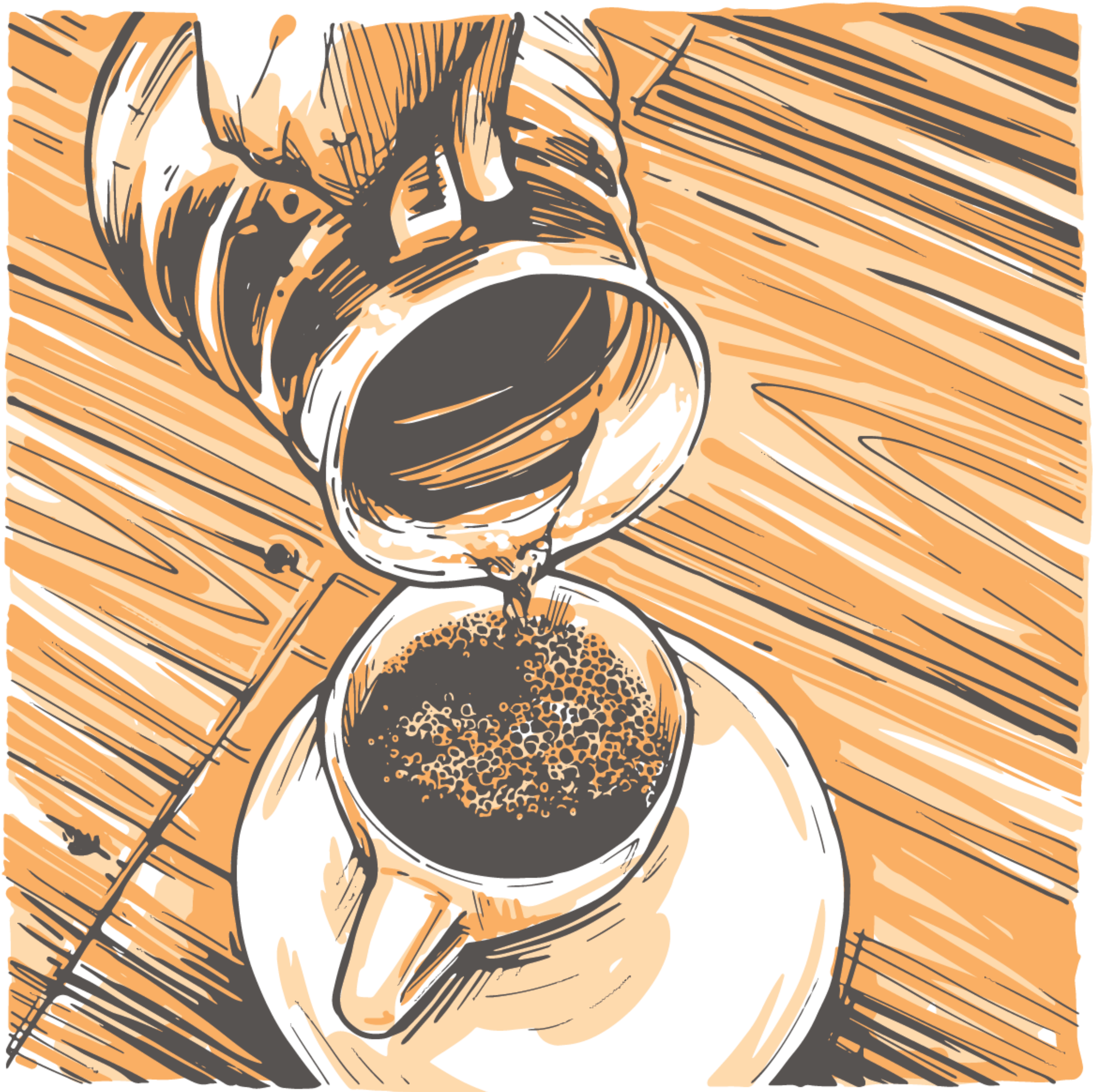
COFFEE BREWING

WETTING, HYDROLYSIS & EXTRACTION REVISITED



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"Brewing can be considered a personal taste adventure."
– Michael Sivetz, *Coffee Technology*

Brewing is one of the most complex yet under-researched topics in coffee. The literature is sparse, much of the science is ancient, and our industry assumptions have been vast. In our SCAA education, we have always stressed the three "stages" of brewing to be wetting, extraction, and hydrolysis (Lingle 2011). These terms have always seemed simple, vague, and mildly scientific, but have not yet been well defined and often leave us with more questions than answers. Of course, we all know anecdotally and theoretically how complicated coffee extraction is as a process, because we have been continually learning about it since our initiation into coffee. I will preface this article by stating that, as we do not have all the answers, there is much to learn!

