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FIREPOT RELIABILITY AND ENGINEERING DESIGN (F.R.E.D)

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Abstract

A voluntary recall of firepot gel fuels was recommended by the Consumer Product Safety Commission (CPSC) due to the large number of incidents during their use. The industry involved in the making of firepot gel fuels, along with the CPSC, agreed that there is a need to improve the safety and operation of the current firepot gel fuels. This MQP project focuses on developing new ways to improve the safety, reliability, and stability of firepots and gel fuels. Our efforts are intended to create new standards and codes, as well as increase the safety of the gel fuels. Background research was conducted to understand the nature of gel fuels and the reasoning behind its removal from the consumer market in recent years. It was found that 76 incidents resulted in 86 injuries and 2 fatalities over a span of two years, which occurred with the use of the current firepots and gel containers. These instances were evaluated by the project team in order to determine the causes of the incidents, namely a low gel fuel viscosity, the use of the storage container, and the stability of the firepot. By utilizing mechanical engineering knowledge and experimental means, the project group designed new safety oriented structures to modify the existing single-fill gel canister to reduce the risk of incidents in the future. A number of tests were conducted to observe and verify some characteristics of the gel fuel and to provide a proof of concept for a safely and reliable gel fuel and firepot. A simple and efficient solution was the incorporation of metal meshing into the current design of the single-use gel fuel cans. The testing of various thicknesses of the meshing showed a significant reduction in the amount of gel fuel released from the container in comparison with the control tests. Salient recommendations were made to help strengthen the safety of firepots and the single-use gel fuel canisters. The group's results showed that firepots and gel fuels can be made safer and reliable to yield marketing opportunities for manufacturers.

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Chapter 1: The Safety and Reliability Concerns of Gel Fuel and Firepot

1.1 Introduction

The dramatic increase in the number of accidents involving the use of firepots and their gel fuel has led to the removal of these products from the market. Since April 2010, the reports filed to the Consumer Product Safety Commission, or CPSC, about gel fuels and firepots have highlighted the numerous dangers injuries and failures presented by the use of these open-flame products. They are unsafe and dangerous because they are easily susceptible to occurrences of tipping, spillage, or cracking. The gel-based alcohol fuel is also hazardous in nature, lacking proper viscosity and being volatile in nature. The gel fuels can burn rather clear and imperceptibly in certain conditions, leading to the vast amount of accidents involved in refilling of the firepot's gel fuel canister. The large quantity of such safety limiting factors led to a voluntary recall of such products, yet there is still a market for these open-flame decorations. Candles, yard torches, and other products are still widespread on the market today, and a safer rendition of the firepot and the gel fuel could lead to their re-entry into the market. Between April 3, 2010, and September 1, 2011, there were 76 recorded accidents involving firepots or the gel fuel that were reported to the Consumer Product Safety Commission. Due to the nature of these incidents, the CPSC Office of Compliance & Field Operations recalled pourable alcohol gel fuels, resulting in 11 voluntary recalls. These recalls lead to the return of over two million bottles of the gel fuel. In the reported events, there were two deaths and 86 injuries reported. Over half of these incidents (48 of the 86 injuries, or 56%) required hospitalization or major treatment due to injuries incurred during the use of firepots and gel fuel. The majority of these events involved the refilling of the container while in use, as the user failed to recognize that the firepot was still ignited. Other situations included: explosion while lighting the firepot, the ejection of the burn cup, explosion of the fuel container, explosion of the firepot during use, tipping over or breakage of the firepot, or explosion while attempting to extinguish the flames. In each case, the CPSC looked to replicate each hazard scenario and determine possible precautions that could be taken in order to minimize the risk of such events happening. However, with the current firepot and gel fuels on the market, the agency felt that there was limited potential for higher safety standards without a major overhaul to the manufacturing of the firepots or the chemical makeup of the gel fuels.

The goal of this project is to improve on the safety of current gel fuels along with its receptacle. Steps to achieve this are: to analyze the current firepot designs, standards, gel composition, and documented safety issues, to design and test improved viscosities of gel and gel containers, and to use research and experiments to reframe and propose new standards to submit to the CPSC.

The following chapter will extrapolate upon the research reports compiled by the CPSC. The reported accidents will be further examined to categorize the findings and determine which changes would be best appropriate in the standards set forth by the ASTM (American Society for Testing and Materials) in regards to the construction of the firepots. In addition, the chemical makeup of the gel fuel will be discussed in an attempt to determine a plausible manner in which to make the gel fuel more viscous to hinder its spillage area.

Chapter 2: Understanding the Purpose and Safety Concerns of Firepot and Gel Fuels

2.1 History of the Firepot

Firepots have played many roles in the history of civilization. Firepots came shortly after fire was discovered. When the firepot came along, it became a useful tool in transporting fire, and eventually evolved into being used for a multitude of other tasks. Modern day firepots still provide the option to enjoy the simplistic appeal of fire.

The firepot originated during early civilization after the invention of fire. The use of these pots that carry fire have been found to date back over 10,000 years. Early humans would use this innovative device as a way to house and control fire, and also provide a means to transport the history altering discovery. By utilizing a firepot, people were able to contain the fire within or around their homes, and made it possible to maintain the fire for extended periods of time by just simply adding more fuel into the pot. Being able to carry and store fire made it easier to start larger fires for cooking or for warmth. An example of humans using the firepot as a source of warmth comes from Kashmir, India. An earthen firepot called a "kandgi" was normally used with a long gown or robe called a "phiran". People from this region would use the kangdi and keep it under their robes to provide warmth during colder nights and months (Sleeping with Kangdi 2012).

Another use for firepots in its earlier years was as a weapon. Ceramic pots would be filled with combustible substances and were launched through the air as projectile weapons, similar to grenades of today. These explosives were also used in sea battles being shot from one ship to another causing considerable damage, and in land battles by being thrown over protective barriers or into defensive trenches (Hamilton 2012). According to the Oxford Universal Dictionary on Historical Principles, it defines a firepot as, "An earthen pot filled with combustibles used as a missile" (Hamilton 2012). Another definition found in a sixteenth century text from Lúcar, Spain in 1588 says:

> Make great and small earthen pottes which must be but half baked,… Fill every of those pottes halfe with grosse gunpowder pressed downe harde,… Also tie round about the middle of every potte a packthreed, and then hang upon the same packthreed round about the potte so many Gunmatches of a finger length as you wil, & when you wil throe any of these pottes among enemies, light the same gun-matches that they may so soone as the potte is broken with his fall uppon the ground, fire the mixture of the potte. Or rather put fire to the mixture at the mouth of the potte, & by so doing make the same to burn before you doe throe the potte from you,… that the small pottes do serve for to be throne out of one shippe into an other in fight uppon the sea, and that the great pottes are to be used in service uppon the lande for the defence of townes, fortes, walles, and gates, and to burne such things as the enemies shall throe into ditches for to fill up the same ditches, and also to destroy emenies in their trenches and campes (Hamilton 2012).

This particular type of firepot was found in Mombasa Harbor, Kenya from the Santo Antonio de Tanna ship wreck which occurred in 1697. The wreck was excavated by the Institute of Nautical Archeology. Ten of these firepot-like weapons were discovered in the shipwreck. The figure below shows sketches of a multitude of firepots that were in use during the 1500-1600s, including the type found in the Santo Antonio de Tanna wreck. They all had a type of rope or handle attached. This made it easier to throw the firepot at the enemy, and in some cases acted as a fuse to extend the time before igniting the contents within the explosive (Hamilton 2012). The following picture shows examples of these weaponized firepots. As can be seen in Figure 1, some have wicks used for timed detonation or roping for projectile launching.

Figure 1: Sketches of firepots used as weapons from 1588- 1628 (Hamilton 2012)

Furthermore, firepots were known to act as a form of cooking utensil. Once humanity learned to cook over fire, a means of containing and focusing the flames through fire-safe containers was necessary and sought for. One example of this cooking version of the device is known as the "adogan". This pottery device was found in West Africa and had a flat bottom and rimmed lip. A hole was located toward the bottom of the pot that functioned as a place to add more fuel in order to stoke the fire. China had its own cooking version of the firepot known as the "Chinese hot pot". Believed to have originated in Mongolia by nomadic tribes over a thousand years ago, the hot pot continues to be a popular cooking dish in contemporary Chinese households (China Tour and Bejing Tour Expert 2012). This device, which normally contains hot soup or stew, is set in the center of the dining area. It keeps the edible contents hot while allowing more ingredients to be incorporated into the broth. Although hot pots originally started out as being heated by coals or wood, many modern homes now utilize the revolutionary power source that is easy-to-use and has no emissions known as electricity (China Tour and Bejing Tour Expert 2012). .

Another use for firepots is for religious purposes. Many religions burn incense during religious ceremonies, and some religions included the of worship fire. This type of container that houses burning incense is called a censer. In some Buddhist and rituals, a person of religious rank walks around with a censer and rocks it like a pendulum from the chains that hold it (Oller 2002). The censer can have numerous holes, normally in some sort of pattern, or has the lid raised, which allows the burned incense to be released as smoke from the pot in order to purify or bless items within the room. The Christian religion uses incense and this instrument in a similar manner (Top 2010). An image of a censer in the midst of burning can be seen in Figure 2. The incense is contained and lit in the bottom of the pot-like device, and the raised lid provides an escape route for the smoke.

Figure 2: Censer in use in a Catholic ceremony (Top 2010)

As humanity progressed throughout the years, the various uses for firepots began to become obsolete. Now, the only purpose for firepots still existing today is for visual pleasure and decoration. As civilizations developed, so did the sophistication of technology. Ovens, stoves, and grilles took the place of open fires needed for cooking; and although some homes may still use fire as a means to keep warm in colder climates, many modern homes and buildings have heating systems that serve the same purpose. There is also another interesting development that has taken place in Australia. An Australian woman named Adama Kamara, has invented a new cooking stove which allows people in developing areas of the world to cook without breathing in toxic fumes that are a result of cooking over an open flame with wood or kerosene (Meyers 2011). Kamara's invention is an inexpensive stove which features holes on top that serve as burners. Under each burner is a holder which contains a wick that sits in clean-burning biodiesel made from vegetable oil, methanol or ethanol, and wood ash. Kamara has called her invention the "Firepot Stove" (Meyers 2011). This new stove is an improvement over the original firepot designs that were used for cooking purposes. The former purposes of firepots, such as cooking and keeping warm, are no longer necessary. Figure 3 depicts a picture of the new firepot stove which could help bring healthier, safer cooking practices to developing lands.

Figure 3: Kamara's Firepot Stove (Meyers 2011)

Firepots have played a large role in human history. Even though these products that were used in the past are not the same as present day firepots, they still set the foundation that aided the development of the modern day fire-related devices and new cookware that so many people enjoy today. Contemporary firepots are used for their aesthetic appeal. People enjoy the orange and yellow flames that are produced by the liquidous fuel source and the design of the pot itself. Firepots have a rich, interesting history that shows how they were developed, changed, and used for multiple purposes throughout the course of human history.

2.2 Firepot Demographics

2.2.1 Sales: Firepots

Mass produced firepots are a relatively new product, with large quantities introduced to the general public only in the past 3 years. The primary purpose of this device is decoration and appeal through a combination of a seemingly wild flame, optional scents and colors, and the exterior design which increases the aesthetic allure to the surroundings. Home and garden retailers, in addition to online shops, have been the most common places of purchase. The product was not marketed prominently until late 2009. In addition, approximately 2.5 million firepots are believed to be currently within the hands of consumers, the majority of which were purchased between 2010 and the first half of 2011(Smith 2011).

2.2.2 Sales: Gel Fuel

Gel fuels have existed far before the invention of the firepot, first being produced in single-use cans as a replacement fuel source for fireplace applications. They were a cost effective, smoke-less, heat producing fuel supply that was used as an alternative to oil; their popularity skyrocketed during the Middle East oil embargo in the 1980s. From 2008 to the present day, over 2.5 million cans of gel fuel have been sold (Smith 2011). Therefore, it is not outside the realm of reason to believe there may be many more millions of cans used and still stored by the consumer.

Figure 4: Alternative use for Gel Fuels, Gel Fuel fireplace

2.2.3 Companies

2.2.3.1 Napa Home and Garden Inc.

Figure 5: Napa Home and Garden, Inc. logo

Napa Home and Garden is a garden wholesaler, based in Duluth, GA, with showrooms in TX, CO, NC, and CA. Between the end of 2009 and the recall, they reported selling 460,000 containers of firepot gel fuel to consumers. These gels were sold in quart and gallon sizes, under the names of “Napafire” and “Firegel”. Thirty-seven accidents, twenty-three of which involved bodily injury, were reported to the company, prompting the CPSC to take action. The company proceeded to recall their product, and offered full refunds of 5-78 US dollars to consumers who returned the gel fuel to the original merchant. Amazon.com and Bed Bath & Beyond were the two largest suppliers of Napa Home and Garden gel fuel (Halbfinger 2011). In 2011, one of the nation’s largest plaintiffs’ litigation firms, Motley Rice, brought two lawsuits against the company on behalf of injured parties relating from two separate incidents in South Carolina (Firepot Lawsuits 2011). More recently, in the summer of 2012, a lawsuit was filed by Chris Kutsor and his family in Alabama due to a flash explosion from a small firepot that resulted in severe burns (Lawson 2011).

2.2.3.2 Bird Brain Inc.

Figure 6: Bird Brain Gel Fuel storage containers (Office of Compliance, CPSC)

According to their website, Bird Brain Inc. is a leading designer and maker of decorative and functional products for the home and garden, based in Ypsilanti, MI. Interestingly, while firepots are now out of the market place, they are still touted as “stunning” on their website. Its gel fuel was produced under the names “Bird Brain Firepot Fuel Gel”, “Bird Brain Firepot Citronella Fuel Gel”, and “Bird Brain BioFuel Gel”. Due to the recall, Bird Brain recalled approximately 1.6 million bottles and can of gel fuel (Bird Brain Recall 2011). In 2011, a lawsuit by Power Rogers & Smith, P.C., a personal injury firm, was brought against Bird Brain and the Target Corporation for injuries sustained by siblings from Harvey, Illinois, who suffered severe burns after a firepot explosion (Power Rogers &Smith 2012). According to the CPSC, Bird Brain was aware of 20 reports of incidents, resulting in 11 injuries that involved first-, second-, and third-degree burns. Consumers of recalled Birdbrain products were offered refunds between 8-18 US Dollars, depending on the product. Sears, K-Mart, Target, Amazon.com, and Buy.com were the major suppliers of Birdbrain firepots and gel fuel (Bird Brain Recall 2011).

