UnCheggable Solutions: Cold-Can-Crusher

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Abstract—**This paper covers our MMAE 432 final project and alpha prototype. We designed and built a canned beverage dispenser that crushes a full can, while dispensing its contents through a cooling system to dispense a cold beverage. Our analysis includes force analyses and thermodynamic analyses. Our prototype was a success and fulfilled our defined need.**

I. Introduction

For the capstone project, students were tasked with designing and fabricating a mechanical device that "solves" a problem in our everyday lives. We defined our need as "limited fridge space limits the amount of cold drinks that can be stored at one time, and similarly: empty cans take up large amounts of space in the trash". Our group, UnCheggable Solutions, decided to design a beverage dispenser that takes a full, room-temperature beverage and dispenses it at 45°F, while crushing the can to a height of 2in. at the same time, for easy disposal (Fig. 1).

Fig. 1 The Cold-Can-Crusher

This project taught students about the proper steps of the mechanical design process. Throughout the design process, students learned how to properly implement the analysis methods and engineering practices learned at IIT. By following the proper steps and utilizing both numerical and experimental analyses, our design fulfilled our functional requirements and produced a quality alpha prototype.

While designing the device, three functional requirements were designated: the ability to pierce and crush a full canned beverage the ability to cool the drink from 72°F to 45°F, and the ability to crush the can to a height of 2 inches. Each requirement was analyzed with numerical methods, then tested in an experiment to verify and fine-tune our design. After our critical function (crushing and dispensing) was demonstrated, we decided that an electrical, automated system would work better than a manual system for our needs. Following our design plans, we constructed our alpha prototype.

Our final prototype consists of two main parts. A PVC body houses the: actuator for crushing the can, puncture plate, funnel for collecting the beverage and adding mixers, and small pump that assists in pushing the beverage through the cooling coil. The second part is a small modified keg filled with ice-water that holds the cooling coil for cooling and dispensing the drink. This final design successfully crushes and cools canned beverages up to a size of 24 oz.

II. Concept Generation and Evaluation

When deciding on our final project, three needs were selected and analyzed; then after meeting with the professor, two of those needs were selected and sketch models were built for each one (see Fig. 2). In addition to the sketch models, basic calculations were performed to demonstrate the feasibility and capability of each proposal.

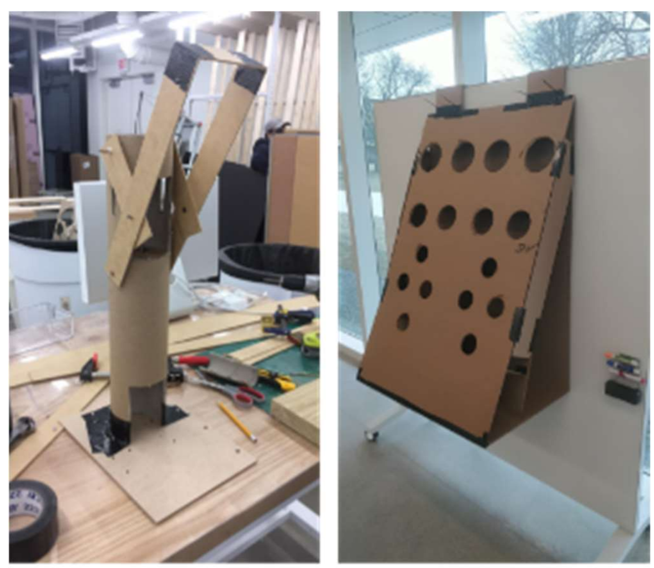

Fig. 2 Sketch models of the can-crusher, and drinking game proposals.

The first proposal was the can crusher. The second was a drinking game like skee-ball, with sensors to detect hits and dispense drinks to players accordingly. After meeting with the professor, we decided to go with the can crusher because it posed more mechanical challenges and possibilities. Functional requirements for the can crusher were then established.

