Final Report

Functional Coffee Cup Insulator

Sarah Don 2009

Abstract:

In order to keep coffee warm during a 2 hour class so that the instructors will not become grumpy, I proposed to conceive, design, prototype, and evaluate a coffee cup insulating device. Conception and design is accomplished via a collaborative, fractal, recursive process of brainstorming and idea selection as documented in my notebook. The resulting design concept is a coffee insulator. The design parameters required the device to keep coffee warm for the duration of Elizabeth and Dave's one-hour class while being made entirely out of cardboard. My coffee cup insulating device met the design requirements while also being ergonomically and aesthetically viable and easily manufacturable in bulk with only a tiny carbon footprint. Drinkability was taken into account and addressed by surveying the maximum safe coffee temperature. When implemented, the coffee insulator will make the world a better place by contributing to the happiness of Elizabeth and Dave. If wildly successful, the device could contribute to the happiness of millions of hot beverage consumers.

Introduction:

A coffee insulating device that would keep a cup of coffee hot for one hour is of significant importance to Elizabeth and Dave (E&D) as well as the larger customer base of drinkers of coffee and other hot beverages. It is commonly observed that hot coffee, once served in a coffee cup, cools. Once cooled, coffee drinkers such as E&D are saddened, and the world would be a better place if they were not sad. To increase the net happiness in the world, this 21W.732 project is to conceive, design, prototype, and evaluate an insulating device that will keep a cup of coffee hot for one hours. In addition to the requirement that the coffee remain hot, the product must satisfy three subsidiary requirements:

- The product must not expose the coffee drinker to undue hazard
- The product must be ergonomic and aesthetically pleasing
- The product must have a small ecological footprint, both in terms of the materials used to construct the product and the labor required to produce the product

These requirements are weighted with the ultimate requirement that the coffee remain hot according to the rubric in Table 1. For environmental and economic reasons, the coffee insulating device is to be constructed of solely cardboard. If the design is successful, E&D will be happy the coffee insulating device could be marketed to the billions of consumers of hot beverages around the world.

Table 1 - Cost of subsidiary requirements

Requirement	Cost Incurred
Safety	The product must pass the tilt test, the pour test, and the roving eye test of due diligence. Any product that does not pass these tests is disqualified.
Ergonomics & Aesthetics	A panel of experts will judge your prototype and place it in one of three categories: top quartile, middle quartiles, and bottom quartile. • Products in the top quartile will have 10 minutes deducted from the time at which the temperature is measured. • Products in the bottom quartile will have 10 minutes added to the time at which the temperature measured.
Eco-friendliness	• If the mass of the product is less than the mass of the coffee, 10 minutes deducted from the time at which the temperature is measured. • If the mass of the product is more than twice the mass of the coffee, 10 minutes will be added to the time at which the temperature is measured. • If the product can be assembled in fewer than 15 minutes, 10 minutes will be deducted from the time at which the temperature is measured. • If the product requires more than 15 minutes to assemble, 10 minutes will be added to the time at which the temperature is measured.

Background:

Thermal model

When the coffee cools, heat is transferred from the coffee liquid to the coffee cup by conduction and then to the air by convection. In order to keep the heat energy from escaping the coffee liquid, the coffee cup needs to be kept warm (to prevent energy from the coffee liquid to "fill" the "energy space" in the cooling coffee cup). To keep the coffee cup warm, it needs to be insulated so that energy from the cup cannot be transferred to the surrounding air. The following equation is Newton's Law of cooling where *Q* is the thermal energy in joules, h is the heat transfer coefficient, *A* is the surface area, *T* is temperature and *t* is time.

$$\frac{dQ}{dt} = h \cdot A(T_{environment} - T_0), \qquad h = \frac{\Delta Q}{A \cdot \Delta T \cdot \Delta t}$$

Futher research would need to be conducted in order to identify the specific heat transfer coefficient for water to cardboard and from cardboard to air for the true rate of cooling of the coffee inside this coffee cup insulating device to be calculated correctly.

