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PHYSICS OF CAPILLARITY AND COFFEE BREWING PROCESS

ФІЗИКА КАПІЛЯРНОСТІ ТА ПРОЦЕСУ ЗАВАРЮВАННЯ КАВИ

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Abstract. *The article considers the physical phenomenon of capillarity and its application in the process of brewing coffee. It discloses factors affecting the extraction efficiency and taste of the beverage, such as surface tension, adhesion, coffee particle size, water temperature and brewing time. The publication emphasizes the importance of understanding these physical aspects to improve the coffee brewing process and develop new technologies in this area. It should be noted that the understanding of capillary physics contributes to improving the quality of coffee and opens the way to new scientific discoveries in the field of coffee making.*

Key words: *capillary physics, coffee brewing process, coffee extraction, temperature, brewing time, roasting level, grinding size, tepping, surface tension, adhesion, coffee particle size and shape, coffee history.*

Introduction.

Capillarity is a phenomenon in which a liquid rises or falls in narrow tubes or porous materials without wetting their walls. This phenomenon occurs due to the surface tension forces of the liquid and the adhesion between the liquid and the walls of the tube. Today, it is a well-studied phenomenon that is widely used in various fields of science and technology.

This phenomenon plays an important role in the coffee brewing process, as it allows hot water to penetrate the ground coffee powder, wetting it. Thanks to this property, water actively moves through the narrow channels between the coffee particles, washing away coffee oils and aromas.

Let's find out how they are related to each other:

- *Surface tension:* Water tends to minimize its surface area. This leads to the formation of a film on the surface of the water, which seems to "pull" it together. This film helps the water to rise through the narrow channels between the coffee particles.
- *Adhesion:* Adhesion is the molecular attraction between different substances. In the brewing process, the adhesion between the water and the coffee powder helps the water to rise through the narrow channels between the coffee particles.
- *The shape and size of the coffee particles:* The size and shape of the coffee

particles affect the speed and efficiency of the extraction. Finely ground coffee has a larger surface area, which results in faster extraction, but can also lead to bitterness.

- *Water temperature:* Hot water dissolves coffee oils and flavors better.
- *Brewing time:* The longer the water is in contact with the coffee, the more coffee substances will be extracted.

The topic is *relevant* and interesting for both scientific research and practical application in coffee brewing. Understanding the *physics of capillarity* allows the coffee roaster to better adjust brewing parameters, such as water temperature, water contact time with coffee beans, and grind level, to achieve optimal coffee flavor and aroma. *Studying the coffee brewing process from a physical point of* view can lead to new scientific discoveries that relate not only to the brewing process itself, but also to the properties of coffee beans and their interaction with water. Understanding the *aspects of brewing contributes to the development* of new methods and technologies for brewing coffee, such as specialized coffee makers, filters and other devices that improve the quality of the drink. The growing interest in high-quality coffee among consumers emphasizes the *importance of* understanding the brewing process and its physical aspects to meet the taste needs of customers.

The connection *between the physics of capillarity and the brewing of coffee* may come as a surprise to many people. Exploring such unexpected connections can be *fun* and *stimulating*. *Consideration of such a topic* provides an opportunity to see how the fundamental principles of physics are applied in everyday situations. The article can contribute to the understanding of processes that seem ordinary but are based on complex scientific principles. The publication contributes to the *popularization of science* among the general public by showing how scientific knowledge can be applied in various spheres of life.

Physics of capillarity.

Capillary phenomena are the rise or fall of fluid in thin tubes.

Let's look at some cases:

1. The *wetting fluid* rises in the capillary above the liquid level in the vessel - this is because it is subjected to Laplace pressure, which is directed upward by surface tension forces.

It turns out that the liquid level is set at a height where the Laplacean and hydrostatic pressures of the liquid in the capillary are balanced.