Pugh charts were used to select specific features and solutions for each requirement. Two Pugh charts were used: one for the crushing action and one for the cooling unit. The Pugh chart for the crushing and action graded each concept on its: weight, manual input, consistency of force, and the ease of use. We looked at two crushing methods: a mechanical lever and a motor. We initially selected a mechanical lever because it would make the device more mobile; but, after reviewing our critical function demonstration we decided that the consistency and cleanliness of the motor was superior. The Pugh chart for the cooling unit graded each concept on its: size, time to dispense, cooling capability, and cost. We looked at two possibilities for the cooling unit: a refrigerated unit and an ice-water cooled coil. We decided on a coil, because it cooled the drinks to the correct temperature and was much cheaper than a refrigeration unit.

Once we decided on the basic concepts for our project, we performed a more detailed analysis to determine the specific parameters of each part.

III. Primary Analysis and Critical Function

Once our functional requirements were established, we performed numerical and experimental analyses to help determine our design choices to meet those requirements. Our initial analysis focused on the force to pierce the can, the cooling capability of the device, and the ability to dispense the beverage. Our critical function prototype was constructed based on this initial analysis (see Fig.3). The results of our critical function demonstration were then analyzed and changes were made to improve our design.

A. The Force to Crush and Pierce a Can

As the critical function of our device, the crushing action of the can is of utmost importance for our product. Our initial calculations determined that cans required 270 lbf to crush, with a piercing force of 65 lbf. These values were extracted from an extensive NASA study, which concluded that failures of thin walled cylinders is highly variable. Due to this stated variability, we compared our results to conventional can crushers, meant for empty cans, and determined that instability of cans in a crushing motion severely decreases the force needed.

This hypothesis was verified by testing the force needed to pierce and crush full cans used a simple nail as the piercing point and weight plates as the crushing load. These tests indicated that 50 lbf is needed to pierce a can, and that 80 lbf is needed to crush the can after it is opened. As such, a modified conventional can crusher was deemed suitable for our device.

B. The Cooling Capability of Coil

After selecting a coil as our cooling unit, a thermodynamic analysis was performed to determine the diameter of the tube, as well as the length needed to cool the drink. Copper tubing was selected because it is the most readily available flexible metal tubing and is commonly used for water line applications.

First, values were selected for our initial calculations; these were based on standard beer brewing materials and practices. A

Fig. 3 Critical function model with detailed view of modified can crusher

Fig. 4 3/16" Cooling Coil

standard diameter of 3/16 in. was used as it is the standard diameter used in homebrewing setups. A flow velocity of 1.48ft/s was selected as our target, as it produces a Reynold's number of 2150, just below the Re=2300 that procures a turbulent flow and a consequential over-foaming of carbonated beverages.

Based on this diameter and flow rate, the coil length was estimated to be 330 in. In order to fit the coil into a reasonable space, we modeled it to fit into a 2L bottle. This produced a coil that was 16 in. tall, with a diameter of 4in. (see Fig. 4).

The thermodynamic calculation indicated that the coil would cool an entire 12 oz. can from 70°F to 45°F in 45 seconds, without any assistance (gravity-fed). As a safety, we estimated that in the real-world the coil would take about a minute and a half. However, we got highly variable flow rates during our experimental process; so, we decided to do a more in depth analysis of the dispensing action and speed of dispensing.

C. The Dispensing Action and Speed

Based on our coil calculations, the device would dispense a cooled 12oz. can in a minute and a half, assuming a perfectly efficient flow. However, in our tests, we found flow rates ranging from 1 to 3 minutes. Based on these variable flow rates, we decided to look for ways to assist the fluid in overcoming the pressure losses from the coil.

We decided to look at different pumps to run in-line with the tubing system. After selecting a basic aquarium pump, we performed a brief test and analysis to ensure that it produced a steady flow.

The pump produced a steady flow and enabled the fluid to overcome initial backpressures from air-bubbles in the tubing; so that even when the pump was turned off, the fluid flowed smoothly. The pump-assisted flow dispensed a full can in a minute and a half.

D. Critical Function Model

Following the primary analysis, we constructed our critical function model based on our findings. Based on our initial estimates, we designed our model with a manual crushing mechanism, with modifications to puncture and dispense the drink. Due to violent crushing of the can, we added a splash shield and rubber seal to prevent the user from being splashed. These changes can be seen in figure 3.

Our critical function demonstration went well, and the device was proved to be capable of crushing and dispensing a full 12 oz. can at 45°F. The dispensing action took about two and a half minutes, as we did not include a pump for the critical function model. And, based on observations and feedback from our demonstration, we decided to make some changes to our design. These changes and the refining of our design were performed in a secondary analysis.