Also, there is a critical insulation point, at which the positive effects of insulation are over shadowed by the heat loss due to the increasing surface area. This is represented by the following mathematical relationship where *R* is the thermal resistance, *k* is the variable for thermal conductivity and *r* is the radius of the insulation.

$$R_{critical} = \frac{k}{h}, \qquad k = \frac{1}{r}$$

Safety analysis

The coffee is poured into the cup when it is approximately 70°C. This temperature may be uncomfortable to drink for Elizabeth and Dave, but it is safe according to www.blackbearcoffee.com. After much in-class discussion, it was determined that the it is more comfortable to drink between 50°C and 60°C according to the collective opinion of the class. The design does not have any sharp edges, so the coffee insulator is safe for Elizabeth and Dave to drink from the original edge of the coffee cup inside the insulator.

Aesthetics and ergonomics

The coffee insulator contains the heat energy inside the coffee cup and prevents the outside surface of the insulator from warming too much, making it comfortable to hold on to. The outside surface of the insulator follows the contours of the regular coffee cup that sits inside and includes a lid for safety, aesthetics and also to keep more heat in. The design does not support a handle, however the cup's diameter is only increased by 14 mm, therefore it is just as easy to hold onto with one hand than the original coffee cup inside.

Materials and labor costs

The entire coffee insulator is made from recycled cardboard and a small amount of glue. Recycled cardboard costs $100 per tonne on average (according to the DPPEA), and the weight of cardboard used to construct the coffee cup insulating device weighs ~95g, making the approximate material cost per device 1¢. Therefore the production of the device is inexpensive and has a small carbon footprint. There is only a small amount of labor and time spent blending the cardboard and waiting for it to dry. If the coffee cup insulating device were to be manufactured on a large scale, processes such as blending the cardboard and drying it could be made much faster.

Methods:

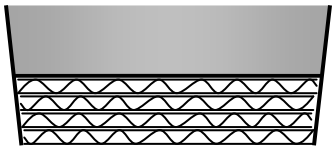
Fig 1 Big picture overview of the coffee cup insulator design

Table 3 Design FRDPARRC

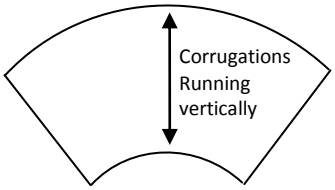
Functional Requirements	Design Parameters	Analysis	Research	Risks	Countermeasures
keeps coffee hot	Must prevent coffee from cooling	The coffee cup should not be exposed	"hot" coffee should be approximately 60°C-70°C	Coffee is still too hot to drink after 2 hours	The coffee insulator is not completely closed.
safe	No sharp edges or leaks	The drinker should drink from the cup's lip	Maximum coffee temperature is approx. 70°C	Coffee could leak and burn the drinker	The original coffee cup would remain completely in tact
ergonomic and aesthetic	Doesn't require a handle, but can't be too wide to hold on to	Should not be too many layers of insulation.	Cardboard looks environmentally friendly; doesn't require a handle to be functional	Not aesthetically pleasing enough to sell	The coffee insulator still resembles a coffee cup and the cardboard finish makes it look environmentally friendly
economical	Can't be too expensive or leave a carbon foot print with manufacturing.	Recycled cardboard will do the job.	If the labor takes too much time, Sarah will get bad grades in other subjects.	Costs too much/requires too much labor to produce	The cardboard is recycled

Device recipe

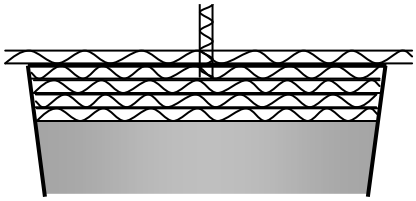
1. The raised bottom of the standard coffee cup was filled in with several layers of corrugated cardboard, as in the following diagram, that made a perfect seal to keep the heat in as much as possible.



2. Recycled corrugated cardboard was fitted around the outside of the standard coffee cup and circular pieces on the bottom and top. This was not a simple rectangle. In order for the sleeve to fit the subtle cone-like contour of the standard coffee cup, the corrugated cardboard had to be cut in the following shape:



3. 100g of recycled cardboard was blended with water in an electric blender. The cardboard had to be torn up into smaller pieces so they didn't just wrap around the blades of the blender.
4. A ~5mm layer of blended cardboard was spread onto the outside surface of the coffee cup insulator sleeve. As the blended cardboard was applied, as much water as possible was removed with paper towels while still being careful not to collapse the corrugations in the cardboard sleeve below.
5. The coffee cup insulator was left to dry in the sun while the lid was constructed.
6. The lid was made of several layers of corrugated cardboard just like the bottom as in the following diagram. Each layer was stuck together with glue and then cut so that the entire lid tapered slightly to fit inside the subtle cone-like shape of the coffee cup.