2. The *non-wetting fluid* descends into the capillaries below the level of the liquid in the vessel, because it is subject to a downward Laplace pressure. This liquid falls to the height at which the Laplace and hydrostatic pressures of the liquid in the vessel are balanced.

Examples of capillary phenomena in nature, everyday life, and technology. Capillary phenomena are extremely common in nature, technology, and everyday life:

- ✓ penetration of nutrients from the soil into plants;
- ✓ moisture rise from deeper soil layers;
- ✓ construction practice;
- ✓ the use of towels, napkins, and gauze.

Plant nutrition is caused by the absorption of moisture and nutrients from the soil, which is possible due to the presence of capillaries in the root system and stem of the plant.

Capillarity must be taken into account when tilling the soil. For example, in order to ensure more intensive evaporation of moisture from the soil, it is necessary to tamp it down. In this case, capillaries are formed in the soil, through which moisture rises and then evaporates. To reduce evaporation, the soil is loosened, destroying the capillaries, and the moisture stays in the soil longer.

Bodies that have a large number of capillaries absorb moisture well. That's why when you dry your hands, a towel absorbs water, and kerosene or molten stearin rises up the wick of a lamp or candle.

Historical coffee review. *The history of coffee and its first discovery*. The origin of coffee and its spread in the world. Around the 10th century, coffee was found in Ethiopia, namely in the highlands of Kaffa, without which millions of people now cannot imagine life. It was found thanks to ordinary domestic goats. The young shepherd noticed that his goats stubbornly ate the reddish berries of small bushes and then began to run and play, becoming very energetic. The inquisitive shepherd decided to taste the berries and leaves of these bushes. He did not like the taste, but he noticed that fatigue left him, and his mood improved significantly. The young man shared his observations with friends and relatives, word of mouth worked and everyone in the area learned about it. Missionary monks also heard the news. The discovery of Ethiopian goats was very interesting and they began to experiment with this plant and its areas. Subsequently, they managed to make a recipe for a decoction of coffee leaves, which miraculously restored people's vigor, relieved fatigue and helped the monks not to fall asleep during long and monotonous prayers. Another coffee drink, which they invented, was prepared by soaking these berries in water [1].

Distribute coffee around the world. About a thousand years ago, Arabica seeds were exported from Kaffa to the Ethiopian region of Harrar, and the species of plant that was exported was called "tipika." In the 15th century, Arabs exported tipiki seedlings to Yemen, where the Yemeni sheikhs themselves began to grow coffee for sale, becoming monopolists in the market. They forbade the export of green grains, so coffee was roasted in Yemen, and from there it was supplied to other countries. Because of this, everyone thought that coffee grew only in Yemen, and did not know about its presence in Ethiopia [2].

Somehow they managed to take green coffee to India, probably thanks to the Indian pilgrim Baba Budan, which opened up the opportunity to grow coffee to others, not only Arab sheikhs.

Until the 17th century, coffee was supplied to Europe from Yemen, but when the drink became popular, the Dutch decided to grow coffee trees themselves, bypassing Arab traders. In 1699, they planted several seedlings on the island of Java, destroying the Arab monopoly and independently began to supply coffee to Europe. Nowadays, Holland ranks 5th among other countries in terms of coffee consumption in the world.

At the same time, the King of Holland gave the King of France several coffee trees, which were taken to Bourbon Island (Reunion) by the French. It soon turned

out that the trees had changed: the leaves became green, without the reddish tint characteristic of tipika, and the grains became more rounded - this was the first mutation of the tipika, which was called bourbon.

French naval officer Gabriel de Clay brought coffee to America. Coffee tree seedlings came to the island of Martinique, and then coffee trees were grown in Colombia, Brazil, Jamaica, Guatemala and Cuba.

Traditions of brewing coffee in different cultures. Coffee is not just a drink, but a real ritual that unites people around their fragrant and rich taste. Each culture has developed a unique way of brewing coffee, investing in the process's traditions, history, and a special view of pleasure.