IV. Secondary Analysis

During our critical function demonstration, we noticed two possible issues with our design. The first being the crushing and piercing action, and the second being with the cooling coil. In our secondary analysis we looked at ways to: improve the crushing mechanism, improve the cooling coil and dispensing, and expand the product capabilities.

A. Improved Crushing

Due to the violent, jerky can-crushing experienced with the manual operation, we decided to look back at our other option: the motorized crushing action. The motorized crushing action rectifies the violent crushing issue, as it crushes the can at a steady rate at all points. Expanding on this we decided that we could either simulate a motor using manual input and a gear system or use an actuator as a last resort.

Because the group members tasked with finding appropriate gear models did not do their work, we were delayed and had to select an actuator to implement in our design. We selected an actuator with an 8 in. stroke and a 300 lbf capacity, that ran on a 12V DC power supply (see Fig. 5). The crushing force of the actuator is significantly higher than the force needed to pierce

Fig. 5 Actuator with crushing plate attached to the end

Fig. 6 Funnel reservoir w/ side funnel
Note: the side funnel is capped off when not in use

and crush the can, and the slow speed of the actuator helps prevent splashing from the can.

B. Improved Cooling Coil

Based on observations and the professor's feedback, we decided to change our sizing. First, we selected a pipe with a ¼ in. interior diameter, then we decided to increase the diameter of the coil to decrease the number of coils which was a significant source of pressure loss. These changes produced a coil that has an outer diameter of 5.5 in. and an overall height of about 8 in.

Following experimental testing, we decided that the cooling was more effective than we had initially thought, allowing us to cut of the length of the coil, without compromising the cooling capability.

C. Expand Product Capabilities

One small, but significant piece of feedback was a suggestion that we expand the capabilities of our product. We investigated this and decided that small changes would have big impacts on the usefulness of our product.

The first expansion came from the actuator, as the large stroke length organically introduced the ability to crush large cans. Our second addition is a small funnel on the side of the collection funnel, that enables bottled drinks, liquors, and other drinks to be poured into the funnel (see Fig. 6). The funnel couples well with the pump, as the pump acts to stir up the contents of the funnel, making it ideal for making mixed drinks.

After completing the secondary analysis, our changes were implemented and tested in our alpha prototype.

V. Alpha Prototype and testing

Following our secondary analysis and changes in design we were able to construct and test our alpha prototype. Most of the parts were manufactured in house. The prototype is composed of a housing for the actuator and crushing assembly, a keg with the cooling coil, controllers for the pump and actuator, and a frame for all of it.

A. The Housing, Crushing Action, and Funnel

The housing is made of PVC and contains the actuator, piercing grate, funnel, and pump (see Fig. 7). PVC is a good material for our application, as it is watertight, and modular. The modularity of the PVC enabled us to construct a housing that hides most of the components, producing a clean looking device.

We selected a 3in. diameter piece of PVC as the core size, as it was large enough for a person to fit their hand in to place and remove a can; and, it is thin enough to hold a can upright and prevent the actuator from shifting.

The actuator crushes the can onto the puncture grate, and dispenses the contents into the funnel reservoir, which is composed of a 3-way pipe connection. The first end is covered by the puncture grate, one end is capped off with the funnel and pump, and the other is left open to allow for additional drinks to be poured into it. A small cap is included to seal the third opening when not in use, see note on figure 6.

The funnel is a 3-D printed piece, that is custom fitted to the funnel reservoir. The outlet of the funnel leads directly to the pump, which sits in the bottom section of the housing. A small section of tubing connects the pump to the cooling coil below.

B. Cooling Unit

The cooling coil is contained inside of a modified keg, with and inlet and outlet cut into it (see fig. 8). The keg is then filled with ice and water to cool the coil. The top is easily removed for quick refills and the connection between the coil and the tube from the pump is press fitted, allowing the keg to be removed from the device. In our prototype, we included a small hand pump to purge the contents of the coil. This enables it to be quickly cycled between different drinks or purged for storage.

C. Controllers and Frame

Two controllers are used to control our electrical devices. One is an AC/DC converter that powers the actuator and includes an up/down control. The other is a simple on/off control for the pump. The actuator is powered on first and crushes the can, the pump is then turned on once the funnel reservoir is being filled and is turned off once that reservoir is empty. The actuator is retracted once it fully crushes the can.