Table 1: Recalled Bird Brain Products

Size	Model Name	Item Number	UPC
16 oz. Bottle	Firepot Clear Fuel Gel	11820010	03913803231-7
16 oz. Bottle	Firepot Citronella Fuel Gel	11820011	03913802866-2
32 oz. Bottle	Firepot Clear Fuel Gel	11820001 11820006 11820007 11820008 11820013 11820024	03913805081-6 03913805081-6 03913805081-6 03913805081-6 03913803591-2 03913807473-7
32 oz. Metal Can	Firepot Clear Fuel Gel	11820014 11820018	03913803160-0 03913803160-0
32 oz. Bottle	Firepot Citronella Fuel Gel	11820002 11820009 11820028	03913805082-3 03913805082-3 03913803592-9
32 oz. Metal Can	Firepot Citronella Fuel Gel	11820020 11820019	03913803161-7 03913803161-7
32 oz. Bottle	BioFuel Gel	11820016	03913803322-2
64 oz. Bottle	Firepot Clear Fuel Gel	11820022	03913803304-8
64 oz. Bottle	Firepot Citronella Fuel Gel	11820023	03913803305-5

2.2.3.3 Bond Manufacturing

Figure 7: Bond Manufacturing Logo

Bond Manufacturing is a a 60 year old lawn, garden, and outdoor living manufacturer based in Antioch, CA. Due to the recall, both the firepots and the gel fuel that they produced were taken off the market. Approximately 16,500 bottles and jugs of gel fuel were affected. The gel fuel was produced under the names "Firebowl Gel Fuel", "Firebowl Gel", while the firepots were "Tabletop Gel Firebowls". No lawsuits have been filed against this manufacturer. Customers who purchased Bond products were offered refunds between 5-20 US Dollars depending on the product. Gordmans, Homeclick, Savemart Supermarkets, Big R Stores, and Hy-Vee were the major suppliers of Bond products (Bond Recall 2011).

Table 2: Recalled Bond Products

Size	**Model Name**	**Item Number**	**UPC**
32 oz.	Firebowl Gel Fuel	6614 0	034613661402
32 oz.	Firebowl Gel Fuel with Citronella	66201	034613662010
64 oz.	Firebowl Gel Fuel	66141	034613661419
64 oz.	Firebowl Gel Fuel with Citronella	66202	034613662027
2 pack	Ceramic Firebowl set	66146	034613661464

2.2.3.4 Sunjel Company (2 Burn Inc)

Through online research, the project group was unable to find any trace of or website that could provide any company information. This may hint that the company has gone out of business.

2.2.3.5 Fuel Barons Inc.

Figure 8: Fuel Barons' gel storage container (Office of Compliance, CPSC)

Fuel Baron has been confirmed to have undergone Chapter 11 bankruptcy on January 24, 2012, due specifically to numerous lawsuits brought against it because of accidents concerning its gel fuel (Fuel Barons 2012). While operational, it was based in Stateline, NV. About 14,000 bottles and jugs of its “OZOfire Pourable Gel Fuel (Formula 4)” and “SUREFIRE Pourable Gel Fuel (Formula 4)” were taken off the market. According to the CPSC, the company was aware of one incident where a man sustained second-degree burns to his hand and wrist. Consumers of Fuel Barons gel fuel were offered refunds between 8-22 US Dollars, depending on the product. Windflame.com was the largest purveyor of Fuel Barons products (Fuel Barons Recall 2011).

Table 3: Recalled Fuel Barons Products

Size	Model
1 QT	OZOfire™ F4 Pourable Gel Fuel
1 QT	SUREFIRE™ S4 Pourable Gel Fuel
1 GAL	OZOfire™ F4 Pourable Gel Fuel

2.2.3.6 Lamplight Farms Inc.

Figure 9: Lamplight Farms gel fuel container (Office of Compliance, CPSC)

A division of W.C. Bradley Co., Lamplight Farms, operates "diverse businesses in the textiles industry, farm implement manufacturing, row crop and livestock production, wholesale supply businesses meeting the needs of industrial and building contractors, retail businesses in outdoor sports equipment and licensed sports apparel, and barbecue grill manufacturing." It is based in Menomonee Falls, Wisconsin. Lamplight is specifically geared toward outdoor torches, citronella fuel, outdoor wax candles, indoor oil lamps, lamp oil, and related goods (About Us 2012). Approximately 217,000 bottles and jugs of its "TIKI Brand Gel Fuel" and "TIKI Brand Citronella Gel Fuel" were recalled. According to the CPSC, Lamplight was aware of one report of a consumer who poured gel fuel on a firepot that was still burning, resulting in burns to a bystander's arm that required medical treatment. Refunds of 10 US Dollars were given to customers who purchased Lamplight products, which were sold in retail stores nationwide, in addition to online availability (Lamplight Recall 2011).

Table 4: Lamplight Farms Products

Size	Scent	UPC
1 QT	Natural	086861094105
1 QT	Citronella	086861100455

2.2.3.7 Luminosities Inc. (Windflame)

Figure 10: Luminosities gel fuel container (Office of Compliance, CPSC)

Luminosities Inc. is a small gel fuel distributor of Fuel Barons Inc. products. While their supplier has gone bankrupt, Luminosities Inc. is still in business. The company now produces its own “safe” gel fuel, and has invented a wick and cap mechanism to their firepots to make them safer, the only company under the recall to do so (No-Spill 2012). Due to the recall, approximately 26,500 bottles of Fuel Barons Inc. “OZOfire Pourable Gel Fuel (Formula 4)” were taken off the market. According to the CPSC, Luminosities has received one report of an incident involving its gel fuel, but with no injuries sustained in the case. Consumers of Luminosities products were offered refunds between 4-12 US Dollars, depending on the product. The major distributor of Luminosities products was Amazon.com (Luminosities Recall 2011).

Table 5: Recalled Luminosities Products

Size	Model	UPC
1 QT	OZOfire™ Pourable Gel Fuel (Formula 4)	UPC 804879254133

2.2.3.8 Pacific Décor Ltd.

Figure 11: Pacific Decor gel fuel container (Office of Compliance, CPSC)

A home accent supplier, who as recent as Spring 2012, prominently markets their "Flamepots" on their website (Our Company 2012). The company is based in Woodinville, WA. Two of their gel fuel products, "Pacific Flame" and "Premium Pourable Gel Fuel", were affected by the recall, removing about 3,600 bottles from the market. According to the CPSC, no lawsuits or reports on accidents involving any Pacific Décor Ltd. products were brought to the company's attention (Pacific Décor Recall 2011). Customers who purchased Pacific Décor products were offered refunds between 10-12 US Dollars, depending on the product purchased. Pacific Décor products were available online, in specialty and gift shops, and in various home and garden stores nationwide. It is important to note that the can version of the gel fuel is used in FRED's experiments, specifically altering the can structure as well as the chemical composition of the gel.

Table 6: Recalled Pacific Décor Products

Size	Model Number	SKU
1 QT	160	095583001605
1 QT (with citronella)	170	095583001704

2.2.3.9 Real Flame

Figure 12: Real Flame single-use gel containers (Office of Compliance, CPSC)

Real Flame is a 30 year old retailer of vent-less gel fuel fireplaces and accessories based in Racine, WI. Under the recall, approximately 100,000 bottles of its "Real Flame" and "Pourable Gel Fireplace Fuel" were removed from the market. While no longer available in conventional brick-and-mortar stores, the "Real Flame" gel fuel is still sold on their website in small cans and quart sized bottles. According to the CPSC, no reports of any accidents involving their gel fuel were brought to the company's attention. Consumers of Real Flame products were offered refunds between 10-13 US Dollars, depending on the product. Target.com, Meijer.com, JCPenney.com, Sears.com, Amazon.com, and Realflame.com were the largest suppliers of Real Flame products (Real Flame Recall 2011).

Table 7: Recalled Real Flame Products

Size	Model Number	SKU
29.9 ounce	2164	752-370012641
1 QT	2164	752-370012641
29.98 ounce with Citronella	2165	752-370021658

2.2.3.10 Smart Solar Inc.

Smart Solar is a leading manufacturer of solar powered garden products for the home and garden, based in Oldsmar, FL. As of late 2012 there is no mention of firepots or gel fuel on their website. Under the recall, about 1,400 bottles of its “Smart Garden” and “Smart Gel” gel fuel were removed from the market. According to the CPSC, no incidents or injuries were caused by their products. Refunds between 10-20 US Dollars were offered to consumers of Smart Solar products, of which the major suppliers were online and selected specialty stores (Smart Solar Recall 2011).

Table 8: Recalled Smart Solar Products

Size	Model Number/SKU	Description
30 oz.	SJ3200	SmartJel Citronella Formula IPA Gel Refill
30 oz.	SJ3201	SmartJel Unscented Formula IPA Gel Refill

2.2.4 Target Market

Due to the phrases used by firepot and gel fuel companies, such as “environmentally friendly”, “eco-friendly”, and “live safe and burn safe”, one can infer that the target market was for people looking to follow the recent trend of living “green” lives. That is to say, rather than using heavy carbon producing fuels such as oil or gasoline for heat and warmth, gel fuel was a clean, more sustainable alternative.

2.2.5 Revenue / Cost

The typical price range for firepots can range between 20-40 US Dollars, while they can be sold for as high as 1,500 US Dollars. The typical price range for a single container of gel fuel is between 5-20 US Dollars. Single-use canisters, whether sold individually or in packs, can be sold anywhere from 3-100 US Dollar depending on the quantity of purchase.

2.3 Firepot Structure and Design

As stated previously, firepots have been around since prehistoric times. The product today is a fairly new device that is used for decorative lighting in many households, whether indoors or outdoors. Consisting of mainly two components, the firepot base and a metal gel burn cup for most models, it is a relatively simple lighting apparatus. The vibrant aesthetic flame produced by the gel fuel source is clean burning and provides an appealing atmosphere. For many this device also provides a fluttering light for a romantic setting.

2.3.1 Materials and Characteristics

The firepot base in circulation today is made primarily of heat resistant materials for safety reasons. The most common heat resistant materials used for firepots are ceramics. This device can also be produced from various glass-ceramic compounds, glasses, stones, and metals.

The majority of these firepots are made of ceramic materials. This is due to the properties of ceramics. Many ceramics are hard, wear-resistant, good thermal insulators, have low thermal conductivity, and high corrosive resistance. The hard and wear resistant characteristics of ceramics make the material a good fit in being a structural support that holds the stainless steel cup in place. In addition, the hardness and wear resistance of the material allows for the extended life of the product, the incorporated design, and the surface finish; thereby preserving the aesthetic appearance of the firepot. A ceramic's high resistance to corrosion also attributes to the protection of the appearance as well as the structural strength. The resistance to chemical degradation is important to the extent of a firepot's life expectancy. Through prevention of chemical degradation, an instrument of this purpose will stay structurally sound and maintain the surface appeal. This does not take into account the treatment and maintenance of the firepot base itself. By being a good thermal insulator, ceramic firepots encase the emanating heat given off by the ignited fuel in the stainless steel housing. Because ceramics are good insulators, they also have a low thermal conductivity. A low thermal conductivity means a material has a high resilience to the transfer of heat energy which increases its temperature. This property prevents the user from experiencing the heat given off of the stainless steel cup when handling the firepot in its entirety. This also prevents the firepot base from initiating burns or a fire when in contact with the surface it is resting upon.

There is a downfall to such a product being made from ceramics. The majority of ceramics are known to be brittle. This is due to the materials inability to deform plastically when subjected to a force. If a ceramic firepot were to fall off of a table, a crack could develop or the entire fixture could be shattered.

Glass-ceramics are unusual in the firepot industry, but still serves as a great material for the product. This material has many of the same characteristics of regular ceramics like hardness, wear-resistance, high corrosive resistance, etc. Glass-ceramics are also among the most thermally shock-resistant materials developed today. Thermal shock is the event when the thermal gradient induces the material to expand by different amounts at different rates in different locations. This is important for the firepot base because it needs to be able to support the gel receptacle under its intense thermal conditions without deforming. The downfall is the exorbitant price of the material, of which can be between $1000 and $10,000 depending on the amount desired.

The next firepot material to discuss is glass, as seen in Figure 13. Just like glass-ceramics, glasses have similar characteristics to ceramics. Glasses are hard, wear-resistant, highly corrosive resistant, etc. There is a challenge presented with the use of glasses that is similar to ceramics. Glasses are brittle and break upon impact with another surface under enough force. One difference from ceramics and glass-ceramics is its low thermal shock-resistance. When introduced to rapid heating or cooling, the glass material is subject to fail by cracking and deforming. The thermal shock-resistance is high enough but limited to handling the temperature change produced by the ignited gel fuel. If the material could not handle it, firepots would not be produced using heat-resistant glasses.

Figure 13: Glass-based Firepots

Another common material used in firepots that are produced for outdoor purposes is stone. Stones like granite and other environmentally resistant materials provide quality characteristics that are desirable for outdoor firepot use. These stones are hard, durable, wear-resistant, inflammable, corrosion resistant, and have low thermal conductivity. Stone-based firepots also have the appeal of nature. Many stones are observed as products of nature and when introduced to a patio or outdoor setting, a stone firepot will add to the appeal of the outdoors. When shined and polished, many stones carry a unique, intriguing, and attractive look.

Figure 14: Granite-Based Firepot

Metal firepots, such as those of Figure 14, are less common than all of the materials listed previously. Since metals have high thermal conductivity, it provides challenges in preventing heat transfer between surrounding people and surfaces. To combat this challenge, a majority of metal firepots are filled with stones that hold the gel receptacle centered away from the metal sides. The image below depicts a copper-coated zinc garden variety firepot as a representation for metal based versions of this product.

Figure 15: Copper-Coated Zinc Firepot

The gel fuel cup is generally made out of stainless steel. The reasons for the use of stainless steels in this application are for its aesthetic appearance, ease in manufacturability, inflammability, high resistance to corrosion, ability to retain its strength at high temperatures, and high resistance to shock when introduced to high and low temperatures. The stainless steel burn cup adds to the artistic reverence of the firepot product. It enhances the overall visual when the product is in action with its subtle glistening appearance over the base.

The ease of manufacturability of stainless steels allows for a cheaper fabrication of the gel cup. Stainless steels are easy metals to machine, weld, form, and fabricate. These qualities, along with the simplicity of the cup itself, allow for the machining process to be fast, easy, and cost-efficient.

By using a metal like stainless steel, the worry of having the gel receptacle catching fire while in use is greatly diminished. Many metals, including stainless steels, are inflammable and do not pose the risk of releasing possibly toxic fumes into the air that could cause harm to the life surrounding the metallic substance.