Espresso is the process of brewing coffee under high pressure. It involves the forced pumping of hot water through finely-ground coffee beans, which leads to a strong and concentrated drink. Starting in Italy, espresso has become an integral part of Italian culture and is now popular around the world, often serving as the basis for other drinks such as lattes and cappuccinos.

The French press is a device for brewing ground coffee beans in hot water, which allows you to get a drink with a rich and rich taste. Known in France as "cafetière," the French press is noted for its simplicity and ability to store natural oils and coffee flavours.

Turkish coffee stands out as a one-of-a-kind way to brew finely ground coffee using a special pot known as cezve. It is prepared with maximum attention to detail and has a deep connection with Turkish culture. The process involves boiling the beans with water and sugar, resulting in a crepe and flavorful coffee drink that is often enjoyed during intimate encounters.

Pur-over uses a more precise and relaxed approach to making coffee. This method includes the gradual pouring of hot water on coffee beans in a controlled way, allowing you to carefully highlight the taste properties. He is inspired by respect for the coffee culture in Japan, where accuracy and craft are highly valued.

Coffee occupies a special place in ***Ethiopian culture***, going beyond the usual drink. The Ethiopian coffee ceremony includes roasting, grinding and brewing green coffee beans right in front of the guests. This solemn event symbolizes hospitality and deepens the bonds of friendship, often uniting communities as they share stories and create strong bonds.

Originating from Hanoi, ***Vietnamese egg coffee*** is an exquisite fusion of strong coffee and juicy egg yolks. This exceptional blend has gained worldwide recognition for its unique flavours. Coffee is brewed directly into a cup containing sweetened condensed milk and egg yolks, resulting in a smooth and creamy delight. He demonstrates the ingenuity of the Vietnamese, the love of coffee and the skill in creating wonderful desserts.

Drip brewing is a well-known and simple method. It involves pouring hot water into ground coffee beans, which are contained in the filter. Water is filtered through the grains, removing caffeine and aroma. Then the resulting coffee is collected in a pan or mug [3].

Capillarity in the coffee brewing process. The brewing process takes place under the pressure of steam seeping from the lower part through the ground coffee in

the middle part, rising to the upper part. Let the drink boil for a couple of minutes (but do not burn to bitterness).The influence of capillary forces on the extraction process. Capillary forces play an important role in the coffee extraction process, affecting the following factors:

1. Extraction speed: Capillary forces lift water through narrow channels in the coffee grounds, which speeds up the extraction process.The finer the coffee grind, the larger the contact surface with water and the stronger the effect of capillary forces.

2. Uniformity of extraction: Capillary forces ensure a more even extraction of coffee substances from the grounds.

This results in a better taste and aroma of the coffee.

3. Control of extraction: Thanks to capillary forces, the speed and degree of coffee extraction can be adjusted.For example, by changing the size of the coffee grind, you can influence the extraction time.

4. Effect on taste: Capillary forces can affect the taste of coffee by extracting various coffee substances from the grounds.For example, finely ground coffee can result in a more bitter taste, as capillary forces extract more caffeine and other bitter substances.

5. Use of capillary forces: There are different methods of coffee extraction that are based on capillary forces. For example, the pourover method uses capillary forces to slowly and evenly extract the coffee grounds from the grounds. It is important to note that capillary forces are only one of the factors that affect the coffee extraction process. Other factors such as water temperature, degree of coffee roasting and grind size also have a significant impact.

The role of capillarity in the formation of the taste and aroma of coffee. Capillarity is a phenomenon in which liquid rises or falls through narrow tubes or channels without wetting their walls. This phenomenon plays an important role in the formation of the taste and aroma of coffee.

1. Impact on extraction: Capillarity facilitates the extraction of coffee substances from ground coffee. As water passes through the coffee grounds, it fills the pores and channels of the coffee particles due to capillary forces. This leads to the dissolution of coffee substances in water, which forms the taste and aroma of coffee.

