Caffeine molecules are naturally found in coffee beans, tea leaves, cocoa and a variety of exotic berries. When ingested, caffeine can act as a stimulant in humans or a toxin in small animals and insects. A certain portion of the human population can’t tolerate increased levels of caffeine in their body. They can experience extreme side effects including, but not limited to irritability, muscle twitching, dehydration, headaches, increased heart rate, and frequent urination. These side effects can be quite unpleasant, which is why many coffee manufacturers decaffeinate coffee.

Introduction

Decaffeination is a fairly easy process since caffeine is polar and water-soluble. The most popular methods of decaffeinating coffee today are, Swiss Water Processing, Ethyl Acetate Processing, Methylene Chloride Processing (Direct and Indirect), and Supercritical Carbon Dioxide Processing.

Swiss Water Processing

The Swiss Water Processing method removes caffeine without using any chemicals, but instead applies the law of simple diffusion. First, unroasted (green) coffee beans are soaked in water until caffeine is dissolved in water. The beans are then discarded, and the solution of water, caffeine, and coffee solids is passed through a carbon filter. The carbon filter is made out of activated carbon, carbon that has been made porous through the process of carbonization (reacting carbon in anaerobic conditions until the gaps between carbon atoms are large enough to allow molecules to pass through). The activated carbon filter has holes large enough to allow water and coffee solids (smaller molecules) to pass through, but not caffeine (relatively larger molecule). After filtration, the mixture that is left is water saturated with coffee flavor molecules – referred as “coffee solids” by the manufacturers. The mixture creates a concentration gradient when added to a fresh batch of coffee beans. Concentration gradients take advantage of the law of simple diffusion- the movement of molecules from an area of high solute concentration to an area of low solute concentration in order to ‘even out’ the uneven distribution of molecules. Since the only difference between the mixture and the fresh coffee beans is the caffeine concentration, caffeine molecules will diffuse out of the beans into the mixture of coffee solids, leaving the coffee beans caffeine free. This method is repeated until the coffee beans are 99.9% decaffeinated, and the flavor is left intact.
Ethyl Acetate Processing

Ethyl Acetate occurs naturally in many fruits, which is why this method is often referred to as natural decaffeination. It is however much cheaper commercially to use synthetic ethyl acetate. This method requires a thorough steaming of the beans until swell. An ethyl acetate aqueous solution is used to wash the swollen beans repeatedly. Ethyl acetate is a polar molecule, which makes it a good solvent for capturing the polar caffeine molecules from the coffee beans (since ‘like dissolves like’). The caffeine molecules bind to the ethyl acetate molecules, and migrate through the cell membranes of cells of the beans. The beans are once again steamed in order to eliminate any ethyl acetate that remains. This method decaffeinates the coffee beans by approximately 97%.

Methylene Chloride Processing

Methylene Chloride ($\text{CH}_2\text{Cl}_2$)

- **Direct Method**- Steamed coffee beans are rinsed directly with methylene chloride which is a polar molecule and is good solvent to organic molecules. The caffeine molecules hydrogen bond to the methylene chloride molecules, and are removed from the coffee beans, leaving the coffee solids (flavor) intact. The resulting coffee beans are 97% caffeine free.
- **Indirect Method**- Coffee beans are rinsed with water, removing the caffeine molecules and coffee solids (similar to the first part of the Swiss Water Process). This solution is then treated with methylene chloride. The caffeine forms hydrogen bonds with the methylene chloride, leaving a coffee flavor aqueous solution. The original coffee beans are soaked on this solution, allowing for the reabsorption of the coffee solids (flavor). The original flavor of the coffee beans is preserved, but are 97% decaffeinated.
Supercritical Carbon Dioxide Processing

Carbon dioxide supercritical fluid (temperature above 31.1 °C and pressure above 73 atm) exhibits both liquid and gas-like behavior. It behaves like gas, and permeates a porous substance, while also exhibiting liquid properties to dissolve substances. Although supercritical carbon dioxide is non-polar, and should only be able to dissolve non-polar substances, certain co-solvents, like water, can be added so that supercritical carbon dioxide can actually dissolve polar molecules like caffeine. Water is more polar than caffeine is, so supercritical carbon dioxide, in the presence of a co-solvent like water, will dissolve the more non-polar substance, in this case, caffeine. In order to use supercritical carbon dioxide to decaffeinate coffee beans, the beans are first steamed until they swell (this is where the co-solvent, water, comes into play). After this, they are immersed in supercritical carbon dioxide which binds to the caffeine molecules and draws them out of the beans, leaving the coffee solids (flavor) embedded in the bean. The resulting coffee beans are about 97% caffeine free. The carbon dioxide is then passed through a charcoal membrane that is selective toward carbon dioxide molecules. Caffeine is stopped by the membrane, because of its larger size relative to carbon dioxide, and collected.

Usage of Removed Caffeine

Once coffee beans have been decaffeinated, all of the extracted caffeine is made into a white powder and sold to the pharmaceutical or food industries. The pharmaceutical industry adds caffeine into certain drugs, including many pain killers. Food industries add caffeine to certain foods like soda, because of its stimulating effect.

References


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