The high corrosion resistance is produced by the chromium component in the stainless steel. The chromium, when introduced to oxygen, produces a protective layer of chromium (III) oxide over the product that prevents rusting and chemical corrosion. The layer of chromium (III) oxide does not hinder the sheen of the steels either. This corrosion resistance is important in preventing degradation of the stainless steel when dealing with the harsh chemicals within the gel fuel.

Since the stainless steel gel fuel receptacle will be in constant contact with the ignited source, the ability to retain its strength is imperative to the products' functionality. By being able to resist the deforming effect of high temperatures, the steel will maintain its shape and structure throughout its use; therefore, preventing any complication that would result from a fallible metal.

Another redeeming quality of stainless steels is the high resistance to thermal shock when introduced to high and low temperatures for any given time. By being in direct contact with the gel fuel and flame immediately after being lit, the change in temperature around the gel receptacle and within its material rapidly increases. That is why it is important to have stainless steel for this material because of its resistance to the rapid temperature change. If other materials are used in its place, the possibility of failure due to thermal shock can increase in probability depending on the substance.

Thanks to the wide variety of materials, the possibilities of firepot designs are significant. These materials and the fabrication processes of these materials allow for firepots to be available in a variety of shapes, sizes, textures, patterns, weights, and colors.

2.3.2 Expenditures Pertaining to Firepots

Ranging from anywhere between five and hundreds of dollars, firepots can be found in many local home improvement stores, garden decoration centers, and online sale sites. The stores listed in the table below are arranged in order of the most expensive firepot prices. Table 9 shows the sales company on the left and the price ranges of the firepots sold on the right.

Table 9: Firepot Sales on Market

Company	Price Range ($)
Lowes	15-40
K-Mart	25-50
Sams Club	28-50
Walmart	30-80
Home Depot	20-310
Amazon.com	7-1500

These prices all depend on the cost of materials, labor, energy, and turning profit. Table 10 represents the costs of the materials with the respective sales units that were relative in November 2012.

Table 10: Expenses for Commonly Used Materials

Material	Name	Cost ($) per Metric Tonnes	Cost per Cubic Meter
Metals	Zinc	1912.40	X
	Stainless Steel	2959	X
Ceramics	Sodium Fluorosilicate	390 - 410	X
	Sodium Silicoflouride	400 - 420	X
	Industrial	700 - 1300	X
	Zirconia	1200-1600	X
Stones	Granite	X	7-18
	Grey Granite	X	3.60-23.60
	Grey White Granite	X	5-35

Table 10 clearly depicts that the price of stainless steels compared to other commonly used materials of firepots is much higher. The table below shows the price of stainless steels as it changed over the past 16 months.

Table 11: Prices of Stainless Steel over the Past 16 Months (World Steel 2012)

World Composite Steel Price and Index US$/tonne				
Month US$/tonne	GLOBAL COMPOSITE CARBON STEEL PRICE	GLOBAL COMPOSITE CARBON STEEL INDEX	GLOBAL COMPOSITE STAINLESS STEEL 304 PRICE	GLOBAL COMPOSITE STAINLESS STEEL 304 INDEX
Click here for forecasts to June 2012				
Nov-12	711	178.2	2959	157.7
Oct-12	717	179.7	2938	156.5
Sep-12	736	184.5	2860	152.4
Aug-12	730	183.0	2899	154.5
Jul-12	734	184.0	2989	159.3
Jun-12	747	187.2	3050	162.5
May-12	788	197.5	3164	168.6
Apr-12	802	201.0	3279	174.7
Mar-12	801	200.8	3451	183.9
Feb-12	812	203.5	3394	180.9
Jan-12	787	197.2	3222	171.7
Dec-11	778	195.0	3249	173.2
Nov-11	788	197.5	3314	176.6
Oct-11	803	201.3	3473	185.1
Sep-11	852	213.5	3742	199.4
Aug-11	842	211.0	3740	199.3
Jul-11	860	215.5	3806	202.8

2.4 Gel Fuel

Firepots that have been on the market for the past several years are fueled on a source of power known as gel fuel. This substance of an alcohol-based nature has a rather gelatin-like consistency and burns similar to other products such as cooking gels. Gel fuels are usually used in minimal amounts in a single instance; as the firepot apparatus is usually not large enough to hold quantities of gel fuel that last more than several hours. This gel fuel is not of a practical nature in terms of light or heat – the flames tend to burn almost invisibly, especially in low quantities of the fuel, and do not give off much heat energy except in the immediate area surrounding the flame. As such, the gel fuel consumed by firepots is mostly of a romantic and ambient nature, used to provide a sense of atmosphere and mood to a situation. Because of this, the gel fuel aims to be non-invasive and inviting, and designed to be as simple of an operation as possible. Several renditions of gel fuels and their refueling apparatuses have come and gone, yet a danger still lurks within the use of these flame sources. The following chapter will outline the fundamental logistics and properties of gel fuels, as well as chemical make-ups and scientific values that can further explain why such accidents are prone to occur. Furthermore, this chapter will explain the limits on the current standards for these products, the possible alternatives or precautions that can be taken, and conclude with the recommendations that had been set forth by the Consumer Product Safety Commission for further deliberation (Duncan 2011).

2.4.1 Common Uses for Gel Fuels

The gel fuel apparatus is most commonly used as the energy source for the decorative firepot ornamentals. Though firepots have been a more recent addition to the market, most noticeably from 2009-2011, these kinds of gel fuels have been on the market since the early 1980's. The original intentions of the gel fuels were to be installed in a fire place and to function simply as a stationary fire source. The use of the gel fuels in this manner meant that fire starting liquids and a storage of logs or artificial logs were no longer necessary. Furthermore, the fire would not need to be stoked, and there would be no embers and ashes to smother and clean up. However, this type of artificial fireplace did not garner as much support, as its non-realistic nature deterred many who desired the emotions and mood of the light, warmth, crackles, and scents of a true burning fire. With the mass introduction of the firepots to the market in the past several years, there has been a vast increase in the amount of gel fuel being sold (Duncan 2011). As it is much easier to tend to a firepot that is small and needs minimal cleaning and care, which can be carried from a dinner table to an outside porch easily, the use of gel fuel-equipped firepots has a substantial appeal. Used as a center piece, the simple yet elegant design of the firepot is complimented by the dancing flames of the gel fuel, sitting inconspicuously within the burn cup of the firepot. As the flames from the 3-5 ounce cans do not last more than several hours or reach great heights or visibilities, the purpose of the firepot is lacking in practical intent; rather, it is solely for visual appeal (Chao 2011).

2.4.2 Companies that Sell Gel Fuel and Sales Figures

Since the introduction of the firepot to the mass market in the United States, there has been a significant increase in the sales of gel fuel over such a time period. Furthermore, there has been an increase in the number of companies that provide the gel fuel in attempts to garner more of the market share. In response to the increase in incident reports filed to the CPSC by the beginning of September 2011, the decision was made to ask for the removal of such products from the market, and a subsequent voluntary recall of the gel fuel products that each company had produced and delivered. The official release from the CPSC, Release #11-315, reads as follows:

> *"The pourable gel fuel can ignite unexpectedly and splatter onto people and objects nearby when it is poured into a firepot that is still burning. This hazard can occur if the consumer does not see the flame or is not aware that the firepot is still ignited. Gel fuel that splatters and ignites can pose fire and burn risks to consumers that can be fatal."* (Office of Communications, Release #11-315)

As of September 1st, the recall initiated by the Office of Compliance and Field Operations has resulted in the returning of over 2 million bottles of gel fuel. In this voluntary recall, there were 12 companies that participated, both nationwide and internationally. The 12 companies are listed in detail, with the inclusion of pertaining information in regards to the extent and reach of the recall.

2.4.2.1 Bird Brain Inc. – Ypsilanti, MI.

Bird Brain Inc. distributors recalled a series of three different products, also varying in the size of the containers provided. The three products in question were as follows: Bird Brain Firepot Gel Fuel, Bird Brain Firepot Citronella Gel Fuel, and Bird Brain BioFuel Fuel Gel. These products were offered in 16, 32, and 64oz bottles, as well as in metal cans of a 32 oz. size. These products, produced in both the U.S. and China, were sold from October 2008 until August 2011, in price ranges of $8-$18. This recall affected almost 1.6 million bottles and cans of the Bird Brain gel fuel products (Office of Communications, Release #12-002 2011).

2.4.2.2 Bond Manufacturing Co. – Antioch, CA

Bond Manufacturing Co. distributors recalled a series of two different products, varying in sizes of containers provided as well as the bundling of value packs. The products in question were as follows: Bond Firebowl Pourable Gel Fuel Bottles and Bond Firebowl Pourable Gel Fuel Jugs. These products were offered in 32 and 64oz bottles and jugs, and a pair of Ceramic Firebowls were offered in a set as well. These products were manufactured in China and were sold from September 2010 until September 2011, in the price range of $5-$20. The recall affected about 16,500 bottles and jugs of the Bond Manufacturing Co. gel fuel products (Office of Communications, Release #11-336 2011).

2.4.2.3 Evergreen Enterprises – Richmond, VA

Evergreen Enterprises, distributing for the manufacturing company 2 Burn Inc. of Milwaukee WI, recalled a series of gel fuel product, with variances in the inclusion of citronella in the containers provided. The product in question was Fireside Gel Fuel Bottles. This product was offered in 12-pack of 30oz cases. These products, manufactured in the United States, were sold from December 2010 until September 2011, in price ranges of $10-$12. This recall affected around 23,400 bottles of the Fireside Gel Fuel bottles of gel fuel products (Office of Communications, Release #12-020 2011).

2.4.2.4 Fuel Barons, Inc. – Stateline, NV

Fuel Barons Inc. distributors recalled a series of two different products, also varying in the size of the containers provided. The two products in question were OZOfire Pourable Gel Fuel (Formula 4) bottles and SUREFIRE Pourable Gel Fuel (Formula 4) bottles. These products were offered in both quart and gallon sized models. These products, manufactured in the United States, were sold from January 2012 until August 2011, in price ranges of $9-$22. This recall affected about 14,000 bottles of the Fuel Barons Inc. gel fuel products (Office of Communications, Release #11-337 2011).

2.4.2.5 Lamplight Farms, Inc. – Menomonee Fall, WI

Lamplight Farms Inc. distributors recalled a series of two different products. The two products in question were as follows: TIKI Brand Gel Fuel bottles and jugs and TIKI Brand Citronella Gel Fuel bottles and jugs. These products were all offered in a one quart sized container. These products, manufactured in the United States, were sold from September 2011 until December 2012, at a price of about $10. This recall affected almost 217,000 bottles and jugs of the Lamplight Farms Inc. gel fuel products (Office of Communications, Release #11-346 2011).

2.4.2.6 Luminosities / Windflame Inc. – Saint Paul, MN

Luminosities/Windflame Inc., distributing for Fuel Barons Inc., recalled a series of gel fuel products. The product in question was OZOfire Pourable Gel Fuel (Formula 4) bottles. This product was offered in a one quart sized bottle. This product, manufactured in the United States, was sold from October 2010 until August 2011, in price ranges of $4-$12. This recall affected about 26,500 bottles and of the Luminosities/Windflame Inc. gel fuel products (Office of Communications, Release #11-340 2011).

2.4.2.7 Marshall Group – Elkhart, IN

Marshall Group distributors recalled a series of products, varying in the inclusion of citronella in the gel fuel for scenting purposes. The product in question was Marshall Garden PatioGlo Bio-Fuel Gel. This product was offered in a 32oz size. This product, manufactured in the United States, was sold from November 2010 until August 2011, in price ranges of $8-$12. This recall affected about 39,000 bottles of the Marshall Group gel fuel products (Office of Communications, Release #12-207).

2.4.2.8 Napa Home & Garden – Duluth, GA

Napa Home & Garden distributors recalled a series of two different products, also varying in the size of the containers provided. The two products in question were Pourable NAPAfire bottles and jugs, and FIREGEL Gel Fuel bottles and jugs. These products were offered in both quart and gallon sized containers. These products, produced in both the U.S. and China, were sold from December 2009 until June 2011, in price ranges of $5-$78, including bundle packages. This recall affected almost 460,000 bottles and jugs of the Napa Home & Garden gel fuel products (Office of Communications, Release #11-255 2011).

2.4.2.9 Pacific Décor Ltd. – Woodinville, WA

Pacific Décor Ltd. distributors recalled a series of products, both with and without the additions of citronella. The product in question is Pacific Flame Pourable Gel Fuel bottles. These products were offered in quart sized containers. This product, manufactured in the United States, was sold from June 2011 until August 2011, in the price ranges of $10-$12. This recall affected almost 3,600 bottles of the Pacific Décor Ltd. gel fuel products (Office of Communications, Release #11-334 2011).

2.4.2.10 Real Flame – Racine, WI

Real Flame distributors recalled a series of three different products, varying in the size and content of the containers provided. The product in question was named Real Flame Pourable Gel Fuel Bottles. These products were offered in a quart sized container, as well as a 29.9oz jug and a 29.98oz citronella added edition. These products, manufactured in the United States, were sold from January 2009 until August 2011, in the price range of $10-$13. This recall affected about 100,000 bottles and jugs of the Real Flame gel fuel products (Office of Communications, Release #11-338 2011).

2.4.2.11 Smart Solar Inc. – Oldsmar, FL

Smart Solar distributors recalled a series of gel fuel related products, varying in the inclusion of citronella in the product provided. The product in question, named Smart Gel Fuel bottles, was offered in two editions of the 30oz container – with and without citronella additives. These products, manufactured in the United States, were sold from January 2011 to June 2011, in the price range of $10-$20. This recall affected about 1,400 bottles of the Smart Solar Inc. gel fuel products (Office of Communications, Release #11-339 2011).

2.4.2 Methods of Gel Fuel Dispensing and Refilling

In common firepots on the market between 2009 and 2011, the most common way to supply the alcohol-based gel fuel to the firepot is in the aforementioned bottles of refillable, pourable gel fuel. However, it has been detailed that such methods of gel fuel application have proven to be rather dangerous. There is another method available for firepot users who do not wish to pour gel fuel mid-use; there are several types of single-use gel fuel cans available on the market. These canisters, usually ranging from about 4-7 ounces in volume, are meant to be burned through in a single sitting and not to be refilled. These one-time "burn cups" usually last for about two hours or so and work just as normal pourable gel fuels do (Chao 2011). However, these single-use cans, manufactured by companies such as Pacific Flame, can only be used in such firepots that have the proper amount of space in the burn cup to hold the entire canister. Furthermore, in the mindset of safety, it is important to note that these single-use burn cups are still susceptible to the tipping over of the firepot. This will still allow for the spillage of the igniting gel fuel in such an instance, and may actually magnify the problem with the ejection of the canister itself (Duncan 2011).