The size of the coffee grind affects capillarity. A finer grind has a greater specific surface area, resulting in greater capillary extraction. This can lead to a more bitter and astringent coffee taste.

Grinding uniformity is also important. If the grind is uneven, capillarity will act differently in different particles of the coffee grounds, which can lead to uneven extraction and an unbalanced taste.

2. Effect on aroma: Capillarity also affects the aroma of coffee. The aromatic compounds of coffee dissolve in water and rise through the capillaries to the surface of the coffee. These compounds then evaporate and are perceived by the sense of smell.The shape and size of the coffee container also affect the aroma. A narrow and tall container promotes the concentration of aromas, and a wide and low one disperses them.

3. Effect on taste:Capillarity affects the taste of coffee, affecting the extraction of coffee substances. Different coffee substances have different flavors and capillarity

can cause some substances to be extracted more than others.This can affect the taste balance of the coffee, making it more bitter, sour or sweet.

Result: Capillarity is an important phenomenon that affects the formation of the taste and aroma of coffee. It affects the extraction of coffee substances, as well as the aroma and taste of coffee. Understanding capillarity can help you make coffee with better taste and aroma.

Things that affects coffee extraction. Coffee extraction is the process of making desirable compounds such as caffeine, lipids, carbohydrates, acids to extract from coffee grounds. This system hides so many physical and chemical principles, that buying the same coffee beans and doing the same manipulations as a barista does to brew coffee can lead to unlikely result. Many people consider the barista's job as easy as pie. Well, Dr David Hoxley, a lecturer in the Department of Chemistry and Physics at La Trobe University and a member of the La Trobe Institute of Molecular Sciences says [4]: "Baristas have a tough job of deciding how to grind the coffee, how to pack it and how to do the tamping – it's a complex multivariate system. They've got beans coming in that may not always be the same, they've got humidity and on their feet they've got to work out how to bring it all together."

So, in short:

- Temperature
- Water chemistry
- Time
- The level of roast
- Grind size
- Pressure for espresso(tamping)

