Table Top Prince Rupert’s Drop Apparatus

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Abstract
The purpose of this project is to engineer a demonstration device that can heat up and quench a sample of glass, producing an extremely tempered Prince Rupert’s Drop. Currently, no apparatus exists that can manufacture such droplets in a short amount of time and in a classroom setting, and drops are generally produced in glass-blowing facilities. In-class production would be highly engaging, and serve to illustrate several materials science and mechanical principles. Several designs were considered, including usage of a gas fueled torch or a ring heating element in combination with a glass rod or glass nuggets in a crucible. The final design incorporates a ring heating element, as well as modules to (i) insert glass feedstock and (ii) quench the molten droplet. A successful design which can both manufacture droplets while simultaneously serve as a material science education device must fulfill the following parameters: speed of creating drops, tabletop size, a visible heating and cooling process, simple power requirements, and the number of drops capable of being produced. Finally, the group has performed experimental, analytical and computational analyses for optimization of the device.

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The Need for Project

The unique properties that exist in a successfully manufactured PRD make it a candidate for a highly visible material science demonstration. Currently, PRDs can only be produced in a glass blowing studio via a kiln, or an outdoor setting with a rudimentary and potentially dangerous method involving an open flame. Furthermore, obtaining PRDs can be tedious and only having the end product ignores an educational opportunity regarding their manufacturing, specifically the visual demonstration of heat transfer and fluid dynamics. Creating a table top apparatus that could produce PRDs safely in a classroom setting would satisfy this need and potentially improve material science education.

The Design Project Objectives and Requirements

To build a machine that creates PRD’s in safe table top size apparatus, with standard power requirements, that will be able to produce PRD’s in a class or lab environment.

- **Design Objectives**
  
  The objective of this project is to create a tabletop apparatus which will safely heat and quench glass, with the purpose of creating PRDs. The design must also focus on visibility, allowing the audience to observe most of the heating and quenching process without much obstruction from the systems components.

- **Design Requirements**
  
  Safety, process visibility, apparatus size, power requirements, number of drops produced, and the time it takes to manufacture the drops are the top design requirements which must be met in order to consider this project successful.

  The apparatus must be small enough to be wheeled into a classroom or lab, and must be powered by 120V standard wall outlet. Furthermore, the process must be visible for education purposes, but designed with a focus on safety so the operator, audience, or environment is never at risk. Lastly, the apparatus must have the potential to successfully produce at least 5 PRDs in a single cycle throughout a 100 minute period.
Design Concepts Considered

The main design challenges that needed to be addressed were: (i) heating method, (ii) droplet formation technique, and (iii) quenching bath design. Several design concepts were considered using various combinations of heating methods, and droplet formation techniques.

**Heating Method**

Several heating methods were explored, including an open flame torch, such as propane, butane or oxyacetylene, an electric heating element or furnace, and a kiln.

**Droplet Formation**

The droplet formation techniques weighed were dripping molten glass under its own weight from a rod feedstock, or pouring variable amounts of glass from a crucible.

**Quenching**

Various quenching fluids were considered for their high specific heats, but water was chosen because it is the safest, most effective, and easiest to obtain and dispose. Further, best practices exist in the literature for quenching of PRDs, and those were followed.

### Recommended Design Concept

**Experimental and analytical investigations supported the final design, which uses a glass rod and a ring heating element to form glass droplets which fall and quench in a water bath below.**

**Design Description**

In the recommended design, a 3’x3’x2’ frame will be constructed and used to support the rod holding apparatus, the heating coil, and the quenching bath. The rod will be suspended above the heating element. The heating element will rest on a platform over a hole large enough to allow the drops to fall through. Below this hole is the quenching bath resting on a moving platform. This platform will allow the quenching bath to slide out from underneath the heating element, allowing for drop retrieval. The frame will also feature a shelf to support the controller of the heating element.

**Analytical/Computational Modeling**

Modeling included two approaches: a mathematical model of the glass being heated, and a computational method of heating and softened droplet formation. The mathematical modeling generated a spreadsheet that can produce the amount of time to heat the glass to a temperature depending upon the diameter of the rod and the set temperature of the heating element. The computational modeling is ongoing with the aim of predicting droplet formation time.
Experimental Investigation

Rod and Torch

In this experiment, a propane torch was aimed at one end of a foot long glass rod, and the softened glass formed a droplet that fell into a bucket of water. Using this method, Prince Rupert’s Drops were successfully made. However, the discoloration found in these drops indicated that the flame may have been too hot, introducing carbon during softening. This indicated that propane should not be used to make drops.

Glass and Crucible Experiment

In this experiment, pieces of glass were placed into a crucible, and a propane torch was aimed into the crucible. The flame was directed at the glass shards for 20 minutes. In this time, the glass did not soften enough for it to be poured from the crucible. This indicated that the crucible should not be used to make drops, as it would be an overly slow process.

Tube Furnace Experiment

In this experiment, a small glass shard was placed on a silicon wafer, and placed inside a tube furnace set to 1000°C. The glass softened very quickly, and by the time the wafer was removed from the tube, it was clearly soft enough to form a droplet. This experiment proved that it was possible to use an electronic heating element (e.g., furnace) to soften to glass enough to allow for drop

Key Advantages

There are numerous advantages to this design. The use of stock glass rod allows the user to easily purchase the required material from craft shops, rather than reach out to custom glass-blowing shops. The coil heating element runs on a standard 120V outlet, eliminating the need for propane of oxyacetylene to be used. It greatly reduces the time needed to melt the glass, ensuring that students can experience the complete drop formation process in a single class period. The sliding platform on which the quenching bath is resting allows the user to remove the droplets away from the heating element, reducing risk. The quenching bath itself is transparent, which should allow students to see the tempering of the glass as it happens. Finally, the entire setup is self-contained, allowing for easy setup and cleanup.
Financial Issues

Although Prince Rupert’s Drops have limited practical use, this device may have a market in material science and mechanical engineering departments around the country. The next step to determine the feasibility of this is to contact material science departments at universities around the country to determine if there is interest, and if so what the price requirements would be. In addition, for usage in classroom settings, the device would need to be easily operated and visually attractive.

Recommended Improvements

As the purpose of this apparatus is educational, it is recommended that the heating process be made visible to the user. People watching the droplets ideally should be able to see the heating of the glass, the formation of the droplet, and the quenching of the molten glass. In the current design, safety considerations remove this ability. Additionally, making the entire process fully automated would allow for the user to explain the physics behind the formation of Prince Rupert’s Drops away from the apparatus while the drops were being made. This would include the lowering of the glass rod into the heating coil, rotating the rod as necessary and the retrieval of the droplets from the quenching bath. However, at the present time the device is nearly automatic, as all that is required by the operator is rod placement and a button press.