2.4.3 Analysis of the Pourable Gel Fuel Containers

With over a dozen individual companies and distributors involved in the firepot and gel fuel industry across the United States in the past several years, there is much variance in the number of different containers that the gel fuel is sold in. Whether it be in bottles, jugs, tubs, or even metal cans, these storage containers are crucial in the overall safety of the product. The warning labels on the container and the container's ability to create a dangerous headspace will be discussed in further detail (Chao 2011).

2.4.4 Pourable Gel Fuel and Container Safety Labels

In order to regulate the storage, transportation, and usage of such alcohol-based flammable liquids as gel fuels, the Directorate for Laboratory Sciences, Division of Combustion and Eco-Safe Systems USA, or ESFS, assessed the containers used for gel fuel storage and the safety factors associated with them. In an overview of the gel fuel refilling containers that were pulled off the market in the 2011 voluntary recall, the ESFS noted that many of the products were deceiving in nature. Many brands sport labels claiming “safe burning” or “environmentally friendly” and are sold in containers similar to quart-sized water bottles. If a consumer were to not carefully read the warning and hazard labels provided, one might overlook the hazardous nature of the gel fuel for its outer looks (Chao 2011).

There are also warning labels present on these gel fuel containers. These labels point out several facts about the product that are essential in understanding basic gel fuel safety. The labels explain the flammable nature of the gel fuel, as well as the dangers that are present in refilling a lit firepot. However, in many cases these labels fail to mention that a firepot may look empty and unlit even if an almost invisible flame is still burning at the bottom of the burn cup. These warning labels also tend to be lost amidst the many other labels on the gel fuel containers, making them much more difficult to distinguish. Upon evaluation of such labels, the ESFS deemed the hazard labels on the gel fuel containers to be ineffective (Chao 2011). Figure 16 shows examples of the warning labels amongst other depictions on bottles of gel fuel from distributors Evergreen Enterprises and Lamplight Farms, Inc.

Figure 16: Pourable Gel Fuels from Evergreen Enterprises and Lamplight Farms, Inc.

2.4.5 The Physical and Visual Characteristics of Alcohol-Based Gel Fuels

Alcohol-based gel fuels are designed to have a minimal odor in the process of their burning. As gel fuel, a source of power for firepots designed to be used as ornamental pieces, they are intended to have a neutral or slightly appealing smell. Most companies that sold gel fuel between 2009 and 2011 offered a version of their product that contained citronella, usable as both an insect repellant and a positive scent (Duncan 2011). Most gel fuels are also clear or of a slightly yellow tint, largely due to the ingredients needed for proper burning. The gel fuel resides within the burn cup, fitted within the firepot itself, so the need for a colorful gel fuel for visual appeal is not readily apparent. Most of the visual appeal of the firepot comes from the dancing flames of the gel fuel, so the hue to the gel is not often a priority.

2.4.6 Gel Fuel Flame Classifications

Under the Federal Hazardous Substance Act (FHSA), the alcohol-based gel fuels are considered flammable. Under the FHSA, any substance that has a flashpoint between 20 degrees Fahrenheit and 100 degrees Fahrenheit is considered as such. The flashpoint of a substance is the temperatures within which the vapors or fumes of that substance are combustible. The National Fire Protection Association (NFPA) also classified gel fuels as a Class 1B flammable substance. This classification groups gel fuels with such materials as lighter fluids and gasoline, showing clearly the volatile nature of the substance (Chao 2011).

2.4.7 Luminosity of Alcohol-Based Gel Fuels

Most fire gel compounds are about 80% ethanol alcohol or isopropanol alcohol. As such, these flames produce very little visible smoke and almost no soot. Because of these efficient fuels, the flames from gel fuels are not very visible, especially in well light rooms or outdoors during peak hours of sunlight. This can give the impression that there is no flame, or that the gel fuel has been extinguished. This notion can be furthered as the gel fuel diminishes, as the decreasing levels of fuel means that the flame recedes further down into the burn cup. This can lead to potentially dangerous situations, as the vapors in the headspace of the gel fuel container can ignite and cause an explosion (Chao 2011).

2.4.8 Burn Duration and Flame Patterns of Gel Fuels

The average gel fuel burn canister is in the size range of 4-7 ounces. These burn cups, when filled, can provide a decorative flame for up to 3 hours if allowed to burn straight through. However, a flame can be snuffed out, lidded after cooling to prevent alcohol evaporation, and lit again at a future time. The flames do not provide a significant course of light or heat, yet they can have some noticeable effects. The flames from a gel fuel canister can reach heights of about 6-8 inches and can burn through moderate amounts of wind without extinguishing. The gel fuel will burn at about 160-180 degrees Fahrenheit, and can output upwards of 2,500 BTU's per hour of usage (Chao 2011).

2.4.9 Suppression and Containing of a Gel Fuel Fire

As the alcohol-based gel fuels designed for use within firepots are of a much different nature than a typical flame, the methods and precautions to be taken to suppress such a fire differ greatly. However, one key tenant of fire-repelling remains the same – the smaller a fire is, the easier it is to contain. The combustion rate of gel fuel increases significantly in accordance with the amount of gel fuel present – or in this case, the volume of the gel fuel that has spilled from the burn cup in the case of an incident. To this extent, the fire from the gel fuel is similar to a standard fire. However, the gel fuel differs in its methods of fire suppression. Due to the viscosity of the gel fuel and the sticky nature of the gelatin, it tends to spread rather than quench when pressed. For this reason, it is advised not to attempt to extinguish any gel fuel ignited on the body or clothing by methods of “stop, drop, and roll”. In several instances, such an attempt was made and led to further burns on behalf of the victim (Chao, Duncan 2011).

2.4.10 The Chemical Makeup and Properties of Alcohol-Based Gel Fuel

2.4.10.1 Gel Fuel Chemistry: An Introduction

The alcohol-based gel fuel used in firepots consists of a compound featuring mostly an alcohol liquid, usually an ethanol or isopropanol, or in some cases, a combination of the two. These alcohols usually comprise about 80% of the total compound. Other ingredients include water, gelling agents, citronella (for scent and deterring insects), and eucalyptus (for scent), among other additives of minor capacities. In most firepot gel fuels, the active ingredient is isopropanol. This alcohol, a colorless, odor-strong, liquid-state gas, is also known by several other names. These are as follows: isopropyl alcohol, propan-2-ol, 2-propanol, IPA, or rubbing alcohol (Duncan 2011).

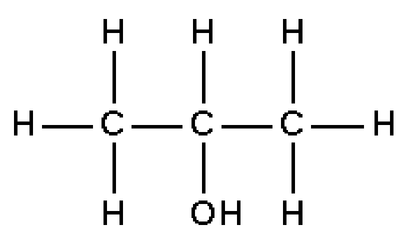


Figure 17: Molecular Depiction of Isopropyl Alcohol

The molecular formula for isopropanol, or C_3H_8O, is shown in Figure 17. In this depiction, the molecule is shown as C_3H_7OH. This is the same substance; however, the placement of the alcohol carbon dictates where that chain of the molecule is placed, and therefore the rendition of the molecular formula. This molecule can also be depicted with the carbon being attached directly to the other two, as opposed to in a chain. This form, known as a secondary alcohol, is written as $(CH_3)_2CHOH$.

2.4.10.2 The Viscosity of Alcohol-Based Gel Fuels and its Importance

Though the alcohol-based gel fuel has a much higher viscosity, the isopropanol itself has a rather liquid nature. At a temperature of 15 degrees Celsius, the alcohol was a viscosity of 2.86cP. This unit, centipoise, represents the amount of force needed to move the substance in question across another layer of such material. As a reference, water has a based viscosity of 1cP and is the basis for the scale. At higher temperatures, the viscosity of the isopropanol decreases, as it gets thinner due to the increase in temperature. For example, at 30 degrees Celsius, the viscosity of the alcohol is reduced to 1.77cP (Duncan 2011). This is in contrast to the viscosity of the gel fuels themselves. According to studies conducted by the CPSC, the gel fuels brought into question during the voluntary recall of the product in 2011 had measures of viscosity in the range of 5000 to 25000cP. These numbers are similar in range to such products as mustard or a light honey, as a reference.

The viscosity of the gel fuel product is an important number to take into consideration when evaluating the safety of such a product. In the accident reports filed to the CPSC in regards to usage of firepot and gel fuel combinations between 2009 and 2011, there was a total of 76 accidents, which resulted in 86 injuries and 2 fatalities. Of these, 52 injuries and both fatalities were direct results of either refueling the firepot or involved the tipping of the firepot. In the case of tipping firepot, a gel fuel of low viscosity leads to a further field of spill of the overturned gel fuel. If the gel fuel were to be of a more solid nature, the spread of the ignited gel fuel would be reduced, potentially leading to a smaller possibility for an incident. In the reported incidents filed to the CPSC, there was a large majority of incidents involving the refueling of the burn cup. In some cases, gel would splash from the bottle, and igniting from the still-lit burn cup, spray ignited gel fuel all around the firepot. It is believed that an increase of the viscosity of this pourable gel fuel, to a thicker concentration, could help to mitigate, or at least minimalize, such a situation (Duncan 2011).

2.4.10.3 CPSC Safety Feature Recommendations of Pourable Gel-Fuel Containers

Upon receiving and compiling incident reports, the Consumer Product Safety Commission deemed it appropriate to research further into both the gel fuel itself and the gel fuel containers. Upon review, the CPSC deemed that the containers for these gel fuels are not sufficient to either be distinguished from ordinary containers, or to provide sufficient safety features such that the potential for product-related injuries can be avoided. It was noted that most bottles of Class 1 flammable liquids, and other hazardous fuels, have sufficient warning labels that clearly describe the potential dangers of using and igniting the product. Furthermore, such containers can have physical safety features such as flame arrestors and vapor venting valves. Upon further deliberation, the CPSC set forth these four criteria that all pourable gel fuel containers should employ, and would be required for further product development. These criteria are as follows:

1. Any safety feature must be permanently attached to the container so that the consumer cannot reasonably remove it;

2. There must be a mechanism to prevent hot gases and/or flames from coming in contact with and igniting the explosive atmosphere in the container headspace;

3. Any safety feature must be robust and continue to function at the end of the foreseeable worst-case life time of the container; and, *4. Any container safety feature must not impede the function of the product, such that the consumer would likely remove or otherwise bypass the safety feature (CPSC 2011).*

The CPSC hopes that such standards can be used in the future as a necessary requirement for all gel fuel products. If these products are available on the market, the CPSC wants to ensure that the safest, most transparent product is put on the market in order to prevent safety hazards like the rash of accidents occurring between 2009 and 2012 (Chao 2011).

2.4.10.4 An In-Depth Analysis of Alcohol-Based Gel Fuels: Concluding Remarks

The gel fuel that has been used in firepots and similar flame-based ornaments over the past several years is, in nature, relatively simple. The idea of burning alcohols, mixed with some form of gelling agent, has been the basis of such products for years. Yet the recent resurgence in the use of these alcohol-based gel fuels gave way to the extensive incident reports filed to the CPSC from 2009 to 2011. Some of this may be due to the familiarity of such projects. Cooking gels, for example, have been used for decades without the threat of market removal. It is, perhaps, the general population's common knowledge of these products that prevents them from seeing how dangerous they can truly be. The human error, after all, can always be present and can lead to such disasters such as burning and even fatalities. However, perhaps there are also challenges provided from the product itself.

The gel fuel products that were available on the market seemed to slip under the radar. After all, no industry standards were enforced or even set forth for such products. As such, the manufacturing companies did not need to follow a strict set of regulations concerning the marketing of their product. Many offered little to no warning hazards, explaining exactly what could happen if used improperly. However, many of the challenges fell on the gel fuel itself.

With a rather low viscosity, gel fuel could easily splash from either the refill container or the burn cup, and in large distances. However, the product was still of a gelatin nature, causing it to adhere to objects it comes in contact with. The gel fuel's flashpoint also meant that the products vapors, so easily trapped in storage, could ignite in most common room temperatures. These vapors also tend to stay trapped in the containers the gel fuel is stored in, as the bottles and jugs provided by the manufacturers tend not to have proper ventilation mechanisms. This can lead to a headspace buildup, and an even further probability of detonation in the presence of a spark. These technical flaws, amongst others, have been seen to cause many of the incidents that called for the product removal from the market. From outlining such issues, one can now look to see the instances of incidents and injuries that have been documented to follow from the use of such products, and how these challenges have caused these instances.

2.5 Incident Reports

On June 14, 2011, the Consumer Product Safety Commission, or CPSC, announced in a press conference that they intended to launch an investigation into the burn accidents related to the gel fuel that is used in most firepots. The CPSC made it abundantly clear that the gel fuels have a hazardous potential to cause burn and poisoning accidents. This warning informed customers that not only can pouring the gel over an open flame may cause fuel splattering and uncontrolled fires, but also that the hydrocarbon chemicals in the gel may cause chemical pneumonia, pulmonary edema, or death if ingested. This conference was directly in the wake of two reported accidents in New York, causing three to be hospitalized, in the prior three weeks (MacDonald 2011). At the time, the CPSC had no set standards specifically for the gel fuel used in the firepots. Meanwhile, the number of gel fuel related incidents continued to climb. With no legal backing from the CPSC, all companies that manufactured the gel fuel chose to voluntarily recall all gel fuel sold to both consumers and retailers. The total number of gel fuel containers returned in 2011 was over two million. One of the larger manufacturers of the gel fuel, Bird Brain Inc. located in Michigan, recalled approximately 1.6 million bottles and cans after becoming aware of 20 separate incidents resulting in eleven injuries (Office of Communications 2011). The large number of accidents caused by the gel fuel associated with firepots initiated a complete halt of a well demanded product in only two short years of being on the market.

The Consumer Product Safety Commission is aware of 76 reported incidents regarding firepots and the gel fuel from April 2010 to September 30, 2011. 60 of these incidents took place in 2011. 84% of these incidents took place between the months of May and August. 10 of the 16 incidents in 2010 took place between these months and 54 of the 60 incidents in 2011 took place between these months and specifically 53% of all reported incidents took place in just the two months of May and June of 2011, as seen in Figure 18 (Chao 2011).

