.

CHAPTER 1
ESSENTIALS OF GOOD BREWING

Although roasted coffee is purchased either in its whole bean or ground form, it is consumed as a beverage. Therefore, the quality of the coffee relates directly to one's ability to transform it into an enjoyable beverage. To make the beverage flavorful, the six essential elements of good brewing practices must be observed.

Coffee begins this transformation as a green bean. The beans come from many growing regions around the world, each with its own distinctive flavor characteristics. Often the green beans are blended. The types of beans, and the proportion in which they are blended, largely determine the flavor found in the beverage. The way beans are roasted-including the rate and length of heating-also plays a critical role in determining the ultimate flavor of the brew.

Before they can be brewed, however, the beans must be ground into small particles that range in size from slightly coarse to extremely fine. A specified portion of these coffee particles is then immersed in the predetermined portion of water. The size of the particles, the specific ratio of coffee to water, the time the coffee is in contact with the water, and the quality of brewing water all affect the flavor.

The Flavor of Coffee

Coffee gets most of its flavor from the great variety of chemical compounds released when the ground particles make contact with water. Under normal circumstances, the water extracts about 80% of the available water soluble, flavoring compounds, which constitute the beverage's aroma, taste, body, and color. Together, these compounds create the sensory aspects of coffee's flavor.

Coffee beverage flavors differ, not only because of difference in blend and roast, but also because the water removes each flavoring compounds significantly contributing to the perception of beverage flavor. The compounds responsible for taste (which dissolve in the water) and for body (which don't dissolve) are less easily removed. Both sets of aromatic and taste compounds contain many different chemical components, which combine to produce different beverage flavors.

During brewing, the total amount of flavoring material in the beverage changes, as does the proportion of each compound. In other words, the flavor changes continuously as time elapses. As a general rule, the most flavorful compounds are extracted first. The longer coffee particles remain in contact with the water, the greater the quantity of less-flavorful compounds released. Prolonged extraction results in an unacceptable beverage flavor. The most desirable mixture of flavor elements occurs before the maximum amount of material available is removed. Consequently, for optimum results, the brewing process must be stopped before the point of maximum extraction.

Six Essential Elements

Here are the six elements necessary to transform roasted beans into a good-tasting beverage:

1. **Correct coffee-to-water ratio.** The finished brew is a balance between strength (solubles concentration) and extraction (solubles yield). Shifting the balance either way greatly affects the final product. For example, coffee is an extremely concentrated flavoring agent and must be diluted with water. The most acceptable ranges of concentration fall between 1% and 1.5% coffee and between 99% and 98.5% water. Coffee strength less than 1% is too weak, and coffee strength above 1.5% is too strong. The most acceptable ranges of yield lie between 18% and 22%, with under-developed yields (those below 16%), creating flavors that are grassy to peanut-like, and over-extracted yields (those above 24%) resulting in bitter and astringent flavors.

   It's also possible to extract a large amount of coffee flavoring material and dissolve it in a small amount of water or, conversely, to extract a small amount of material and dissolve it in a large volume of water. The brewing formula becomes the guide for selecting proper coffee-to-water ratio to control both the solubles concentration and yield.

2. **A coffee grind that matches the brewing time.** Once the coffee brewing formula is established, the method of brewing and the operation of the equipment come into play. To prevent under-development or over-extraction of the flavoring compounds, the correct particle size (grind) of the coffee must be matched to the brewing method and type of equipment used. As a general rule, longer brewing times should be paired with larger (coarser) particles, and shorter brewing times should be paired with smaller (finer) particles.

3. **Proper operation of brewing equipment.** Brewing equipment normally controls three variables:

   - **Time of contact between the coffee grounds and water.** It takes time for the coffee particles to absorb the water, for the water to dissolve and extract the soluble material in the particles, and for the dissolved material to migrate into the beverage. Because water extracts different chemical compounds from ground coffee at different rates, the mixture of soluble materials in the beverage changes continuously. Therefore, controlling the brewing time contributes to optimal extraction and produces uniform results.

- **Temperature of the water.** Cold water doesn't extract coffee as completely or as rapidly as hot water. Water that ranges in temperature from 195°F to 205°F (*92°C-96°C*) liberates the aromatic materials more rapidly and permits proper extraction of other solubles within a reasonable time. As a general rule, the temperature should remain constant throughout the brewing cycle.

- **Turbulence.** As water passes through and over the coffee grounds, it creates a mixing action known as turbulence. Sufficient turbulence is necessary to first wet the coffee particles and then to cause the water to flow uniformly through them. Wetting allows the water to penetrate the particle fibers, and a uniform flow allows the soluble material to dissolve. In addition, adequate turbulence prevents the water that is in immediate contact with the coffee from becoming so saturated with dissolved material that it can no longer remove additional flavoring compounds.

4. **Optimum brewing method.** Using the same type of coffee in different brewing equipment will create coffee beverages with different taste and body characteristics. The equipment's design will use one of six basic methods to extract the flavoring materials for the ground coffee:

   - **Steeping.** In this brewing method, coffee grounds in a container are mixed with hot water, left in contact with the water for a specified length of time, and then separated from the extract or brew. The time of contact depends on the particle size, the water temperature, how much the grounds are agitated, and how quickly the grounds are separated from the beverage.

   - **Decoction.** Loose coffee grounds are mixed in a container with water that continues to boil for an arbitrary length of time. Complete extraction usually occurs during this preparation method, due to the elevated water temperature of 212°F (100°C), and the extreme turbulence created by boiling water.

   - **Percolation.** The ground coffee is placed in a container that serves both as a brewing chamber and as a means of separating the grounds from the beverage. A pump moves the hot water to and through the coffee repeatedly. First the water, followed by the beverage extract, recirculates through the grounds. In this case, the time of contact depends upon grind size, the temperature of the water or extract, and the rate of recirculation.

   - **Drip filtration.** As with percolation, the grounds are placed in a container that serves both as a brewing chamber and as a means of separating the grounds from the beverage. In this method, however, the hot water flows through the coffee only once. The extract drips from the brewing chamber into a pot or other beverage receiver. The time of contact depends principally upon the rate that water flows into the brewing chamber and the size of the grind. Other important factors include the water temperature, the chamber's shape, and the type of filter.

   - **Vacuum filtration.** This method, which uses a two-chamber device, is a variation on the steeping method. Steam pressure forces hot water from the lower chamber up through a filtering unit and into the upper chamber, which contains coffee. Escaping vapor and stirring serve to agitate the coffee and water. When heat is removed after an arbitrary length of time, steam condenses in the lower chamber and creates a vacuum. The vacuum pulls the beverage down through the filter and into the lower chamber but leaves the grounds behind. The time of contact depends on how quickly a vacuum forms, the properties of the filter unit, and the particle size of the ground coffee.

   - **Pressurized infusion.** Pressurized water (between 2 to 10 atmospheres of pressure) is forced through the coffee grounds, which are compacted into a small cake in the brewing chamber. The combination of heat and the force of the water extracts soluble flavoring materials, emulsifies insoluble oils, and suspends both ultra-fine bean fiber particles and gas bubbles. This creates a beverage with an extremely high solubles concentration. To produce a uniform beverage with this method, rapid brewing times and extremely fine particle sizes are essential. The brewing temperature, 190°F-195°F (*88-92°C*) is slightly lower than for other methods.

   Most of these brewing methods will produce a quality coffee beverage; decoction and percolation are the exceptions because over-extraction leads to undesirable tastes.

5. **Good-quality water.** When preparing a coffee beverage, water is just as important as the coffee. In fact, water represents more than 98% of the beverage. Water that contains some minerals favors

the development of optimum beverage tastes. As a rule, water containing 50-100 parts per million (3-6 grains) of dissolved minerals will produce the best tasting beverage. The water should taste like fresh, good-quality drinking water, have no odor, and contain no visible impurities.

Water that's very soft or very hard doesn't yield the most acceptable beverage and should be treated before being used for coffee brewing. For example, water filters can remove insoluble materials and sediments, and demineralization can remove excessive dissolved solids. Activated charcoal-or preliminary chlorination that's followed by an activated charcoal treatment-can take away odors. In many instances, polyphosphate treatment of the water will prevent scaling and corrosion of brewing equipment without affecting beverage flavor.

Water softening treatment that substitutes sodium ions for dissolved minerals **is not recommended** especially for water containing high concentrations of bicarbonate solids. This treatment often increases alkalinity, which has an undesirable physical effect on coffee's taste. In addition, this method of treatment will increase the coffee's contact time with water, causing over-extraction of the grounds and objectionable bitterness in the beverage.

6. **An appropriate filtering medium.** Unless something separates the extract from the coffee grounds, the resulting beverage will be murky and difficult to drink. Filters, to varying degrees, clarify the beverage by separating the insoluble material from the brew. As a result, the filtering method directly affects the body of the beverage-and indirectly affects the flavor of the beverage.

   Body, which contributes to flavor, is created in part by the insoluble materials that the water carries into the finished brew. These insoluble materials (principally oils and small particles of bean fiber) create brew colloids, which trap soluble material and gases that are later released on the palate. This time-delayed release of flavoring materials adds to the overall enjoyment of the beverage.

   Filters fall into four general categories:

   - **Perforated metal plates.** These plates have holes that allow extract to leave the brewing chamber yet hold back some of the fine particles in the coffee grounds. The size and number of holes vary but must relate to the size of the grind used in the brewing equipment. Perforated plates provide virtually no clarification of the beverage, enabling most fine and very fine particles to pass through.
   - **Woven wire screens.** Compared to metal plates, wire screens provide a greater number of smaller holes in the filter barrier. The screens can be woven to hold back different amounts of the fine particles but, compared to perforated metal plates, offer only slightly better clarification of the beverage.
   - **Cloth.** Either sewn into bags or shaped to cover various forms, cloth can serve as a filtering medium. The type of cloth and weave determine its retentive capabilities. Very good beverage clarity can be achieve with material having, at most, a weave of 64 x 60 threads per inch and a weight of 5.75 square yards per pound.

     Before their first use, cloth filters require soaking and rinsing in hot water. With ongoing use, special procedures are necessary to prevent the filter from absorbing oils that later decompose and alter beverage flavor. Cloth filters should be stored in cold water after each use.
   - **Paper.** Of the four types of filters, paper yields the clearest beverage. With paper, however, it is difficult to establish ideal brewing conditions: Paper is weak and, without adequate support, often resists the flow of beverage to such an extent that over-extraction occurs. Paper filters should be strong enough to permit the use of wire supports that does not impede the flow of extract. In addition, paper should not transfer any tastes to the brew or by itself impede the flow of extract.

A Successful Transformation

Ultimately, the coffee beverage's quality depends on one's ability to follow the steps outlined above. Even if one begins with one of the world's finest coffees the result may be a less-than-ideal beverage, if, for example, an inappropriate brewing method or poor quality water is used. A successful transformation from beans to beverage requires understanding – and adhering to – these six essential elements of brewing.

CHAPTER 2
ANALYSIS OF THE FINISHED BREW

When coffee is brewed, hot water removes most of the water-soluble material in roast-and-ground coffee by a process that combines dissolving and extracting. The water first penetrates the grounds, dissolves some of the chemical components it encounters, makes a solution of these materials, and then exits the grounds to produce the familiar beverage or extract. Coffee contains many chemical compounds, and each one behaves differently. Depending on their chemical nature, some compounds dissolve rapidly when they come into contact with water; other dissolve slowly.

Measuring the solubles yield and concentration–how much soluble flavoring material is removed from the grounds and how much is present in the beverage–relates directly to organoleptic (sensory) studies of what constitutes acceptable beverage flavor. In other words, measuring solubles concentration and solubles yield focuses on the taste aspect of the beverage's flavor, providing a means of assessing cup quality.

However, analyzing or objectively measuring the quality of brewed coffee – or of any food or beverage product – often proves difficult. The Coffee Brewing Institute (CBI) studied this problem during the late 1950s and eventually developed a method to measure the amount of dissolved flavoring material present in the beverage.

Much simpler to do than chemical analysis, CBI's method provided the coffee industry with an objective approach to beverage evaluation and offered a reasonable language for discussing coffee, brewing, and equipment performance. It introduced a simple, practical, and useful control system for monitoring and maintaining beverage quality.

CBI's method was based on measuring the concentration of soluble coffee flavoring material dissolved in the beverage relative to the amount of water, and then graphically calculating the solubles yield given the specific coffee-to-water ratio used to produce the brew. This simple method of evaluation continues to be a highly useful analytical tool, even by today's advanced technology standards.

Oven-Dehydration Method

When using the oven dehydration method to measure solubles concentration, the manner of beverage preparation doesn't matter. The steps in the analysis, however, do not vary. They are:

1. Obtain a representative portion of brewed coffee-about four ounces.
2. Filter the sample through a coffee-type paper filter to remove any insoluble sediments or fine grounds. (It may be necessary to filter to brew two or three times to obtain a sediment-free solution.)
3. Using an analytical balance, weigh a small, clean, and dry aluminum dish to the nearest tenth of a milligram. Transfer a small portion *(exactly 10 milliliters)* of the clarified solution to the dish.
4. Put the dish, with its contents, into a drying oven that maintains a constant temperature of 221ºF to 230ºF *(105ºC-110ºC)*. Let three hours elapse. During this period, the heat drives off all the water; only the non-volatile material that was extracted from the coffee remains.
5. When the drying period has ended, transfer the dish to a desiccator – a small vessel, containing a drying agent that can be tightly sealed. In the desiccator, the dish and the solids cool to room temperature without picking up moisture from the air. This requires 15 minutes.
6. Re-weigh the dish. The difference between the first and second weighing represents the amount of soluble solids in the brewed coffee expressed in grams per 10 milliliters of beverage. To obtain the concentration of soluble material in the beverage expressed in terms of *percent solubles concentration*, multiply the weight of the residue by 10, which now represents the number of grams per 100 milliliters of beverage that can be directly interpreted as percent. *(Note: the metric system defines a milliliter as the volume of 1 gram of water at 4ºC and 760mm pressure.)*

TABLE 1

Analysis of Coffee Beverage for Soluble Solids

Weight of dish plus solids	= 1.5007 grams
Weight of dish alone	= 1.3689 grams
Weight of solids	= 0.1318 grams
Percent soluble solids in beverage	– Weight of solids in 10-milliliter portion times 10
	= 0.1318 X 10
	= 1.32 percent
Ounces of soluble material per gallon	= percent soluble solids times 1.333
	= 1.32 X 1.333
	= 1.76 oz per gallon

Source: Coffee Brewing Center Publication No.27

The beverage described in Table 1 shows a solubles concentration of 1.32%. If 60 grams of roast-and-ground coffee per liter of water were used in preparing this brew, the quality of finished brew would be 0.875 liters. Therefore, the quantity of soluble flavoring material removed during the brewing process was 11.55 grams (1.32 grams/0.1 liters x 0.875 liters). This translates into a solubles yield of 19.25% (11.55 grams divided by 60 grams). Expressed another way, if 11.55 grams of soluble flavoring material are extracted from 60 grams of roast-and-ground coffee and dissolved in 0.875 liters of water, the resulting beverage would contain 13.20 grams of flavoring material per liter or have a solubles concentration of 1.32%.

The quantity of soluble material can also be calculated from one gallon of beverage by multiplying the percent soluble solids by the appropriate conversion factor. The conversion factor changes grams to ounces and liters to gallons and equates the result to 100 milliliters of brew (0.0352 ounces/gram ÷ 0.2642 gallons/liter ÷ 0.1 liters/100 milliliters = 1.333).

TABLE 2

Weights of Soluble Solids in 10 Replicate 10-Milliliter Volumes from an Urn

Sample No.	*Weight of Solid Grams*	*Soluble Solids %*
1	0.1395	1.395
2	0.1392	1.392
3	0.1395	1.395
4	0.1397	1.397
5	0.1397	1.397
6	0.1395	1.395
7	0.1401	1.401
8	0.1393	1.393
9	0.1396	1.396
10	0.1396	1.396
Average	0.1396	1.396

Standard Deviation = 0.0001 55/9 = 0.00025

95% confidence limits = 0.1396 ± √ 2.228 (0.00025)
= 0.1396 ± 0.0006
= 0.1390 and 0.1402

Source: Coffee Brewing Center Publication No. 27

Table 2 demonstrates the precision of this method. It shows the results of testing 10 identical portions (each 10 ml in volume) of a beverage prepared in an urn; the brewing formula called for two gallons of water per pound of coffee. The average of the 10 weights equals 0.1396 grams. The standard deviation, which measures dispersion or variation of results, equals 0.00025 grams. Given the confidence level, if the analysis of this beverage is repeated 100 times, 95 of the measurements would fall between the limits of 0.1390 and 0.1402 grams. The actual precision of this method is about 0.5% when dealing with quantities of this magnitude.

The beverage described in Table 2 has a soluble solids content of 1.396%. When converted to ounces per gallon (1.396 x 1.333) this equals 1.86 ounces per gallon. Using two gallons of water and one pound of coffee in the urn would produce 1.75 gallons of finished brew. Therefore, the quantity of material extracted from the pound of coffee is 3.25 ounces (1.86 x 1.75) or 20.3% (3.25 oz. ÷ 16 oz.).

Here's another way to express the same findings: If 3.25 ounces (20.3%) of soluble material are extracted from one pound of coffee and dissolved in 1.75 gallons of water, the beverage would contain 1.86 ounces of solids per gallon or have strength of 1.396% soluble solids. This simple analysis clearly shows the relationship between solubles concentration and solubles yield. It is possible to extract a large amount of material and dissolve it in a small volume of water or, conversely, to extract a small amount of material and dissolve it in a large volume of water.

To some extent, the brewing formula controls both solubles concentration and yield. If the values for two of the three factors – percent solubles concentration, percent solubles yield, and brewing formula – is known, one can calculate the value of the third. For purposes of illustration and calculation, assume that each pound of coffee will absorb and retain 32 ounces of the water used in preparation (*one gram absorbs 2.086 ml*). Table 3 shows the numerical interrelationship between soluble solids in the beverage, extraction from the grounds, and brewing formula.

For example, if the beverage contains 1% soluble solids (read across the top of 1.00) and the extraction from the grounds is assumed to be 20% (read down the left column to 20), then the only way to satisfy these conditions would be to use 2.63 gallons of water in preparation (move down the column under 1.00 and across to the right from 20% to 2.63). Only one brewing formula will result from each specific combination of soluble solids and extraction.

Figure 1 illustrates the data that appear in Table 3. This graph, which is used in the same manner as Table 3, depicts the relationship of the three factors. Although it may be necessary to estimate the values on each scale, approximations of extraction values within one tenth of one percent (0.1%) are quite possible. For example, to obtain a beverage that contains 1.00% soluble solids, one would need to extract 15.0% of the coffee if the brewing formula were 2 gallons per pound. If the formula were 3 gallons per pound, 24.0% of the coffee must be extracted to give the same solubles concentration value.

Many coffee roasters and foodservice operators expressed interest in using oven-dehydration to objectively evaluate coffee beverages and to standardize their brewing procedures. However, few organizations had the laboratories or personnel to make the required measurements. Others

TABLE 3

Interrelationship between Soluble Solids, Extraction and Brewing Formula

Soluble Solids, oz./gal.		0.07	0.13	0.27	0.40	0.54	0.67	1.34	1.47	1.61	1.74	1.88	2.01	2.14	2.28	2.41	2.55	2.68
Soluble Solids, %		0.05	0.10	0.20	0.30	0.40	0.50	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
Brewing Formula, Gallons per Pound																		
Extraction %,	oz. / lb.																	
5	0.80	12.18	6.21	3.23	2.24	1.73	1.43	0.86	0.78	0.73	0.70	0.66	0.64	0.61	0.59	0.57	0.55	0.54
10	1.60	24.12	12.18	6.21	4.22	3.23	2.63	1.43	1.32	1.23	1.16	1.09	1.04	0.99	0.94	0.90	0.87	0.84
15	2.40	36.06	18.15	9.20	6.21	4.71	3.82	2.03	1.87	1.73	1.62	1.52	1.43	1.36	1.29	1.23	1.18	1.13
16	2.56	38.45	19.34	9.79	6.60	5.01	4.06	2.15	1.98	1.83	1.71	1.60	1.51	1.43	1.36	1.30	1.25	1.19
17	2.72	40.84	20.53	10.39	7.01	5.31	4.30	2.26	2.08	1.93	1.80	1.69	1.59	1.51	1.43	1.37	1.31	1.25
18	2.88	43.22	21.73	10.99	7.40	5.61	4.54	2.39	2.19	2.03	1.89	1.77	1.67	1.58	1.50	1.43	1.37	1.31
19	3.04	45.61	22.92	11.58	7.79	5.91	4.78	2.50	2.30	2.13	1.98	1.86	1.75	1.66	1.57	1.50	1.43	1.37
20	3.20	48.00	24.12	12.18	8.19	6.21	5.01	2.63	2.41	2.23	2.08	1.94	1.83	1.73	1.64	1.57	1.49	1.43
21	3.36	50.39	25.31	12.78	8.60	6.51	5.25	2.74	2.52	2.33	2.17	2.03	1.91	1.81	1.71	1.63	1.56	1.49
22	3.52	52.78	26.51	13.37	8.99	6.81	5.49	2.87	2.63	2.43	2.26	2.11	1.99	1.88	1.78	1.70	1.62	1.55
23	3.68	55.16	27.70	13.97	9.40	7.10	5.73	2.98	2.74	2.53	2.35	2.20	2.07	1.96	1.85	1.76	1.69	1.61
24	3.84	57.55	28.90	14.57	9.79	7.40	5.97	3.10	2.84	2.63	2.44	2.29	2.15	2.03	1.92	1.83	1.75	1.67
25	4.00	59.94	30.09	15.17	10.18	7.69	6.21	3.22	2.95	2.73	2.54	2.37	2.23	2.10	1.99	1.90	1.81	1.73
30	4.80	71.88	36.06	18.14	12.18	9.20	7.40	3.82	3.49	3.22	2.99	2.80	2.63	2.48	2.34	2.22	2.13	2.03
35	5.60	83.82	42.03	21.13	14.17	10.69	8.60	4.42	4.04	3.72	3.46	3.22	3.02	2.85	2.69	2.56	2.44	2.33
40	6.40	95.76	48.00	24.12	16.16	12.18	9.79	5.01	4.58	4.22	3.91	3.65	3.43	3.22	3.04	2.90	2.75	2.63

Source: Coffee Brewing Center Publication No. 27

did not want to spend the money and effort required to properly equip a laboratory. Consequently, the CBI offered a mail-service program for analysis of beverages prepared anywhere in the world.

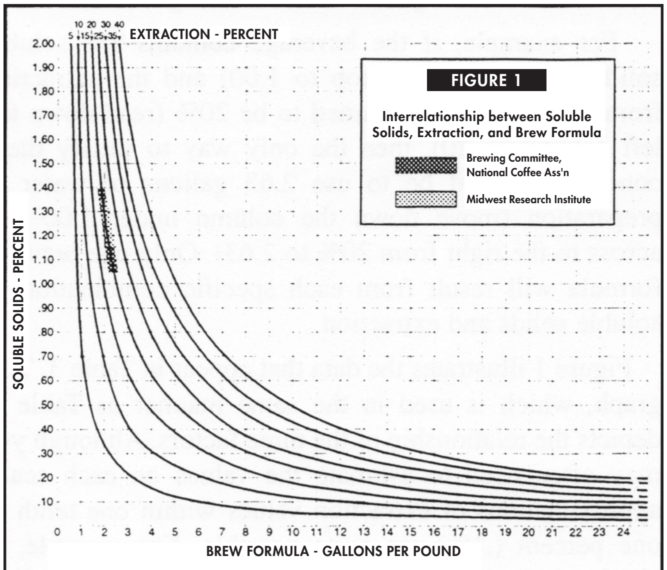


FIGURE 1

Interrelationship between Soluble Solids, Extraction, and Brew Formula

Source: Coffee Brewing Center Publication No. 27

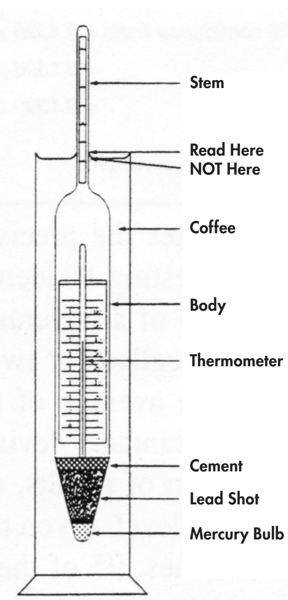
CBC also developed a simpler, more practical method for use in roasting plants, equipment manufacturing facilities, and foodservice operations. The new method used a specially designed hydrometer to measure the specific gravity of the coffee beverage. The specific gravity directly relates to the amount of flavoring material in solution.

Coffee Hydrometer Method

A hydrometer is a closed glass tube. One end is weighted with a lead shot; a small closed tube, containing a measuring scale, tops the other end. The lower portion of the hydrometer also contains a thermometer that registers liquid temperatures. When the hydrometer is placed into water – or some other liquid such as coffee at the proper temperature – it floats. The depth to which it floats depends not only on the size of the tube and amount of lead shot in the lower end, but also on the temperature of the liquid and, in the case of coffee, on the amount of dissolved material in the beverage.

DIAGRAM 1

Coffee Hydrometer



Source: Coffee Brewing Center Publication No. 40

In the small closed tube at the top of the coffee hydrometer, a scale is divided into seven major units; each is subdivided into five smaller units. To calibrate the hydrometer, it must be suspended in pure water at 140°F (*60°C*). Once it sinks until almost completely immersed, adjust the scale so that the top mark, which is 0, is level with the liquid surface. The hydrometer is now calibrated.

When the hydrometer is floated in coffee, however, it will not sink quite so deeply. The dissolved solids tend to support it. The greater the amount of dissolved solids, the higher the instrument will float. The scale reading, between 0 and 7, measures the buoyancy, or strength, of the beverage relative to pure water. A weak, under-developed, or diluted beverage would register a lower number reading near 2 or 3. A strong, over-extracted, or concentrated beverage would raise the reading to 5 or 6.

By itself, a reading on the hydrometer scale means nothing. Instead, one must convert the arbitrary scale in the stem into percent solubles concentration. Empirical testing showed that correlation factor equal to 3.97. In other words, one could calculate the percent solubles concentration at 140°F (*60°C*) by dividing the scale reading by 3.97. CBC developed a table to permit simple conversions of hydrometer readings.

It often proved inconvenient, or even impossible, to read the hydrometer when the coffee's temperature was exactly 140°F (*60°C*). Consequently, CBC calculated a series of correction factors so that hydrometer readings could be taken in the range of 130°F-150°F (*55°C-65°C*). Either subtract the correction factor for temperatures below 140°F (*60°C*), or add it for those above.

Direct-Reading Hydrometer Method

The hydrometer was not as precise a measuring technique as the over-dehydration method. Cleanliness of the hydrometer and the user's skill played a role in determining the final results. The units themselves often showed slight variations in readings.

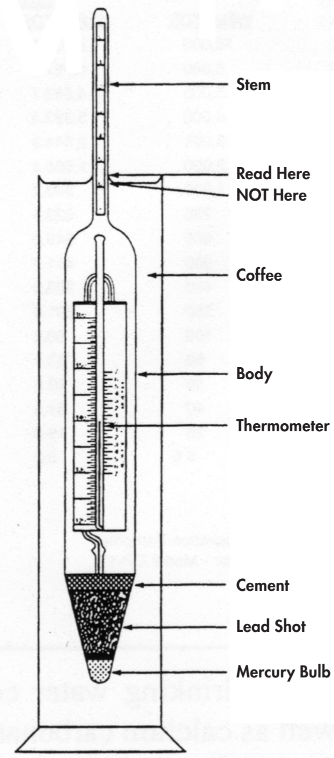
The development of a direct-reading hydrometer refined the process of evaluating the coffee beverage in terms of strength and extraction. The new hydrometer featured a temperature correction scale directly under the thermometer capillary. Calibration involved calibrating the hydrometer stem to percent soluble solids instead of specific gravity numbers.