Fig. 7 PVC housing, puncture grate, 3D printed funnel, and the pump

Fig. 8 Cooling coil in the 2-piece keg

The frame holds everything together and looks like a tower. The keg rests on a small elevated platform, that allows for a cup to be placed at the outlet. The PVC housing is suspended over the keg and is held in place by hose clamps. The two controllers are attached to the back of the frame.

The frame and PVC pieces were painted black and blue to compliment the keg and give our product a cleaner look. The permanent fittings were secured with glue, while the removable fittings were secured with screws. Any joints that are in contact with water or fluid are sealed with silicone caulking to prevent leaking.

Our product is designed for the actuator, pump, and puncture pieces to be replaced if needed as these are the parts that experience the most wear.

D. Testing

Our cool-can-crusher is a very successful prototype. It can crush cans up to 24 oz. in size and cools them to 45°F. it is capable of cooling 30x12oz. cans before the ice needs to be replaced. Figure 9 depicts the different sized cans all crushed to the same height of 2 in. It takes a minute and a half to crush, cool, and dispense a 12oz. can. These results verify our design and indicate that our prototype is suitable for refinement and eventual release as a product.

VI. Market Analysis

Our product currently has no direct competitors and fills a unique spot as a product that both crushes and cools a can at the same time. The quick cooling and dispensing of the beverage means that our device can dispense 30 cans in 45 minutes, which is 15 minutes faster than cooling the same amount in a refrigerator. This makes our device ideal for saving space in a refrigerator or for use somewhere a refrigerator can not be taken.

The ability to mix drinks also enhances our products usefulness, as it can also be used in a bar-setting as a replacement for standard mixing cups which take a comparable time to make a drink.

Future versions of our product could expand on some of these qualities to make it specialized, depending on our target demographic.

VII. Future Improvements and Next Steps

Before our design is put into production, some minor aspects need to be improved and our materials need to be more rigorously selected.

A. Improvements

Based on our product's testing results, there are some improvements needed. The most important improvement would be finding a cooling coil that better balances flow rate with cooling capability. Even with upsizing, our coil had some difficulties overcoming the pressure losses and selecting a larger coil may enable us to forgo the pump-assistance.

Along the same lines, we could revert to a manual crushing action by finding a good gear set that enables the user to turn a wheel to slowly crush the can; in the same way that the actuator works.

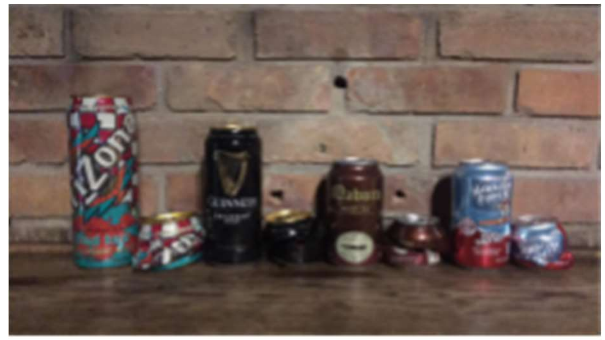

Fig. 9 Cans crushed to 2 in.

Changing our product to a completely manual one would enable it to be used anywhere. As even with battery packs, there are limitations to the use of electronics.

B. Material Selection

Prior to production, we will need to select the materials to be used in our final product. We would probably design our pump, keg, funnel, and metal pieces to be manufactured and not modified to limit the amount of glue/ caulking we would need to maintain good fits. We would probably also design our housing pieces to be molded to the exact form that we need. The material in the frame would also be changed, as wood is heavy and bulky compared to metal or polymer alternatives.

In addition to physical changes, we would need to do an extensive market analysis to see how to best pitch our product.

VIII. Conclusion

Overall, our project was a success and we fulfilled our functional requirements of crushing, cooling, and dispensing a canned beverage in a short amount of time. Through this project, valuable lessons were learned about engineering design and working in a group setting. This project helped students integrate their past 4 years of classroom learning into a cohesive project, that challenged them to utilize all their skills. It was a great test of our engineering capabilities and ability to work in a team environment.