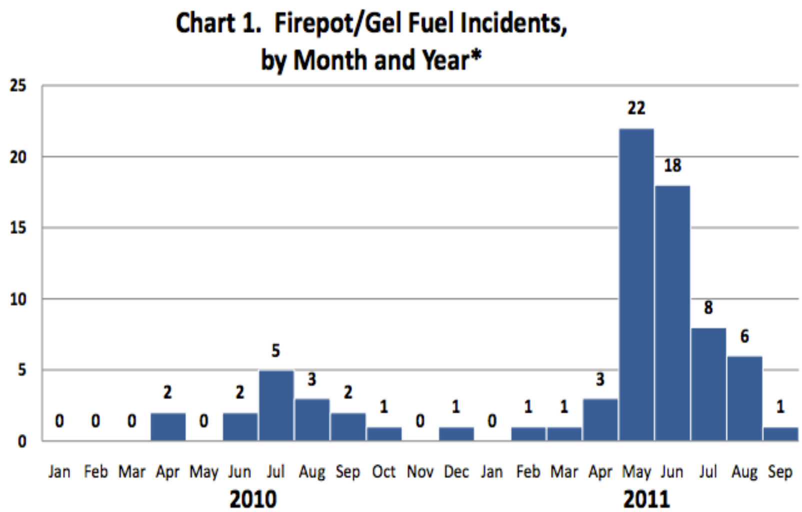


Figure 18: CSPC Reported Firepot Incidents by Month and Year

It is highly likely that the reason for the spike in accidents during the summer months is because consumers use the product in warmer weather as opposed to cooler weather.

The Consumer Product Safety Commission has categorized each incident as a result of one of eight different mechanisms unless not enough information could be provided:

Refueling: This case occurs when a consumer attempts to pour gel fuel into an actively lit burn cup. The flame ignites the vapors in the fuel container causing an explosion. 49 incidents, or 64%, were caused by refueling. Refueling incidents have caused 61 injuries and two fatalities. 35 of these injuries required hospitalization for burn treatment.

Explosion while lighting: This case occurs when the gel fuel has already been poured into the gel can and an explosion takes place while lighting the gel. Five incidents, or about 7%, were caused by an explosion while lighting. Explosions while lighting incidents have caused nine injuries. Four of these injuries required hospitalization for burn treatment.

Fuel container explosion: This case occurs when the fuel container explodes after it is placed away from the firepot. Engineering analysis suggests that these incidents occur when a small flame was present in the burn cup while it was being refueled which may have ignited the vapors in the container. Two incidents, or about 3%, were caused by a fuel container explosion. Fuel container explosion incidents have caused two injuries. Both of these injuries required hospitalization.

Burn cup ejection: This case occurs when the burn cup spontaneously ejects from the firepot while in use. Although members the CPSC were unable to replicate this scenario, the staff speculates that the pressure inside the firepot built up and ejected the cup due to inadequate ventilation. Six incidents, or about 8%, were caused by a burn cup ejection. Burn cup ejection incidents have caused three injuries. One of these injuries required hospitalization.

Explosion during use: This case occurs when the fuel in the burn cup spontaneously explodes during use. Members of the CPSC were unable to replicate this scenario, but the staff speculates it may be caused by exposure to contaminants. Four incidents, or about 5%, were caused by an explosion during use. Explosion during use incidents have caused three injuries. One of these injuries, a 5-year-old child, required hospitalization for burn treatment.

Tip over: The case occurs when the firepot is bumped into or knocked over while in use causing burning gel fuel to spill out of the burn cup. Three incidents, or about 4%, were caused by a tip over. Tip over incidents have caused six injuries, including two children. Four of these injuries required hospitalization for burn treatment.

Firepot base breakage: This case occurs when the firepot base breaks while in use. Members of the CPSC were unable to replicate this scenario, but the staff speculates that this is caused when pressure inside the firepot builds up and ruptures the base. Three incidents, or about 4%, were caused by a firepot base breakage, including one incident where ceramic shards became airborne. Firepot base breakage incidents have not caused any injuries.

Explosion while snuffing flame: The case occurs when an explosion takes place while the consumer attempts to snuff the flame. Members of the CPSC were unable to replicate this scenario. One incident, or about 1%, was caused by an explosion while snuffing the flame. Explosions while snuffing the flame incidents have not caused any injuries.

Not enough information: There have been three incidents, or about 4%, where not enough information was given to identify the failure mechanism. These incidents have cause three injuries, one of which required hospitalization (Chao 2011).

Table 1. Reported Firepot and Gel Fuel Incidents: Scenarios and Injury Severity*						
Incident Scenario	**No. of incidents**	**No. of "no-injury" incidents**	**No. of Injury incidents**	**No. of Injured Victims (minimum counts**)**	**No. of Hospitalized Victims *(minimum counts**)***	**No. of Deaths**
Refueling firepot *(pouring fuel/immediately post pouring)*	49	0	49	61	35	2
While actually lighting fuel *(after filling or refilling firepot)*	5	0	5	9	4	0
Fuel storage container exploded *(delayed, not while pouring fuel)*	2	0	2	2	2	0
Metal burn cup ejected spontaneously while in use	6	3	3	3	1	0
Explosion of fuel in burn cup while in use	4	1	3	3	1	0
Firepot tip-over incidents	3	0	3	6	4	0
Firepot broke spontaneously while in use	3	3	0	0	0	0
Explosion while snuffing	1	1	0	0	0	0
Limited Details (preclude classification of scenario)	3	1	2	2	1	0
Totals (all cases)	**76**	**9**	**67**	**86**	**48**	**2**

**Per HS and EPHA joint review of incidents reported up to 9/30/11.*
. *minimum counts because some incidents cases have limited details*

Figure 19: CPSC Reported Incidents, Injuries, and Severity

The cause of 49 incidents, or 64%, was refueling while the firepot was in use, shown in Figure 19. This mechanism has caused sixty-one injuries, including 35 hospitalizations and two fatalities making it by far the most dangerous firepot incident. When a consumer is pouring gel into a burn cup while in use, the container is tipped on its side which contains most of the flammable vapor as opposed to allowing it to escape out of the top. The flame may travel from the burn cup up the stream of pouring gel fuel into the container. When the flame enters the container, the trapped flammable vapors ignite and explode. The explosion ignites the remaining gel fuel inside the container before the expanding gasses force the fuel out of the container. This results in a fireball and flaming gel being ejected from the container which may burn anyone in the near vicinity (Chao 2011). This phenomenon is depicted in Figure 20.

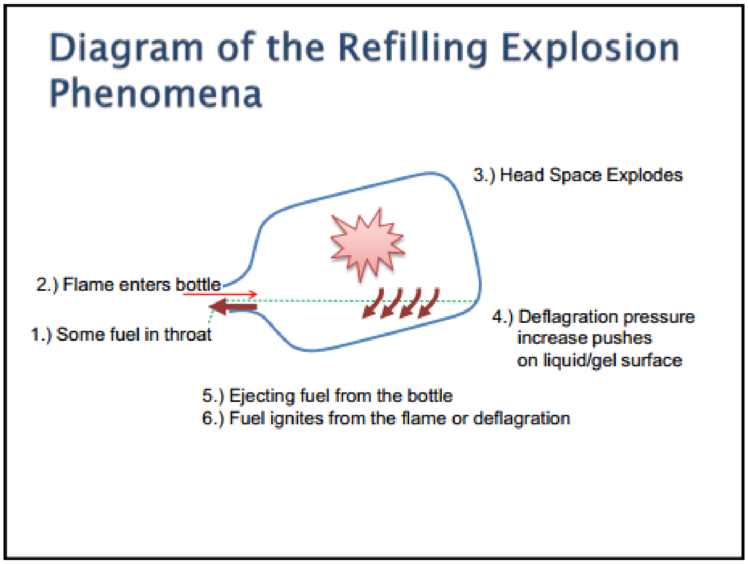


Figure 20: CPSP Model for Refueling Explosion

Firepot related injuries present a risk to all humans regardless of age. The most common injuries are burns ranging from minor burns to severe burns requiring hospitalization. Hospitalized victims are typically admitted for between ten to 76 days. Any type of severe burn may cause long, painful, and expensive treatment. The burns are very painful and may lead to complications such as fluid loss and infection, permanent damage, and emotional trauma. Due to the large number of incidents resulting in injuries and fatalities, an investigation into the product is necessary and firepot standard intervention is required.

Chapter 3: Methodology

3.1 Introduction

The following chapter in this report will outline the testing and procedural script to be followed in order to achieve the desired results of experimental testing. The tests, which will be described at a later point in this chapter, aim to give feedback and verification of the original danger presented by the use of firepots and their alcohol based gel fuels. Furthermore, additions to and alterations of both the gel fuel itself and its burn cup receptacle will help to give insight into possible changes that could be made to the product in order to make for an overall safer experience. At the end of experimentation, the objective is to evaluate all of the resulting collected data and come to a reasonable conclusion to each individual test conducted. This will be done in the hopes of finding these results to be favorable – as such, to see limited spilling of the gel fuel in tests which involve the use of viscosity-altered gel fuels and modified gel fuel burn cups to minimize (or eliminate) the volumetric flow rate of gel fuel out of the firepot. This methodology chapter will outline each of these modifications to the gel fuel, as well as the procedures needed in order to complete such additions or changes. The chapter will further outline the design and function of the actuation mechanism, and the procedure followed for data collection and evaluation. The chapter will conclude with a general synopsis of the expected results, which will hopefully point with strong evidence towards a smarter and safer design for the gel fuel used in firepot products.

3.2 Different Tests

In order to determine the safest possible design for the gel fuel, a series of tests must be completed that ensure that all feasible renditions of the product are considered and tested extensively. Each of the different sets of testing to be done, excluding the necessary control testing, are based off of either a mechanical addition or change to the burn cup of the gel fuel, or a chemical change to the compound of the gel fuel itself. The idea behind each addition will be examined further in the following, give a brief overview of each potential design change as well as the logic behind such a change.

3.2.1 Gel Fuel Control

The first series of testing to be done is that of the control group. In any good test, a control test is vital so as to allow for a series of base data collected values that all of the tests including variables are to be based off of. In this experimentation, the control group for testing is to be the burning and knocking over of a normal gel fuel can. The gel fuel in question, Pacific Flame's disposable single-fill gel fuel can, is a 4.75 liquid ounce container that is meant to be inserted into the burn cup and used in a single instance without refilling. This gel fuel container will be of the same fashion as the remainder of the variable-including tests. The control testing will be completed in the hopes that the collected results will be of a similar nature to that of the reports filed and experiments completed by the CPSC themselves.

3.2.2 Half-full Control

This group of experimental testing is similar to that of the first category. The half-full group is also a control, and does not include any changes to the gel fuel or the burn cups. However, these tests will include the removal of about half of the volume of the gel originally packaged in the product. The amount of gel fuel will be measured by the weight of the single-use can via a gram scale. The results of this testing will help to give a better understanding of the accidents filed in regard to firepots, and will give realistic data that represents many of the accident cases that occurred while the firepot was in the middle of use.

3.2.3 Meshing Layer

This testing group is the first category that involves a mechanical change to the design of the gel fuel's packaging. This iteration of the product includes a steel wire meshing across the top of the can, acting as a sort of screen. The material being used is a cold rolled steel mesh of, with a size of 18 gauge. The lattice of steel across the mesh ring allows for a decrease in the open surface area of the ring down to 43%, in effect reducing the amount of area for gel fuel to potentially leak from by over half. In the case of an incident, a ring of this (or similar) meshing welded to the top of the inner surface of the gel fuel tin could allow for a reduction in the spilling of the gel fuel from slight tipping, horizontal positioning, or even knock over and impact. A modeling of such meshing can be seen in Figure 21.

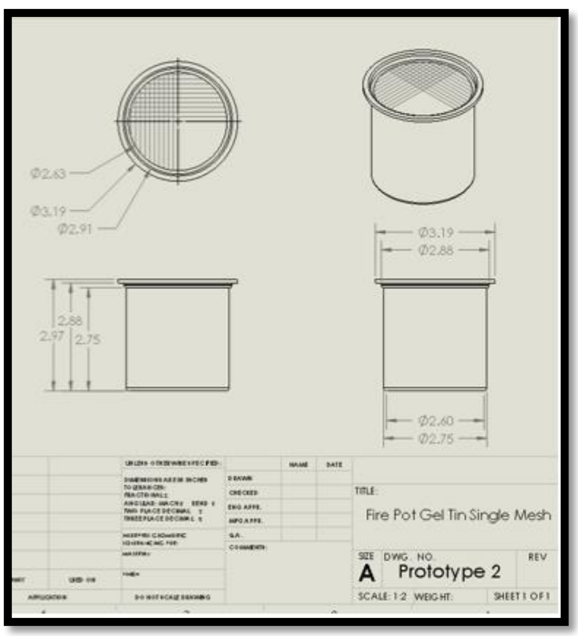


Figure 21: Original Burn Cup Design

3.2.4 Burn Cup Lip

Another possible rendition of the gel fuel cup involves the addition of a rim or lip to the edge of the topmost surface of the gel fuel can. The goal of such a design is to allow for a fully open top to the gel fuel can to allow for the complete visual appeal of the lit firepot, yet to minimize the size of the opening in case of a tip over. For example, take a standard burn cup with a diameter across the opening of 2.625 inches. With a ¼" washer (all the way around) welded to the top of the burn cup, that opening will be decrease to 2.125". This results in a decrease in the area of the opening from 5.41 square inches to 3.55 square inches. This is a dramatic decrease in the size of the opening, and would greatly reduce the flow rate of the gel fuel out of the burn cup in the accidental case of a knock over of ignited gel fuel. A depiction of such an idea can be seen in Figure 22.

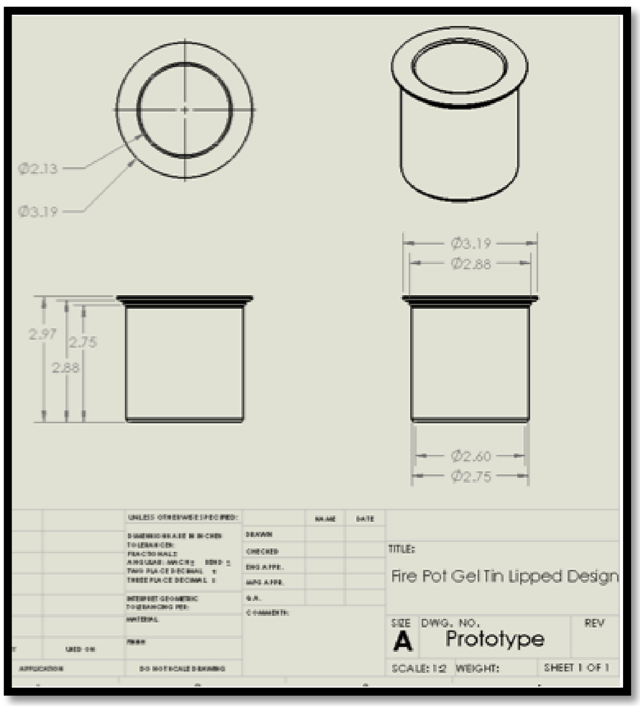


Figure 22: Lip Modification for Burn Cup

3.2.5 Pectin Additive

This design idea (as well as the next several following) will focus on the aforementioned chemical side of the modeling and testing the gel fuel. On way to make the gel less viscous, or thicker, would be to add a thickening agent to the gel and allow it to take on a more Sterno – like solid gel state. To do this, such ingredients as pectin can be added. Pectin, a graining substrate, is known to thicken in water and will not react violently when heated or burned. The full gamut of experimental procedures will be run with a certain amount of pectin mixed in with gel fuel, which will be repackaged via pouring back into the gel fuel single-use cans.