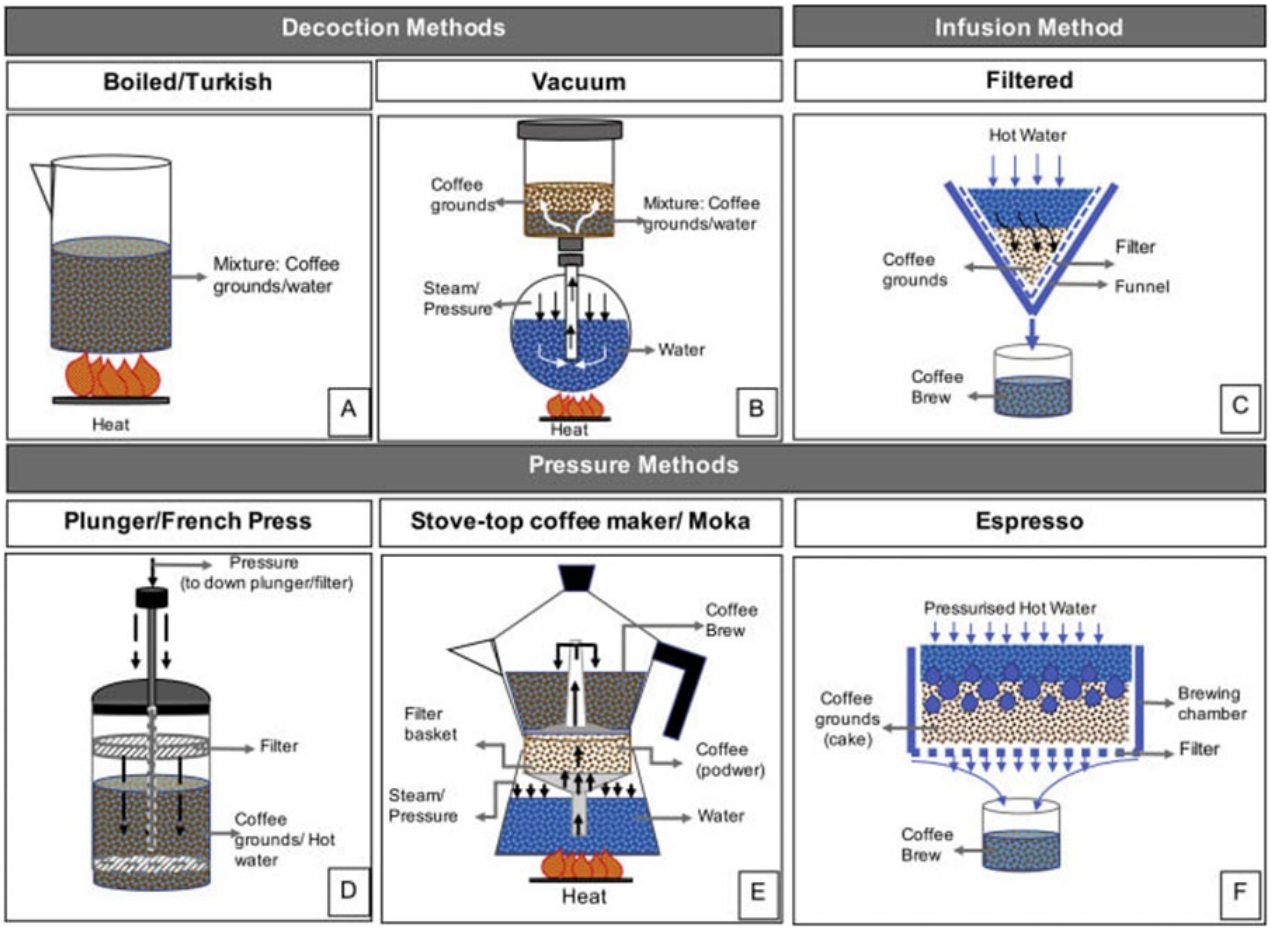
All of numbered above play crucial role in making the extraction hit the sweet point.

Going into details, a coffee that's under-extracted is quite sour, while over-extracted is really bitter. So the main aim is to balance this two things and get this sweet flavor.

Temperature: affects the rate of extraction. The higher temperature of water, the quicker all compounds extract. But it should be remembered that it's tougher to control the process of brewing, in order not to make the taste too bitter. On the flipside, if your temperature is too low, coffee will be under-extracted, that makes it taste sour and lack of body (Cold brew is an exception, due to balanced time aspect).

Water chemistry: The Specialty Coffee Association's water standards give an ideal target as water with the following characteristics: no odor or color; zero chlorine; a pH of 7.0; alkalinity of 40 ppm; and calcium hardness of 50-175 ppm CaCO3. Unless you're interested in researching water chemistry, all you need to know is that the ideal water for brewing coffee is clean, soft and free of chlorine.

Brewing time: everything depends on the way coffee is made. In a drip system, the contact time should be approximately 5 minutes. If you are making your coffee using a French Press, the contact time should be 2-4 minutes. Espresso has an especially brief brew time – the coffee is in contact with the water for only 20-30 seconds.



The level of roast:

Roasting is needed to unlock the flavor of beans. Heat is required to trigger chemical reactions to get compounds that are soluble in water.

Grind size: larger, coarse particles are more permeable, which means the hot water flows more quickly through them. And if the water flows too quickly, you're likely to get an under-extracted coffee. And vice versa, using smaller particles makes the water slow down its flow. But when these fine grinds are steeped in water for too long, more of the bitter, caffeine flavor seeps out – resulting in an over-extracted coffee.

Pressure for espresso (or tamping) – is a process that helps to compress the aggregate of different practical sizes, that is required to resist the hot water. Shortly, with tamping you can also adjust the water's speed, which influences on coffees' taste.

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