These changes eliminated the need for separate conversion and correction tables, greatly simplifying the task of obtaining final soluble solids figures. In addition, the expanded thermometer capillary enabled users to obtain improved accuracy when reading the temperature corrections.

In spite of these improvements, hydrometers remain awkward and time-consuming to use in the field. The glass instruments are fragile and require constant cleaning. They are also slow. To ensure accurate readings, beverages brewed at a temperature of 200°F (*93°C*) must cool to 140°F (*60°C*). On average, the cooling-down period takes 20-30 minutes. Best measurements are obtained when the results of three readings are averaged.

DIAGRAM 2

Direct-Reading Coffee Hydrometer



Source: Coffee Brewing Center Publication No. 61

Conductivity Meter Method

In the mid 1970s, a new measurement technique was developed. It used conductivity – the property of a fluid to conduct an electric current – as the basis for analysis. As a weak electrolytic solution, coffee acts as a partial conductor of an electric current. The quality of electric current that the beverage conducts in relationship to a fixed voltage, is proportional to the amount of soluble material present in solution. By measuring the current, one can determine the percentage of solubles concentration.

The coffee conductivity meter is an adaptation of *Total Dissolved Solids* (TDS) instruments that are used to determine the quantity of dissolved solids in water. Because the quality of dissolved solids in parts per million weight is directly proportional to conductivity in micromhos per unit volume, a conductivity measurement can indicate the amount of dissolved solids in the water sample. Table 4 shows the relationship of coffee total dissolved solids to conductivity as measure in micromhos.

TABLE 4

Relationship Between Conductivity and Dissolved Solids

Conductivity Michromhos	Water TDS	Dissolved Solids: Coffee TDS	NaCl-ppm	CaCO3-ppm
15,000	10,000	8,734.9	8,400	7,250
10,000	6,660	5,767.8	5,500	4,700
7,500	5,000	4,283.7	4,000	3,450
6,000	4,000	3,393.5	3,200	2,700
4,500	3,000	2,544.9	2,300	2,000
3,000	2,000	1,680.4	1,550	1,300
1,500	1,000	840.2	750	640
1,125	750	623.9	560	475
1,000	666	549.0	490	420
750	500	411.7	365	315
600	400	326.0	285	250
375	250	201.6	175	150
150	100	80.6	71	60
100	66	53.1	47	40
75	50	39.8	35	30
60	40	31.5	28	24
37.5	25	19.6	17.5	15
10	6.6	5.2	4.7	4

Source: Presto-Tek Corporation Pamphlet Coffee Test Meter - Model DP-17

Published 1975

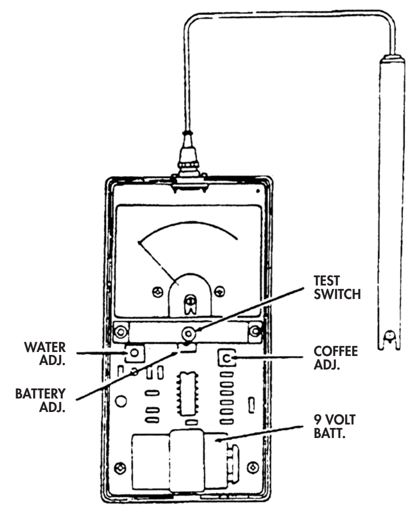
The average drinking water contains other dissolved solids as well as calcium carbonate. These other minerals often have a higher weight per ion and, therefore, are higher in parts per million for a given conductivity value. TDS meters are generally calibrated to more closely approximate municipal water characteristics.

Not all dissolved coffee flavoring material ionizes when extracted by water during the brewing process. Empirical testing has demonstrated that the proportion of ionized compounds to non-ionized compounds remains constant in the typical range of solubles concentration of the coffee beverage. By determining the conversion relationship of the dissolved solids found in the coffee to conductivity – and calibrating the way the instrument reads in the solution of known conductivity – one can align the measurement reading so that the numerical values for parts per million (ppm) and solutions concentration correspond. This requires using a multiplier of 10; for instance, 1,000 ppm is equivalent to 1% solubles concentration, or 1,250 ppm is equivalent to 1.25% solubles concentration. This makes possible a direct reading of solubles concentration from a TDS meter.

The first correlation studies between conductivity and coffee solubles concentration were undertaken in 1974, by Presto-Tek Corporation, in cooperation with Lingle Bros. Coffee, Inc. The studies showed that, in the range of 0.50% to 1.50% solubles concentration, a nearly linear relationship existed between conductivity and coffee dissolved solids (1% solubles concentration equaled a conductivity reading of 1,803 micromhos). This work led to the first coffee conductivity meter, which was produced in 1975.

DIAGRAM 3

Presto- Tek Corporation Coffee Test Meter



MODEL DP-17

In 1996, Agtron, Inc., in cooperation with the Specialty Coffee Association of America, conducted further research using new testing procedures with more advanced analytical equipment. The study refined the correlation between conductivity and solubles concentration for Arabica coffee blends roasted to Agtron/SCAA roast value #50, and extracted at a 20% solubles yield in a full range of values from 0.20% to 2.20% solubles concentration. This advanced research combined with a new generation of microprocessor-based TDS meters, allows for a correlation between conductivity and solubles concentration with an accuracy within 10 ppm (0.01% solubles concentration), in the range of 1% to 1.60% dissolved solids.

The coffee conductivity meter performs the same function as the coffee hydrometer, but has several distinct advantages: It measures solubles concentration almost instantaneously, requiring only a few seconds for the measurement. It records a direct read-out of the percent solids in solution, eliminating the need for interlocking charts and graphs. It is compact, portable, and easy to use. In addition, a conductivity meter can measure dissolved solids (hardness) of the water used to prepare the beverage. Once the water hardness is determined, one can make a mathematical adjustment that eliminates the effect of these solids on the measurement of the dissolved coffee solids.

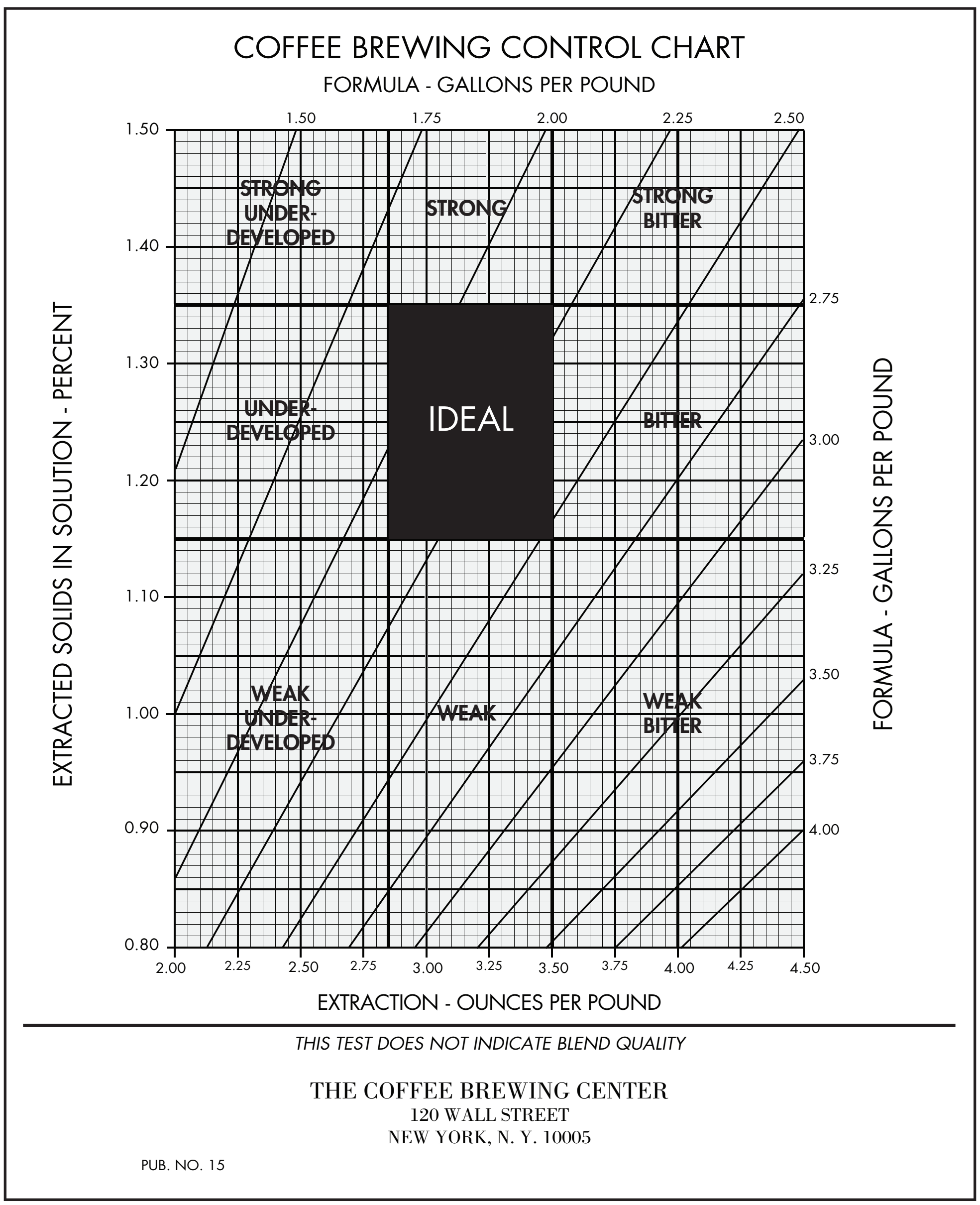
Continued development in electronic circuitry has resulted in instruments that are smaller, more accurate, and less expensive than units originally available. Once properly calibrated, the conductivity meter provides rapid, accurate, and portable analytical tool for direct measurement of soluble concentrations.

The simple calibration procedure requires a standard sample fluid and some training of the user. Because temperature affects the relationship between conductivity and dissolved solids, the instruments are calibrated at room temperature (*77ºF/25ºC*). Most modern instruments feature a temperature-compensating circuit that automatically corrects for measurements taken at non-standard temperatures. For practical considerations, the units are designed to operate in the range of temperature values most often encountered, but tend to make the quickest reading when measuring fluids at room temperature. Typically a small portion of the coffee beverage is allowed to cool below 120ºF (*49ºC*) before the measurement is taken.

Development of the Coffee Brewing Control Chart

Regardless of the method of measurement used, objective analysis of the coffee beverage remains a fundamental part of understanding and evaluating the many factors that influence brew quality. During their years of operation (1952-1975), the CBI, and later the CBC, conducted extensive research in all facets of coffee brewing. Much of that work centered on objectively measuring strength and extraction and led to the creation of a Coffee Brewing Control Chart (See page 12).

Although the chart's subjective parameters for strength and extraction caused debate within the coffee industry, CBI's and CBC's approach to analyzing brewing methods and equipment brought many necessary improvements in beverage quality. The Coffee Brewing Control Chart is extremely useful for objectively analyzing the coffee beverage, particularly when evaluating appropriate grinds for use with specific types of coffee brewers, or when evaluating brewing equipment performance with a given product.



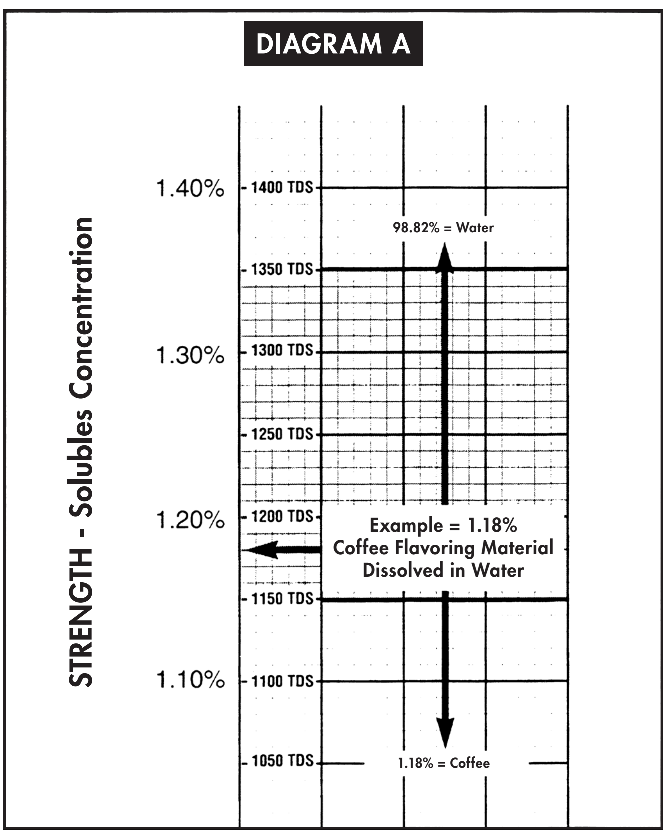
CHAPTER 3
COFFEE BREWING CONTROL CHART

The Coffee Brewing Control Chart provides a simple, graphic representation of the inter-relationship between the three primary variables of **strength**, **extraction**, and **brewing formula**. Together, these three variables create the aroma, taste, and body of the coffee beverage.

Strength is a measure of the *solubles concentration*. It is expressed as a percentage, comparing the amount of coffee flavoring material to the amount of water in the final beverage. **Extraction** is a measure of the *solubles yield*. It is also expressed as a percentage, comparing the amount of coffee flavoring material in the beverage to the amount of coffee grounds used to prepare the beverage. The **brewing formula** is expressed as the *ratio of coffee to water* used when brewing the coffee.

Strength (Solubles Concentration)

Coffee is an extremely intense flavoring agent. A typical coffee beverage contains approximately 1.2% coffee flavoring material and 98.8% water. The weakest coffee acceptable to the average person is about 0.5% coffee and 99.5% water. The strongest acceptable beverage (excluding espresso) is about 1.8% coffee and 98.2% water.



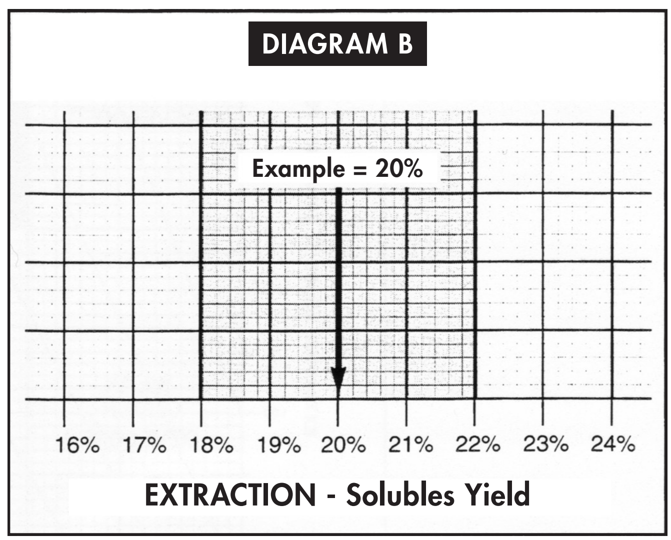
As shown in Diagram A, the left-hand side of the Coffee Brewing Control Chart indicates strength. Strength, expressed both as a percentage and in total dissolved solids (TDS), starts with 0.80% TDS at the bottom of the chart and extends to 1.60% at the top. Each horizontal line represents one hundredth (1/100) of a percent TDS change in the beverage's strength.

For example, if measurement of the coffee brew resulted in a reading of 1.18% TDS, that would mean the brew contained 1.18% coffee and 98.2% water. This result is represented on Diagram A by a horizontal line intersecting the left-hand axis at 1.18% TDS.

Extraction (Solubles Yield)

Approximately 28% of the organic and inorganic matter contained in roasted coffee beans will readily dissolve in water. The remaining 72% is cellulose bean fiber that isn't water soluble under normal brewing conditions.

The water-soluble flavoring material is bound up in the cellulose fiber of the roasted beans. Only after the beans are ground and the particles immersed in hot water will the solid flavoring materials dissolve, changing into liquid and gases. The solid materials dissolve at different rates, which means that different solubles yields will contain different mixtures of liquids and gases. Each mixture, or unique combination of solubles yield, will exhibit a different flavor.



As shown in Diagram B, the bottom of the Coffee Brewing Control Chart indicates solubles yield. The amount of extraction, expressed as a percentage, starts with 14% on the left-hand side of the chart and extends to 26% on the right-hand side. Each vertical line represents one-fifth percent (0.20%) change in the yield of soluble flavoring material from the amount of roast-and-ground coffee used to prepare the brew.

For example, a reading of 20.0% at the bottom of the chart would indicate that 3.20 ounces of flavoring material had been removed from each pound (16 oz.) of coffee; or a 0.70 ounces yield from a 3.5-ounce batch; or that 2 grams were extracted from each measure (10 g) of coffee used in preparing the brew.

Brewing Formula (Coffee-to-Water-Ratio)

The coffee brewing formula is a ratio, which is defined as the weight of ground coffee to the volume of water used in preparing the brew. For simplicity, the brewing ratio is often expressed as the weight of coffee required to prepare a standard-size batch. For example:

- Grams of coffee per each serving, either 6 fluid ounces (180 ml) per standard U.S. cup or 125 milliliters (4.25 fl. oz.) per standard European cup from home brewing devices.
- Grams of coffee per liter of water for European brewers.
- Ounces of coffee for each 64 fluid ounces of water for half-gallon to gallon-and-a-half batch commercial brewers.
- Gallons of water per pound of coffee for urn brewers.

On the Coffee Brewing Control Chart, as shown in Diagram C, the diagonal lines that cross the chart from left to right represent brewing formulas. The specific coffee-to-water ratio is displayed across the top of the chart and down the right-hand side. Each diagonal line represents a different coffee-to-water ratio; the strongest ratios appear in the upper left-hand corner, and the weakest ratios appear in the chart's lower right-hand corner.

Once a coffee-to-water ratio has been established, one can draw a linear relationship between the strength of the beverage and the amount of soluble flavoring material extracted from the coffee. For any given brewing formula, increases in solubles yield will cause proportional increases in solubles concentration; and decreases in solubles yield will cause proportional decreases in solubles concentration.

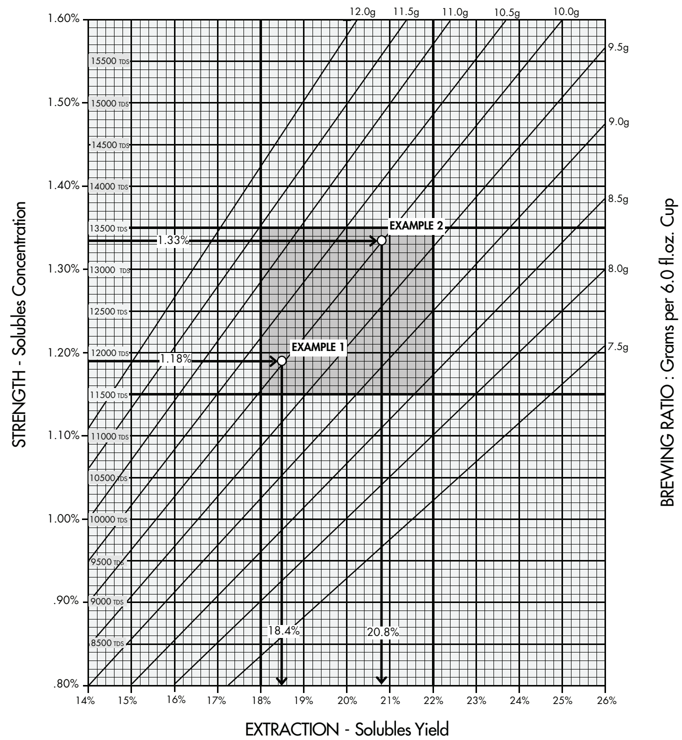
Assume, for example, one uses 10 grams of coffee and 6 fluid ounces of water to prepare a single serving. If, during the brewing process, 1.84 grams of coffee flavoring material were removed (18.4% extraction), the resulting beverage would show strength of 1.18% TDS dissolved coffee flavoring material (See Diagram C, Example 1).

On the other hand, suppose it was determined the resulting beverage showed strength of 1.33% TDS dissolved flavoring material. Then the yield of material removed from the grounds during the brewing process would be 2.08 grams (20.8% extraction) for this brewing formula (See Diagram C, Example 2).

DIAGRAM C

COFFEE BREWING CONTROL CHART

BREWING RATIO : Grams per 6.0 fl.oz. Cup



Objective Measurement

This simple analysis clearly shows the relationship between strength and extraction. It is possible to remove a large amount of flavoring material and dissolve it in a small volume of water. This results in a beverage with a very high concentration of solubles – espresso is a good example. Conversely, it is possible to extract a small amount of material and dissolve it in a large volume of water. That would result in a beverage with a very low concentration of solubles – tea is a good example. To some extent, the brewing formula will control both solubles concentration and solubles yield (See Table 1).

If the values for any two of the three factors (strength, extraction, and brewing formula) is known, one can calculate the value of the third. In this manner, one can objectively measure and study the inter-relationships of the critical variables in the brewing process, which involve the blend, roast, grind, time, temperature, turbulence, and water quality.

Subjective Evaluation

The coffee beverage derives its flavor from two sources – aroma (gases) and taste (liquids). During the brewing process, aroma is extracted much more rapidly than taste. In fact, the gases are almost immediately driven out of the grounds when they come in contact with hot water.

TABLE 1

Interrelationship between Soluble Solids, Extraction and Brewing Formula

Soluble Solids, oz./gal.		0.07	0.13	0.27	0.40	0.54	0.67	1.34	1.47	1.61	1.74	1.88	2.01	2.14	2.28	2.41	2.55	2.68
Soluble Solids, %		0.05	0.10	0.20	0.30	0.40	0.50	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
		Brewing Formula, Gallons per Pound																
Extraction %,	oz. / lb.																	
5	0.80	12.18	6.21	3.23	2.24	1.73	1.43	0.86	0.78	0.73	0.70	0.66	0.64	0.61	0.59	0.57	0.55	0.54
10	1.60	24.12	12.18	6.21	4.22	3.23	2.63	1.43	1.32	1.23	1.16	1.09	1.04	0.99	0.94	0.90	0.87	0.84
15	2.40	36.06	18.15	9.20	6.21	4.71	3.82	2.03	1.87	1.73	1.62	1.52	1.43	1.36	1.29	1.23	1.18	1.13
16	2.56	38.45	19.34	9.79	6.60	5.01	4.06	2.15	1.98	1.83	1.71	1.60	1.51	1.43	1.36	1.30	1.25	1.19
17	2.72	40.84	20.53	10.39	7.01	5.31	4.30	2.26	2.08	1.93	1.80	1.69	1.59	1.51	1.43	1.37	1.31	1.25
18	2.88	43.22	21.73	10.99	7.40	5.61	4.54	2.39	2.19	2.03	1.89	1.77	1.67	1.58	1.50	1.43	1.37	1.31
19	3.04	45.61	22.92	11.58	7.79	5.91	4.78	2.50	2.30	2.13	1.98	1.86	1.75	1.66	1.57	1.50	1.43	1.37
20	3.20	48.00	24.12	12.18	8.19	6.21	5.01	2.63	2.41	2.23	2.08	1.94	1.83	1.73	1.64	1.57	1.49	1.43
21	3.36	50.39	25.31	12.78	8.60	6.51	5.25	2.74	2.52	2.33	2.17	2.03	1.91	1.81	1.71	1.63	1.56	1.49
22	3.52	52.78	26.51	13.37	8.99	6.81	5.49	2.87	2.63	2.43	2.26	2.11	1.99	1.88	1.78	1.70	1.62	1.55
23	3.68	55.16	27.70	13.97	9.40	7.10	5.73	2.98	2.74	2.53	2.35	2.20	2.07	1.96	1.85	1.76	1.69	1.61
24	3.84	57.55	28.90	14.57	9.79	7.40	5.97	3.10	2.84	2.63	2.44	2.29	2.15	2.03	1.92	1.83	1.75	1.67
25	4.00	59.94	30.09	15.17	10.18	7.69	6.21	3.22	2.95	2.73	2.54	2.37	2.23	2.10	1.99	1.90	1.81	1.73
30	4.80	71.88	36.06	18.14	12.18	9.20	7.40	3.82	3.49	3.22	2.99	2.80	2.63	2.48	2.34	2.22	2.13	2.03
35	5.60	83.82	42.03	21.13	14.17	10.69	8.60	4.42	4.04	3.72	3.46	3.22	3.02	2.85	2.69	2.56	2.44	2.33
40	6.40	95.76	48.00	24.12	16.16	12.18	9.79	5.01	4.58	4.22	3.91	3.65	3.43	3.22	3.04	2.90	2.75	2.63

Source: Coffee Brewing Center Publication No. 27

(Compared with ground coffee, the perception of aromatics decreases by 75% when the coffee is brewed.) Although they are an important part of the overall flavor profile, the volatile aromatic components don't contribute to taste. The taste components come from the soluble flavoring material removed from the coffee grounds that remain in a liquid form. Flavoring material that does not dissolve (transform into a liquid) cannot be tasted. It does, however, create mouthfeel and is referred to as the coffee's body.

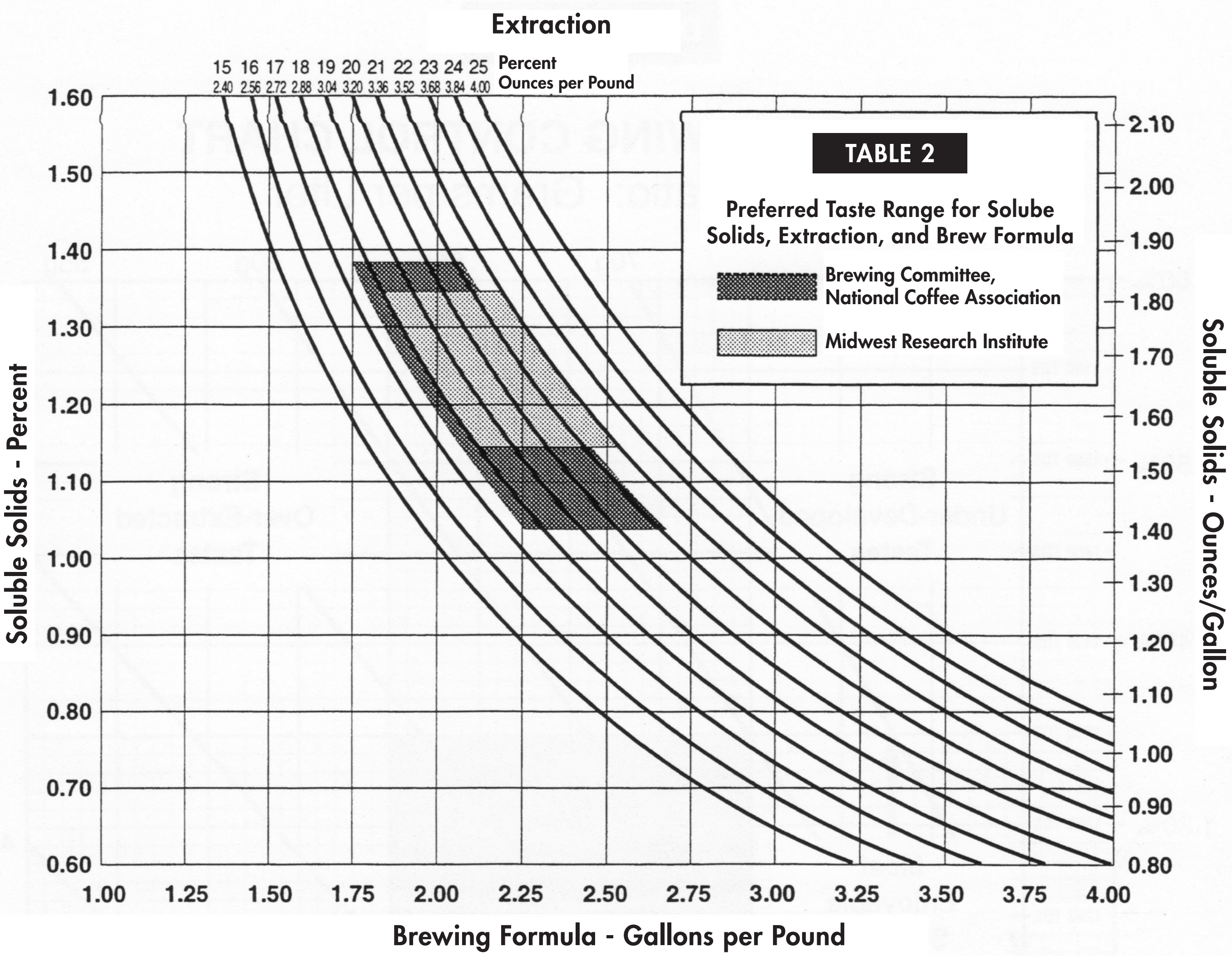
Compared to aroma, taste is extracted more slowly. Because body also slowly increases during the brewing period, taste and body are closely associated. Consequently, one can use the concentration of the dissolved flavoring material as a measure of taste and body build-up. When taken in conjunction with objective measurements that pinpoint solubles yields, subjective evaluations will confirm under-development – characterized by either undesirable grassy or peanut-like tastes due to low solubles yield – or over-extraction, which results in astringency and bitterness due to high solubles yield (see Table 2).