3.2.6 Molasses Additive

Similar to the previous modeling design, the addition of molasses to the gel fuel will help to thicken the gel and thereby lower the viscosity. Molasses, a liquid ingredient common in cooking and baking, will thicken the overall concentration of the gel fuel. Furthermore, such as addition could potentially add a pleasant scent to the burning gel fuel, and is not known to have any negative consequences of burning such as volatile explosions or eruptions.

3.2.7 Polyvinyl Alcohol Additive

This final design change idea for the gel fuel involves one last addition to the gel fuel itself. Polyvinyl alcohol, a substance found in both a liquid and a granulated state, will be mixed in with the gel fuel to act as a thickening agent. In the case of this experiment, a small granule – powered form of the polyvinyl alcohol will be used in concert with the gel fuel in order to make a thicker substance. As the polyvinyl alcohol itself is flammable in nature, there is no foreseeable danger in the addition of such a product to the existing gel fuel.

3.3 Preliminary Procedure for Each Variable

For each of the potential design changes to be used in the gel fuel or in its burn cup receptacle, there are individual processes that must be taken to prepare each of the changes for experimental procedures. The following subsections will outline the basic steps required in order to properly make such changes for each of the categories.

3.3.1 Gel Fuel Control

As this preliminary test represents the control group, no additional steps must be taken.

3.3.1.1 Complete Listing of Materials

The necessary materials for preparation of the gel fuel control test are as follows: Pacific Flame gel fuel single-use can, a gram meter, and a screwdriver or can opener.

3.3.1.2 Setup of Control Testing

To test the gel fuel control group, the weight of the can with the unburned gel fuel inside must be measured. To do so, the cover of the gel fuel cup must be removed. This can be done by using either a screwdriver to pry it off, or a can opener. The weight of the full can must be measured on the gram scale (this will also be done after testing to measure the amount of gel fuel burned). After this, the cover of the gel fuel can should be placed back on, so as to prevent evaporation of the alcohol if the testing is not to be done immediately. The gel fuel can is now ready for the experimental testing, which will be described in full in a following section.

3.3.2 Half-full Control

Similar to the original control group named "Gel Fuel Control", this series of tests will not require a large amount of preparatory work before the testing procedure.

3.3.2.1 Complete Listing of Materials

The necessary materials for preparation of the half-full control test is as follows: Pacific Flame gel fuel single-use can, a gram meter, a screwdriver or can opener, a spoon or ladle, and an extra gel fuel can or container.

3.3.2.2 Setup of Control Testing

To test the half-full control group, the weight of the can with the proper amount of unburned gel fuel inside must be measured. To do so, the cover of the gel fuel cup must be removed. This can be done by using either a screwdriver to pry it off, or a can opener. Now, a partial amount of the gel fuel must be removed with the spoon, and should be set aside in the extra container. The weight of this can must be measured on the gram scale (this will also be done after testing to measure the amount of gel fuel burned). After this, the cover of the gel fuel should be placed back on, so as to prevent evaporation of the alcohol if the testing is not to be done immediately. The gel fuel can is now ready for the experimental testing, which will be described in full in a following section.

3.3.3 Meshing Layer

The experimental meshing layer testing will involve the attaching of the mesh ring to the gel fuel can to allow for tip-over testing to be accomplished.

3.3.3.1 Complete Listing of Materials

The necessary materials for preparation of the meshing layer test is as follows: Pacific Flame gel fuel single-use can, a gram meter, a screw driver or can opener, 18 gauge cold rolled steel meshing sheets, scissors or cutting knife, a handheld welding unit, and welding safety equipment.

3.3.3.2 Construction of Design for Testing

To test the meshing layer group, the cold rolled steel must first be attached to the top of the gel fuel can. To do so, the cover of the gel fuel cup must be removed. This can be done by using either a screwdriver to pry it off, or a can opener. Now, a ring the size of the burn cup's inner diameter must be cut from the sheet of meshing. Using the proper safety equipment, this must now be welded to the top of the inside face of the gel fuel can. Once completed, ensure that the meshing layer is firmly fixed within the gel fuel can. Now the weight of the can with the proper amount of unburned gel fuel inside must be measured. The weight of this can must be measured on the gram scale (this will also be done after testing to measure the amount of gel fuel burned). After this, the cover of the gel fuel can should be placed back on, so as to prevent evaporation of the alcohol if the testing is not to be done immediately. The gel fuel can is now ready for the experimental testing, which will be described in full in a following section.

3.3.4 Burn Cup Lip

This experimental testing of the additional lip will involve the attachment of the steel washing or ring to the gel fuel can's inner rim in order to continue on to tip-over testing.

3.3.4.1 Complete Listing of Materials

The necessary materials for preparation of the burn cup lip test is as follows: Pacific Flame gel fuel single-use can, a gram meter, a screw driver or can opener, a stainless steel washer of the proper outer diameter, a handheld welding unit, and welding safety equipment.

3.3.4.2 Construction of Design for Testing

To test the burn cup lip group, the stainless steel ring must first be attached to the top of the gel fuel can. To do so, the cover of the gel fuel cup must be removed. This can be done by using either a screwdriver to pry it off, or a can opener. Now, a ring the size of the burn cup's inner diameter must be selected in order to ensure a snug fit. Using the proper safety equipment, this must now be welded to the top of the inside face of the gel fuel can. Once completed, ensure that the washer is firmly fixed within the gel fuel can. Now the weight of the can with the proper amount of unburned gel fuel inside must be measured. The weight of this can must be measured on the gram scale (this will also be done after testing to measure the amount of gel fuel burned). After this, the cover of the gel fuel canister should be placed back on, so as to prevent evaporation of the alcohol if the testing is not to be done immediately. The gel fuel can is now ready for the experimental testing, which will be described in full in a following section.

3.3.5 Pectin Additive

This version of experimentation will involve the use of a pectin additive to the gel fuel in order to increase the viscosity, thereby thickening the gel fuel. This will be done in the hopes that spillage of the gel will be minimized in the case of a tip over accident.

3.3.5.1 Complete Listing of Materials

The necessary materials for preparation of the pectin additive test is as follows: Pacific Flame gel fuel single-use can, a gram meter, a screw driver or can opener, packages of pectin granules, an extra non-flammable container, and a measuring spoon and stirring spoon.

3.3.5.2 Process of Mixture for Design Process

To initiate testing of the pectin additive to the gel fuel, the two materials must be mixed together. To do so, some of the original gel fuel must be removed from the burn cup so as to allow for the addition of more volume. Remove several spoons full of gel fuel from the container, and remove to the extra non-flammable container as it will not be needed further in this experimentation. Measure the remaining amount of weight on the gram scale. For the pectin additive, about one third of the initial volume of the gel fuel must be removed. This will leave approximately 3.17 fluid ounces of gel fuel in the container. Now, the pectin powder is to be poured into the partially full gel fuel container and gently stirred. The container should be filled to the same amount as when the container consisted of a full quantity of gel fuel. The pectin will start to dissolve into the gel fuel, resulting in the thickening of the substance. Once this has been completed, the lid must be fixed back onto the gel fuel container so as to prevent further evaporation of the alcohol in the gel fuel before testing. This modified gel fuel is now ready for testing.

3.3.6 Molasses Additive

This version of experimentation will involve the use of a molasses additive to the gel fuel in order to increase the viscosity, thereby thickening the gel fuel. This will be done in the hopes that spillage of the gel will be minimized in the case of a tip over accident.

3.3.6.1 Complete Listing of Materials

The necessary materials for preparation of the pectin additive test is as follows: Pacific Flame gel fuel single-use can, a gram meter, a screw driver or can opener, 8 oz bottles of standard cooking molasses, an extra non-flammable container, and a measuring spoon and stirring spoon.

3.3.6.2 Process of Mixture for Design Process

To initiate testing of the pectin additive to the gel fuel, the two materials must be mixed together. To do so, some of the original gel fuel must be removed from the burn cup so as to allow for the addition of more volume. Remove several spoons full of gel fuel from the container, and remove to the extra non-flammable container as it will not be needed further in this experimentation. Measure the remaining amount of weight on the gram scale. For the molasses additive, about one third of the initial volume of the gel fuel must be removed. This will leave approximately 3.17 fluid ounces of gel fuel in the container. Now, the molasses is to be poured into the partially full gel fuel container and gently stirred. The container should be filled to the same amount as when the container consisted of a full quantity of gel fuel. The molasses will start to mix into the gel fuel, resulting in the thickening of the substance. Once this has been completed, the lid must be fixed back onto the gel fuel container so as to prevent further evaporation of the alcohol in the gel fuel before testing. This modified gel fuel is now ready for testing.

3.3.7 Polyvinyl Alcohol Additive

This version of experimentation will involve the use of a polyvinyl alcohol additive to the gel fuel in order to increase the viscosity, thereby thickening the gel fuel. This will be done in the hopes that spillage of the gel will be minimized in the case of a tip over accident.

3.3.7.1 Complete Listing of Materials

The necessary materials for preparation of the polyvinyl alcohol additive test is as follows: Pacific Flame gel fuel single-use can, a gram meter, a screw driver or can opener, packets of polyvinyl alcohol granules, an extra non-flammable container, and a measuring spoon and stirring spoon.

3.3.7.2 Process of Mixture for Design Process

To initiate testing of the polyvinyl alcohol additive to the gel fuel, the two materials must be mixed together. To do so, some of the original gel fuel must be removed from the burn cup so as to allow for the addition of more volume. Remove several spoons full of gel fuel from the container, and remove to the extra non-flammable container as it will not be needed further in this experimentation. Measure the remaining amount of weight on the gram scale. For the polyvinyl alcohol additive, about one third of the initial volume of the gel fuel must be removed.

This will leave approximately 3.17 fluid ounces of gel fuel in the container. Now, the polyvinyl alcohol powder is to be poured into the partially full gel fuel container and gently stirred. The container should be filled to the same amount as when the container consisted of a full quantity of gel fuel. The polyvinyl alcohol will start to dissolve into the gel fuel, resulting in the thickening of the substance. Once this has been completed, the lid must be fixed back onto the gel fuel container so as to prevent further evaporation of the alcohol in the gel fuel before testing. This modified gel fuel is now ready for testing.

3.4 The Actuation Mechanism

In this experiment, the actuation mechanism will be used in order to initiate each of the individual gel fuel tests. Upon ignition of the gel fuel and the first series of measurements for the FRED sheet, the actuation mechanism will be used to knock over the gel fuel containers from a safe distance.

3.4.1 Design and Parameters of Actuation Mechanism

The actuation mechanism is a compact device that operates with the pulling of a release lever, which will allow for a swinging arm to rock downward and cause impact with the gel fuel can that is in position. The mechanism is constructed mostly of a metal pendulum arm and a particle wood base and steel dowel. The arms are connected to the cross-beam dowel by a series of sheet metal screws, and the striker on the pendulum consists of a 2.5 inch lag bolt. The structure allows for contact with the gel fuel canister at about half height, or 2.75 to 3 inches from the ground level. The pendulum can be pulled up to different heights, which allows for different degrees of angles for the pendulum arm to originate from. The current design allows for a 60 degree angle of the pendulum, giving an optimum distance for the striker am to travel before contact with the gel fuel canister. In this particular test, the actuation mechanism is clamped to the top of a workbench, resulting in a height of 31.5 inches above the ground surface of the testing areas. Due to the flammability and the dangerous nature of the gel fuel, the striker arm is released via a release pin that is connected to a aluminum rod. This rod can be pulled from a distance, allowing for the striker arm to contact the burning gel fuel canister from a safe distance.

3.4.2 Calculations of Force and Impact of the Actuation Mechanism

The actuation mechanism is based on the simple principle of a pendulum arm. At the end of this arm is a weight point, which acts as the striker in this experimentation. When released from a certain height or angle, the striker will swing downward and towards the gel fuel can that has been put in place. A simple pendulum, similar in nature to the device used in this experimentation, can be seen in Figure 23.

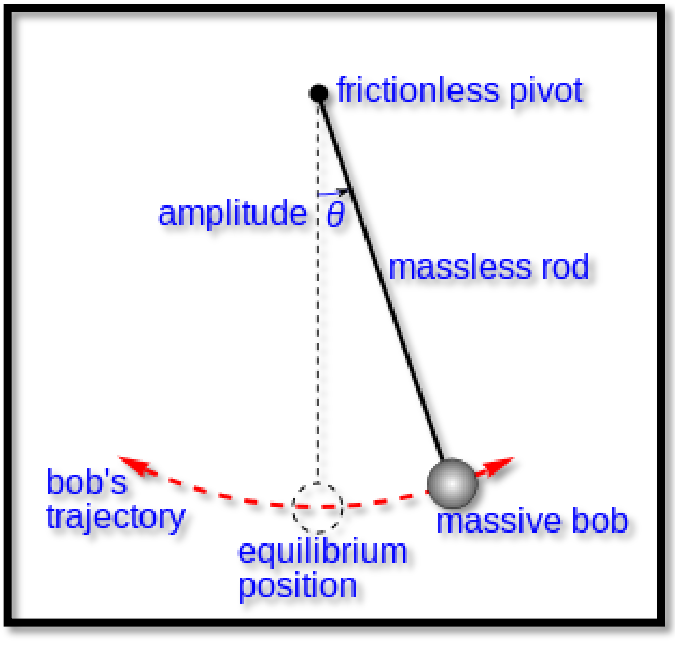


Figure 23: Visual Representation of Simple Pendulum

As seen in this simplified representation, several different assumptions were made in order to more easily solve the system and calculate a reasonable force value. The first assumption to be made was that the system could be represented in two dimensions, as the movement of the pendulum in the z plane was negligible. Therefore, such calculations were deemed unnecessary. It was also assumed that the pivot about the fulcrum (in this case, the steel dowel) of the system was a frictionless mechanism, and that the mass of the pendulum arm itself was negligible compared to that of the striker itself. It was also assumed that the equilibrium point of the system occurred when the pendulum arm was at bottom dead center (BDC). This is also the position that the gel fuel can was positioned at so as to result in a force applied to the can when the striker head reaches BDC. With these assumptions in hand, simple calculations can be run to acquire the impact force from the pendulum.