WETTING

For coffee to be brewed it must first be wetted, which means the coffee grounds must absorb water. This is a physical process which can be explained via many simple yet interacting variables. First, we must consider that coffee is ground into a distribution of particle sizes. The size of the grounds, their density and placement/distribution in the bed of coffee, and the method of water addition will all influence the speed of wetting. Certainly, if any external agitation occurs during the wetting phase, this will influence the speed and evenness of the process. We can think of the coffee bed as similar to a soil, where the rate of water infiltration depends on particle size and shape (e.g. gravel vs. sand), the initial moisture content of the particles, porosity, gas solubility, pressure, and particle swelling (Hillel 2004).

Coffee grounds, during wetting, swell and after the brewing is complete retain a proportion of the water dispensed onto them, depending on particle size (Sivetz and Desrosier 1979; Mateus and others 2007; Cammenga and others 1997). As air, volatile compounds, and other gases (primarily carbon dioxide) are displaced during this wetting, we might notice an effervescence, or coffee "blooming" associated with it (Clarke and Macrae 1985). A portion of these gases can also be dissolved into the water or the coffee slurry. In certain brew methods, we can think of the wetting period as responsible for the "bloom" of the coffee. In other brew methods, such as those in the immersion category, the wetting phase of brewing may take place very quickly. In espresso, certain machine manufacturers have included a "pre-infusion" to allow the coffee bed to be wetted prior to the main extraction event.

As coffee technicians and professionals, we usually like our coffee bed to be wetted in a uniform manner, so that later the coffee can be extracted in a regular flow and time, but the best baristas know that this to be an impossible task. Ideally, if we believe that the best coffee flavor comes from evenly wet and extracted coffee particles, we try and minimize the deviation in grind size and wetting time. However, the jury is still out on the merits or drawbacks of a normal grind particle distribution! As with all coffee brewing – it is a matter of personal preference.

EXTRACTION

As the coffee grounds are wet, gases and volatile compounds are dissolved and lost, and soluble compounds are simultaneously drawn out from the coffee. This primarily occurs as chemical and physical reactions between the coffee and the water, and we call it extraction. Really, the term can be used in this context interchangeably with brewing, as the extraction process makes up the nuts & bolts of coffee brewing. Chemical engineers might call it "leaching" or "percolation" (Clarke 1987; Petracco 2001). When chemists speak of extraction they are referring to the specific separation of a particular substance from a mixture (or whole product). In our case, we are separating many important soluble solids from a ground coffee product. When a product is brought into contact with a solvent, some components of that product behave as soluble and others as insoluble. In brewing, ground coffee is our product and water is the "universal" solvent. In truth, without extraction, we would forever just have coffee grounds in water. It turns out, the term "extraction" that we use today refers to a few different types of reactions that are acting to transfer coffee solubles from coffee to water over time to create our coffee beverage. Currently, the method the coffee industry has to quantify extraction is as the percentage of solubles yield (aka brewing yield) from the amount of coffee grounds used to prepare the brew (Lingle 2011; Petracco 2001; Clarke 1987). This has generally been agreed upon to be ideal between 18-22% (Sivetz and Desrosier 1979; Lockhart 1957). Anything under or over that has been characterized, from a sensory standpoint, by low extraction yields exhibiting a sour, sweet flavor and high extraction yields with bitter, astringent flavors, respectively (Petracco 2001; Rao 2010).