Balance Between Strength and Extraction

Repeated studies by the Coffee Brewing Center (CBC) identified three principals that define the relationship between strength and extraction. Later studies conducted by the Nordic Coffee Brewing Center confirmed these same principles:

1. A narrow range exists from extraction of the most flavorful soluble material. Solubles yields below 18% tend to have grassy and peanut-like tastes and are classified as *under-developed* tastes. Solubles yields above 22% tend to have unpleasant astringent and bitter tastes and are classified as *over-extracted* tastes. Extraction levels between 18% and 22% exhibit the most desirable flavors.
2. Concentration levels of soluble flavoring material have a broader range. Solubles concentrations below 1.15% coffee TDS are considered *weak*. They tend not to present the flavor of the coffee at an intensity where all of the components are above the taste threshold of the average person. Concentration levels above 1.35% coffee TDS are considered *strong*. They tend to present the flavor components at too intense a concentration to be easily perceived. For the average person, solubles concentrations between 1.15% and 1.35% tend to offer the most enjoyable level of intensity. (Note: Flavor intensity can also relate to the degree of the coffee's roast, which will cause the threshold between *too weak and too strong* to vary slightly for different roast values. Research done by the Coffee Brewing Institute and the Nordic Brewing Center involved roast values in the range of Agtron/SCAA color tiles #65-#55.
3. To reach the optimum flavor, solubles concentration needs to be in balance with solubles yield. In other words, the most flavorful mixture of soluble flavoring material is presented at the most pleasing level of concentration. To reach this optimum balance between strength and extraction (which CBC referred to as *Ideal*), brewing formulas must fall within these specified ranges:

- 9-11 grams of coffee per 6 fluid ounces of water for single cup brewers – or 6.25 - 7.75 grams of coffee per 4.25 ounces of water for European (*125 ml*) size cups.
- 50-60 grams per liter for brewers calibrated in the metric system. (Note: The Brewing Center of Norway recommends brewing formulas in the range of 60-70



Source: Coffee Brewing Center Publication No. 27

grams of coffee per liter of water.)

- 3.25 - 4.25 ounces of coffee per 64 fluid ounces of water for half-gallon brewers.
- 2.5 - 2.0 gallons of water per pound of coffee for urn brewers.

With coffee-to-water ratios that exceed the specified range, it is impossible to maintain a solubles concentration level low enough to be pleasurable when removing all of the desirable flavoring material. On the other hand, if coffee-to-water ratios fall below the specified ranges, it is impossible to achieve solubles concentrations high enough to be pleasurable without removing the flavoring materials that cause the beverage to become astringent and bitter.

Brewing Analysis Graph

The Coffee Brewing Control Chart is excerpted from a larger Coffee Brewing Analysis Graph that depicts the full range of possible outcomes from any set of brewing parameters. The full graph starts at 0% on each axis and theoretically extends to 100% at each end. The working range of the graph actually extends to 2% strength and 35% extraction. Because the useful range for meaningful study of coffee brewing lies between 0.80%-1.60% strength and 14.0%-26.0% extraction, only this range appears on the Coffee Brewing Control Chart.

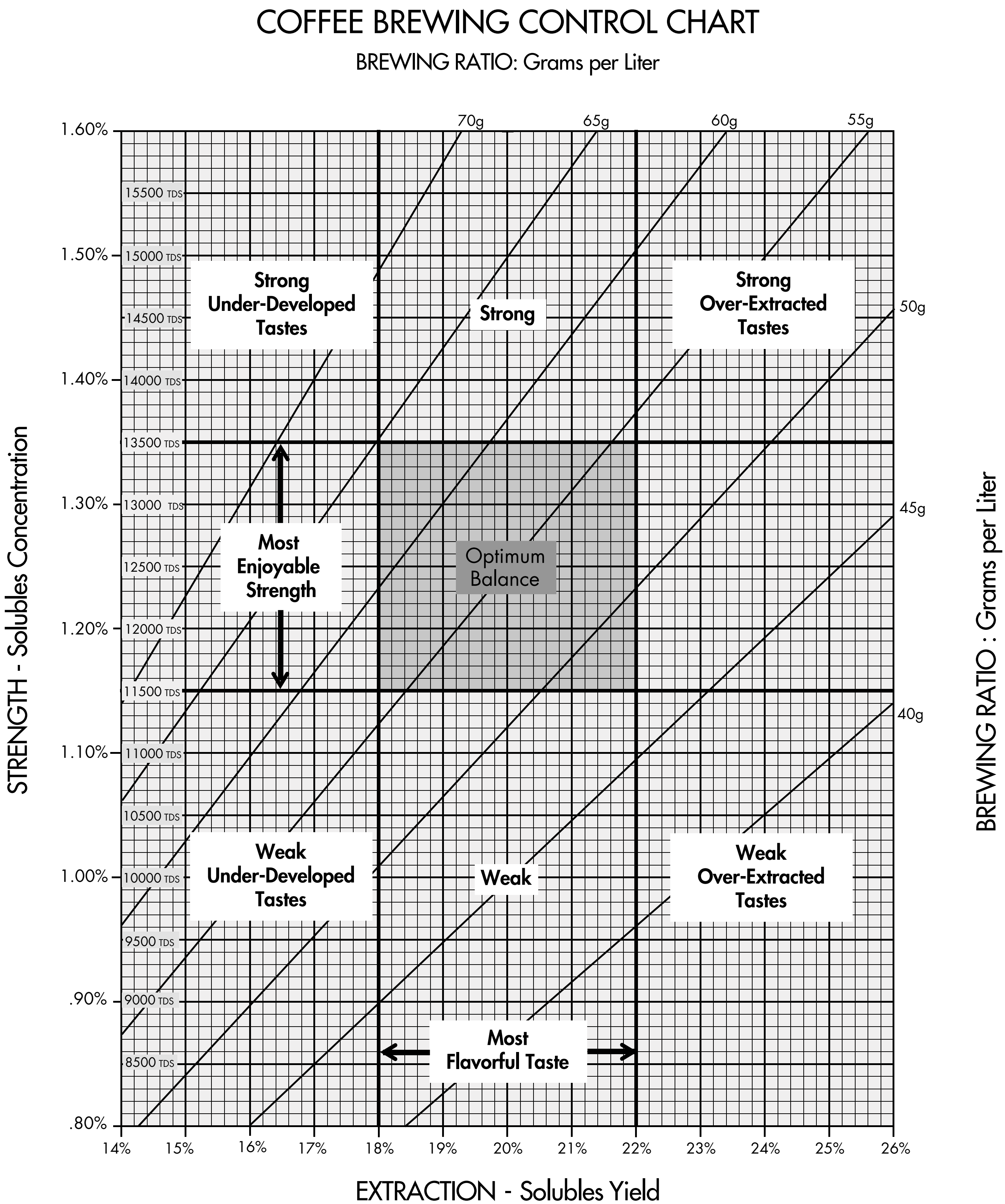
The Coffee Brewing Analysis Graph shows brewing ratios in grams per liter. These ratios can be converted to either ounces-per-half-gallon or gallons-per-pound using Tables 3 and 4.

Using the Chart

As noted above, the Coffee Brewing Control Chart allows one to study the inter-relationship between strength and extraction and to evaluate the various effects of changing the coffee's blend, roast, or grind. It can also be used to measure differences caused by the time, temperature, and turbulence of various brewing methods.

To use the Coffee Brewing Control Chart, first measure

DIAGRAM D


COFFEE BREWING CONTROL CHART
BREWING RATIO: Grams per Liter
70g
65g
60g
55g
50g
45g
40g
1.60%
1.50%
1.40%
1.30%
1.20%
1.10%
1.00%
.90%
.80%
15500 TDS
15000 TDS
14500 TDS
14000 TDS
13500 TDS
13000 TDS
12500 TDS
12000 TDS
11500 TDS
11000 TDS
10500 TDS
10000 TDS
9500 TDS
9000 TDS
8500 TDS
Strong Under-Developed Tastes
Strong
Strong Over-Extracted Tastes
Most Enjoyable Strength
Optimum Balance
Weak Under-Developed Tastes
Weak
Weak Over-Extracted Tastes
Most Flavorful Taste
14%
15%
16%
17%
18%
19%
20%
21%
22%
23%
24%
25%
26%
STRENGTH - Solubles Concentration
EXTRACTION - Solubles Yield
BREWING RATIO : Grams per Liter

the strength of the coffee beverage being studied by using one of the methods previously discussed (See Chapter 2). Once the strength is known, locate the intersection of the horizontal line on the graph corresponding to the strength and the diagonal line depicting the brewing ratio used to prepare the coffee. At this intersection, draw a vertical line to the bottom of the chart to represent the extraction of the flavoring material from the coffee. Then read the percent of solubles yield from the bottom of the chart.

The four Coffee Brewing Control Charts that follow depict strength and extraction relationships for these brewing formulas:

- Grams per 6 fluid ounces.
- Grams per liter.
- Ounces per half gallon.
- Gallons per pound.

Benefits to the Industry

Measuring taste and body build-up as an objective means of evaluating cup quality and beverage acceptability has many uses. The exercise aids in understanding the inter-relationship between blend, roast, and grind – an important consideration as coffee roasters seek to improve product quality. Equipment manufacturers find it helpful to understand the inter-relationship between time, temperature, and turbulence as they evaluate the design of new brewing equipment and modifications to brewers already in use. Such measurements also help pinpoint the effects of water composition on coffee brewing and can serve as the basis of quality control programs for business selling coffee beverages.

In short, systematically studying coffee brewing in all its aspects, using objective measurements of dissolved coffee flavoring material, provides all coffee professionals with a greater knowledge and understanding of how to transform high-quality beans into high-quality beverages.

TABLE 3

Formula Conversion Table for Half-Gallon Coffee Brewers
Conversion of Water - Ounces Formulas to Gallons per Pound

Coffee (Ounces)

Water (Fluid Ounces)	2.00	2.25	2.50	2.75	3.00	3.20	3.25	3.50	3.75	4.00	4.25
50	3.12	2.78	2.50	2.27	2.08	1.95	1.92	1.79			
51	3.18	2.83	2.55	2.32	2.13	1.99	1.96	1.82	1.70		
52	3.25	2.89	2.60	2.37	2.17	2.03	2.00	1.86	1.73		
53	3.31	2.95	2.65	2.41	2.21	2.07	2.04	1.89	1.77		
54	3.37	3.00	2.70	2.46	2.25	2.11	2.08	1.93	1.80		
55	3.43	3.06	2.75	2.50	2.29	2.15	2.12	1.96	1.83	1.72	
56	3.50	3.11	2.80	2.55	2.34	2.19	2.15	2.00	1.87	1.75	
57	3.56	3.17	2.85	2.59	2.38	2.23	2.19	2.03	1.90	1.78	
58	3.62	3.23	2.90	2.64	2.42	2.27	2.23	2.07	1.94	1.82	1.71
59	3.68	3.28	2.95	2.68	2.46	2.31	2.27	2.11	1.97	1.85	1.74
60	3.75	3.34	3.00	2.73	2.50	2.35	2.31	2.14	2.00	1.88	1.76
61	3.81	3.40	3.05	2.77	2.54	2.38	2.35	2.18	2.03	1.91	1.79
62	3.88	3.45	3.10	2.82	2.59	2.42	2.38	2.22	2.07	1.94	1.82
63	3.94	3.50	3.15	2.86	2.63	2.46	2.42	2.25	2.10	1.97	1.85
64	4.00	3.56	3.20	2.91	2.67	2.50	2.46	2.28	2.13	2.00	1.88
65	4.06	3.62	3.25	2.96	2.71	2.54	2.50	2.32	2.17	2.03	1.91
66	4.12	3.67	3.30	3.00	2.75	2.57	2.54	2.36	2.20	2.07	1.94
67	4.19	3.72	3.35	3.04	2.79	2.61	2.58	2.39	2.23	2.10	1.97
68	4.25	3.78	3.40	3.09	2.83	2.65	2.51	2.43	2.27	2.13	2.00

Source: Coffee Brewing Center Publication No. 15A

TABLE 4

Formula Conversion Table for Gram-Liter Coffee Brewers
Conversion of Water - Gram Formulas to Ounces per Half-Gallon

Coffee (Grams)

Water (Fluid Ounces)	30	35	40	45	50	55	60	65	70	75	80
50	1.57	1.82	2.08	2.34	2.60	2.86	3.12	3.39	3.65	3.91	4.17
51	1.59	1.86	2.12	2.39	2.66	2.92	3.19	3.45	3.72	3.99	4.25
52	1.62	1.89	2.16	2.44	2.71	2.98	3.25	3.52	3.79	4.06	4.33
53	1.65	1.92	2.21	2.48	2.76	3.04	3.31	3.59	3.87	4.14	4.42
54	1.68	1.98	2.25	2.53	2.81	3.09	3.37	3.66	3.94	4.22	4.50
55	1.72	2.00	2.29	2.58	2.86	3.15	3.44	3.72	4.01	4.30	4.58
56	1.75	2.04	2.33	2.62	2.92	3.21	3.50	3.79	4.08	4.36	4.67
57	1.78	2.08	2.37	2.67	2.97	3.27	3.56	3.86	4.16	4.45	4.75
58	1.81	2.11	2.42	2.72	3.02	3.32	3.63	3.93	4.23	4.53	4.84
59	1.84	2.15	2.46	2.76	3.07	3.38	3.69	4.00	4.30	4.61	4.92
60	1.87	2.19	2.50	2.81	3.12	3.44	3.75	4.60	4.38	4.69	5.00
61	1.90	2.22	2.54	2.86	3.18	3.49	3.81	4.13	4.45	4.77	5.09
62	1.94	2.26	2.58	2.91	3.23	3.55	3.85	4.20	4.52	4.85	5.17
63	1.97	2.30	2.62	2.93	3.28	3.61	3.94	4.27	4.60	4.92	5.25
64	2.00	2.33	2.67	3.00	3.33	3.67	4.00	4.33	4.67	5.00	5.34
65	2.03	2.37	2.71	3.05	3.39	3.72	4.06	4.40	4.74	5.08	5.42
66	2.06	2.40	2.75	3.09	3.44	3.78	4.13	4.47	4.81	5.16	5.50
67	2.09	2.44	2.79	3.14	3.49	3.84	4.19	4.54	4.89	5.24	5.59
68	2.12	2.48	2.83	3.19	3.54	3.90	4.25	4.61	4.96	5.32	5.67

Source: SCAA

DIAGRAM E

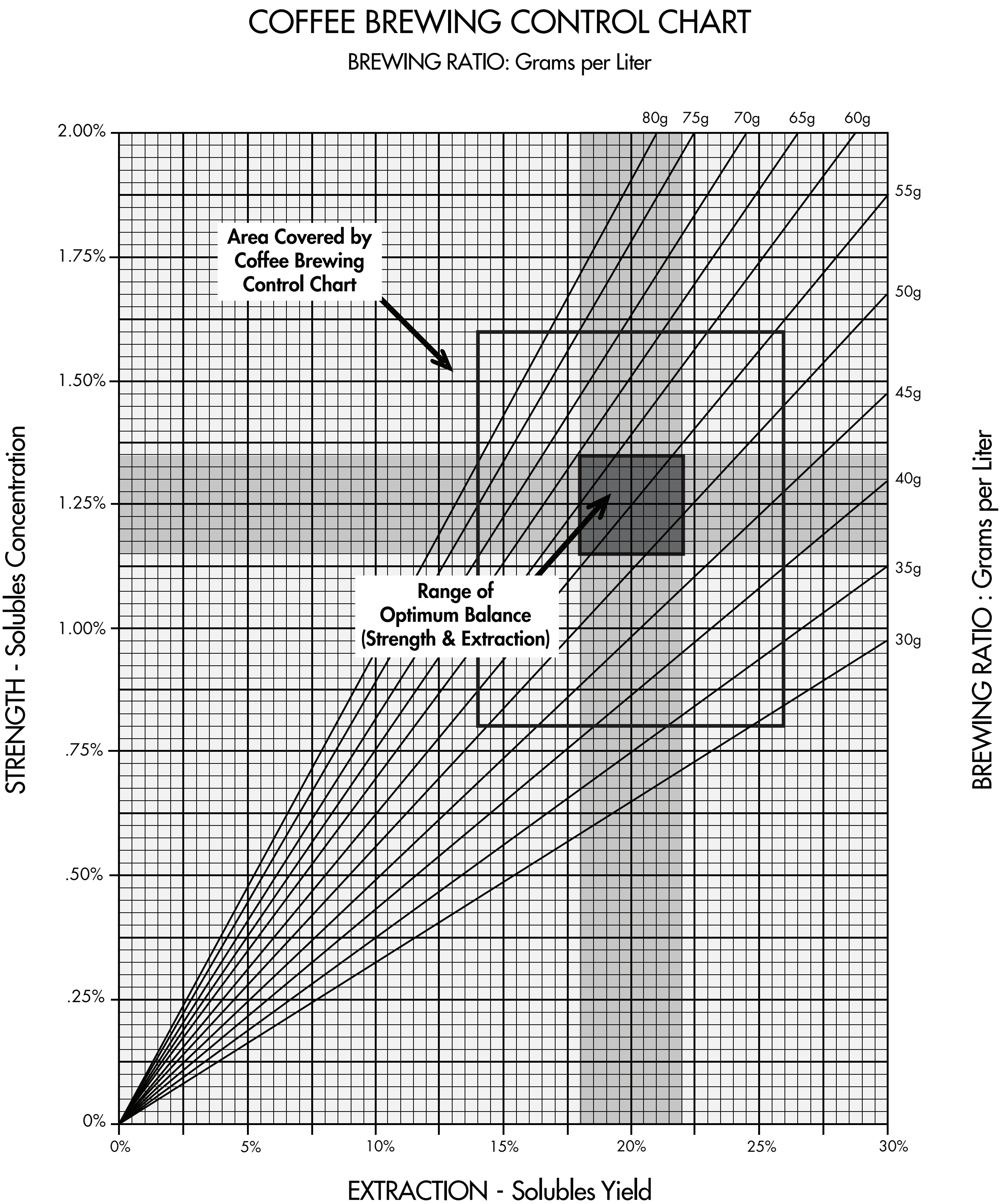

COFFEE BREWING CONTROL CHART
BREWING RATIO: Grams per Liter
80g
75g
70g
65g
60g
55g
50g
45g
40g
35g
30g
2.00%
1.75%
1.50%
1.25%
1.00%
.75%
.50%
.25%
0%
0%
5%
10%
15%
20%
25%
30%
Area Covered by Coffee Brewing Control Chart
Range of Optimum Balance (Strength & Extraction)
STRENGTH - Solubles Concentration
BREWING RATIO : Grams per Liter
EXTRACTION - Solubles Yield

DIAGRAM F

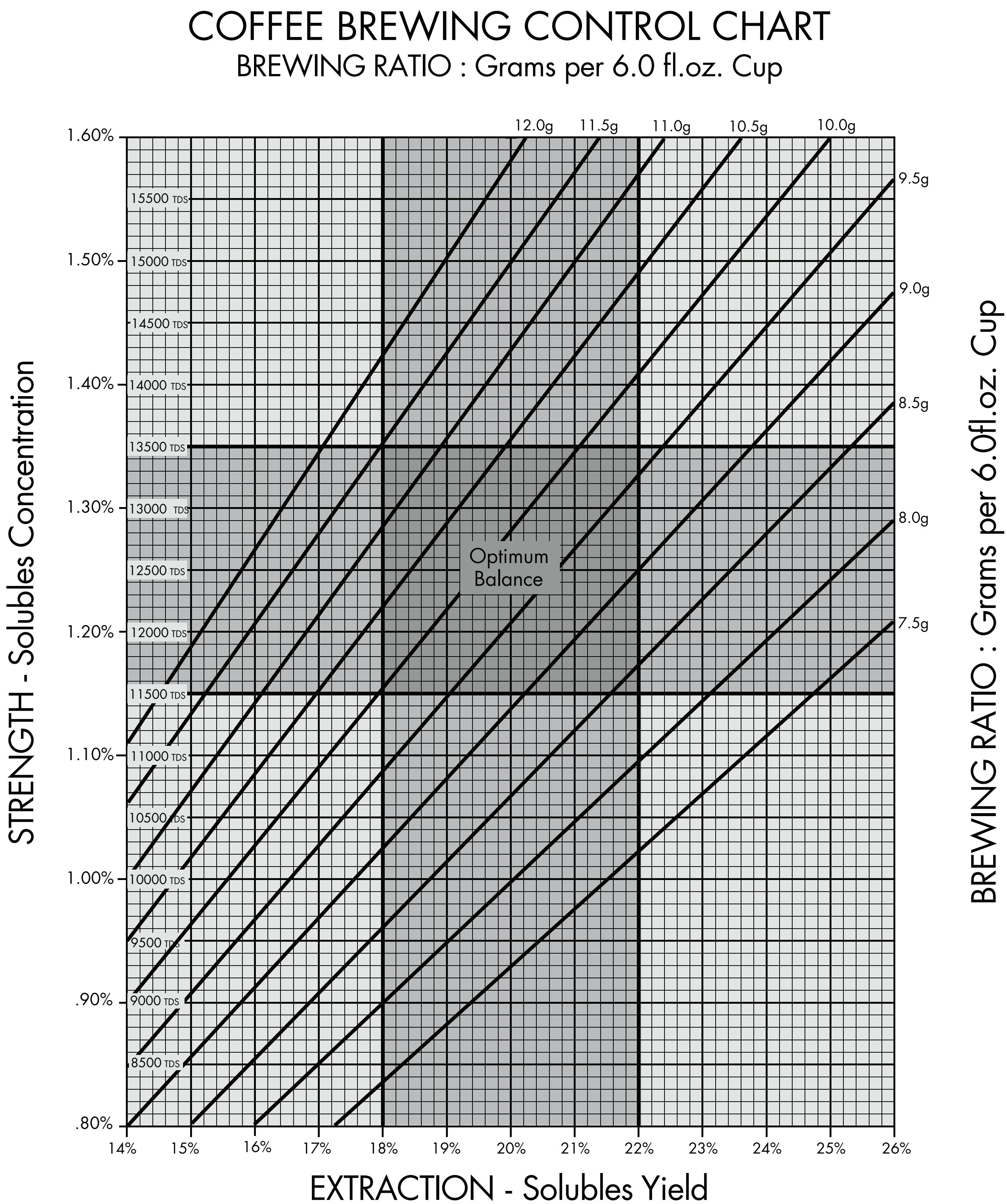

COFFEE BREWING CONTROL CHART
BREWING RATIO : Grams per 6.0 fl.oz. Cup
12.0g
11.5g
11.0g
10.5g
10.0g
9.5g
9.0g
8.5g
8.0g
7.5g
1.60%
1.50%
1.40%
1.30%
1.20%
1.10%
1.00%
.90%
.80%
15500 TDS
15000 TDS
14500 TDS
14000 TDS
13500 TDS
13000 TDS
12500 TDS
12000 TDS
11500 TDS
11000 TDS
10500 TDS
10000 TDS
9500 TDS
9000 TDS
8500 TDS
Optimum Balance
STRENGTH - Solubles Concentration
BREWING RATIO : Grams per 6.0fl.oz. Cup
14%
15%
16%
17%
18%
19%
20%
21%
22%
23%
24%
25%
26%
EXTRACTION - Solubles Yield

DIAGRAM G

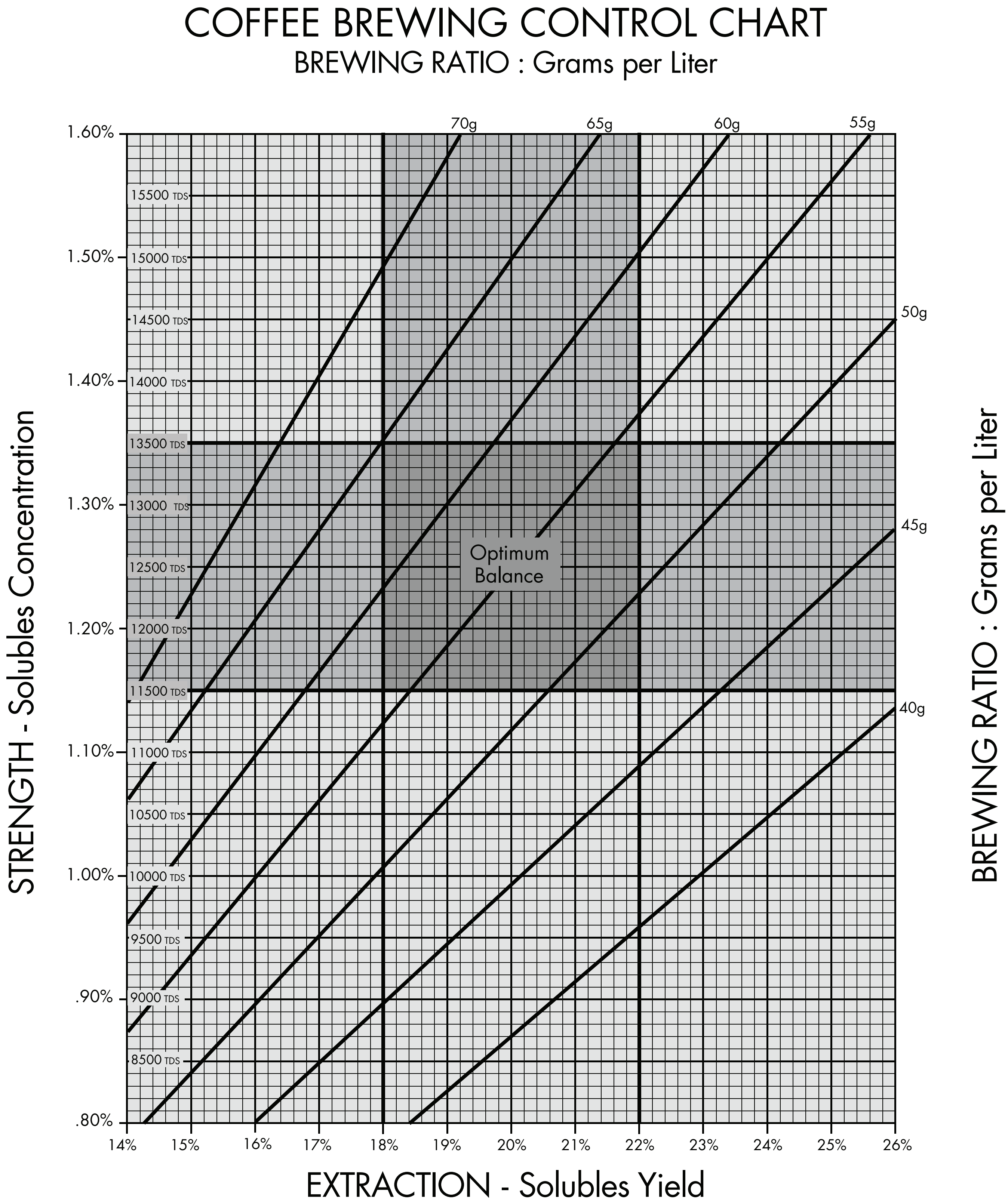

COFFEE BREWING CONTROL CHART
BREWING RATIO : Grams per Liter
70g
65g
60g
55g
50g
45g
40g
1.60%
1.50%
1.40%
1.30%
1.20%
1.10%
1.00%
.90%
.80%
15500 TDS
15000 TDS
14500 TDS
14000 TDS
13500 TDS
13000 TDS
12500 TDS
12000 TDS
11500 TDS
11000 TDS
10500 TDS
10000 TDS
9500 TDS
9000 TDS
8500 TDS
Optimum Balance
14%
15%
16%
17%
18%
19%
20%
21%
22%
23%
24%
25%
26%
STRENGTH - Solubles Concentration
BREWING RATIO : Grams per Liter
EXTRACTION - Solubles Yield