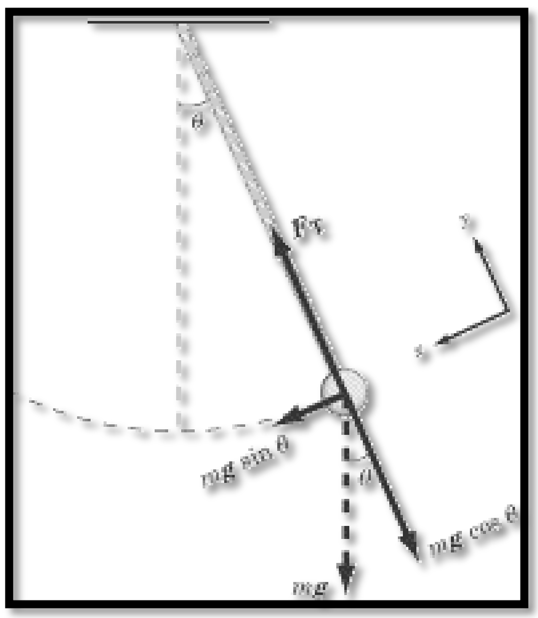


Figure 24: Impact Force Visual Representation

Shown in Figure 24 is the same system, this time with the appropriate symbols for certain values in place of assumptions. In this experimentation, the desired output will be the horizontal force of the system as it approaches the gel fuel can. In this simplified system, the equation for the horizontal impact force from the pendulum – actuated striker head is as follows:

$$F = mg \sin \theta$$

Where m is the mass of the object at the end of the pendulum, g is the gravitational force, and $sin\theta$ is the sine function of the angle the pendulum arm is released from with respect to the equilibrium point. Now, plugging in the appropriate values for each of these variables the equation leaves a resulting force.

$$F = mg\sin\theta$$

$$F = (103.6grams)(9.81m/s^2)(sin87^{\circ})$$

$$F = (0.1036)(9.81)(0.99)$$

$$F = 1.01\text{N}$$

3.4.3 Resulting Force and Useful Output of the Actuation Mechanism

Based upon the previous calculations, the resulting force that the actuation mechanism will apply to the gel fuel canister is 1.01 Newtons. Though a relatively small force, the mass of the canisters themselves reach values of only about 150 grams or so, and in some trials only half of that value. As such, a relatively small pendulum can be used in order to create the required tip over. If a great force is needed, it should be noted that the angle of the pendulum can be increase to raise such a value. Also, additional weight can be added to the striker to accommodate higher forces. This resulting force of 1.01 Newtons will be used in each experiment as the initial force applied to the gel fuel canister for the tip-over tests.

3.5 An Analysis of the Gel Fuel Testing Chamber

In order to complete testing on the gel fuel products via use of the actuation mechanism, a safe area must be used for testing. As this experimentation involves the intentional spilling of ignited gel fuel products, an enclosed area in which the flame can burn and be contained and extinguished in case of an emergency. Here on the WPI campus the use of the fire laboratories of the Fire Protection Engineering department are available for use. The flammable-product testing "hood" allows for ignition of products in a room sized area with appropriate equipment and safety measures, while retaining a constant atmosphere to complete testing in over an extended period of time.

3.5.1 Dimensions and Materials of the Testing Chamber

The fire protection engineering laboratories offer their large hooded chamber for experimental procedures on a larger caliber. For these tests, such an area will be required so as to allow for adequate room for the gel fuel to spill and for distances to be measured. The room itself is 8 feet wide and 12 feet in length, with a ceiling height of 10 feet. There are three walls, allowing for complete access and entrance to the room from one side. This is the side from which the actuation mechanism will propel the ignited gel fuel, allowing the flames to spread into the room and safely away from the experimenters. The room is composed of a stainless steel structure, and is completely covered in sheetrock on all 5 sides. This allows for burning of the surfaces, and the inspection of burnt areas and ashes, without the burning through of the room. The entire hood is held about 12inches off of the ground, on a layer of cinderblocks, to allow for proper ventilation under the hood as well.

3.5.2 Safety Precautions Taken in Testing Chamber

In order to ensure the safest possible testing of the ignited gel fuel, the group members are to take certain safety precautions into consideration and make sure that safety is a priority when testing. First of all, the safety measures and hazard equipment should be known to all members of the group, as well as extinguisher and fire blanket locations and usage. Furthermore, each group member (as well as anyone else in the immediate area) should be wearing safety goggles and non-nylon clothing. As the gel fuel will be tipped into the chamber, the group members should be sure to stand outside of the chamber and away from the direction of the propulsion. Members should only enter the chamber to examine the spilled gel fuel after the area is inspected and it is deemed safe to enter in the workspace.

3.5.3 Additional Safety Equipment and Various Materials

In accordance with both state and school regulations, the laboratory is outfitted with safety equipment in varying types and locations. There are handheld extinguishers present throughout the area, both foam and chemical in substance. There is also a fire blanket located on the wall right outside the hood. As the experimentation involves the handling of a gelatin substance, the emergency shower / eye flush station may need to be used to remove any gel fuel that comes into contact with anyone during testing.

3.6 Procedural Role for Each Team Member

The outlined procedure is not one that can safely be completed by only one or two individuals. As such, the procedure has been broken down into portions to be designated out to 4-5 people, depending on the availability of certain individuals. This allows for each team member to have a specific job, and ease of communication between members in the case of an emergency. It is important to note that each member should be fully aware of each other member's responsibilities, so as to allow for potential reminders and a timely and efficient testing schedule. The following sections will outline roles designated to each individual and at which points in the experimental timeline such actions should take place.

3.6.1 Actuation Mechanism User

The role of this individual is to perform the actions required to physically conduct the experiment. First, the prepared gel fuel cans must be weighed for the initial volume. Then, these cans must be placed in the proper alignment in front of the actuation mechanism. At the proper time, initial observations of the burning gel fuel should be dictated to the recorder and a thermocouple should be used to measure for initial temperature readings of the burning gel fuel. At the allotted time, the release lever on the actuation mechanism must be pulled for the tip-over testing of the gel fuel can to commence.

3.6.2 Result Measurer

The role of this individual is to measure any pertinent distances and values of worth throughout the experimentation and the tip-over test. Using a measuring tape, the general dimensions of the burning gel fuel flame should be dictated to the data recorder while the flame is burning and is waiting in position to be launched by the actuation mechanism. Upon spilling of the gel fuel, the dimensions and location of all gel fuel positions must be measured and dictated to the data recorder to have an accurate rendition of the gel fuel spill.

3.6.3 Data Recorder

The role of this individual is to record any and all data pertinent to the experimentation. Before the tip-over test can begin, this individual should record the name of this specific test, names of those present, and the date and time. Initials reading such as the weight of the fuel canister should be recorded, as well as observations and burning temperature as dictated by the actuation mechanism user. Upon release of this devise and the following gel fuel spillage, the data recorder must write down the measured values given to them by the result measurer. With time permitting, a visual representation of the spilled gel fuel should be drawn so as to allow for easier recollection and data analysis at a future time.

3.6.4 Procedure Photographer / Film Compiler

The role of this individual is to create as much visual evidence and data from the experimental procedure as possible. These include pictures and videos of the lit gel fuel while in position to be tipped over. This will help to give a sense towards the sound and color of flame, something of note in the particular cases of the chemically altered gel fuels to be tested in this project. The release of the actuation mechanism must be recorded, as well as several seconds of the burning gel fuel on the ground. After this, several overhead images of the spill scene should be taken, as it will allow for an important visualization of the data after the testing is complete.

3.6.5 Procedure Timer / Tracker

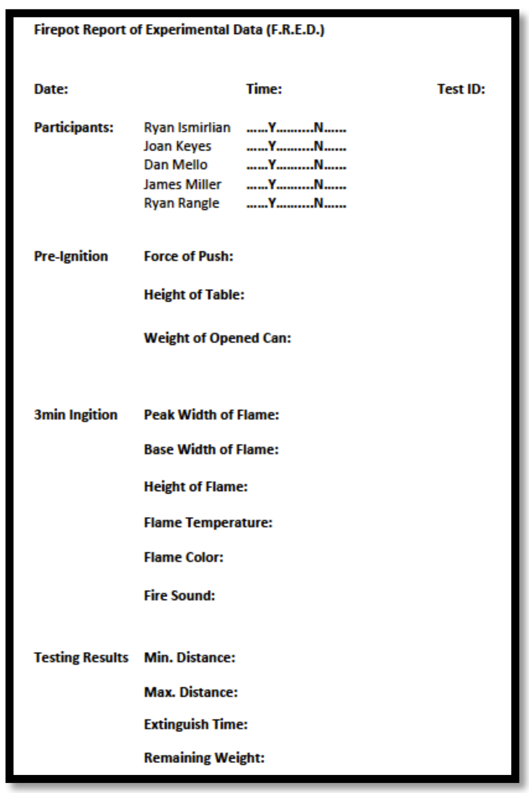
The role of this individual is to keep the experiment on time and of an efficient nature. The timer should also call out when certain aspects of the experiment are to be conducted, keeping a constant interval to allow for balanced testing results. From the moment the gel fuel is placed in front of the actuation mechanism and lit, the timing of the experiment commences. From there, exactly three minutes are to be measured off before initial measurements are taken so as to allow for the gel fuel to properly begin its burning cycle. From that point, two more minutes are to expire before the actuation lever is to be released and the data can be collected. The timing devise must be kept running until all the spilled gel fuel has finally extinguished.

3.7 Desired Results Collection from Testing Methods

Upon completion of testing, there are a desired set of results which will give the experimentation the appropriate data to make proper assumptions about the different sets of tests. Each tests much be individually identified with its own test number, as well as an unused gel fuel can. Each test will be documented real-time via the use of pictures of the resulting tip-over radius as well as a video of the actuation mechanism and the flight of the gel fuel can itself. This data will be re-created in a visual format, to be explained in the following section. Furthermore, the initial setup and measured values at the beginning of each test will also be recorded to ensure that each test undergoes the same procedure and that all initial conditions (barring the induced variables) remain constant.

3.7.1 Preliminary Testing: FRED Sheet

In order to record the initial conditions for each experiment, a data collection sheet was used that compiled measured data from each gel fuel can tip-over trial. This sheet, known as the FRED sheet (Firepot Report of Experimental Data), was a list comprised by the testing group which included all that the group found necessary to evaluate before each test could be initiated. A sample of the FRED sheet can be seen in Figure 25.


Firepot Report of Experimental Data (F.R.E.D.)

Date: **Time:** **Test ID:**

Participants:
Ryan Ismirlian ......Y..........N......
Joan Keyes ......Y..........N......
Dan Mello ......Y..........N......
James Miller ......Y..........N......
Ryan Rangle ......Y..........N......

Pre-Ignition
Force of Push:
Height of Table:
Weight of Opened Can:

3min Ingition
Peak Width of Flame:
Base Width of Flame:
Height of Flame:
Flame Temperature:
Flame Color:
Fire Sound:

Testing Results
Min. Distance:
Max. Distance:
Extinguish Time:
Remaining Weight:

Figure 25: Data Collection Sheet for each Test

3.7.1.1 Initial Gel Fuel Can Weight

The first parcel of data to be collected is the initial weight of the gel fuel can. Depending on the particular trial, this could include a full can, a can with about half of the gel fuel removed, or either of these with the addition of a new compound of fuel or the meshing / cup lip additions. In each of these scenarios, the cover of the gel fuel can is to be removed before the measurement. Using a common ground scale, the unit is to be calibrated and the mass of the gel fuel can is to be measured in grams and recorded to a constant number of significant figured on the FRED sheet.

3.7.1.2 Height of Initial Flame

This data value represents the maximum height of the flames that protrude from the gel fuel can upon initial burning. After the three minute period of igniting the gel fuel has passed, a ruler or measuring tape is to be used to record the highest peak to which the flames reach up until the use of the actuation mechanism to start the tip-over process. This is important to ensure that each individual can of gel fuel being used is burning equally and not an explosive hazard or dud. The height of the initial flame is to be measured in inches from the upper most lip of the gel fuel's burn cup, and recorded on the FRED sheet.

3.7.1.3 Base Width of Initial Flame

This data value represents the maximum width that the flame will reach at the base of the flame, which represents the opening of the gel fuel burn cup itself. This number is important to ensure that the entire width of the gel fuel tin's opening is being utilized. Furthermore, in the case of the lipped burn cup modification, the base width of the flame should be decrease do to the smaller opening that will be available for the ignited gel fuel. This width should be measured in inches at the three minute mark, and recorded on the FRED sheet for each individual test.

3.7.1.4 Peak Width of Initial Flame

This data represents the maximum width that the flame will reach at the upper heights of its flame. This number is important to ensure that the flame is within a safe level and is not burning out of control. Furthermore, this number will help to indicate whether or not the any additional meshing or lip to the gel fuel tin is hindering the flame to an undesirable extent. This width should be measured in inches at the three minute mark, and recorded on the FRED sheet for each individual test.

3.7.1.5 Temperature of Flame

The data entry represents the temperature of the flame around its base at the initial value recording time of three minutes after ignition of the gel fuel. The temperature of the flame is important to know, so that the group members will have an exact value to pair with the intensity of the flame, especially in such tests as the gel fuel compound additives. This temperature will also be a good indication of whether or not the mechanical additions to the burn cup itself will hinder the potency of the flame itself, and by extension its temperature. For collection of this data, a calibrated thermocouple is to be used. The measuring end of the instrument is to be placed within the fire at the base of the flame, yet not in contact with the gel fuel itself. This value, in degrees Celsius, is to be recorded on the FRED sheet.

3.7.1.6 Color, Sound, and Scent of Flame

These values to be recorded during the initial testing time are desired so as to help the group members gain a full picture of the overall experience of firepot usage. Each test will have a unique set of parameters, varying in the amount of gel, the chemical makeup of the gel, and physical changes to the container the gel fuel is being burned in. As such, each of these variables will alter the overall experience of using such a gel fuel in a firepot. Customers will want a pleasant smelling, calm, and visually appealing flame from the gel fuel. In particular, the tests involving additions of other ingredients to the gel fuel compound will no doubt cause changes in the way in which the substance will burn. Any changes that significantly alter this in a negative manner will need to be questioned and reevaluated. Simple descriptions of the color, sound, and scent of the flame, along with any noticeably major discrepancies, can be recorded and noted on the accompanying FRED sheet.