Soluble compounds can exit the coffee grounds through a few different types of chemical reactions, all dependent on temperature, time, and agitation. In fact, they may go through more than one of the below processes. The chemical reactions which occur during coffee extraction are:

DISSOLUTION PROCESSES

Water solubility of compounds allows them to be dissolved into the water and hence extracted into the coffee beverage. Examples include chlorogenic, acetic, malic, and other acids, caffeine and trigonelline (Arya and Rao 2007). There are two types of dissolution, named molecular and ionic for their mecha nism. Compounds such as salts and acids usually dissolve ionically, as opposed to caffeine, which dissolves molecularly. This Dissolution of water soluble compounds happens naturally when water moves over the coffee grounds during brewing.

HYDROLYSIS

Hydrolysis is the name for a general chemical reaction that occurs when water reacts with another compound to alter it or break it down. During extraction, insoluble or large soluble coffee compounds can be 'loosened' from the coffee particles via hydrolysis reactions (Cammenga and others 1997). This is one type of reaction that contributes to the extraction from coffee of solubles, typically larger organic acids. There is some debate as to how important this particular reaction is to coffee brewing (Clarke 1987; Thaler 1979). When compounds go through hydrolysis go through the process of being 'hydrolyzed'.

DIFFUSION PROCESSES

Wherever solutes are not distributed uniformly throughout a solution, this creates a concentration gradient. Consequently, solutes diffuse from zones of high concentration to where it is lower. In coffee, this means areas of high coffee concentrations (the grounds) to areas oflow coffee concentration (the water). An important particular case where these concentration gradients result in the diffusion of compounds is called osmosis. Osmosis is the net movement of solvent molecules through a membrane (in this case, a cell wall) into a region of lower solute concentration. This occurs in order to equalize the solute concentrations on both sides of the "membrane" (the cell wall). This movement of molecules via diffusion does not require stirring and would occur even without the active motion of gravity washing the water over the coffee or other agitation. Diffusion can be calculated based on Fick's Law, which states that diffusion is a function of time, temperature, liquid viscosity, layer depth, and solute concentration in both the liquid and the solid, among other factors. Fick's Law is fully described in the "Percolation" chapter of Illy & Viani (Petracco 2005b).

IMPORTANT CONSIDERATIONS

ORDER OF REACTIONS

What is important about the above ways by which soluble solids can be extracted from coffee into water is that more than one of these forces can AND WILL be working simultaneously. As soon as an individual coffee particle is wetted and more water moves over its surface, it is going to start the extraction process. This means that each individual coffee particle will have its own brew time. The solute concentration of the liquid (coffee) that is passing over coffee grounds will change as it flows through the coffee bed, therefore changing the diffusion rate via Fick's Law. Finally, don't forget that the brewed coffee itself will be going through many chemical reactions during the brewing process, even after it has gone through a filtration medium and fallen into its brew reservoir.

TEMPERATURE

Heat is a key factor influencing coffee extraction, which has not been addressed fully in the above explanation. Generally, as brewing temperature increases, coffee extraction (total and rate) increases (Merritt and Proctor 1959; Rao 2010). When compounds are broken down due to heat, it is called thermal degradation, this process largely occurs during roasting. We brew coffee with hot water (generally agreed to be ideal between 195 and 205°F), and we know that heat accelerates all chemical reactions, as demonstrated by the Arrhenius equation (Petracco 2005b).

Heat also is known to increase the solubility of many chemical compounds. Thus, heat can work in the two ways simultaneously to affect coffee extraction; acceleration of chemical reactions, and by increasing the solubility of certain compounds.

On the other side of the coin, when we brew coffee at room or refrigerated temperatures, we must extend the brew time in order to get the "same" extraction, numbers-wise. Where the cold brew process lacks in temperature, it makes up for in time. Coffee solubles display significantly decreased solubility in room temperature water. Increasing the brew time to hours instead of minutes allows for maximal extraction of the solubles from the coffee grounds. That being said, we must note that the two final beverages (hot and cold brewed) are not expected to exhibit the same chemical composition.