DIAGRAM H

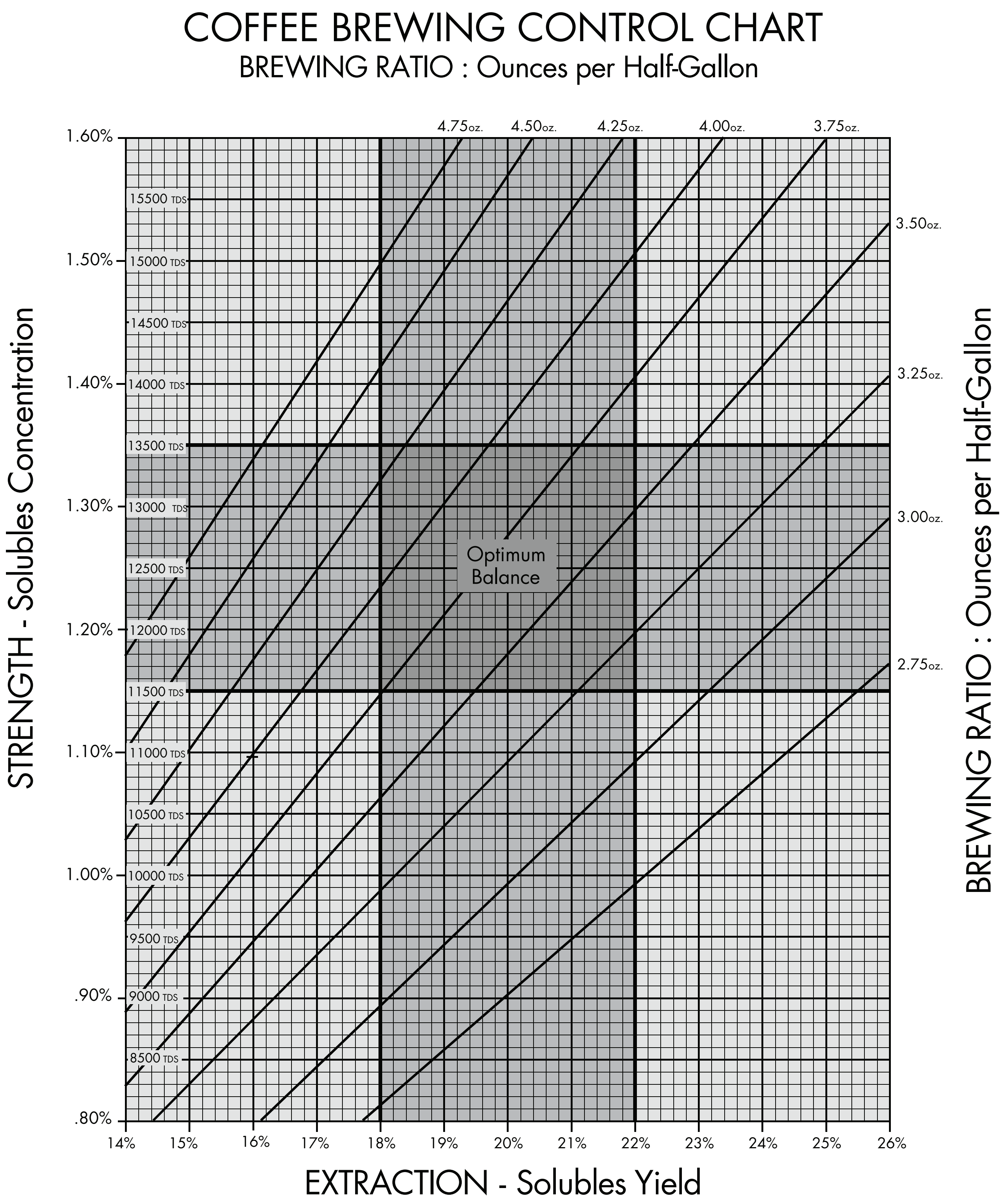
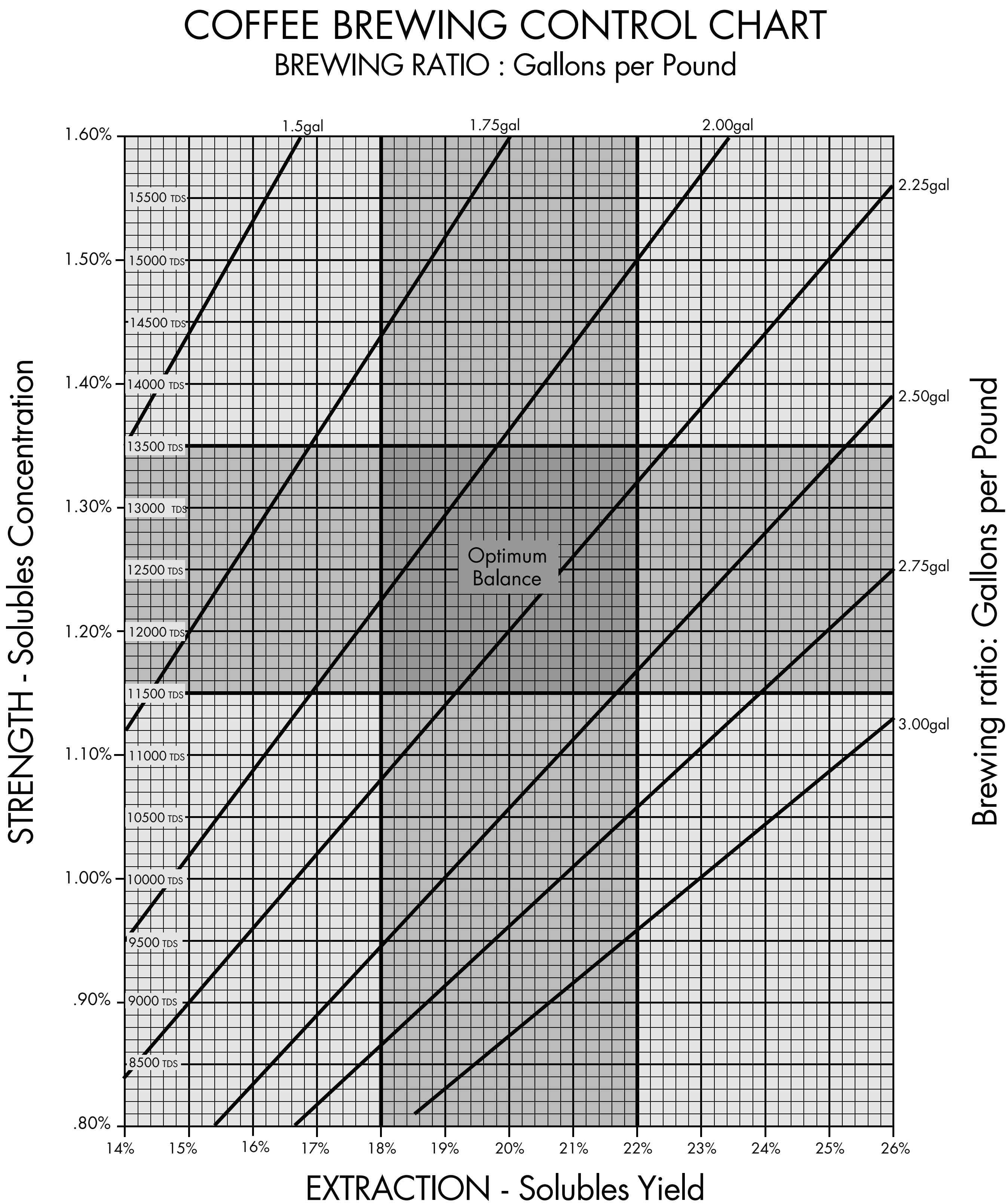

COFFEE BREWING CONTROL CHART
BREWING RATIO : Ounces per Half-Gallon
4.75oz.
4.50oz.
4.25oz.
4.00oz.
3.75oz.
3.50oz.
3.25oz.
3.00oz.
2.75oz.
1.60%
1.50%
1.40%
1.30%
1.20%
1.10%
1.00%
.90%
.80%
15500 TDS
15000 TDS
14500 TDS
14000 TDS
13500 TDS
13000 TDS
12500 TDS
12000 TDS
11500 TDS
11000 TDS
10500 TDS
10000 TDS
9500 TDS
9000 TDS
8500 TDS
Optimum Balance
14%
15%
16%
17%
18%
19%
20%
21%
22%
23%
24%
25%
26%
STRENGTH - Solubles Concentration
EXTRACTION - Solubles Yield
BREWING RATIO : Ounces per Half-Gallon

DIAGRAM I


COFFEE BREWING CONTROL CHART
BREWING RATIO : Gallons per Pound
1.5gal
1.75gal
2.00gal
2.25gal
2.50gal
2.75gal
3.00gal
1.60%
1.50%
1.40%
1.30%
1.20%
1.10%
1.00%
.90%
.80%
15500 TDS
15000 TDS
14500 TDS
14000 TDS
13500 TDS
13000 TDS
12500 TDS
12000 TDS
11500 TDS
11000 TDS
10500 TDS
10000 TDS
9500 TDS
9000 TDS
8500 TDS
Optimum Balance
14%
15%
16%
17%
18%
19%
20%
21%
22%
23%
24%
25%
26%
STRENGTH - Solubles Concentration
EXTRACTION - Solubles Yield
Brewing ratio: Gallons per Pound

CHAPTER 4
THE BREWING PROCESS

There's a craft in brewing good coffee. For any given product, the key lies in finding the optimum balance between the strength of the brew and the degree of extraction from the roast-and-ground coffee.

Strength refers to the brew's intensity – how concentrated it is – and needs to be adjusted for consumers' individual tastes, just as the volume on a stereo would be adjusted. Strength can be quantified as the percentage of solubles concentration in the brew. Extraction refers to the brew's acceptability – which specific flavoring materials have been removed from the grounds – and needs to be controlled to optimize taste, much like the mix of treble and bass coming from the stereo's speakers needs to be adjusted. Extraction can be quantified as the percentage of solubles yield from the amount of coffee grounds used in preparing the brew.

Aroma + Taste = Flavor

The strength of coffee is associated with the chemical compounds that hot water can extract from the roasted, ground beans. Some of these solubles evaporate easily and are responsible for the brew's aroma, while others are not so volatile and are the source of the brew's taste (see Table 1). Aroma and taste combine to produce coffee's flavor. The insoluble compounds – those that don't dissolve – become the coffee's body.

TABLE 1

Chemical Compositions of Soluble and Insoluble Portions of Roasted Coffee*
(Approximate, Dry Basis)

Nonvolatiles	**% Solubles**	**% Insolubles**
Carbohydrates (53%)		
Reducing Sugars	1 - 2	–
Caramelized Sugars	10 - 17	0 - 7
Hemi-cellulose (hydrolyzable)	1	14
Fiber (not hydrolyzable)	–	22
Oils	–	15
Proteins (N x 6.25); Soluble Amino Acids	1 - 2	11
Ash (oxide)	3	1
Acids (nonvolatile)		
Chlorogenic	4.5	–
Caffeic	0.5	–
Quinic	0.5	–
Oxalic, Malic, Citric, Tartaric	1.0	–
Volatile Acids	0.35	–
Trigonelline	1.0	–
Caffeine (Arabicas 1.0%; Robustas 2.0%)	1.2	–
Phenolics (estimated)	2.0	–
Volatiles		
Carbon Dioxide	trace	2.0
Essence of Aroma and Flavor	0.04	–
Total	**27 - 35%**	**73 - 65%**

**Source: Sivetz and Desrosier (1979)*

Roasted coffee contains vastly different amounts of aroma and taste materials. The beverage gets its taste from the extractable non-volatile materials, which potentially amount to about 30 pounds in each 100 pounds of coffee. In contrast, the extractable volatile materials amount to less than one-half ounce to each 100 pounds of coffee. In other words, the ratio of taste to aroma components is about 1,000 to 1. Consequently, the perception of beverage strength relates directly to the perception of taste.

The acceptability of the taste perception is also tied to the brew's chemical composition, which changes continuously during the brewing cycle. The changes occur because each flavoring compound dissolves at a different rate.

Three Phases of the Brewing Process

To achieve the optimum balance between strength and extraction, it is essential to control the brewing process. The brewing process itself proceeds in three stages:

1. **Wetting.** As the bean fiber absorbs hot water, gas is driven from the coffee particles and interstitial voids (the small space inside the particles). This phase prepares the particles for extraction of the solubles.
2. **Extraction.** During this second phase, the water-soluble flavoring compounds dissolve, rapidly moving out of the bean fibers and entering the water.
3. **Hydrolysis.** At this point, large molecules of water-insoluble carbohydrates break down into smaller molecules that are water soluble. These are mostly reducing sugars but also include some proteins.

24 Variables of Coffee Brewing

Because the brewing process proceeds in three distinct phases – wetting, extraction, and hydrolysis – the design and operation of the brewing equipment have a direct bearing on the composition of the flavoring material in the brew. Therefore, controlling the brewing process means controlling not only the variables related to the coffee, but the variables related to the brewing equipment as well.

In total, 24 variables interact during the brewing process. Controlling all these variables to achieve the optimum balance between strength and extraction is a true craft. The variables can be categorized as follows:

TABLE 2

Variables Affecting Strength and Extraction

Coffee Product	
Blend Components:	1. Ratio of blend components 2. Bulk density of beans 3. Chemical composition of beans
Roast Development:	4. Methodology of roasting 5. Rate of roasting 6. Degree of roast 7. Rate of degassing
Grind:	8. Average size of particles 9. Size distribution of particles 10. Particle shape
Brewing Equipment	
Time of Brewing:	11. Time of water contact
Temperature:	12. Contact temperature 13. Temperature gradient during brewing
Turbulence:	14. Complete wetting 15. Uniform flow 16. Particle movement
Filtering Method:	17. Method of separation 18. Degree of clarification
Holding Conditions:	19. Length of time and method of holding 20. Holding temperature
Ingredients	
Brewing Forumla:	21. Coffee (by weight) 22. Water (by volume)
Water:	23. Water composition 24. Water treatment

Coffee Product

The coffee roaster usually has the responsibility for controlling the 10 variables related to the coffee product.

- **Blend components.** The **(1) ratio of different coffees** used in the blend can range from a single origin coffee on one extreme, to a mix of Arabica and Robusta coffees on the other. Also affecting the blend is the beans' **(2) bulk density** – a measure of the beans' weight in relation to their physical volume. Finally, the **(3) chemical composition** of the beans themselves affects the brew's resulting flavor and intensity. Chemical composition varies by the type of coffee plant and the micro-climate in which it grows.
- **Roast development.** The **(4) methodology of roasting**, particularly the efficiency of heat transfer within the beans, determines if the beans are uniformly roasted from the outside to the center of the bean. The **(5) rate of roasting** controls both the structural expansion of the bean fibers (which affects extraction rates) and the chemical composition of the roasted beans (which affects the flavor of the extract). Other variables include the **(6) degree of roast**, usually evaluated by the beans' color, and the **(7) rate of degassing**, which generally relates to the method of storage, or length of time before brewing.
- **Grind.** Relative to brewing, a critical aspect of the coffee product is the grind, or particle size. Within certain limits, the amount of soluble material extracted from the coffee varies inversely with the particle size: The smaller the particles, the greater the extraction (see Table 3). In controlling the particles size, both the **(8) average size** of the particles and the **(9) size distribution** of the particles creating the average, must be taken into account (see Table 4). In addition, the **(10) particle shape** will affect the rate at which soluble material can be extracted from the coffee.

TABLE 3

Effect of Particle Size of Coffee Grounds on Extraction of Soluble Solids

Particle Size (Tyler Screeen #)	Contact Time (in seconds)	Soluble Solids (as percent)	Extraction (oz. lb.)
on #10	142	0.63	1.67
on #14	143	0.73	1.93
on #20	136	0.93	2.45
on #28	156	1.28	3.40
on #40	292	1.46	3.87

- Water: coffee ratio at 2 ¼ gallons per pound
- Water temperature at 200° F
- Results averaged from five trials with each size fraction

Source: Coffee Brewing Center, Publication #40

TABLE 4

Particle Size and Distribution for Typical Grinds

	Regular	Drip	Fine
Percent on			
#10 mesh	13%	0%	0%
#14 mesh	20%	7%	0%
#20 mesh	25%	33%	10%
#28 mesh	30%	40%	60%
Percent thru			
#28 mesh	12%	20%	30%

Source: Coffee Brewing Center, Publication #118

Brewing Equipment

Ten of the variables balancing strength and extraction relate to the brewing equipment. Of these, six involve time, temperature, and turbulence, which are usually controlled by the equipment manufacturer.

- **Time of brewing.** The **(11) contact time** (how long coffee remains in contact with the water) determines the percentage of solubles yield. The longer the contact time, the greater the extraction of soluble materials. Generally speaking, rapid extraction occurs during the first third of the brewing cycle, yielding as much as 70% of the available soluble material.
- **Temperature.** For proper extraction to occur, water must reach the coffee at **(12) contact temperatures** near 200°F (*94°C*), and the **(13) temperature gradient** must remain in a constant range between 195°F and 205°F (*92°C -96°C*) (See Table 5).
- **Turbulence.** Turbulence is affected by the way the water is distributed over the bed of grounds, leading to **(14) complete wetting** of the coffee; the velocity of the water flowing through the coffee bed, creating a **(15) uniform flow rate**; and the bed's size, depth, configuration, and degree of containment, limiting the **(16) particle movement**. The design of the brewer's spray head and brew basket controls turbulence. A successful design results in complete wetting of all of the coffee particles in the brew basket, a uniform flow of water though the entire bed of coffee, and a separation of the particles while they are in contact with the water.

TABLE 5

Effect of Change in Water Temperature on Beverage Solids and Extraction from Grounds

Temperature (°F)	Beverage Solids (as percent)	Grounds Extraction (oz. / lb.)
205	1.22	2.85
195	1.30	3.00
185	1.24	2.87
165	1.11	2.58
125	0.98	2.08
85	0.63	1.48

- Urn grind coffee
- Water: coffee ratio at 2.00 gallons per pound
- Time of contact at 3 minutes

Source: Coffee Brewing Center, Publication #40

The person preparing the beverage usually has control of the four remaining variables related to brewing equipment.

- **Filtering method.** The type of filter determines the **(17) method of separation** of the finished brew from the coffee grounds and the **(18) degree of clarification** – the extent to which the non-soluble materials are removed from the brew as it passes into the holding container. The type of filter often establishes the configuration of the brew basket, while the degree of clarification relates directly to the amount and size of brew colloids suspended in the beverage.
- **Holding conditions.** The **(19) length of time and method of holding** are critical aspects of preserving the coffee's flavor. For best results, coffee should be served immediately after brewing or held in a sealed thermal container when not immediately served. Coffee stored in a heated, open vessel increases in strength as water evaporates from the brew; it also changes in flavor because the applied heat causes the chemical compounds to change. A **(20) holding temperature** between 175ºF and 185ºF (*80ºC-85ºC*) should be maintained throughout the holding period for optimum flavor and serving temperature requirements. Important chemical compounds in coffee's tastes are most stable in this temperature range. At no time should the temperature drop below 175ºF (*80ºC*).

Ingredients

Once the coffee product and brewing equipment have been selected, the person preparing the beverage directly controls the final four variables.

- **Brewing formula.** The most important variable related to ingredients is the **(21) ratio of coffee** (by weight) to **(22) water** (by volume). To bring the variables related to both the product and equipment into play, the coffee-to-water ratio must fall within the range of preferred strength and desired extraction (See Table 6).

  Too much coffee (or too little water) will result in beverages that have an under-developed flavor if brewed at the preferred strength, or too strong a taste if brewed at the desired degree of extraction. Too little coffee (or too much water) will result in beverages that have an over-extracted and often bitter flavor if served at the preferred extraction, or too weak a taste if brewed at the desired degree of extraction.

TABLE 6

Effect of Water: Coffee Ratio on Beverage Solids and Extraction from Grounds

Water: Coffee Ratio (gallons per lb.)	Beverage Solids (as percent)	Grounds Extraction (oz. / lb. and %)
1.62	1.76	3.35 - 20.9%
2.00	1.22	2.85 - 17.8%
2.35	1.13	3.15 - 19.6%
2.67	1.00	3.20 - 20.0%
3.33	0.79	3.25 - 20.3%
4.00	0.67	3.30 - 20.6%

- Urn grind coffee
- Water temperature at 205°F
- Time of contact at 3 minutes

Source: Coffee Brewing Center, Publication #40

- **Water. (23) Water composition** is a critical aspect of coffee brewing. Water contains dissolved minerals that not only give it taste, but also contribute to coffee's taste. If present in too great an amount, these dissolved inorganic substances will interfere with the brewing process by either restricting the flow of the water through the coffee particles, or by preventing soluble material in the coffee from entering the extract. Water may also contain excess concentrations of hydrogen ions or hydroxide ions, which unfavorably alter its chemical properties. Water may also contain organic compounds that give it an unpleasant odor. **(24) Water treatment** can improve the flavor of the coffee by removing unwanted chemicals, such as chlorine. Certain methods of water treatment, however, may also detract from the brew by adding unwanted compounds, such as sodium, which interfere with the brewing process, or affect the beverage acidity.

Maintaining Control

To master the craft of coffee brewing, the many variables that contribute to both the strength (intensity) and extraction (acceptability) of coffee flavor must be controlled. The skill lies in learning how to control all of the variables so that the solubles concentration is balanced with the solubles yield, resulting in the *perfect cup* of coffee that exceeds consumers' expectations of its pleasure.

Although the possible combinations of the 24 variables are virtually limitless, one can provide reasonable control over the process by adhering to the key principles of good brewing: Quality blends, excellent equipment, clean water, and the proper brewing ratio.

CHAPTER 5 GRIND

If a whole, roasted coffee bean is placed in water and subjected to heat and agitation long enough, the coffee flavoring material eventually would be extracted from the bean. Obviously, such a brewing method would require too much time to be practical.

If, however , a whole, roasted bean is cut in half before brewing, the water would have two new surfaces to touch. If these pieces were again cut in half, four new surfaces would be presented to the water. By continuing to reduce the size of the bean's particles from whole bean to fine grind, ultimately there would be more than 4,000 times the number of particles, and 16 times the surface area per unit weight of coffee immersed in hot water, when compared to the whole, roasted bean (See Table 1). Consequently, roasted coffee beans are broken down into smaller particles for brewing.

TABLE 1

Particle Size vs. Number of Particles per Unit Weight

Particle Size Description	Size mm	No. Particles per Gram	Increase Part. / gm	Ratio of Increase	Total Area sq. cm / gm
Whole bean	6.00	6	—	—	8
Cracked bean	3.00	48	42	1	16
Coarse grind	1.50	384	336	8	32
Regular grind	1.00	1,296	912	22	48
Drip grind	0.75	3,072	1,776	42	64
Fine grind	0.38	24,572	21,500	512	128
Espresso grind	0.20	491,440	466,868	11,115	240

Source: Sivetz and Foote (1963)

Cutting apart the coffee bean exposes much greater surface area, allowing for the liberation of carbon dioxide (CO_2) gas and for absorption of hot water. At the same time, it shortens the distance from the center of each particle to the surface, thereby greatly reducing the distance (and time) the coffee flavoring materials travel to reach the coffee extract. Greater surface exposure also increases the amount of fats, oils, and ultra-fine particles that form colloidal suspensions in the coffee brew.

The process of reducing whole, roasted coffee beans to small particles is called grinding. This general term encompasses crushing, rubbing, grating, cutting, tearing, milling, compressing, and any other process that progressively reduces the size of coffee particles. No process will produce complete uniformity of particle size. Therefore, the goal in grinding is to create a uniform distribution of particle sizes within a specified range.

Factors Influencing Grinding

The individual properties of the coffee beans greatly influence grinding results. For example, one should never grind warm beans immediately after roasting. They would be too soft, and grinding would leave them crushed, flattened, and scarred. It is best to grind coffee beans after they have cooled and become hard and brittle. Understanding the differences in bean properties enables one to make grind adjustments, and thus achieve the desired distribution of particles sizes. These differences include:

- **Moisture content.** Beans are physically softer when they have been cooled by water quenching. They are most brittle when air-cooled without additional moisture.
- **Degree of roast.** When ground, light roast coffees tend to be tenacious, pliable, and tough. They do not break apart as easily as hard, brittle, dark roasted beans. Darker roasts, consequently, will always produce more fine particles than lighter roasts.
- **Brittleness.** Even the natural origin of the coffee makes a difference in terms of strength, resilience, pliability, and hardness during grinding. Given the same degree of roast, new-crop coffees give fewer fine particles that past-crop coffees. Compared to Arabica coffees, Robusta coffees differ in the particle size distribution. And high-grown coffees show different characteristics than those grown at lower elevations.

TABLE 2

How Degree of Roast Affects Grinding

Screen	Grind Set #4		Grind Set #5		Grind Set #6		Grind Set #7	
Mesh	Light	Dark	Light	Dark	Light	Dark	Light	Dark
#10	0.0%	0.0%	0.5%	0.1%	5.8%	3.0%	14.7%	13.6%
#14	15.4%	6.5%	27.9%	18.3%	42.7%	31.5%	43.5%	37.2%
#20	48.9%	45.3%	43.7%	41.4%	30.3%	33.4%	21.8%	23.2%
#28	20.6%	26.3%	15.3%	20.9%	10.8%	16.0%	9.9%	12.4%
PAN	14.8%	21.7%	11.9%	18.9%	10.2%	15.4%	10.0%	13.0%
Total	99.7%	99.7%	99.3%	99.6%	99.8%	99.3%	99.9%	99.4%

*Light = "Cinnamon" - (Agtron / SCAA Color tiles #95 - #85)
* Dark = "Italian" - (Agtron / SCAA Color Tiles #35 - #25)
Grind Setting # 4 = Fine
Grind Setting # 7 = Coarse

Source: Sivetz and Foote (1963)

Setting Grind Standards

In the late 1940s, the U.S. Department of Commerce established a simple laboratory testing procedure for measuring particle size distribution. The equipment consisted of four sieves – each with a different size wire screen – and a Ro-Tap shaking machine. The sieves were stacked one atop the other, with the coarsest screen at the top and the finest on the bottom. (Note: The wire screens originally used in the procedure were manufactured by the W.S. Tyler Co. and classified by Tyler's standard mesh sieve sizes of #10, #14, #20, and #28 screens. The corresponding U.S. Standard sieves are #12, #16, #20, and #30, respectively.)