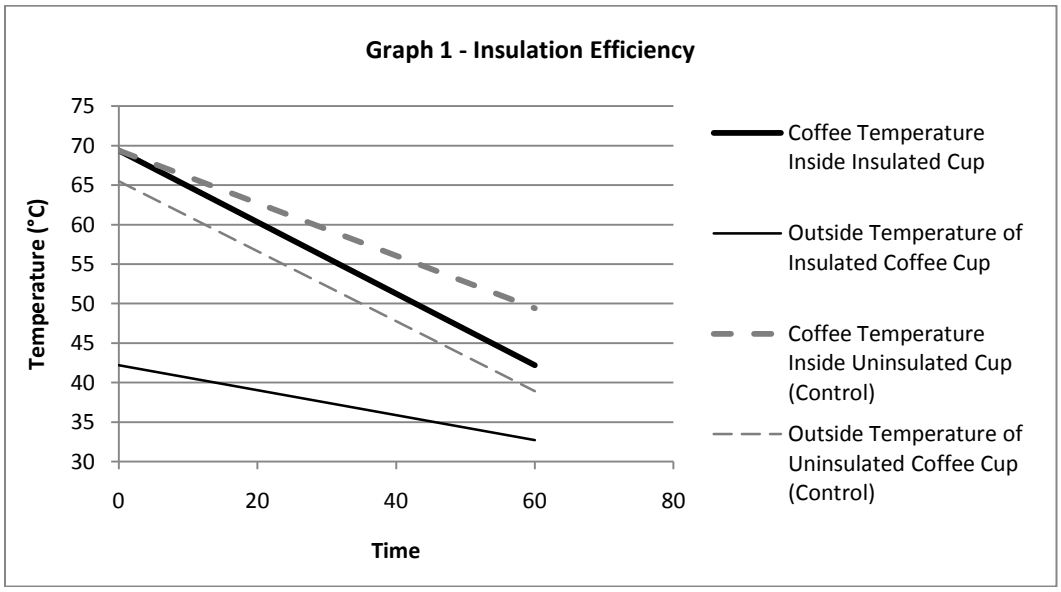


Device testing

The ability of the coffee insulating device to keep coffee hot will be evaluated by measuring the temperature of a cup of coffee one hour after the coffee container ¾ full of freshly brewed coffee (or hot water) has been placed in the device. Aesthetics, ergonomics, and economics will be factored in as noted in Table 1. The tilt test is executed by tilting the surface to the angle at which the coffee would pour from the coffee container. The tilting should be gentle and occur over a period of 3 to 10 seconds. The pour test requires that the coffee can be poured from the name it device into another coffee cup without spilling coffee. The roving eye of safety test is intentionally left vague.

Analysis:

The functional coffee cup -insulating device worked as expected. Compared to the control model of a plain coffee cup with no insulation, the coffee was kept 1.17 times warmer. As shown in Graph 1 below, over the course of the one-hour test, the temperature of the coffee kept in the insulated coffee cup only decreased by 20°C, whereas the coffee in the control standard coffee cup with no insulation lost 27°C.



It was also interesting to observe that the coffee cup insulating device kept the surface temperature of the cup relatively low compared to the temperature of its contents. As shown in Graph 1 above, the insulation kept the surface temperature ~22°C lower than the temperature of the cup's contents on average. However, the surface of the standard uninsulated coffee cup was only 3-4°C below the temperature of the cup's contents thus making it too hot to comfortably and possibly even safely hold onto with bare hands. This illustrates the extent of the ergonomics that accompany this device and its practicality for coffee drinkers such as Elizabeth and Dave.

The coffee cup insulating device also passed the tilt test as discussed in the previous section. The liquid was able to be poured from the coffee cup with ease because the lip of the original inside coffee cup was not altered as part of the construction of the surrounding insulation.

Conclusion:

In conclusion, the coffee cup insulating device design that was prototyped and tested in this study proved to be a functional, ergonomic and economically viable solution to the unhappiness of coffee drinkers when their coffee cools too rapidly. As well as the low cost and eco-friendliness of the manufacturing process, the result is aesthetically pleasing while serving its original purpose as a coffee cup insulator. If this product could be implemented successfully, coffee drinkers all over the world would be much happier.