There is much anecdotal and some scientific evidence that too much heat (temperatures above 205°F) result in the extraction of bitter and astringent compounds, reducing the likeability of the brewed coffee (Merritt and Proctor 1959; Andueza and others 2003; Sivetz and Desrosier 1979; Petracco 2001). In particular, the sensory perception of bitterness and astringency of coffee has been found to increase with brewing temperature (Andueza and others 2003). Of course, in reality temperature is not able to be examined as a single variable in the coffee brewing process, thus making it difficult to study.

OTHER

BREWING METHOD

Certain brewing methods transport additional components (not only coffee solubles) of the ground coffee to the final beverage. A simple example is Turkish coffee, where suspended solid particles (spent grounds) keep swimming in the final beverage. Another case is espresso: an instance (probably the only one) where along with soluble material there is presence of an all-important fraction of coffee oil, forming an emulsion (Petracco 2005a). However, the above lesson did not describe the intricacies of these methods.

WATER CHEMISTRY

We are aware that certain aspects of water chemistry may affect the extraction of coffee components. Some of the foundational research on this topic has been established for decades (Lockhart and others 1955; Campbell and others 1958; Pangborn and others 1971; Beeman and others 2011; Lingle 2011). This work tended to focus on impurities, off-flavors, and holistic measurements of calcium and other dissolved solids. However, more recent research is beginning to shed light on the impact specific cations (calcium, magnesium, or potassium) in water have on the extraction of different coffee constituents (Hendon and others 2014).

TIME

Interacting with temperature, time will certainly influence the amount of and type and amount of compounds extracted from coffee (Lee and others 1992). There is only very basic evidence of specific types of compounds in the coffee extract being reliably dependent on time (Merritt and Proctor 1959). Ultimately, this is another variable in brewing coffee which can never be separated from the other linked factors.

COFFEE GRIND

In fact, it is practically impossible to extract soluble solids from coffee without grinding it. Of course, the finer the grind, the smaller the particle size, the greater the surface area and therefore additional contact between coffee grounds and water (Clarke 1987). The grind size and shape thus is correlated with pore space of the coffee bed. The coffee grind has also been found to influence the rate of caffeine extraction (Spiro and Selwood 1984).

AGITATION/TURBULENCE

Finally, if any turbulence/agitation occurs, including but not limited to the movement of water through the coffee grounds, this will influence extraction. Certainly if the rate of flow around coffee grounds is increased, this will lead to a higher rate of extraction.

COFFEE QUALITY

Certainly brewing method and coffee extraction can influence the hedonic evaluation of a coffee beverage. However, we have to admit that we cannot make a defective, low quality coffee taste like a beautiful, high quality coffee via the brewing process. All processing and handling, freshness, flavor quality, and unique and favorable flavor characteristics can only be allowed to shine or be destroyed during brewing. The heavy burden in this final step lies with the barista, and thus the role of extraction is the final act in the glorious opera that is the coffee chain.

WHAT IS LEFT OVER?

There are certain large molecules which are not extracted from the coffee. This could be for a few reasons. First, the compounds might not be soluble in water. These compounds would be what we call "water insoluble". We generally consider a compound not soluble nor hydrolysable because of their chemical structure, orientation or size. We know these insoluble compounds to include macro components of the coffee cell walls, which survive the roasting process (Petracco 2005b). These are polysaccharides such as cellulose and hemicellulose, and other polymers such as lignin (Arya and Rao 2007; Redgwell and others 2002; Fischer and others 2001). Hemicellulose is composed of three sugars, mannose being the most abundant, followed by galactose and arabinose, which are all found in the coffee cell wall (Mussatto and others 2011; Passos and others 2014). However, if these larger molecule are not hydrolyzed during a long, hot coffee extraction, they are often left over. Larger molecules, such as proteins or those deriving from protein degradation can be left in the coffee grounds.

For example, high molecular weight melanoidins largely remain in the spent coffee bed, while smaller melanoidins, grouped under the definition "soluble fibers," are important to the brew inasmuch as they provide color and possibly taste and texture (Bekedam and others 2006; Bekedam and others 2008). Some ash and corresponding minerals are also not extracted into the coffee brew, such as potassium (when not as salts), phosphorus, and magnesium, among others (Mussatto and others 2011).

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