The procedure involved placing a measured sample (usually 100 grams) into the top sieve, covering it, and placing the stack of four sieves into the Ro-Tap shaker for five minutes. When the shaking cycle ended, all the sieves were removed from the shaker and each one was carefully weighed with its contents. In this manner, one could determine the percentage of coffee particles remaining in each sieve. Those percentages translated into a particular grind designation.

Based on this method of analysis, the coffee industry adopted a common set of grind designations in 1948. At the time, a majority of the coffee roasters voluntarily agreed to follow the system of classification, which divided grinds into three groups: regular, drip, and fine. The new terminology was intended to replace the variety of names used throughout the industry, although some of the non-standard terms still exist today.

TABLE 3

U. S. Department of Commerce
Recommended Coffee Grinds

Grind Designation	Amount of Coffee Retained On 10 & 14	Amount of Coffee Retained On 20 & 28	Amount of Coffee Passing Through 28 Mesh	Tolerances Passing Through Not Less	Tolerances Passing Through Not More
Regular	33%	55%	12%	9%	15%
Drip	7%	73%	20%	16%	24%
Fine	0%	70%	30%	25%	40%

Source: U.S. Department of Commerce

TABLE 4

Coffee Industry Grind Terminology
Non-Standard Usage

Regular	Drip	Fine
Coarse	Urn	Silex
Percolator	All-Purpose	Vacuum
Open Pot	Medium	Very Fine
Steel Cut	Universal	Extra Fine
Roller Cut		Pulverized
Electric Percolator		

Source: Coffee Brewing Center, Publication #54

Within each grind classification, extensive tests determined which particle size distribution achieved satisfactory extraction results when used with appropriate coffee brewers, based on the average length of time in the brewing cycle. For example, tests demonstrated that if a coffee grind was called *drip* it would work best in the drip-filtration brewing method when the sieve analysis showed that 20% of the grind would pass though a 28-mesh sieve.

Both cup tests and laboratory analysis showed that the most important variable in each designation was the percentage of the ground coffee that passed through the 28-mesh sieve. The tests also indicated that each grind classification could allow some tolerance while still maintaining efficient grind standards.

Matching Grind to Brewing Method

The grind, or particle size distribution, plays a critical role in the brewing process. **For proper extraction to occur, the grind must be appropriate for the coffee maker being used.** For example, suppose a coarse grind of coffee is used in a filter-drip brewer, which normally operates on a 3-to-4 minute brewing cycle. Insufficient surfaces will be exposed to the water during the short length of the brewing time, resulting in the weak and tasteless coffee brew. On the other hand, if a fine grind is used in a coffee urn, which operates on a 6-to-8-minute brewing cycle, the coffee will be over-extracted and bitter.

Coffee brewed in single-cup brewers, such as those found in the vending industry, requires much smaller particles. (To measure smaller particles sizes in a Ro-Tap shaker, replace the top two sieves with two smaller sieves at the bottom of the stack.) Table 5 gives examples of fine grinds for single-cup brewers.

TABLE 5

Examples of Single Cup Vending Grinds

Mesh Sieve Size	Rowe Batch Brewer		Vendo Batch Brewer		Single Cup Brewer	
# 10	0%		–		–	
# 14	3%	± 3%	2%	± 2%	–	
# 20	32%	± 5%	33%	± 5%	1%	± 1%
# 28	43%	± 5%	40%	± 5%	15%	± 4%
# 35	–		15%	± 2%	37%	± 5%
# 48	–		–		27%	± 5%
Pan	22%	± 3%	10%	± 2%	20%	± 3%

Source: Coffee Brewing Center, Publication #154

Espresso brewing, which takes between 20 and 30 seconds for each cup (1.0-1.5 fluid oz./ 30-45 ml) requires even finer grinds. In an espresso grind, each gram of coffee contains approximately 500,000 particles of ground coffee – that is 20 times finer than conventional fine grind coffee.

Because espresso is a multi-phases system (it produces a solution, an emulsion, a suspension, and a foam), grind control is absolutely essential for proper brewing and to produce a flavorful beverage. Generally, espresso grinds are set individually for each specific combination of coffee beans, brewing equipment, and ambient conditions at the location of preparation.

If the particle size is further reduced to finer than that required for espresso brewing, the ground coffee becomes a coarse powder. This process is pulverization. Stone-ground, pulverized coffee is used to prepare Turkish coffee, a beverage popular in the Moslem cultures in Arabia and Indonesia. This brewing method calls for mixing the powdered (also mashed and flaked) grounds with water and sugar and brining the mixture to a boil three times. The resulting beverage is then poured away from the grounds into a cup. In Arabia it is often toped with ground cardamom for additional flavoring.

In selecting the proper grind for any given brewer, it is essential to match the particle size with the brewing time. Too coarse a particle size will result in grassy, under-developed coffee tastes. Too fine a particle size will result in bitter, over-extracted tastes.

CHAPTER 6 TIME, TEMPERATURE, AND TURBULENCE

The brewing process starts the moment hot water touches the coffee grounds and stops when the water and coffee grounds are separated. The period during which the water remains in direct contact with the coffee is known as the brewing time. The most desirable beverage results when the brewing process is completed within the time period prescribed for the coffee's grind.

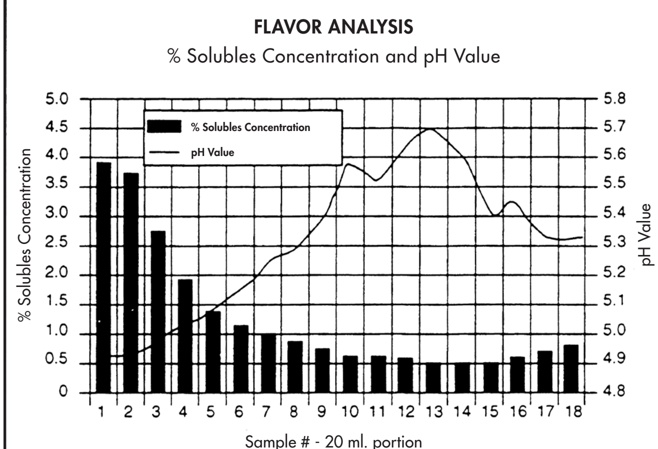
Using a fine grind of coffee, the correct brewing time would range from 1 to 4 minutes. A drip grind requires 4 to 6 minutes, and a regular grind calls for a 6 to 8 minute brewing time. These times apply regardless of the equipment used, or the quantity being prepared. The finer the grind, the greater the surface area exposed to the water. That means the dissolved flavoring materials have a shorter distance to travel to reach the water; therefore, the solubles extraction is more rapid and thorough.

Hot water removes the coffee-flavoring solubles effectively and rapidly. This holds true both in quantity and quality. The coffee brew extracted during the beginning of the brewing cycle is very dense and dark caramel in color. As water extraction continues, the eluted (extracted) beverage becomes less concentrated and lighter in color. Near the end of the brewing cycle, the extract is pale and appears almost like water.

If the coffee brew was analyzed in terms of its flavor, as quantified by the solubles concentration and pH of the eluted beverage (See Diagram 1), one would find that the extract removed during the first third of the brewing process (samples 1-6) would have the best flavor with the least bitterness and astringency. It would also have the highest solubles concentration (ratio of coffee flavoring material to water) than at any other point in the brewing cycle, as well as the lowest pH (greatest acidity). If the coffee brew was analyzed during the second third of the extraction process (samples 7-12), this effluent would have an average solubles concentration three times lower than the first third, while exhibiting a decrease in acidity of almost five times the level of the first third.

If the brewing cycle continues through the final third (samples 13-18), the effluent coffee beverage would be unpalatable. During this phase, the desirable solubles have been exhausted and the solubles that produce bitterness and astringency have become dominant. The point at which bitterness and astringency dominate the coffee's taste characteristic is referred to as over-extraction.

DIAGRAM 1



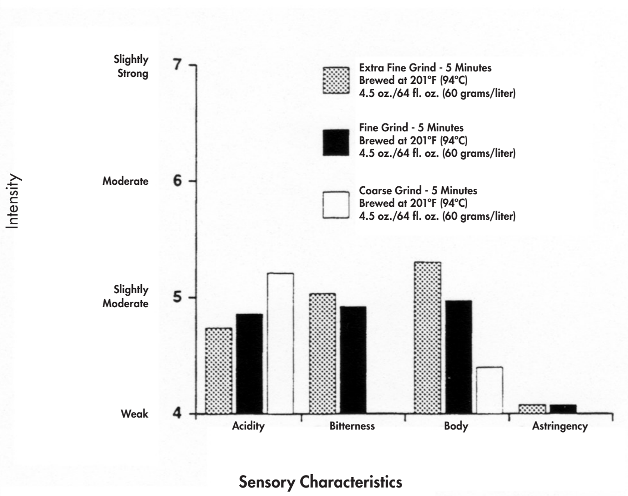
SOURCE: Braun inc. - engineering study

Time's Relationship to Extraction

As shown in Figure 1, controlling the grind is the most effective way to control the bitterness and astringency associated with over-extraction. Making the particle sizes larger will noticeably decrease these two taste flaws without seriously reducing the brew's acidity of body.

FIGURE 1

Effect of Grind Size on Coffee Taste and Mouthfeel



Source: ICO Technical Unit - Quality Series - Report No. 9

Chemical analyses indicate that all coffee brews contain very low concentrations of amino acids. However, those made from coarsely ground coffee contain a lower concentration of amino acids compared to brews made from finely ground coffee. Similarly, concentrations of other non-volatile acids vary with grind sizes. Acetic, citric, malic, and phosphoric acids appear in lower concentrations in brews made from coarsely ground coffee compared to brews made with either finely, or extra finely, ground coffees. Quinic acid increases as the grind size decreases, but the differences among concentrations are small.

Concentrations of chlorogenic acids and caffeine – two important components of the coffee beverage – clearly reflect the effect of grind size on the extraction of coffee solids. Tests have detected the highest concentrations of both in brews (extracts) prepared with extra finely ground coffee, intermediate amounts in brews made with finely ground coffee, and the lowest concentrations in brews prepared with coarsely ground coffee.

Compared to grind or temperature, brewing time plays a smaller role in determining the relative differences in the taste characteristics of acidity, bitterness, body, and astringency (See Figure 2). Once the brewing time is determined – usually by the design of the equipment – the coffee's flavor only can be controlled by selecting the correct grind.

TABLE 1

Chemical Changes Resulting from Variations in Grind Conditions

FATTY ACIDS, SUCROSE, ORGANIC ACIDS AND CAFFEINE CONTENT OF COFFEE BREWS PREPARED USING DIFFERENT BREWING CONDITIONS[1]

BREWING CONDITIONS

		Grind Change	
Coffee Grind	**Extra Fine**	**Fine**	**Coarse**
Brewing Temperature (°C)	94	94	94
Contact Time (min)	5	5	5
Coffee Constituent		**Concentration (mg/l)**	
Fatty Acids			
Palmitic acid (16:0)	3.63	5.90	5.03
Linoleic acid (18:2)	4.50	5.96	6.27
Sucrose[2]	37.33	126.67	126.67
Lactic acid	308.33	194.50	109.67
Acetic acid	209.00	225.67	242.67
Citric acid	440.00	461.00	325.00
Malic acid	163.67	137.00	119.33
Phosphoric acid	82.00	77.33	68.33
Quinic acid	510.00	495.00	435.33
Chlorogenic acids	1,177.00	1,064.67	700.00
Caffeine	727.67	685.00	531.33

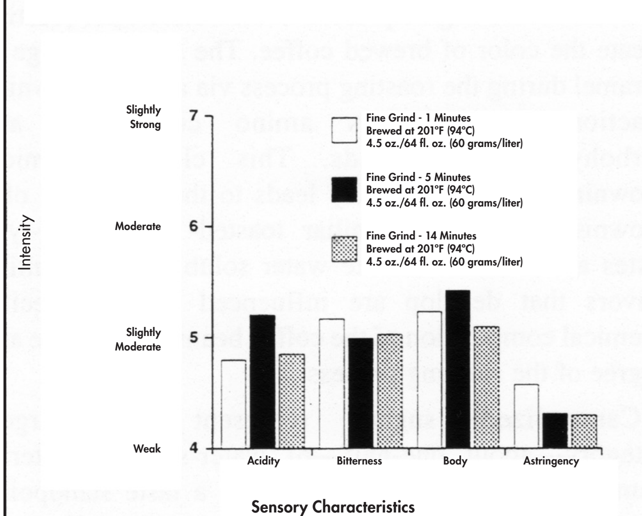
[1] Average of three coffee brew analysis

[2] Poor reproducibility of HPLC method due to the low content on all coffee brews

Source: ICO Technical Unit - Report No. 9

FIGURE 2

Effect of Grind Size on Coffee Taste and Mouthfeel



Source: ICO Technical Unit - Quality Series - Report No. 9

TABLE 2

Chemical Changes Resulting from Variations in Time Conditions

FATTY ACIDS, SUCROSE, ORGANIC ACIDS AND CAFFEINE CONTENT OF COFFEE BREWS PREPARED USING DIFFERENT BREWING CONDITIONS[1]

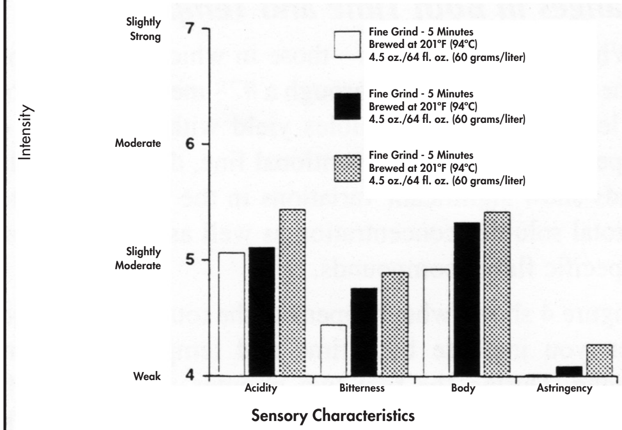
BREWING CONDITIONS			
		Time Change	
Coffee Grind	Fine	Fine	Fine
Brewing Temperature (°C)	94	94	94
Contact Time (min)	**1**	**5**	**14**
Coffee Constituent		**Concentration (mg/l)**	
Fatty Acids			
Palmitic acid (16:0)	4.97	5.90	5.87
Linoleic acid (18:2)	6.70	5.97	6.37
Sucrose[2]	135.00	126.67	275.00
Lactic acid	56.67	194.50	125.67
Acetic acid	261.00	225.67	242.00
Citric acid	343.33	461.00	355.33
Malic acid	109.33	137.00	100.33
Phosphoric acid	75.00	77.33	75.67
Quinic acid	525.00	495.00	556.67
Chlorogenic acids	955.33	1,064.67	988.33
Caffeine	665.33	685.00	688.67

[1] Average of three coffee brew analyses

[2] Poor reproducibility of HPLC method due to the low content on all coffee brews

FIGURE 3

Effect of Grind Size on Coffee Taste and Mouthfeel



Source: ICO Technical Unit - Quality Series - Report No. 9

Temperature's Effect on Taste

Second to grind, temperature has the greatest influence on the brew's taste attributes. Sensory evaluation shows that both acidity and body increase when the coffee is brewed at higher temperatures, whereas bitterness and astringency decrease with lower temperatures. The rate at which each chemical component in roast-and-ground coffee in contact with water is dissolved, not only is different because of each compound's nature, but also directly depends upon the temperature of the water at the time of extraction. Figure 3 illustrates the difference in sensory evaluation based on changes in brewing temperature.

TABLE 3

Chemical Changes Resulting from Variations in Temperature

FATTY ACIDS, SUCROSE, ORGANIC ACIDS AND CAFFEINE CONTENT OF COFFEE BREWS PREPARED USING DIFFERENT BREWING CONDITIONS[1]

BREWING CONDITIONS			
	Temperature	**Change**	
Coffee Grind	Fine	Fine	Fine
Brewing Temperature (°C)	**70**	**94**	**100**
Contact Time (min)	5	5	5
Coffee Constituent		**Concentration (mg/l)**	
Fatty Acids	3.26	5.90	6.53
Palmitic acid (16:0)	3.83	5.97	8.30
Linoleic acid (18:2)	83.33	126.67	110.00
Sucrose[2]	121.00	194.50	187.33
Lactic acid	151.33	225.57	187.00
Acetic acid	388.33	461.00	332.00
Citric acid	131.00	137.00	122.50
Malic acid	86.33	77.33	80.00
Phosphoric acid	348.33	495.00	383.33
Quinic acid	872.67	1,064.67	1,067.67
Chlorogenic acids	579.33	685.00	694.33
Caffeine			

[1] Average of three coffee brew analysis

[2] Poor reproducibility of HPLC method due to the low content on all coffee brews

Source: ICO Technical Unit - Report No. 9

Changes in Both Time and Temperature

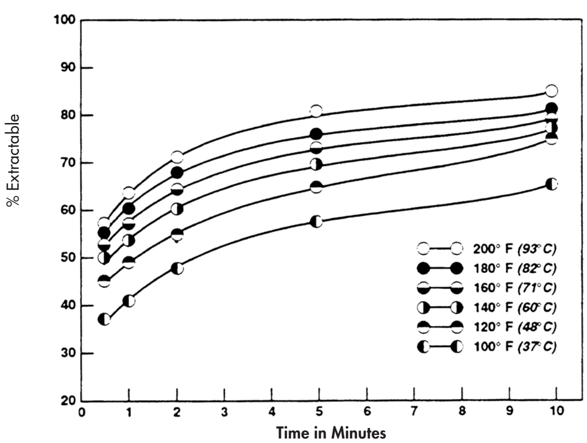
While extra fine grinds – those in which 70% or more of the particles will pass through a #28 mesh sieve – show the least variation in solubles yield with either time or temperature changes; conventional fine, drip, and regular grinds show significant variations in the extraction rates for total solubles concentration, as well as concentrations of specific flavor compounds.

Figure 4 shows what happens to the total soluble solids when both time and temperature during brewing are increased. During the first two minutes of brewing, the coffee grounds rapidly release soluble material. The solubles yield during this period is approximately 18%-20%, which represents 65%-75% of the available flavoring material. Although the rate of release remains similar for all time periods, the amount of soluble material released relates directly to the brewing temperature.

Figure 4 also shows that, in terms of quantity of flavoring materials released, only a slight change takes place between 2 and 5 minutes, but almost no change occurs between 5 and 10 minutes. Beyond 5 minutes of brewing time, the water has removed more that 80% of the available soluble material, which represents a solubles yield of approximately 24%. Because the goal in coffee brewing is to extract between 18% and 22% of the available flavoring material, this shows that brewing times greater than 5 minutes tend to result in bitter and astringent tastes, unless prepared from grinds that are sufficiently coarse.

FIGURE 4

Extraction Rates for Soluble Solids in Coffee Brew



Source: CBC Publication #47
(fine grind; commercial blend; 53.25 grams/liter;
A.O.A.C. methods of analysis, 8th ed. 1955)

Color in the Coffee Brew

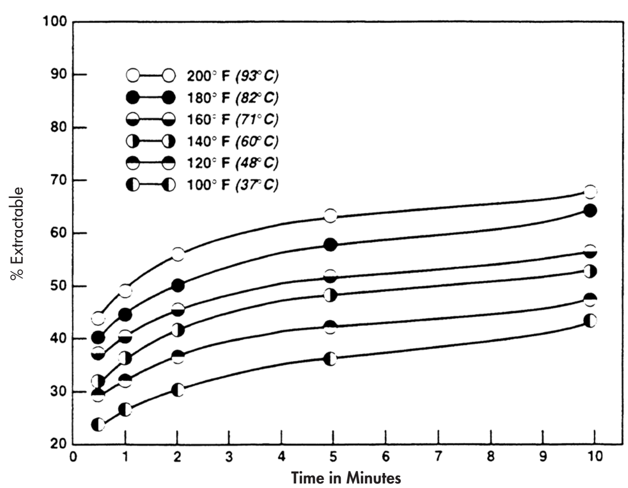
Caramelized sugars present in the coffee after roasting create the color of brewed coffee. The sugars change to caramel during the roasting process via a sugar-browning reaction that involves amino compounds and carbohydrate compounds. This classic chemical browning reaction typically leads to the formation of a brownish color and familiar toasted (or roasted) type tastes and aromas that are water soluble. The resulting flavors that develop are influenced by the specific chemical composition of the coffee beans and the rate and degree of the roasting process.

Caramelized sugars represent the largest category – about one-half of water-soluble material found in the coffee beverage. From a taste standpoint, they contribute to the overall perceived caramel-like taste of the coffee beverage. Their contributions to coffee's aroma are difficult to assess because of the great number, complexity, and stability of the aromatic compounds. In general, the caramelized sugars tend to contribute the aromatic sensation perceived as nutty, caramelly, or chocolaty.

Pigmentation (often referred to as color) is an approximation of the amount and degree of caramelized sugars entering the extracted beverage. As Figure 5 indicates, the majority of the extractable material related to color enters the brew within the first 2 minutes of the brewing cycle and depends upon the water reaching the correct temperature.

FIGURE 5

Extraction Rates for Color in Coffee Brew



Source: CBC Publication #47
(fine grind; commercial blend; 53.25 grams/liter;
A.O.A.C. methods of analysis, 8th ed. 1955)

Other Brew Components

Table 4 illustrates how both the amount of coffee solubles and the brew's chemical composition change during the extraction process. A comparison of extraction rates for a 2-minute contact time at a temperature of 200ºF (*94ºC*) – the conditions recommended for coffee brewing – showed the highest rate for trigonelline, followed by caffeine, soluble solids, chlorogenic acid, phenolic compounds (originally and incorrectly classified as tannins), and color. Therefore, it appears that extraction proceeds more rapidly for trigonelline and caffeine under normal brewing conditions than for the other components.

TABLE 4

Average Values for Selected Components in Coffee Brew

Time in minutes	Soluble soilds	Color dry basis	Caffeine dry basis per g	Trigonelline	Chlorogenic acid dry basis	Phenolic Compounds
200°F Temp. (93°C)	(%)		(%)	(%)	(%)	(%)
0.0	13.8	73	0.77	0.69	2.69	1.06
1.0	15.2	81	0.86	0.76	3.00	1.23
2.0	17.3	93	0.99	0.83	3.54	1.36
5.0	19.5	108	1.07	0.88	4.15	1.52
10.0	20.4	113	1.10	0.89	4.37	1.57
180°F Temp. (82°C)						
0.5	13.5	68	0.75	0.66	2.58	0.91
1.0	14.7	75	0.79	0.72	2.82	1.12
2.0	16.5	85	0.92	0.76	3.33	1.27
5.0	18.9	98	1.02	0.87	3.92	1.49
10.0	19.6	107	1.06	0.88	4.16	1.51
160°F Temp. (71°C)						
0.5	12.8	63	0.67	0.58	2.36	0.51
1.0	13.4	67	0.71	0.67	2.51	0.63
2.0	15.3	73	0.81	0.73	2.96	0.84
5.0	17.9	90	0.98	0.88	3.72	1.00
10.0	19.0	94	1.07	0.88	3.84	1.37
140°F Temp. (60°C)						
0.5	12.3	54	0.59	0.52	2.23	0.45
1.0	12.6	59	0.68	0.65	2.30	0.50
2.0	13.7	64	0.72	0.68	2.67	0.70
5.0	16.9	82	0.92	0.85	3.39	0.89
10.0	18.6	89	1.02	0.88	3.73	1.23
120°F Temp. (48°C)						
0.5	11.0	50	0.57	0.51	2.08	0.30
1.0	12.2	53	0.67	0.64	2.22	0.47
2.0	12.9	58	0.67	0.66	2.63	0.65
5.0	15.7	71	0.86	0.81	2.98	0.83
10.0	18.2	80	0.99	0.86	3.49	1.17
110°F Temp. (37°C)						
0.5	9.04	40	0.48	0.40	1.58	0.23
1.0	9.43	42	0.50	0.48	1.69	0.29
2.0	11.60	49	0.58	0.62	2.26	0.47
5.0	14.30	62	0.77	0.77	2.68	0.47
10.0	15.80	65	0.82	0.79	2.98	0.77

Source: CBC Publication #47

Extraction rates for each compound increased with increasing temperatures of extraction. In respect to time, extraction rates for soluble solids, pigmentation (color), and chlorogenic acid increased during the 10-minute brewing period, although the increase was less pronounced after the first two minutes. Extraction rates decreased in the following order: trigonelline, caffeine, soluble solids, chlorogenic acid, phenolic compounds, and pigmentation (color). Time had no apparent effect on extraction rate after the first five minutes for trigonelline at temperatures from 140ºF (*60ºC*) to 200ºF (*94ºC*).

Table 4 also suggests that the bitterness and astringency experienced in over-extraction results from a build-up in the concentrations of chologenic acids and phenolic compounds during the later stages of the brewing process. Possibly, the non-volatile acids are interacting with the higher levels of potassium found in the minerals – ashes (salts) present in brewed coffee that may contribute to the displeasing aspects of over-extracted brews. The exact causes of the flavor change created by over-extraction are currently not known.

Here are brief descriptions of the five major components of coffee brew:

- **Trigonelline.** A bitter organic compound that occurs naturally in green coffee at about 1% by weight (the same percentage as caffeine in Arabica coffees). Light roasting will degrade about 10% of the trigonelline when bean temperatures rise above 425ºF (*218ºC*). When bean temperatures reach 455ºF (*235ºC*), as in medium to moderately dark roasts, as much as 80% of the trigonelline can be degraded. For very dark roasts, above bean temperatures of 475°F (*246°C*), nearly 100% of the trigonelline will be degraded.

TABLE 5

Chemical Composition of Brewed Coffee[1]

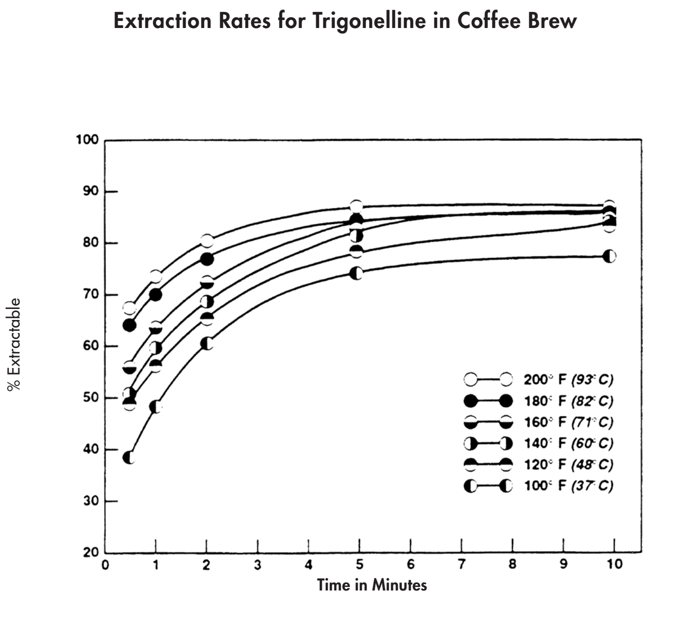
Constituent	Rothfos (1986)	Pictet (1987)	Sivetz (1987)
Polysaccharieds (%)	24.00	24.10	—
Soluble Carbohydrates (%)	—	—	35.00
Chlorogenic Acids (%)	14.80	15.00	—
Minerals-Ashes (%)	14.00	14.10	16.00
Proteins (%)	6.00	6.00	5.00
Caffeine (%)	4.80	4.80	5.00
Trigonelline (%)	1.60	1.60	—
Monosaccharides (%)	0.40	1.20	—
Carboxylic Acids (%)	—	3.00	—
Non Volatile Acids (%)	1.60	—	31.00
Volatile Acids (%)	1.40	—	—
Saccharose (%)	0.80	—	—
Lipids (%)	0.80	—	1.00
Volatile Aromatic Substances (%)	0.40	—	2.00
Nicotinic Acidds (%)	0.08	—	—
Unknown Substances (%)	29.40	29.90	—

[1] Percentages given on a dry basis.
Compositions reported are as published by authors.

