SENIOR CAPSTONE/
SENIOR DESIGN EXPERIENCE
2025

All-Day Caffeine Supplement

Lukas Sizemore[1], Sophie Remmey[2]

[1]Biological Engineering; [2]Biological Engineering;

PURDUE UNIVERSITY
Agricultural and Biological Engineering

Objective

College students are increasingly relying on caffeine to fuel their academic routines. 70% of students report using caffeine at least two times a week. However, most forms of caffeine intake, from coffee to tea to energy pills, have short lived effects and dramatic spikes in uptake, followed by a "crash". The objective of this project is to design a readily available over-the-counter supplement that provides lasting all-day energy. We plan to target a subset of the total student population of all Big Ten Universities which is an initial target group of about 30,000.

Alternatives

One idea for an alternative product design is “Russian Nesting Doll” capsules. A special capsule with a shell made to release its contents with a delay would be filled with the API and placed inside a larger capsule with additional API. Because this was a very unique idea, Unique idea would make an automated capsule filling process tedious or difficult. An alternative for the current caffeine extraction process was microwave digestion. In this process, microwaves are used to break down the tea or coffee for extraction. However, it requires specialized equipment that failed a cost-benefit analysis.

Process Design

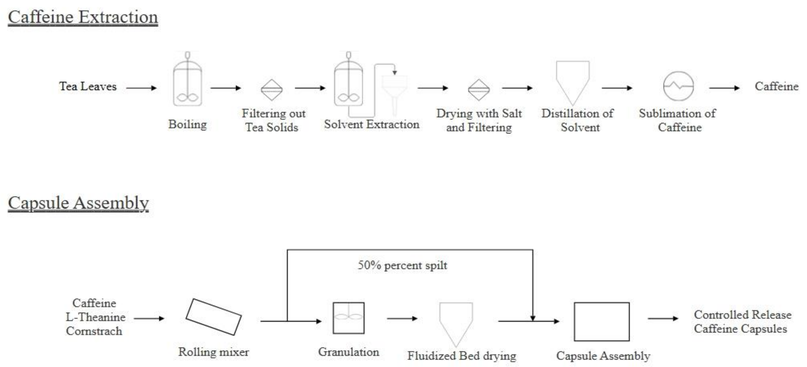

Figure 1: Process Flow Diagram of entire process split into 2 stages of Caffeine Extraction and Capsule Assembly

Caffeine Extraction

The caffeine source for the supplement is from green tea leaves to allow for supplemental revenue in the form of decaffeinated tea leaves and its relatively high concentration of Caffeine at 2% mass. The first stage of process is boiling the tea leaves in a bioreactor with water and calcium carbonate. The second stage is filtering out the tea leaves in a Nutsche filter. The third stage is mixing in ethyl acetate and removing the denser phase in a mixer settler unit operator. The fourth stage is removing water by adding MgSO4 to extract and then filtering out hydrous MgSO4. The fifth stage is distillation of remaining solution to remove ethyl acetate. The final stage is a sublimation stage on the crude extract containing just dry tannins and caffeine. This step will result in the second highest loss of caffeine behind the boiling step. The system can be optimized to increase rate of volatilization of caffeine. One round of caffeine extraction was done resulting in yield of about 20% of the expected amount.

Figure 2: Photo of white capsules from freepik.com

SUPPLEMENT FORMULATION

There are four main stages of supplement formulation. First, caffeine, L-theanine, and cornstarch are mixed in a rolling drum mixer to ensure even mixing. Then half of the batch is sent to a wet granulation step where it is mixed with a Eudragit s100 and ethanol solution. Next the wet granulation product is dried in a fluidized bed. Finally, the capsules are filled with both the delayed release granules and the instant release powder mix. No testing was done on release of capsules due to lack of ingredients.

Optimization

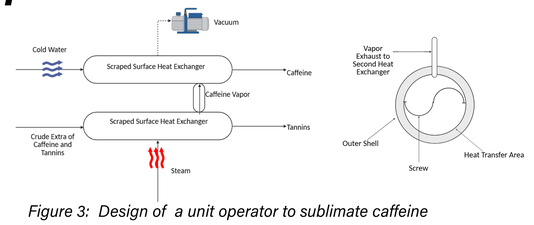

Figure 3: Design of a unit operator to sublimate caffeine

To optimize the process to extract caffeine a modified heat exchanger can be used. The sublimation of caffeine is dependent on the temperature of volatilization and settling temperature. This allows caffeine volatize quickly and then crystalize. The two scraped surface heat exchangers were chosen because of their ability to move powders and handle a large range of temperatures. The optimal temperatures for each exchanger is 20°C and 250°C. This was found using Python.

SUSTAINABILITY

Solar panels can be used on the factory roof and any available green space to offset carbon footprint and energy demands. To implement a zero-waste process, salts, ethyl acetate, and water will be recaptured, used tea leaves can be sold as decaffeinated tea, and tannin byproducts can also be sold for other uses.

Conclusion and Recommendation

The process to manufacture controlled release caffeine supplements is a material and labor-intensive process. This has allowed for some optimization such as the dual scraped surface heat exchanger design. However, further optimization can be done in the process. The following operations can be optimized:

- Boiling step in extraction to increase initial caffeine extraction
- Wet granulation and drying of powders for capsule
- Switching to synthetic production of caffeine