Source: ICO Technical Unit - Report No. 9

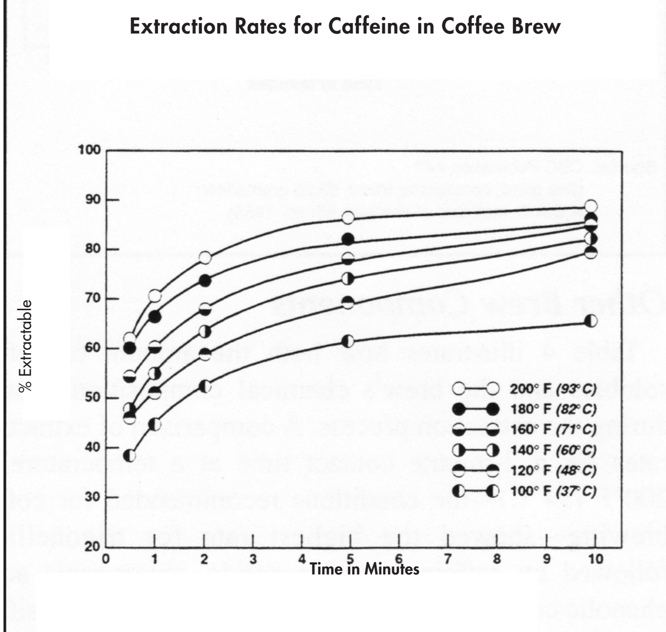
As shown in Figure 6, more than 80% of the available trigonelline enters the eluted beverage during the first two minutes of the brewing cycle. Time has no apparent effect after the first five minutes for this component at temperatures of 180ºF (*82ºC*), 160ºF (*71ºC*), and 140ºF (*60ºC*). The very slight difference for 200ºF (*94ºC*) is not significant.

FIGURE 6



Source: CBC Publication #47
(fine grind; commercial blend; 53.25 grams/liter;
A.O.A.C. methods of analysis, 8th ed. 1955)

FIGURE 7



Source: CBC Publication #47
(fine grind; commercial blend; 53.25 grams/liter;
A.O.A.C. methods of analysis, 8th ed. 1955)

- **Caffeine.** Along with other alkaloids such as quinine and strychnine, caffeine is a bitterness stimuli for taste receptors on the back of the tongue. In its pure form, caffeine is a white, crystalline powder that is odorless, but has a bitter taste. Caffeine has no significant effect on the perception of saltiness or sweetness in the brew, but significantly enhances the perception of sourness and bitterness.

Arabica beans contain caffeine at approximately 1.1% by weight and Robusta beans at approximately 2%-2.2% by weight. Caffeine also is found in tea leaves (2.0%-4.0% by weight), cola nuts (1.5% by weight), and cocoa pods (0.1% by weight).

Chemically, caffeine remains stable during the roasting process, except for minute amounts sublimed at temperatures above 300°F (*149°C*) that collect in roaster exhaust pipes. Reduced roasting temperatures and lighter roasts reduce caffeine loss.

As shown in Figure 7, caffeine is readily water-soluble at temperatures above 175°F (*80°C*). More than 80% of the available caffeine enters the eluted beverage within the first two minutes of the brewing cycle. Caffeine values for the two highest temperatures tend to level off after the first two minutes. For temperatures of 160°F (*71°C*), 140°F (*60°C*), and 120°F (*49°C*), caffeine levels gradually increase over the 10-minute period. For the 100°F (*37°C*) temperature, values begin leveling off after the first two minutes.

- **Chlorogenic acid.** Chlorogenic acid occurs in green coffee at about 7%, but roasting decomposes about one-third to one-half of it. Chlorogenic acid, which is completely water soluble, greatly affects the ultimate taste of the brew. It constitutes between 12% and 18% of the total solubles.

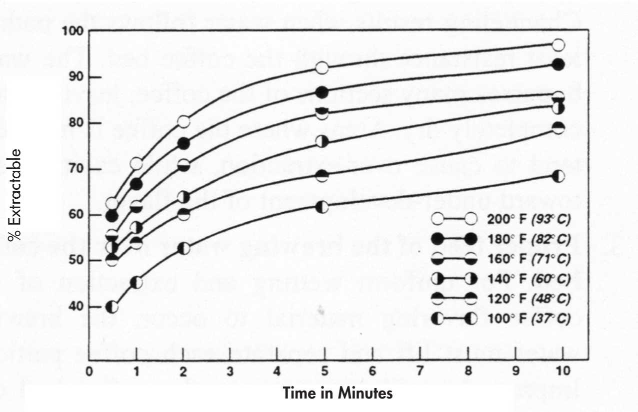
The organoleptic (sensory) properties of chlorogenic acids haven't been studied in depth, but it is generally believed that they tend to have slightly bitter but markedly pronounced astringent characteristics. The lower chlorogenic acid contents of Arabica coffees presumably relate to the superior beverage quality of those coffees. Also, it's believed that chlorogenic acids are part of the lingering bitter aftertaste associated with some coffees.

When heated, chlorogenic acid breaks down into caffeic and quinic acids. This breakdown increases the total acid content of the beverage, which can be measured as a pH change. Such acid increases and changes bring unpleasant taste changes, creating an acerbic (bitter and sour) beverage taste.

Chlorogenic acids can be divided into three broad classifications, each showing a slightly different chemical composition. Studies have shown that each classification reacts in a distinctly different manner during the roasting process. Some are destroyed rapidly, and others appear at virtually identical levels for dark roasted coffees.

FIGURE 8

Extraction Rates for Chlorogenic Acid in Coffee Brew



Source: CBC Publication #47
(fine grind; commercial blend; 53.25 grams/liter;
A.O.A.C. methods of analysis, 8th ed. 1955)

Figure 8 shows the rapid extraction of chlorogenic acids during the first minutes of the brewing cycle. While the extraction rate tends to level off after the first five minutes, extraction of chlorogenic acid during the last five minutes is greater than that of either caffeine of trigonelline.

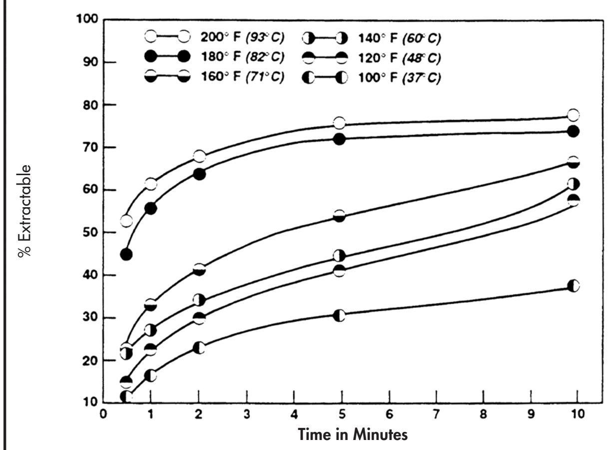
- **Phenols.** Usually present in light roasted coffee beans at fairly low concentrations, phenols increase as roasting continues. They have smoky, burnt, spicy, clove-like, and bitter aromas, and also impart astringency to the beverage taste. Dark-roast and Robusta coffees tend to have relatively high concentrations of phenols.

  Phenolic compounds correlate more with the intensity of astringency rather than bitterness. In the early research on chemical compounds contained in coffee, those relating to astringency were thought to be tannins, similar to those found in tea.

  As Figure 9 illustrates, extraction of phenolic compounds tends to level off after the first two minutes of brewing time for temperatures of 200°F (*94°C*) and 180°F (*82°C*). However, marked increases occur over the 10-minute period for temperatures of 160°F (71°C), 140°F (*60°C*), and 120°F (*48°C*). The curve of 100°F (*37°C*) remains comparatively flat.

FIGURE 9

Extraction Rates for Phenolic Compounds in Coffee Brew



Source: CBC Publication #47
(fine grind; commercial blend; 53.25 grams/liter;
A.O.A.C. methods of analysis, 8th ed. 1955)

- **Potassium.** In brewing roast-and-ground coffee, approximately 90% of the mineral constituents, particularly the potassium, is extracted into the brew. Like caffeine and chlorogenic acid content, potassium is found in greater amounts in Robusta-type coffees compared to Arabica coffees.

  Like all salts, there is a correlation between the concentration of the salt and its perceived taste. Increasing concentrations of potassium initially start as sweet, change to bitter, become salty and finally become sour. It is also possible that the potassium present in the brew is interacting with other taste components by modulating the type or intensity of their taste stimulation. Further research is needed to more fully understand the potassium's effect on the brew.

TABLE 6

Estimated Coffee Ash Distribution

	Green Coffee	Roast Coffee	Soluble Powder	Dry Spent Grounds
Dry weight relations[1]	1.176	1.00	0.380	0.620
Percent ash content, dry basis	4.00	4.71	10.00	1.47
Weight ash per unit weight roast coffee, dry basis	0.0471	0.0471	0.038	0.0091

Percentage Distribution of Ash Components

Mineral Oxide	Percent Total: Green, Roast Ash %	Solubles Ash % Total	Solubles Ash % Sol	Grounds Ash % Tol	Grounds Ash % Grds.
K_2O	62.5	52.0	75.59	10.5	33.65
P_2O_3	13.0	3.0	4.36	10.0	32.05
CaO	5.0	2.0	2.90	3.0	9.62
MgO	11.0	8.0	11.63	3.0	9.62
Fe_2O_3	1.0	0.4	0.58	0.6	1.92
Sa_2O	0.5	0.4	0.58	0.1	0.32
SiO_2	1.0	—	—	1.0	3.21
SO_3	5.0	2.0	2.90	3.0	9.61
Ci	1.0	1.0	1.46	—	—
	100.0	68.8	100.00	31.2	100.00

[1] Assuming 15 percent weight loss on roasting.

Source: Sivetz and Desrosier, Coffee Technology

Turbulence's Influence on Brewing

After time and temperature, turbulence is the third factor that affects coffee brewing. Turbulence causes coffee particles to separate and thereby allow for a uniform flow of water through and past them. Without sufficient turbulence, the water will fail to uniformly extract flavoring materials from all portions of the coffee bed. In this situation, some sections of the coffee bed are under-extracted, adding grassy to peanut-like flavors to the brew, while other sections are over-extracted, mixing bitter and astringent tastes into the brew.

The three aspects of turbulence are:

1. **Wettability** of the coffee grounds. For extraction to occur, the coffee particles must first absorb water. Wettability, a characteristic of roast-and-ground coffee, relates to the coffee's ability to absorb water at a uniform rate. As a general rule, each ounce of coffee will absorb two ounces of water *(each gram will absorb 2.086 ml of water)*.

   Principally, the interstitial voids within each particle of coffee absorb the water. Once the water has completely surrounded a coffee particle (both inside and out), the coffee flavoring material begins to move out of the bean's cellular structure and into the surrounding water.

   Some coffee particles accept water more readily than others. This condition can be attributed to a variety of factors, including the origin of the coffee, the age of the green coffee, non-uniform roasting of the coffee bean, or an excess of oil surrounding the cellular structure of the ground particle. Surges of carbon dioxide gas from freshly ground coffee, which form a protective envelope around each particle, can also contribute to incomplete wetting. In addition, unusually high concentrations of minerals in the brewing water, particularly calcium (Ca) and sodium (Na) bicarbonate (HCO_3), will interfere with the wetting process.

   Non-uniform wetting causes inconsistent extraction. It tends to create a channeling of the water flow; some portions of the coffee bed are over-extracted, due to excessive water flow, while other portions deliver under-developed flavors because the coffee particles weren't fully extracted. This problem becomes readily apparent in equipment using relatively short brewing times, particularly single-cup brewers.

2. **Control of the bed height.** The coffee bed must be level, and in gravity-fed brewing system, should measure from 1 to 2 inches (*2.5-5.0 cm*) in depth. If the brewing equipment doesn't meet these conditions, under-or-over-extraction and inconsistency follow.

   Beds less than 1 inch (*2.5 cm*) high will lead to a light, bitter brew. Those that exceed 2 inches (*5.0 cm*) slow down the cycle and channel the water flow, thus creating off-flavors and bitter taste. Channeling results when water follows the path of least resistance through the coffee bed. The water bypasses many sections of the coffee, leaving them completely dry. Areas where the coffee is mounded tend to cause over-extraction, while cavities tend toward under-development of the flavor

3. **Proper feed of the brewing water over the coffee bed.** For uniform wetting and extraction of the coffee flavoring material to occur, the brewing water must lift and separate each coffee particle. Improperly applying water to the coffee bed can contribute to a faulty brew. Correct water feed depends upon the brew basket and spray head working on concert.

   In addition to creating the proper bed depth of 1-2 inches (*2.5-5.0 cm*), the brew basket must be large enough to allow the coffee grounds to expand. During brewing, they swell up to approximately 50% of their original size. Therefore, a coffee-bed depth of 2 inches (*5.0 cm*) requires a brew-basket depth of at least 3 inches (*7.6 cm*).

The brew basket must also regulate the flow of the water through the coffee bed. Ideally the flow is restricted, so that the coffee particles remain in constant suspension in a pool of water throughout most of the brewing cycle. This requires that the exit spout of the brew basket allows a smaller amount of water to flow out than is dispersed by the spray head – but not so little that the brew basket overflows.

Feeding water to the ground coffee must be done uniformly and gently to ensure that the entire area of the coffee bed receives equal treatment. If one section of the bed is wetted down with more pressure than other areas, the brew will be totally inconsistent and over-extracted. When manually feeding water, for example, pour it slowly, and in a circular fashion, to guarantee complete and uniform wetting.

When brewing equipment feeds the water automatically, the design of the spray head becomes of prime importance. To determine the spray head's efficiency, examine the spent coffee grounds after the brewing cycle has ended. The entire bed should be uniformly wetted, particularly around the sides of the brew basket. A light tan foam spread evenly on the surface of the grounds should be seen. If the foam presents a discernible pattern reflecting the number and placement of water delivery points in the spray head, it indicates segregated flow dynamics and probable channeling in the coffee bed.

In some volume-brewing situations, all of the water may not be able to pass through the bed of coffee in the prescribed amount of time. This is particularly true when the bicarbonate content of the brewing water is high enough to restrict the water flow. In these cases, it may be necessary to divert some of the water (up to 40%) around the coffee. This procedure, known as "bypassing," prevents over-extraction.

Brewing Standards

Table 7 summarizes the standards that must be met to produce a flavorful beverage – one that has been extracted properly from roast-and-ground coffee and contains the ideal amount and composition of flavor compounds.

TABLE 7

Standards Established for Brewing Coffee by the Coffee Brewing Center (USA) and the Nordic Coffee Center (Norway)

Standard	CBC[1]	NCC[2]
STRENGTH (% Solubles Concentration)	1.15 - 1.35%	1.30 - 1.55%
EXTRACTION (% Solubles Yield)	18 - 22%	18 - 22%
BREWING FORMULAS (Coffee to Water Ratios)	3.25 - 4.25 OZ. per 64 FL. OZ.	60 - 70 grams per 1.0 liter
BREWING TEMPERATURE	195 - 205° F	92 - 96° C
BREWING TIME	1 to 4 min. - fine grind 4 to 6 min. - drip grind 6 to 8 min. - regular grind	1 to 5 min. - fine grind 5 to 8 min. - coarse grind
HOLDING TEMPERATURE	175 - 185° F	80 - 85° C

[1] *Source: The Coffee Brewing Center (1966) Equipment Evaluation Publication No. 126. New York.*

[2] *Source: The Norwegian Coffee Brewing Center (1980) Evaluation and Approval of Home Coffee Makers Publication No. 6B.*

CHAPTER 7
WATER

Coffee drinkers in the United States consume more than 18 million bags – or approximately 2 billion pounds – of coffee each year. Assuming that each pound of coffee is prepared with about 3 gallons of water, slightly more than 6 billion gallons of water are needed annually to quench the U.S. population's thirst for coffee. Because it typically represents 98%-99% of the coffee beverage, water understandably has a major influence on beverage quality.

Pure water is a simple combination of two gases, hydrogen and oxygen. When they unite, these gases form a familiar liquid. Of course, water can take on other physical forms as well. When the temperature drops below 32°F (*0°C*), it solidifies as ice. When the temperature rises above the 212°F (*100°C*), water becomes a gas, as steam. It will also contain hydrogen (H+) and hydroxide (OH-) ions that alter its chemical properties.

As usually encountered, water is never pure. It contains many chemical compounds in an infinite variety of combinations and concentrations. Some of these materials, if presented in relatively large amounts, can cause unusual tastes, odors, and colors. These are called dissolved, or soluble, materials because they form such an intimate and complete a mixture with the water, that even filtration cannot separate them.

Water may also contain undissolved (or insoluble) materials. Some of these are living organisms, such as bacteria or molds that aren't usually visible, or even large visible organisms. Insolubles may also include non-living materials, such as fine dirt and sand. Municipalities use filters or fine screens to remove the undissolved or suspended material and also chemically treat water intended for human consumption to destroy any living organisms it may contain.

Regional Differences

The U.S. Department of Interior views water as a valuable natural resource and has compiled information about all of the principal water supplies used by more than 2,300 of the country's largest cities and towns. Table 1 shows several examples of chemical analyses of water supplies and illustrates the wide variation of chemical composition that can occur. In fact, every water supply is unique because it comes in contact with different soil and receives different municipal treatments.

Some local water supplies have high levels of certain mineral ions. For example, salt-water intrusion into Galveston's (Texas) water supply gives it more than 400 parts per million (ppm) chlorides. Sarasota's (Florida) has 800 ppm sulfates. Deep wells in Michigan and certain arid geographical areas have more than 1,000 ppm minerals, creating a high enough alkaline taste to be considered brackish.

Standards for Drinking Water

Virtually all of the water (99%) flowing out of municipal taps is used for general purposes – watering lawns, washing clothes and dishes, disposing of waste, fighting fires, and so forth. Less than 1% is destined for consumption in food and beverages. With so much water literally poured down the drain, cities do not find it economically feasible to use treatments that produce top-quality drinking water.

To qualify as safe to drink, according to the U.S. Public Health standards, water must be clear, odorless, and tasteless. It must be free of bacteria and contain less than the following: 0.2 ppm of copper, 0.3 ppm of iron, 250 ppm of sulfates, 250 ppm of chlorides, 100 ppm of magnesium, and 1,000 ppm of total dissolved solids. The standards also specify no more than 10 ppm alkalinity (but no caustic alkalinity) and less than 50 ppm of sodium or potassium alkalinity.

Water that is safe to drink, however, does not necessarily

TABLE 1

Analyses of Water Supplies Used by Large Cities in the United States

Component	City											
	Boston, MA	New York, NY	Chicago, IL	Los Angeles, CA	San Francisco, CA	Indianapolis, IN	Cleveland, OH	St. Louis, MO	Kansas City, KS	Galveston, TX	Sarasota, FL	Pittsburgh, PA
(Fe) Iron	0.10[1]	0.03	0.09	0.04	0.02	0.11	0.12	0.01	0.01	0.00	0.56	0.30
(Ca) Calcium	4.00	13.00	39.00	25.00	1.10	67.00	39.00	23.00	75.00	30.00	14.00	60.00
(Mg) Mangnesium	0.40	4.30	10.00	5.00	1.40	20.00	7.30	9.70	22.00	9.70	0.30	18.00
(Na) Sodium	1.80	3.00	3.30	34.00	0.40	6.20	8.70	33.00	59.00	351.00	530.00	49.00
(K) Potassium	0.70	1.40	0.70	4.00	–	1.60	1.30	33.00	5.60	351.00	16.00	49.00
(CO_3) Carbonate	0.00	0.00	0.00	2.00	0.00	0.00	0.00	13.00	0.00	0.00	0.00	0.00
(HCO_3) Bicarbonate	7.00	36.00	132.00	138.00	7.00	206.00	103.00	20.00	237.00	336.00	161.00	17.00
(SO_4) Sulfate	5.60	20.00	23.00	23.00	1.60	67.00	30.00	109.00	172.00	1.00	817.00	248.00
(Cl) Chloride	3.40	5.80	7.20	17.00	1.00	10.00	20.00	17.00	29.00	422.00	168.00	58.00

[1] All data given in ppm

Source: CoffeeBrewing Center Publication No. 6 make the best coffee. Although safe and acceptable for general use, municipal water often carries tastes and odors that can become objectionable when used for food or beverage preparation.

Potential Problems

When considering the level at which impurities in the water will react adversely with coffee's flavor, it is important to view their concentration in relationship to the concentration of coffee flavoring material.

For example, a coffee beverage containing 1.0% coffee and 99.0% water has a concentration of 10,000 parts of coffee flavoring material for each 1 million parts of water. If the coffee is brewed with water containing 100 ppm total dissolved solids, the resulting mixture of dissolved solids to coffee flavoring material is 100-10,000 or 1.0%. Depending on the type and nature of the dissolved solids, a 1.0% concentration is high enough to affect the coffee's flavor, even though the concentration level in the water (100 ppm) produces no detectable odor or taste.

Regard a water supply as a potential source of brewing problems if it has any of the following characteristics:

- **A total dissolved solids content above 300 ppm.** Generally speaking, water with a total dissolved solids content below 300 ppm will not cause brewing problems. In fact, a level of dissolved solids between 100 and 200 ppm gives water the "crystal fresh" taste of mountain spring water.

  Demineralized water, which contains less than 10 ppm of dissolved solids, is not recommended for coffee brewing. During the 1960s, the CBI conducted extensive studies to establish taste thresholds for both water and coffee containing the minerals most commonly found in municipal drinking water. Table 2 shows the point at which the average person begins to detect various minerals.

  Therefore, if the total concentration of dissolved solids of all types is below 300 ppm, there should not be a problem in brewing coffee, unless the mixture of dissolved solids also contains iron.

- **An iron content above 2 ppm.** Preparing coffee with water that contains iron at concentrations as low as 10 ppm, yields a beverage that stands out, not because of flavor changes, but for changes in color or appearance – particularly when cream is added. Although the concentration in the water is extremely low, the iron combines with the phenols in the coffee extract to produce typical greenish (iron-like) colors. Differences are detectable even at 1 ppm levels of concentration. At levels ranging from 4 to 7 ppm, some question of acceptability arises. At levels exceeding 7 ppm one can readily perceive a very definite and unpleasant greenish cast.

- **A combined calcium and magnesium content above 100 ppm.** Calcium and magnesium are principal elements in the earth's crust. They dissolve in water as it percolates through the soil. The build-up of dissolved calcium and magnesium make water hard and is responsible for scaling, liming, and other undesirable mineral deposits on brewing equipment. These deposits occur as the water is heated and the calcium and magnesium combine with silica, sulfate, and carbonate to precipitate out of solution and attach to metallic surfaces. While not directly affecting the flavor of the brew, scale and lime deposits in boilers prevent efficient heating of the water, cause failure of thermostat-relay operation, block inlet and feed pipes, and lead to other difficulties that cause brewing equipment to malfunction.

TABLE 2

Threshold Concentration of Ions in Water Solution and Concentration in Coffee Beverage

Ion	*Threshold in Water ppm*	*Concentration Detectable in Coffee Beverage ppm*
$NaHCO_3$		
Na^+	290	377
HCO_3^-	770	1000
Na_2CO_3		
Na^+	34	96
$CO_3^=$	44	125
Na_3PO_4		
Na^+	75	–
$PO_4^=$	105	–
NaAc		
Na^+	140	–
Ac^-	360	–
NaCl		
Na^+	135	258
Cl^-	210	400
KCl		
K^+	340	410
Cl^-	310	450
KAc		
K^+	680	–
Ac^-	1020	–
$CaCl_2$		
Ca^{++}	125	300
Cl^-	222	530
MgSO		
Mg^{++}	100	200
$SO_4^=$	400	800
$Fe(SO_4)_3$		
Fe^{+++}	10	10
$SO_4^=$	25	25

Source: Coffee Brewing Center Publication No. 6

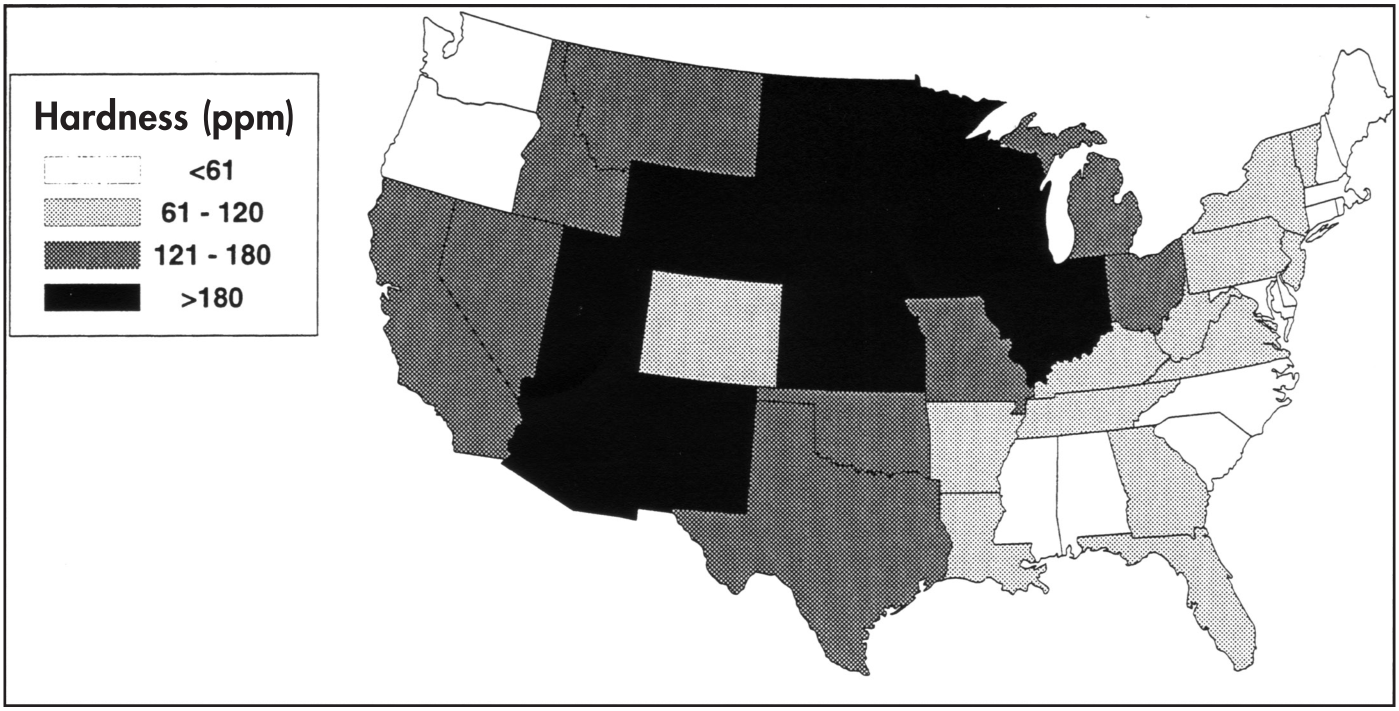


TABLE 3

City Waters as Received

	pH	Hardness (as $CaCO_3$) ppm	Sodium (as NaCl) ppm	Potassium (as KCl) ppm	Carbonate (as CO_3–) ppm	Bicarbonate (as HCO_3–) ppm
Dallas, TX	8.6	421	299	3	nil	439
Los Angeles, CA	9.1	266	115	7	nil	210
Denver, CO	8.5	116	64	3	nil	89
Memphis, TN	8.9	63	29	2	nil	94
Philadelphia, PA	8.1	89	27	4	nil	45
Woonsocket, RI	5.0	16	7	1	nil	11
Providence, RI	8.3	33	9	1	6	18
Boston, MA	7.0	16	7	1	nil	14

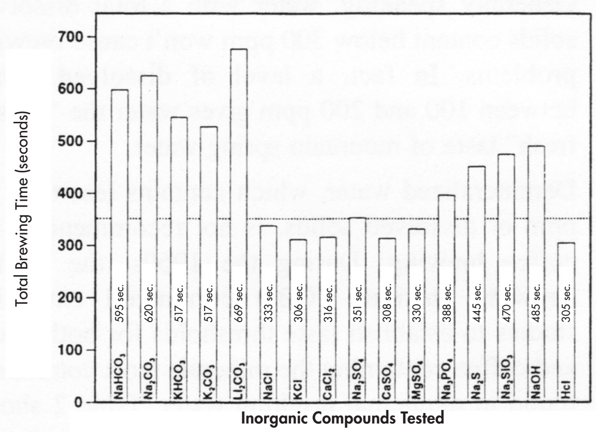
Four City Waters After Softening

	pH	Hardness (as $CaCO_3$) ppm	Sodium (as NaCl) ppm	Potassium (as KCl) ppm	Carbonate (as CO_3–) ppm	Bicarbonate (as HCO_3–) ppm
Dallas, TX	9.2	18	963	2	nil	461
Los Angeles, CA	9.5	9	700	5	nil	306
Denver, CO	9.6	6	350	3	nil	77
Philadelphia, PA	7.8	7	155	1	nil	75

Source: Coffee Brewing Center Publication No. 311

FIGURE 1

Brewing Times of 400 ppm of Various Inorganic Compounds in Deionized Water



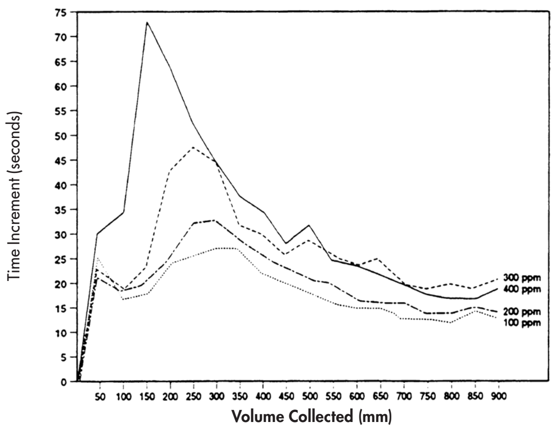
Note: Reference line at 350 seconds is brewing time using pure deionized water.
Source: Coffee Brewing Center Publication No. 31

- **A carbonate-bicarbonate alkalinity above 100 ppm.** More than any other group of compounds normally found in municipal water supplies, carbonates and bicarbonates retard the flow of water through the coffee bed, especially when their concentration exceeds 100 ppm (See Figure 1). The greatest change of the flow rate occurs at the beginning of the brewing cycle (See Figure 2). The flow rate decreases as the concentration of carbonate-bicarbonate compounds increases (See Figure 3). The retarding effect can be so great that it prevents all the water from passing through the coffee bed within an acceptable time. In these instances, the coffee brewing system requires the addition of a water bypass device.

The flow-rate problem is further compounded if the water has been treated by a zeolite softening system. Through ion exchange, this process replaces the minerals in the water – principally calcium and magnesium – with sodium. When combined with the bicarbonates already in the water, the sodium bicarbonate forms a shiny, slimy material that binds the coffee particles together and blocks the passageways through which the water would normally flow. As shown in Figure 4, this extends the brewing time, thereby causing over-extraction of the flavoring material and leading to excessive astringency and bitterness.

FIGURE 2

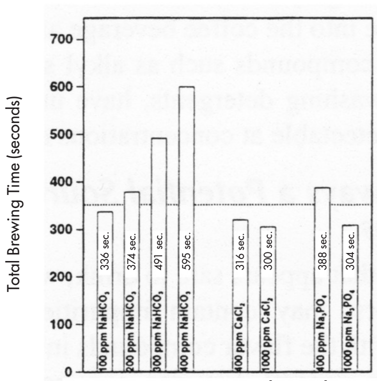
Time Effect of Varying the Sodium Bicarbonate Concentration on the Brewing Rate



Source: Coffee Brewing Center Publication No.31

FIGURE 3

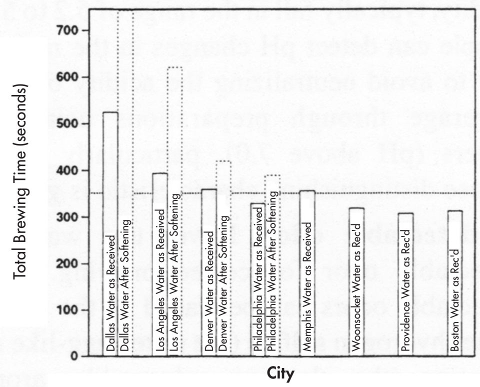
Effect on Total Brewing Time of Varying Concentrations of Compounds in Solution



Note: Reference line at 350 seconds is brewing time using pure deionized water.
Source: Coffee Brewing Center Publication No. 31

FIGURE 4

Effect on Zeolite Softening Process on the Total Brewing Time of Carbonate Hard Waters



Note: Reference line at 350 seconds is brewing time using pure deionized water.
Source: Coffee Brewing Center Publication No. 31

- **A combined sodium-potassium content above 50 ppm.** At low concentrations, these salts actually add to the perception of sweetness in the brew. However, as its concentration increases, the sodium tends to increase the perception of sourness in the fruit acids present in the beverage. At the same time, the potassium increases the perception of the bitterness of the phenolic compounds present in the brew. Fortunately, few municipal water systems are plagued by excessive concentrations of either sodium or potassium.
- **An Acidity (pH) below 7.0 and alkalinity (pH) above 7.0.** Pure water has a pH of 7.0. Chemically, its pH is neutral, acting neither as an acid nor a base. At this point an equal number of hydrogen and hydroxide ions are present in the water. (Note: The pH scale values, which range from 0.00 to 14.0, are exponential: As they decrease from 7.0, each pH whole number indicates 10 times greater concentration of hydrogen ions; as they increase from 7.0, each pH whole number indicates 10 times greater concentration of hydroxide ions.

As the pH measurement of the water decreases below 7.0, it shows an increase in the presence of hydrogen ions, which lead to aqueous solutions that have sour tastes. In addition, when water becomes a weak acid because of an excess of hydrogen ions, it tends to increase the water solubility of other compounds. As the pH measurement of the water increases above 7.0, it shows an increase in the presence of hydroxide ions, which lead to aqueous solutions that have bitter tastes. In addition, when water becomes a weak base because of an excess of hydroxide ions, it tends to reduce the acidity of aqueous solutions through the formation of salts.

Coffee usually has an acidity of approximately 5.0 on the pH scale. Acidy coffees will reach a pH between 4.7 to 4.8, while mild coffees range from 4.9 to 5.1. Robusta coffees, noted for their lack of acidity, typically fall in the range of 5.2-5.5. Most people can detect pH changes in the range of 0.1. Try to avoid neutralizing the acidity of the coffee beverage through preparations using alkaline waters (pH above 7.0), particularly for coffees whose distinguishing characteristic is good acidity.

- **A detectable odor.** Never use water with a detectable odor for coffee brewing. Generally, detectable odors can be traced to the presence of hydrogen sulfide (the rotten egg-like aroma), chlorine (the cleaning solvent-like aroma), or ammonia (the uric acid-like aroma). Different odors in water may also be the result of decaying organic material.

  Hydrogen sulfide, a problem in some southern states, is easily detectable at low levels of concentration – 0.05 ppm in water and 0.12 ppm in coffee. Water containing hydrogen sulfide can normally be treated by adding chlorine to oxidize the hydrogen sulfide before using it to brew coffee.

Chlorine Treatment

Municipalities commonly add chlorine to water to kill any bacteria present. Because it is easy to use, readily available, inexpensive, and effective, chlorine has become a popular anti-bacteria agent. More than 96% of people living in municipalities have access to water treated with chlorine.

When treatment is properly done, the chlorine completely oxidizes as it attacks the bacteria and leaves no residue. Most municipalities, however, choose to over-chlorinate the water to make absolutely certain it cannot transport infectious bacteria. Consequently, residual chlorine in municipal water supplies is a common problem when brewing coffee.

Chlorine by itself has a low taste threshold concentration for both water (5 ppm) and for coffee (100 ppm). But the chlorine from the water often combines with the phenols from the coffee to create chlorophenol. This compounds has a highly objectionable, medicinal taste that can be detected at a very low level of concentration (0.001 ppm) in the coffee beverage. Chlorine must be removed by some type of activated carbon filter before coffee brewing.

TABLE 4

Threshold Concentrations of Selected Odor-Producing Chemicals

Odor-producing chemicals

Compound	Threshold in water ppm	Threshold in coffee brew ppm
Ammonia	34.0	140.0[1]
Chlorine	5.2	108.0
Chlorophenols		
ortho -	0.006	0.001
para -	0.9	3.60
para -	1.35[2]	1.33[2]
Hydrogen sulfide	0.05	0.12[3]
Phenol	60.0	105.0

Detergent: water softeners

Compound	Threshold in water ppm	Threshold in coffee brew ppm
Calgon	200.0	935.0
Disodium dihydrogen versenate	120.0	825.0
Tide	12.0	100.0
Trisodium phosphate	225.0	1,550.0

[1] Color change prevented use of higher concentrations.
[2] Tap water substituted for redistilled water in water solution and coffee brew.
[3] Losses by volatilization made higher levels difficult to measure.

Source: Coffee Brewing Center Publication No. 38

Cleaners: An Additional Problem

One additional problem indirectly related to water quality can occur. Cleaning compounds are used both on the brewing equipment and coffee cups to remove coffee tars, accumulations of insoluble proteins in the brew. If the cleaning compounds are not thoroughly rinsed off, they'll dissolve into the coffee beverage as it is brewed or served. Some compounds such as alkyl sulfonate, found in many dishwashing detergents, have unpleasant tastes that become detectable at concentrations above 100 ppm.

Water-Always a Potential Source of Problems

Even water that appears safe to drink, with no apparent tastes or odors, may contain impurities that interact unfavorably with the flavor compounds in the coffee once it's brewed. In general, one can assume that the same coffee will exhibit different flavor characteristics when prepared with waters taken from different municipalities. Always remember that water accounts for more than 98% of the coffee beverage.

CHAPTER 8
FILTERING DEVICES

The primary purpose of the filtering device is to separate the grounds from the coffee beverage after the brewing cycle has concluded. The device usually consists of two parts:

1. **A rigid structure** that shapes and contains the bed of coffee grounds as water passes through them.
2. **A filtering medium** – usually wire mesh, woven fabric, or pre-formed paper-that prevents the grounds from passing through into the finished beverage.

When operating effectively, the filtering device also achieves the following objectives:

- **Provides a level bed of coffee.** This is necessary for uniform extraction from each particle of coffee. In general, this is accomplished manually as the grounds are placed in the filtering device. If the coffee bed is not level – if some sections are deeper than others – the water will not pass through at an even rate. As a result, some sections will be more highly extracted than others. The net result is uneven extraction throughout the bed of coffee.
- **Provides a proper depth of the bed of coffee.** For the best results, the filter device should provide a bed depth of 1.5 inches (*3.8 cm*), plus or minus 0.5 inches (*1.2 cm*). (See Appendix A for equations relating coffee volumes to the size of filtering devices.)

  If the bed is too thin, less than 1-inch (*2.5 cm*) deep, the water will pass through too rapidly. The result will be weak, poorly extracted coffee. Beds that exceed 2 inches (*5.0 cm*) in depth lend themselves to the possibility of channeling. This occurs when water, in following the path of least resistance, sets up a channel through which it flows most readily. Some areas in the bed of coffee will remain completely dry, while the coffee grounds surrounding the channels will become over-extracted. Channeling results in bitter, unpleasant flavors.
- **Supports the grounds so they don't touch the finished beverage.** If the grounds are left hanging in the brew, the brewing time is extended indefinitely. The result is over-extraction. Also, separating the grounds after brewing becomes more difficult because a large volume of finished beverage surrounds the coffee bed, requiring additional time for complete drainage.
- **Provides multiple drainage points.** More than one point is necessary to promote uniform flow of the water through the coffee bed. This ensures proper wetting and extraction of the coffee grounds. At the same time, multiple points prevent over-extraction of those parts of the coffee bed that would otherwise remain in prolonged contact with the water.

  Wire screens and perforated metal plates perform this important function if kept clean and unclogged. Cloth filters generally require special shapes and support devices to prevent them from sagging, which would cause the water to drain in a single stream from the lowest point. Paper filters require some type of supporting grid or cradle. Otherwise, the paper collapses against the brew-basket wall and limits the drainage area to a small center section of the filter.
- **Allows water to pass through in the proper amount of time.** Using a fine grind of coffee, the correct brewing time ranges from 1-4 minutes. For a drip grind, the appropriate time is 4-6 minutes; a regular grind required 6-8 minutes. These times apply regardless of the equipment used or the quantity being prepared.

  Ideally, the filter retards the flow of the water long enough to create a slight steeping of the coffee particles. This brief steeping period allows the coffee flavoring material to migrate from the center of the coffee particles to the surface, where it enters into solution with the water flowing past. If the water passes through the coffee particles too rapidly, rinsing occurs: The water removes flavoring material only on or near the surface of the coffee particles.

  To create the optimum flow rate, perforated plates and metal discs need a sufficient number of properly sized holes. For example, wire-mesh screens should range from 60 to 100 mesh to adequately separate the coffee particles from the brew while still allowing the water to flow freely through the coffee bed. In cloth filters, the weave of the material will control the flow rate. Paper filters also have varying degrees of permeability. Select both cloth and paper filters on the basis of which permeability will provide the correct flow rate for the brewing application.
- **Allows the desired amount of undissolved materials, both sediment and oils, to pass into the final beverage.** This is the most important role played by the filtering device. Removing the oil and undissolved material (often referred to as sediment) is known as clarification. The degree of clarification is largely a matter of personal choice. Turkish coffee brewed in ibriks, for example, is served without any physical separation of the grounds. At the other extreme is instant coffee, which is completely water soluble and contains no oil or sediment. It is virtually lacking in body or mouthfeel.

The type of filter directly affects the body of the finished brew, which, in turn, affects the flavor of the beverage. The body is created by the insoluble materials, principally oils and micro-fine pieces of bean fiber, that are rinsed off the coffee particles. These insoluble materials create brew colloids, which trap soluble flavoring materials and gases in the brew. The colloids break apart as the coffee is consumed, simultaneously releasing the aromas in one's palate as the brew reaches the taste buds.

This simultaneous presentation of taste and aroma creates coffee's flavor. Because the filter controls the amount of brew colloids present in the finished brew, it has a direct bearing on the formation and retention of beverage flavor. Brew colloids create a time-delayed release of flavoring materials that adds to the overall enjoyment of the beverage.

Metal and Cloth Filters

In terms of promoting or retarding formation of brew colloids, each type of filter has advantages and disadvantages. In addition, some are easier to use or less expensive to buy. For example, metal plates, discs, and woven screens cost more to purchase initially. Compared to the costs of disposable cloth or paper filters, however, they are far less costly over the life of the equipment.

Wire screen sizes from 100 to 200 mesh completely separate the grounds from the finished brew yet still allow both oil and bean fibers to pass through and form large numbers of brew colloids. But these devices require constant attention and frequent cleaning. If not properly maintained, they become clogged with coffee oils and residues that produce off-flavors. If roughly handled, their pores may become ruptured; this results in excessive and localized leakage of ground particles into the finished brew.

Cloth filters require the most attention to remain clean and free from foreign materials that can migrate into the beverage. If the cloth is of poor quality, or if the stitching stretches, the beverage will be muddy and contain excessive sediment. Another difficulty in using cloth filters can be traced to the vegetable origin of the material used in their manufacture. The constant and high temperatures required by the brewing equipment accelerate the breakdown of cloth fibers and increase the variety of chemicals absorbed into the cloth.

The weave of the cloth will affect both the flow rate of the water through the bed of coffee and the degree of beverage clarification. In the typical manufacture of cloth urn bags, muslin offers the fastest flow rate and the least clarification, while flannel offers the slowest flow rate and the greatest clarification of the brew. In general, excellent beverage clarity can be achieved by using material that has a weave of 64 x 60 threads per inch and a weight of 5.75 sq. yards per pound.

Pros and Cons of Paper

Although chemical laboratories have used filter papers for more than 100 years, the coffee industry began using them relatively recently. The application can be attributed to a coffee brewer, in the shape of an hourglass, exhibited in New York City's Museum of Art in 1943. The brewer, which featured a paper filter, received an award in 1958 for one of the best designed products of modern times. Filter paper played a big part in the commercialization and widespread use of the half-gallon brewer.

Paper filter brewers offer a number of advantages. The paper provides a high degree of beverage clarity and controls the flow rate of water thorough the coffee bed. Paper filters don't clog or permit excessive brewing times. In addition, they are very easy to handle – rather than cleaning the filters, you simply dispose of them along with the spent grounds.

However, paper filters have a number of potential drawbacks. For filter paper to give consistent results, it must not shed its fibers. It should be free of pinholes, possess an even texture, remain resistant to temperature, and have high wet-strength properties. If the paper's fluting and shape don't hold up during brewing, the filter will fall away from the sides of the brew basket and possibly cause the water to bypass the coffee bed.

Most important, **filter paper should not leave an aftertaste**. Unfortunately, most filter papers are not taste free. Because of its porosity, paper easily absorbs foreign odors that are readily transmitted to the coffee beverage. To combat this problem, filter papers must be properly packaged and stored to prevent contamination from external sources and to prevent the development of mold or mildew.

The speed of beverage filtration has a direct bearing on the paper's contribution to taste. Highly permeable paper filters spend less time in contact with the coffee brew, thereby reducing their taste contribution to a low or negligible level. Slower filter papers tend to impart more of their taste to the finished brew.

The filter device forms an integral part of the coffee brewer because it can affect contact time and water turbulence. Even if the brewer stipulates the use of one type of filter, the quality of filter used can usually be selected. In that way, one can choose the proper filter to achieve the desired level of convenience and beverage clarity.

APPENDIX A

RELATIONSHIP OF COFFEE BED DEPTH TO VOLUME OF FILTER

By E.E. Lockhart

These calculations apply only to devices in which water is poured, sprayed, or dripped into a basket containing ground coffee, and from which the extract drains, or is drawn by action of gravity.

Condition 1: The depth of grounds will be maintained within a range not exceeding 2 inches.

Condition 2: The roasted, ground coffee is assumed to have a bulk density of 22 pounds per cubic foot. One pound of coffee will occupy 78.5 cubic inches.

Condition 3: The basket holding coffee, and in which extract is prepared, is assumed to be cylindrical in shape.

The volume of a cylinder is given by the following formula:

$$V = \frac{\pi D^2 h}{4} \qquad (1)$$

V = volume in cubic inches

π = 3.142 (a constant)

D = diameter in inches

h = depth in inches

The diameter of a cylinder is given by the following formula:

The relationship between weight of coffee and the volume it occupies is as follows:

$$D = \sqrt{\frac{4\,V}{\pi\,h}} \qquad (2)$$

$$V = 78.5\ p$$

V = volume in cubic inches

p = weight in pounds

One cubic foot = 1, 728 inches

Formula 2 may also be written in terms of pounds as:

$$D = \sqrt{\frac{4 \times 78.5 \times p}{\pi\,h}} \qquad (3)$$

or

$$D = 10\sqrt{\frac{p}{h}} \qquad (4)$$

As interest centers on diameters in relation to weights of coffee for different depths, formula (4) may be rewritten as follows:

$$D = \frac{10}{\sqrt{h}}\ \sqrt{p} \qquad (5)$$

now let

$$F = \frac{10}{\sqrt{h}} \qquad (6)$$

F = a factor, the value of which is determined by the depth

Formula (5) then becomes:

$$D = F\ \sqrt{h} \qquad (7)$$

Table 1 gives F values for depths ranging from ½ to 2 inches.

TABLE 1

F Values in Relation to Depths of Dry Coffee

$$F = \frac{10}{\sqrt{h}}$$

h	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.50	14.14	14.00	13.87	13.74	13.60	13.48	13.37	13.24	13.12	13.02
0.60	12.92	12.80	12.71	12.59	12.50	12.41	12.32	12.22	12.12	12.03
0.70	11.95	11.86	11.79	11.71	11.63	11.55	11.47	11.40	11.32	11.25
0.80	11.19	11.11	11.04	10.98	10.92	10.85	10.79	10.72	10.66	10.60
0.90	10.54	10.48	10.42	10.37	10.31	10.26	10.22	10.15	10.10	10.05
1.00	10.00	9.95	9.90	9.85	9.80	9.75	9.71	9.66	9.63	9.57
1.10	9.54	9.48	9.45	9.40	9.36	9.32	9.28	9.25	9.21	9.16
1.20	9.13	9.09	9.05	9.02	8.97	8.94	8.90	8.87	8.84	8.80
1.30	8.77	8.73	8.70	8.66	8.63	8.60	8.57	8.55	8.51	8.48
1.40	8.45	8.42	8.38	8.36	8.33	8.30	8.27	8.24	8.22	8.19
1.50	8.16	8.13	8.10	8.08	8.05	8.03	8.00	7.97	7.95	7.93
1.60	7.90	7.88	7.85	7.83	7.80	7.78	7.76	7.74	7.71	7.69
1.70	7.67	7.65	7.63	7.60	7.58	7.56	7.54	7.52	7.49	7.47
1.80	7.45	7.43	7.41	7.39	7.37	7.35	7.33	7.31	7.29	7.27
1.90	7.25	7.23	7.21	7.19	7.18	7.16	7.14	7.12	7.10	7.09
2.00	7.07									

Source: Coffee Brewing Center Publication No. 57

With this formula (7), it is now possible to calculate the diameter of the coffee basket or urn riser, corresponding to any weight of coffee in depths between ½ and 2 inches. This formula applies to both home and institutional brewing devices. Table 2 applies to smaller, home coffee makers. Table 3 applies to larger institutional equipment. For convenience, Table 4 contains frequently used square roots.

Frequently, it is necessary to know the capacity of a coffee maker in terms of servings. If the diameter of the coffee maker basket or urn riser is measured, the number of servings for any depth of coffee between ½ and 2 inches may easily be calculated. In the case of home equipment, for which this calculation is often needed, note that one service equals 0.35 ounces or 0.022 pounds; 45 portions of coffee are obtained from one pound of coffee if 2.25 gallons of water are used.

Consequently,

$$S = 45\,p \qquad (8)$$

S = number of servings
p = pounds of coffee

$$p = \frac{S}{45} \qquad (9)$$

or

Now substituting formula (9) in (7) above:

$$D = F\sqrt{\frac{S}{45}} \qquad (10)$$

or

$$S = \frac{45\,D^2}{F^2} \qquad (11)$$

TABLE 2

Home Coffee Maker Baskets

Diameter of basket required to accommodate servings and weights of coffee in limiting depths

	Weight			Depth (inches)				
Servings*	grams	pounds	$\sqrt{p}$	1/2	3/4	1	1½	2
1	10	0.022	0.148	2.09	1.71	1.48	1.21	1.05
2	20	0.044	0.210	2.97	2.43	2.10	1.71	1.48
3	30	0.066	0.257	3.63	2.97	2.57	2.10	1.82
4	40	0.088	0.297	4.20	3.44	2.97	2.42	2.10
5	50	0.110	0.332	4.69	3.84	3.32	2.71	2.35
6	60	0.132	0.363	5.14	4.20	3.63	2.97	2.57
7	70	0.154	0.392	5.55	4.53	3.92	3.20	2.77
8	80	0.176	0.420	5.94	4.85	4.20	3.42	2.97
9	90	0.198	0.445	6.30	5.14	4.45	3.63	3.14
10	100	0.220	0.469	6.64	5.42	4.69	3.83	3.32
11	110	0.242	0.492	6.97	5.70	4.93	4.02	3.48
12	120	0.264	0.514	7.27	5.95	5.15	4.20	3.63
15	150	0.330	0.574	8.13	6.64	5.75	4.69	4.06
20	200	0.441	0.664	9.39	7.17	6.64	5.42	4.69
25	250	0.551	0.742	10.49	8.58	7.43	6.06	5.25
30	300	0.661	0.813	11.51	9.40	8.13	6.64	5.75
35	350	0.772	0.879	12.42	10.30	8.79	7.18	6.21
40	400	0.882	0.939	13.27	10.84	9.39	7.67	6.63
45	450	0.992	0.996	14.10	11.51	9.96	8.13	7.05
50	500	1.102	1.049	14.82	12.13	10.49	8.58	7.42
75	750	1.652	1.286	18.18	14.85	12.86	10.49	9.10

* One serving of beverage requires one Approved Measure of coffee equal to 10 grams, 0.35 ounce or 0.022 pound.

Source: Coffee Brewing Center Publication No. 57

TABLE 3

Coffee Urn Risers

Diameter of riser required to accommodate weights of coffee in limiting depths

	Depth (inches)		
Pounds	1	1½	2
0.25	5.0	4.08	3.5
0.5	7.1	5.77	5.0
1	10.0	8.16	7.1
2	14.1	11.53	10.0
3	17.3	14.1	12.2
4	20.0	16.3	14.1
5	22.4	18.3	15.8
6	24.5	20.0	17.3
7	26.4	21.5	18.7
8	28.3	23.1	20.0
9	30.0	24.5	21.2
10	31.6	25.8	22.4
15	38.7	31.6	27.4
20	44.7	36.5	31.6
25	50.0	40.8	35.4
30	54.8	44.7	38.7
35	59.2	48.3	41.8
40	63.2	51.6	44.7
45	67.1	54.7	47.4
50	70.7	57.7	50.0

Source: Coffee Brewing Center Publication No. 57

TABLE 4

Square Roots of Numbers to 100

	0	1	2	3	4	5	6	7	8	9
	0.00	1.00	1.41	1.73	2.00	2.24	2.45	2.64	2.83	3.00
10	3.16	3.32	3.46	3.60	3.74	3.87	4.00	4.12	4.24	4.36
20	4.47	4.58	4.69	4.80	4.90	5.00	5.10	5.20	5.30	5.38
30	5.48	5.57	5.66	5.74	5.83	5.92	6.00	6.08	6.16	6.24
40	6.32	6.40	6.48	6.56	6.63	6.71	6.78	6.86	6.93	7.00
50	7.07	7.14	7.21	7.28	7.35	7.42	7.48	7.55	7.62	7.68
60	7.74	7.81	7.87	7.94	8.00	8.06	8.12	8.18	8.25	8.31
70	8.37	8.43	8.48	8.54	8.60	8.66	8.72	8.77	8.83	8.89
80	8.94	9.00	9.06	9.11	9.16	9.22	9.27	9.33	9.38	9.43
90	9.49	9.54	9.59	9.64	9.70	9.75	9.78	9.85	9.90	9.95
100	10.00									

Source: Coffee Brewing Center Publication No. 57

In some home and institutional coffee makers, coffee baskets hold coffee in depths less than 1 inch, or more than 2 inches. The useful depth depends largely on the design and efficiency of water spreader plates and filters. These, together with the coffee, impede the flow of water and control brewing time. If they are designed to control the time of beverage preparation within the limits recommended – 4-6 minutes for filter-drip makers – extraction should proceed normally.

However, extremes in dimension should be avoided. Experience indicates that baskets designed to accommodate coffee bed depths between 1 and 2 inches perform more satisfactorily than others. The formulas given above can be used to determine compatible depths and diameters outside the limits recommended. (E.E. Lockhart developed the above calculations while serving as head of the Coffee Brewing Institute.)

APPENDIX B

QUALITY ASPECTS OF PAPER FILTERS

For filter papers to give consistent results, they must exhibit the following four characteristics:

1. **Proper rate of water flow through the paper.** This property of the filter paper is referred to as *permeability* and is typically measured based on the flow rate through a 1-inch diameter flow area under a 2-inch pressure head of water. For best results in coffee brewing, this flow rate should be approximately 16 fluid ounces (475 milliliters) per minute. If measured as a flow rate flow rate through a coffee brewer, as this translates into 40-55 fluid ounces (1,200-1,600 milliliters) per minute.
2. **Stability throughout the brewing process.** This property is determined by four factors.
   - **The number of flutes (ridges) on the sides of the filter.** These allow the filter to hold its shape after being saturated with water and also allow the coffee extract to pass through it at a faster rate because of greater surface area.
   - **The stiffness of the sidewall.** This allows the filter to remain upright in the brewing basket and prevents it from collapsing onto the bed of coffee grounds and diverting the water from the spray head.
   - **The overall tensile (wet burst) strength.** This prevents the paper from bursting under the weight of wet coffee grounds in unsupported areas. Wet burst strength is typically designed into the filter paper by the addition of resins during the manufacture of roll-stock paper from wood pulp.
   - **The crepe surface.** This feature prevents the accumulation of micro-fine coffee particles in the fractional voids (pores) of the paper (which is also known as muddying). Because the coffee particles don't adhere to the filter paper's surface, a better-known flow rate is achieved.

   All of the properties relating to the stability of the filter paper during the brewing process are linked to the paper's density, which is commonly measured as its basis weight. This property is usually expressed as the weight of 500 sheets (a ream) of 24-inch by 36-inch paper. Lightweight papers fall between 16 and 18 pounds, standard weight between 18 and 20 pounds, premium weight between 20 and 25 pounds, and heavy weight greater than 25 pounds. The heavier the weight of the paper, the greater the ability of the paper manufacturer and converter to build in the most desirable features that improve all aspects of the paper's stability during the brewing process.
3. **Minimum taste contribution to the coffee beverage.** Filter paper is made from natural wood pulp, which inherently contains a great deal of oils, tars, sugars, lignites, and other chemical compounds, such as turpentine. The manufacturing process removes the vast majority of these impurities during bleaching and purifies the paper. Depending on the type and amount of processing, the wood pulp changes in color from natural Kraft (brown) to varying degrees of white. After cleaning, resins are added to bond the bleached wood fibers into roll-stock paper.

   The taste residue remaining in the paper directly relates to the manner in which the wood fibers have been cleaned and bonded. It is also directly proportional to the length of time the paper filter is in contact with the water. Reduced contact time caused by faster flow rates reduces the taste contribution from the paper to lower or negligible levels.

   In addition, filter papers are porous and tend to pick up foreign odors. These are readily transmitted to the coffee beverage during brewing. To prevent odor absorption, coffee filter papers should be packaged in non-odor-permeable plastic.
4. **Proper size for the brew basket and volume of coffee.** The filter paper must fit the basket brew properly, allowing it to maintain its form when suspended on the metal grid of the brew basket and avoid becoming sealed against the solid wall of the basket. It must be of sufficient height to allow for the swelling of the coffee grounds in the brew basket, which is caused by a faster in-flow of water than outflow of beverage during the brewing cycle.

CHAPTER 9
HOLDING AND SERVING TEMPERATURES

In describing the shelf life, or stability, of green coffee, the industry normally expresses the time period in years – for example, new crop, current crop, or past crop. After it has been roasted, coffee's shelf life is measured in days. Although some disagree on the exact time frame, most people concur that stale flavors become detectable 4 to 14 days after roasting, unless adequate steps are taken to protect the roasted coffee's fresh flavor.

Beverage Stability

During no other phase in the development of coffee's flavor, from the harvesting of the cherries to the roasting of the beans, does the degradation of the flavor occur as rapidly as it does once the coffee's been brewed. After the roasted coffee is ground and brewed, the freshness of the beverage is measured in minutes. The change becomes noticeable 15 minutes after brewing. After 30 minutes, the beverage is no longer considered acceptable. After 60 minutes, the flavor will deteriorate to the point of being highly objectionable.

Maintaining brewed coffee's freshness is a function of both the temperature and the conditions under which coffee is held after brewing. The objective is to create a stable environment for the volatile aromatic and fragile taste compounds that make up coffee's delicate flavor.

This is accomplished by holding the coffee in a manner that reduces the rate at which the volatile aromatic compounds are driven out of the brew, reduces the rate at which the non-volatile taste compounds change within the brew, and reduces the rate at which the water molecules evaporate and thereby change the solubles concentration in the brew. Generally this is most readily accomplished by maintaining a holding temperature between 175º and 185ºF (*80ºC-85ºC*) in a closed and insulated container.

Factors Causing Flavor Change

Three primary factors cause the flavor change. They are described below:

1. **Coffee's highly volatile aromatic substances constantly migrate from and to the brewed coffee's surface.** As seen in Table 1, virtually all of the compounds found in coffee's aroma have boiling points well below that of water. This means that they are in a gaseous state and leave the surface of the brew as soon as they reach it.

TABLE 1

Analysis of a Coffee Aroma Essence

	Mol wt	Percent	BP C	BP F	Relative Flavor Importance[1]
Acetaldehyde	44	19.9	21	70	1
Acetone	58	18.7	56	133	2
Diacetyl	86	7.5	88	190	1
n - Valeraldehyde	86	7.3	102	216	2
2 - Methylbutyraldehyde	86	6.8	91	196	2
3 - Methylbutyraldehyde	86	5.0	91	196	2
Methylfuran	82	4.7	63	145	2
Propionaldhyde	58	4.5	49	120	2
Methylformate	60	4.0	32	90	2
Carbon Dioxide	44	3.8	-78	-108	–
Furan	68	3.2	32	90	1
Isobutyraldehyde	72	3.0	63	145	1
Pentadience (isoprene)	68	3.0	30	86	2
Methylethyl ketone	72	2.3	80	176	2
C_4 - C_7 paraffins and olefins	–	2.0	35	95	2
Methyl acetate	74	1.7	57	135	2
Dimethyl sulfide	62	1.0	38	100	1
n - Butyraldehyde	72	0.7	75	167	1
Ethyl formate	74	0.3	54	129	2
Carbon disulfide	76	0.2	46	115	2
Methyl alcohol	32	0.2	65	149	3
Methyl mercaptan	48	0.1	6	43	1
		100.0			

[1] *1.large; 2. medium; 3. small*

SOURCE: Sivetz and Desrosier, CoffeeTechnology

In an open container the gases escape into the surrounding air, causing a loss and change of coffee's aroma as they exit. In a closed container, however, the gases can escape only until the vapor pressure in the container reaches an equilibrium level. After reaching this level, the volatile flavoring compounds return to the coffee brew as fast as they escape. The rate of escape and the equilibrium level for each gaseous component of the aroma is a function of its boiling point.

The important exception to this change in the brew's aromatic components is the formation of mercaptans (sulfur-containing organic compounds). The mercaptans, although small in number, contribute significantly to pleasurable aspects of coffee's aroma. Studies have shown that at temperatures between 175ºF and 195ºF (*80º-90ºC*) the quantity of marcaptans present in the brew actually increases. It is almost as if a miniature roasting process were taking place in the brew during the initial holding period. Beyond 60 minutes of holding time, these important aromatic-flavor compounds are more likely to decompose rather than form.

TABLE 2

Mercaptan Content Under Varying Holding Conditions

The mecaptans content (expressed as sulfyhdryis) of standard coffee brew

Time of holding	Mercaptan concentration (as - SH) in parts per billion Holding temperature							
	63°C		73°C		83°C		93°C	
	p.p.b.	p.p.b. at "0"	p.p.b.	p.p.b. at "0"	p.p.b.	p.p.b. at "0"	p.p.b.	p.p.b. at "0"
(hours)		%		%		%		%
0	56.7	—	56.7	—	56.7	—	56.7	—
1	49.5	87.3	57.9	102.0	71.0	126.0	71.0	125.0
3	50.5	89.1	47.2	83.5	51.9	91.6	54.1	95.5
6	52.2	92.2	53.1	93.8	45.9	81.0	39.5	69.6
24	37.0	67.0	31.2	55.0	28.0	49.4	24.1	42.6

SOURCE: Coffee Brewing Center Publication No. 41

2. **The elevated brewing temperature causes coffee's non-volatile liquid compounds to chemically change.** As shown in Table 3, coffee's non-volatile flavoring compounds are composed principally of sugars, proteins, ash (mineral oxides), acids, trigonelline, caffeine, and phenolic compounds. The degree and rate of change relate to the chemical stability of each of these compounds.

TABLE 3

Chemical Compositions of Soluble and Insoluble Portions of Roasted Coffee

(Approximate, Dry Basis)

	Percent	
	Solubles	**Insolubles**
1. Carbohydrates (53%)		
Reducing Sugars	1 - 2	—
Caramelized Sugars	10 - 17	7 - 0
Hemi-cellulose (hydrolyzable)	1	14
Fiber (not hydrolyzable)	—	22
2. Oils	—	15
3. Proteins (N X 6.25); amino acids are soluble	1 - 2	11
4. Ash (oxide)	3	1
5. Acids, non-volatile		
Chlorogenic	4.5	—
Caffeic	0.5	—
Quinic	0.5	—
Oxalic, Malic, Citric, Tartaric	1.0	—
Volatile Acids	0.35	—
6. Trigonelline	1.0	—
7. Caffeine (Arabicas 1.0; Robustas 2.0%)	1.2	—
8. Phenolics (estimated)	2.0	—
9. Volatiles		
Carbon Dioxide		
Essence of aroma and flavor	Trace	2.0
	0.04	—
Total	27 - 35	73 - 65

Note: Volatiles may be classed chemically as acids, amines, sulfides, carbonyls (aldehydes and ketones), and others. Non-volatiles may be classed chemically as acids, carbohydrates, proteins, oils, phospholipids, minerals and others.

SOURCE: Sivetz and Desrosier, CoffeeTechnology

The most distinctive change is an increase in the coffee's acidity. This occurs as the chlorogenic acid, which constitutes approximately 15% of the solubles in the finished brew, breaks down into caffeic acid and quinic acid during the holding period. This easily recognized taste change causes the coffee to become acerbic; An increasingly sour and bitter taste characterizes these two acids.

Because chlorogenic acid accounts for such a large portion of the solubles concentration in the finished brew, holding coffee at a temperature where the chlorogenic acid remains stable is a key consideration. Studies have shown that it is most stable when the coffee beverage is held at temperatures between 175ºF and 185ºF (*80ºC-85ºC*) for fewer that 60 minutes. Held at lower temperatures or for longer periods of time, chlorogenic acid decreases in its concentration in the beverage, forming the by-products of caffeic and quinic acids.

TABLE 4

Chlorogenic Acid Content Under Varying Holding Conditions

Recovery of chlorogenic acid from standard coffee brews
(Concentration of chlorogenic acid)

Time of holding	Temperature of holding (° C)							
	63°C		73°C		83°C		93°C	
	Std. brew	Acid at "0"	Std. brew	Acid at "0"	Std. brew	Acid at "0"	Std. brew	Acid at "0"
(hours)	(u.g. / ml.)	%	(u.g. / ml.)	%	(u.g. / ml.)	%	(u.g. / ml.)	%
0	2450	—	2450	—	2450	—	2450	—
1	2360	96.4	2370	96.8	2430	99.4	2410	98.5
3	2270	92.6	2270	92.6	2300	94.0	2270	92.5
6	2180	89.0	2160	88.2	2170	88.5	2060	84.1
24	2150	87.8	2120	86.5	2080	85.0	1980	80.9

SOURCE: Coffee Brewing Center Publication No. 41

Studies show that quinic acid remains stable under normal conditions for holding brewed coffee at temperatures between 175ºF and 185ºF (*80ºC-85ºC*). Therefore, once the decomposition of chlorogenic acid reaches this state, it doesn't contribute to further changes in the beverage flavor. On the other hand, caffeic acid exhibits marked instability under the same holding conditions. That indicates caffeic acid may be one of the principal sources of the unpleasantly sour taste changes that occur when brewed coffee is held for extended periods.

Because applied heat also induces chemical changes, the beverage's stability relates directly to the manner in which the compounds are held. In general, high levels of direct heat increase the rate of chemical change. To maintain the stability of the majority of non-volatile compounds, avoid placing the holding vessel on a source of direct heat. This is best accomplished by using an insulated container. By avoiding the application of direct heat to the surfaces of the vessel containing the brew, the rate at which the non-volatile flavoring compounds change form will be reduced.

Studies have shown that caffeine and trigonelline in the coffee brew stay completely stable at holding temperatures between 175ºF and 185ºF (*80Cº-85ºC*).

Their chemical compositions do not change, even after 24 hours. Although these compounds contribute to the bitterness of the brew's initial flavor, it is highly unlikely that any deterioration in the finished brew's flavor can be attributed to the destruction, loss, or chemical action of caffeine or trigonelline.

No studies have yet been undertaken to determine how other non-volatile flavoring compounds in the coffee brew may change. The sugars, proteins, mineral oxides, and phenolic compounds play a major role in creating the beverage's taste. Taste changes occur as these compounds either decompose at elevated temperature or react with other compounds during the holding period.

3. **The water molecules vaporize and leave the brew, causing the remaining flavoring compounds to further concentrate.** As the flavoring materials become more concentrated, the strength of the brew increases and causes a perceptible change in taste. With the simultaneous change in the type of soluble material present in the brew, such as chlorogenic acid breaking into caffeic and quinic acid, this increased concentration level creates a highly objectionable taste.

   The rate of evaporation is a function of the beverage temperature, how much of the brew's surface is exposed to air, and the pressure over the exposed surface area. Holding coffee in a closed and insulated container, or at least minimizing the surface area exposed to air, greatly reduces the amount of water driven out of the brew through evaporation.

Serving Temperatures

The serving temperature of the beverage plays a key role in both the physiological and psychological enjoyment of coffee's flavor. The temperature is important because of the expectations that link certain temperatures with certain foods, its effect on the volatility of aroma-creating compounds, and the change in sensitivity to the primary tastes as temperature varies.

Serving temperatures preferred for hot beverages of all types typically range from 155°F to 175°F (*70°C-80°C*) for the average consumer. On a psychological level, the preferred temperature relates to a person's tactile pain threshold – the point at which the kinetic energy of the fluid triggers an initial response on the free nerve endings of the tongue.

It is difficult to separate the threshold sensation of pain from an individual's reaction to the sensation. Some people derive pleasure from an excessive stimulation of the free nerve endings on their tongues, as when eating excessively hot curries or chilies, when sipping simmering hot coffee, or when drinking distilled beverages straight. A certain degree of adaptation to this type of stimulation is involved, in addition to the psychological differences in the desirability of pain. While no quantitative data are currently available on these phenomena, coffee needs to be served at temperatures hot enough to meet the psychological and physiological expectations of stimulation of the coffee drinker.

The temperature of the brew also directly affects the amount and composition of the aromatic compounds released from the fluid as it is sipped. Some of the most important components of coffee's aroma have boiling points about 150°F (*65°C*); therefore, one cannot perceive them except at elevated beverage temperatures (See Table 1).

Temperature also has a direct bearing on one's ability to perceive different basic tastes, primarily reducing the ability to perceive either sweet or salty taste sensations. As the temperature changes, the perceived taste characteristics of the coffee beverage also change. For the average person, the most pleasing balance in the basic tastes (sweet, salty, sour, and bitter) occurs when the beverage is served at temperatures above 160°F (*70°C*).

The actual temperature of the coffee beverage in the cup differs from the temperature at which the brew reaches the tongue. The temperature of the beverage begins to decrease as soon as the brew leaves the holding container. The vessel into which it is poured acts as a thermal sump, absorbing heat at a rate dependent on the type, density, and existing temperature of the cup. In addition, the temperature on the surface of the fluid in the cup decreases at a rate much faster than the body of the fluid because the surface fluid is attempting to reach an equilibrium temperature with the air above it.

As the fluid on the surface is sipped into the mouth, it undergoes a final temperature drop as the brew is sprayed in small quantities over the surface of the tongue. This is the temperature experienced by the coffee drinker and normally falls within the moderately hot temperature range of 130°F-155°F (*55°C-70C*). [Note: 125°F-130°F (*50°C-55°C*) is the typical exit temperature of hot water from the sink faucet.]

Hold and Serve at the Correct Temperatures

Although relatively little is known about the rapid and intense transformations that occur in coffee's flavor after it's brewed, studies have shown the changes occur in a matter of minutes.

To maintain the freshness of brewed coffee's flavor, hold it at a uniform temperature between 175°F and 185°F (*80°C-85°C*) in a closed and insulated container, without the application of direct heat. While the actual serving temperature is a matter of individual preference, coffee should be served in the average temperature range for hot beverages, 155ºF-175ºF (*70ºC-80ºC*) to be both physiologically and psychologically pleasing.

CHAPTER 10
SELECTION OF BREWING EQUIPMENT

Just as roasting creates the components of coffee's flavor from green beans, brewing releases those flavoring materials from roast-and-ground coffee and into the final brew. The method of brewing – whether filtration, percolation, decoction, steeping, or pressurized infusion – greatly affects the type and amount of flavoring material removed. In addition, the filtering device, mechanical operation of the brewer, and the material used in its construction, all contribute to the final quality of the coffee's flavor.

Four Operational Performance Criteria

As a result, selecting brewing equipment requires one to objectively evaluate its operational parameters: **Ensure the equipment has the capability of delivering all of the coffee's flavor created by the roasting process.** To do this, a brewer must fulfill the following four criteria:

1. **Water temperature and recovery time.** A coffee brewer must be able to deliver a steady supply of hot water so that brewing temperatures are maintained at 195ºF - 205ºF (*92ºC-96ºC*) during at least 90% of the brewing cycle. It is not acceptable for the equipment to begin the brewing cycle at the correct temperature and then, because of insufficient heating capacity, finish the cycle 10ºF - 15ºF (*5ºC-10ºC*) lower. Brewing temperatures that fall below 195ºF (*92ºC*) do not extract the full flavor of the coffee – particularly high-quality, specialty-grade coffees.

   The recovery time refers to how quickly the brewer can attain the proper brewing temperature again after completing a brewing cycle. When determining the brewer's capacity, factor in the recovery time. For example, a half-gallon brewer may be able to brew a pot of coffee every 5 minutes, which indicates a capacity of 12 pots per hour. However, if the brewer requires an additional 10 minutes to recover to the proper brewing temperature, its true capacity decreases to 4 pots per hour.

2. **Water delivery.** Brewers offer three methods for bringing hot water in contact with the bed of coffee grounds: hand pouring, application by spray head, and pressurized flow.

   Regardless of the method used, the equipment must be capable of wetting the entire bed of coffee grounds evenly and thoroughly in the first 10% of the brewing cycle. Because coffee brewing proceeds in three distinct phases – wetting, extraction, and hydration – the wetting process must be completed before extraction begins. Otherwise, the brewing water will not uniformly extract the soluble flavoring material as it passes through the bed of coffee grounds.

   Uniform extraction also requires evenly distributed water turbulence. This is easy to accomplish when the water is poured by hand or when the brewer uses pressurized infusion. It is more difficult to obtain sufficient turbulence using a spray head, particularly when the water is gravity fed. Ideally, the water turbulence will lift, separate, and tumble each particle of coffee in the bed, thereby allowing for a uniform extraction rate from each particle and causing a slight foaming on the surface of the coffee bed.

3. **Brewing time.** Brewing begins the instant the water comes in contact with the coffee grounds and ends when a vast majority of the non-absorbed water has passed through the filter device. To control the extraction of the flavoring material, the water contact time must match the particle size of the ground coffee.

   Correct brewing time depends on the grind of coffee used. These times are 1-4 minutes for fine grinds, 4-6 minutes for drip grinds, and 6-8 minutes for regular grinds. Large-volume brewers generally operate on longer brewing cycles because so much water must pass over the coffee; therefore, these brewers use regular grinds. However, some small, automatic filter brewers also have extended brewing times because of the way they heat and deliver the water; such brewers require coarsely ground coffee.

4. **Brew basket and filtering device.** Both the brew basket's size and shape, as well as the filtering method, must work together with the water feed to achieve uniform wetting and extraction.

   The brew-basket design must allow for a level bed of coffee, 1-2 inches (*2.5 - 5.0 cm*) in depth. It must be large enough to hold the necessary amount of ground coffee that will achieve the required balance between strength and extraction. Ideally, the brew basket will hold from 9-11 grams of coffee for each 6-fluid-ounce cup of its rated capacity (*6-8 gr per 125 ml cup*). Also, it should offer multiple drainage points, be large enough to prevent backup and overflow of coffee grounds, and be strong enough to prevent the wetted grounds from touching the finished brew. Finally, make sure the brew basket is easy to clean and compatible with the type of filtering method used.

The preferred filtering method depends on how much clarity is desired in the final beverage. Paper, cloth, wire screens, and perforated metal plates all work well, providing they do not impart any taste to the finished brew. For example, ensure reusable cloth and metal filters can be easily cleaned.

Evaluating Efficiency

One can objectively measure all four of the brewer's operational performance criteria described above with just a few basic tools. For example, one can determine the time of the water flow, the temperature gradient of the water during the brewing cycle, and the size of the brew basket with a watch, a thermometer, a tape measure, and a measuring scale.

To evaluate the interaction of the water-delivery method and brew basket, use a device that measures the coffee's strength in conjunction with the Coffee Brewing Control Chart to calculate the extraction rate from the bed of coffee grounds (See Chapter 3). In this manner, it can be determined whether the brewer extracts the desired amount of soluble flavoring materials from the required amount of ground coffee, as determined by the capacity of the coffee brewer.

For example, a 10-cup filter-drip brewer with a 6-minute brewing cycle should have a brew basket that can hold 100 grams, plus or minus 10 grams, of drip-grind coffee. Water passing over the 1-inch to 2-inch (*2.5cm - 5.0 cm*) bed of coffee grounds at 195°F - 205°F (*92°C-96°C*) should extract between 18% and 22% of soluble material from the coffee. That would result in beverage strength (solubles concentration) between 1.15% and 1.35% of flavoring material in solution.

Mechanical Reliability

Mechanical reliability is a function of both the volume of coffee prepared by the brewing equipment and its degree of automation. Performance criteria differ from home and commercial applications. At home, a brewer with an 8-10 cup capacity is usually sufficient. Commercial locations, however, require brewers large enough to meet demand at peak periods, yet not so large that coffee is held for a long time during slow periods.

For commercial use of coffee brewers, base the calculations on the number of people served, multiplied by the typical serving size; Include refills if applicable. Determine the brewer's output based on the complete brewing cycle plus recovery time. When considering the amount of beverage needed for slack periods, figure the equipment should prepare no more than the amount served in a 15-minute period. Otherwise, make provisions to store the brew in sealed, insulated containers.

Most home brewers call for manual activation. Foodservice brewers are often automated, meaning they are more expensive and require a higher level of service and preventive maintenance. While manual coffee brewing can be easily controlled if the personnel involved are properly trained and permanently assigned to the task, automatic equipment presents significant savings in labor costs – although it doesn't guarantee a high-quality beverage.

Water, the universal solvent, also plays a role in the reliability of brewing equipment. As it flows through city pipes, most municipal water carries small particulates – small pieces of sediment. To prevent these from clogging the water valves in the brewer, some type of water-straining device is needed.

Also, water dissolves various minerals as it percolates through the earth and into the water table. These minerals attach themselves to the metal surfaces in the heating chamber, causing scale build-up. To keep the brewer operating correctly, periodically remove these mineral deposits from the brewer's heated surfaces.

Materials of Construction

Coffee reacts chemically on certain materials. Avoid tin plate, aluminum, copper, and nickel as materials of construction for parts that come in contact with the coffee brew. Bitterness, astringency, and metallic tastes will result when these materials touch the beverage and produce a chemical reaction. Copper and nickel are especially detrimental to coffee's flavor.

Brewers made with plastic components, especially brew baskets, should meet the established criteria for food-grade plastics. Surfaces that are in long-term contact with water must meet NSF and FDA food-zone guidelines on water contact, and be non-leachable (meaning no migration of chemicals entering the water). Further, the plastic surfaces must not absorb water, nor impart a taste or odor to the water. Surfaces that are in short-term contact with water must have a high surface hardness, must not absorb coffee stains readily, should have a nice cosmetic look, and must meet UL and NSF guidelines for food-zone materials.

All of the plastics must comply with FDA Regulation 21, which applies to materials used in the area of food contact. As long as plastics meet or exceed these requirements, they will be suitable for all non-commercial applications in coffee brewer construction. In many commercial applications, plastic surfaces tend to pit and warp when exposed to prolonged high temperatures. Pitting makes it difficult to remove coffee residues, increasing the likelihood that residual coffee oils will lead to off-flavors. For high volume commercial applications, it is generally best to select brewers with glass, porcelain, and food-grade stainless steel components. These materials have no effect on the flavor of the brewed coffee. In addition, electro-plating of other materials, such as silver, can create composite materials chemically inert to coffee.

Pay special attention to materials that come in contact with the water heated to brewing temperatures. Near 205ºF (*96°C*), water can leach out both taste and odors from various materials-particularly plastic tanks and rubber tubing.

Ease of Sanitation

Any part of the equipment that comes in contact with the finished brew must be accessible for easy cleaning. Avoid equipment with hidden areas, narrow channels, or parts not removable for cleaning. In addition, thoroughly rinse off all cleaning materials so they do not leave any taste residues on the brewer's surface.

Whether used in the home or in foodservice locations, brewing equipment must be free of electrical and mechanical hazards and easy to clean. It should combine maximum mechanical efficiency, maximum reliability, and ease of service. Its size and capacity should match the volume of coffee required. Most importantly, however, brewers should meet four operational performance criteria related to water temperature and recovery time, water delivery, brewing time, and brew-basket capacity.

Evaluation of brewing equipment

The extraction of flavoring material from roast-and-ground coffee proceeds along pathways dictated by the natural laws of physics and chemistry. Only by understanding and applying those laws can an equipment designer create a brewer that delivers a high quality beverage.

Although appearance and aesthetic aspects of equipment certainly play a role in overall design, the first requirement of a brewing device is to deliver a coffee beverage of desirable flavor. Similarly, the convenience of assembly/disassembly and easy access to parts for efficient, economical service of equipment come into play. These factors, however, also take a back seat to the brewer's performance. A brewer that looks good and is easy to assemble offers no benefit to the consumer if it prepares a poor tasting beverage. As a result, equipment designers must know as much about the science of brewing as they know about the art of design.

SCAA Brewer Certification Program

The Specialty Coffee Association of America (SCAA) will evaluate coffee brewing devices for the coffee industry, based on the parameters outlined on the SCAA website (www.scaa.org). In its role as an independent testing authority, SCAA will analyze the data obtained from detailed examination of a brewer's operating performance criteria and report the results to its manufacturer. If appropriate, SCAA will also recommend modifications that can enhance the brewer's performance.

Benefits of Precise Standards

Adhering to precise brewing standards that are universally understood offers numerous benefits. First and foremost, the standards will lead to a higher level of consumer satisfaction. The more nearly perfect beverages that are available for consumption whenever coffee is prepared, the more coffee will be sold. In turn, the more equipment will be needed, and the more reasonable and rewarding use of accessory features will prevail. In addition, standards form a firm foundation for successful advertising and promotion efforts.

People do not buy or consume coffee for its nutritional value. Rather, they buy and consume it for the pleasure and satisfaction that comes through the aroma, taste, and body of the coffee brew. To the specialty coffee industry feels the responsibility to ensure that pleasurable experience takes place. By accepting this responsibility, the specialty coffee industry can ensure a growing number of cups sold, pounds purchased, and consumers satisfied.

NOTES

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