3.7.1.7 Final Time for Extinguishing of Gel Fuel

This data value, though coming in chronological order after the tip-over testing of the gel fuel container, has been recorded to the FRED sheet for simplification and ease of handling of the large amount of data. This value will represent the total time, from the initial ignition of the gel fuel, until the spilled gel fuel completely extinguishes. This is to include any amount of ignited gel fuel that spills from the can, though not including any of the remaining gel fuel in the can itself. Once all of the gel fuel has burned through, stop the timer and record the final time on the FRED sheet. At this point the work station can be cleaned and further testing can commence.

3.7.2 Dimensions and Distances of Gel Fuel Material from Testing Platform

This last series of data inputs are some of the most crucial to proper analysis of the experimental data and coming to a feasible conclusion in regards to different tests. After each test, the result measurer should use a yard stick or tape measure and measure out the dimensions of each of the spots of gel fuel that have spilled out from the burn cup. Furthermore, the distance of each location from the origin (the actuation mechanism and its table) in both left/right and front/back orientations, should be measured, and dictated to the data recorder.

3.7.3 Graphical Representation of Resulting Gel Fuel Dispersion

Upon collection of the dimensions and distances of gel fuel material from the testing platform, each set of data should be plotted out on a spreadsheet or chart according to the dimensions and locations of each spillage. This will allow for a replication of the overhead view of each and every accident, where additional notes can be transcribed for clarification in any test run. These graphical representations will help the examiners to evaluate each group of tests as a whole, and see if there are any trends in the overall performance of one of the induced variables. This will allow for the group to come to conclusions in regards to the best possible solution or solutions to the posed problem.

3.8 Conclusion

As in any accurate experimentation, a proper procedure must be followed in order to obtain reliable and useful results. The methods outlined in this chapter aim to give both guidance and reason to each step of the process in order to enable proper data collection. In looking to find evidence supporting the increase safety of the gel fuel product, the group outlined several possible additions to the gel fuel itself as well as changes to the canister in which these single-fill products are packaged. This chapter outlined the logic behind each, as well as the procedure required in order to make the appropriate changes to the gel fuel. Each group member was given a certain set of responsibilities – and with each member doing their part, a collective procedure could be formulated. This chapter also gave an overview of the testing space as well as the actuation mechanism and the physics behind its use. This device, when set up in the testing chamber, was used to create the tip-over simulation to allow for collection of data. Using a fill-in sheet, video and photo documentation, and recording of measured values, each unique test run was given a complete and comprehensive evaluation to ensure the best possible conclusion from those tests. These test results, and the practical knowledge that they hold, will be discussed in the following chapters.

Chapter 4: Results of Experimentation and Testing

4.1 Introduction

The following chapter in this report will act as a follow up to the proceeding chapter. The methodology chapter outlined the unique designs that were to be tested, the procedure used to obtain the desired results, and the unique roles that each group member would take in order to carry out a safe and well-recorded experiment. This chapter will highlight each of these different tests and why they were tested in the scope of this experiment. The raw data of each test will also be presented, as well as graphical depictions of each so as to allow for a visualization of the measured results. Furthermore, certain elements to note from each experiment will be pointed out, as well as a brief interpretation of what each test concluded.

4.2 Control Test of Full Gel Fuel Containers, Take 1

4.2.1 Experimentation Goals

This experimental test was completed so as to form a basis for which further tests could be compared to. In these control tests, the opened can of gel fuel was to be tested with no alterations or variables. From this, results from further testing, including changes to the gel fuel composition or the design of the burn cup can be compared and conclusions could be drawn. The first series of control tests were evaluated using a full can of gel fuel, allowing for simulation of a recently filled and ignited gel fuel cup.

4.2.2 Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date:	15-Feb-13	**Time:** 3:30 PM	**Test ID:** Control 1
Participants:	Ryan Ismirlian	......Y................	
	Joan Keyes	......Y................	
	Dan Mello	......Y................	
	James Miller	......Y................	
	Ryan Rangle	......Y................	
Pre-Ignition	**Force of Push:**	**2.97 Newtons**	
	Height of Table:	**31.5 in**	
	Weight of Opened Can	**154.5grams**	
3min Ingition	**Peak Width of Flame:**	(0.5 in	
	Base Width of Flame:	2 in	
	Height of Flame:	4.25 in	
	Flame Temperature:	624.3 C	
	Flame Color:	blue base, orange ring, yellow flame	
	Fire Sound:	gentle crackle	
Testing Results	**Min. Distance:**	*see attached sheets*	
	Max. Distance:	*see attached sheets*	
	Extinguish Time:	15:58.5	
	Remaining Weight:	88.31grams	

Figure 26: Initial Control Test Data

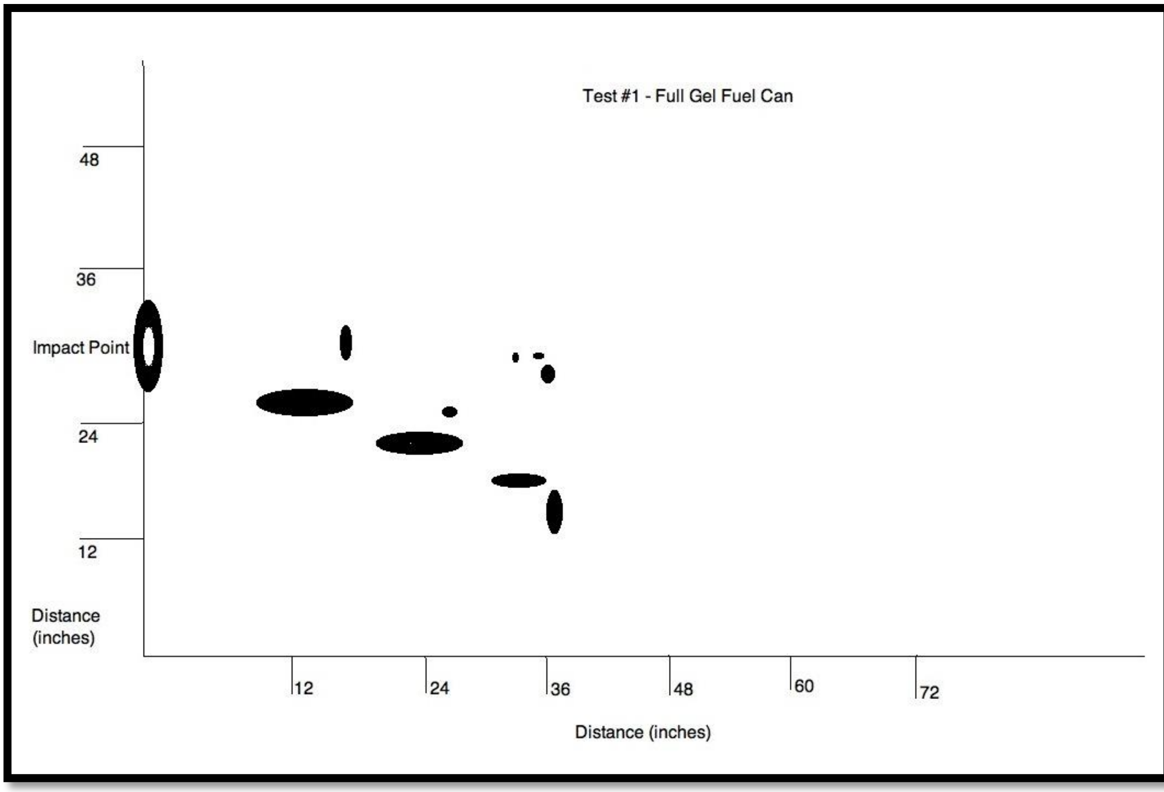


Figure 27: Resulting Spill Data for Control Test 1

4.2.3 Key Experimentation Aspects of Note

In this rendition of the experimental testing, there are several interesting points of note. As one can see from the graphical representation of the spillage, the gel fuel tended to all fall in one direction. This was due to the fact that the impact of the gel fuel can on the ground projected the gel fuel at such an angle. Most of the spilling was contained to 36 inches of the platform from which the actuation mechanism launched the gel fuel, a value far less than the given 5-9 feet range offered by the incident reports from the CPSC.

4.2.4 Interpretation of Experimental Data

From this sample of experimentation, it can be seen in Figures 27 how the simple opened gel fuel canister can lead to spillage of the gel fuel upon impact with the floor. Though the gel fuel did not spill as far as expected, this may be due to the material onto which the can was tipped. The sheetrock used on the laboratory flooring may be more cushioning than a standard floor, which may absorb much of the force of the impact of the gel fuel can. However, most of the gel fuel spilled out of the can upon impact, and there were several large puddles of the burning gel fuel that burned for a notable duration. In the case of a real spill over of gel fuel, an unattended firepot could result in serious damage due to the large amounts of gel fuel that were ignited.

4.3 Control Test of Full Gel Fuel Containers, Take 2

4.3.1 Experimentation Goals

This experimental test was completed so as to form a basis for which further tests could be compared to. In these control tests, the opened can of gel fuel was to be tested will no alterations or variables. From this, results from further testing including changes to the gel fuel makeup or the design of the burn cup could be compared and conclusions could be drawn. This first series of control tests were evaluated using a full can of gel fuel, allowing for simulation of a recently filled and ignited gel fuel cup.

4.3.2 Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date:	21-Feb-13	**Time:** 3:15 PM	**Test ID:** Control 2
Participants:	Ryan Ismirlian	......Y...............	
	Joan Keyes	......Y...............	
	Dan Mello	......Y...............	
	James Miller	..............N........	
	Ryan Rangle	......Y...............	
Pre-Ignition	**Force of Push:**	**2.97 Newtons**	
	Height of Table:	**31.5 in**	
	Weight of Opened Can	**153.2grams**	
3min Ingition	**Peak Width of Flame:**	0.5 in	
	Base Width of Flame:	2 in	
	Height of Flame:	3.5 in	
	Flame Temperature:	677.6 C	
	Flame Color:	blue base, orange ring, yellow flame	
	Fire Sound:	gentle crackle	
Testing Results	**Min. Distance:**	*see attached sheets*	
	Max. Distance:	*see attached sheets*	
	Extinguish Time:	19:49.8	
	Remaining Weight:	73.99grams	

Figure 28: Control Test 2 Data

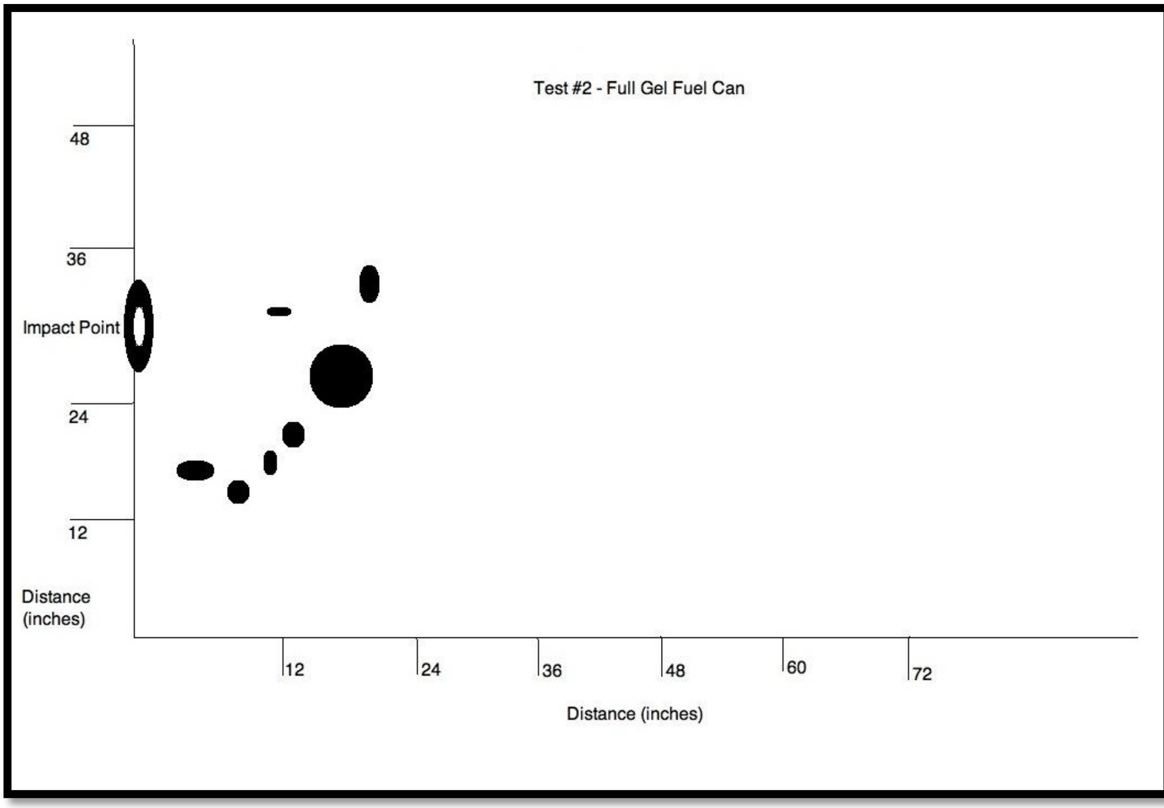


Figure 29: Resulting Spill Data for Control Test 2

4.3.3 Key Experimentation Aspects of Note

In this rendition of the experimental testing, the gel fuel again did not spill very far from the actuation mechanism where the gel fuel was to be launched from. This was due to the manner of the falling gel fuel container. The burn cup spun in the air as it was falling, and landed with the open face of the burn cup facing the initial site. This meant that the gel fuel was projected back from the final landing spot of the burn cup, about 20-21 inches from the impact point. Due to the lack of distance of the burn cup's travel, the spilling was contained to a small area, yet as in the first experimentation run most all of the gel fuel was spilled and subsequently burned up.

4.3.4 Interpretation of Experimental Data

From this sample of experiment, it can be seen in Figure 29 how the simple opened gel fuel canister can lead to spillage of the gel fuel upon impact with the floor. Though the gel fuel did not spill as far as expected, this may be due to the material onto which the can was tipped. The sheetrock used on the laboratory flooring may be more yielding than a standard floor, thereby absorbing much of the force of the impact of the gel fuel can. However, most of the gel fuel spilled out of the can upon impact, and there were several large puddles of the burning gel fuel that burned for a notable duration. Furthermore, the gel fuel spilled backwards towards the impact point, which could lead to potential danger to the user of a firepot in the case that the individual accidently spilled the substance which in turn poured towards them. In the case of a real spill over of gel fuel, an unattended firepot could result in serious damage due to the large amount of gel fuel that was ignited.

4.4 Control Test of Full Gel Fuel Containers, Take 3

4.4.1 Experimentation Goals

This experimental test was completed so as to form a basis for which further tests could be compared to. In these control tests, the opened can of gel fuel was to be tested will no alterations or variables. From this, results from further testing including changes to the gel fuel makeup or the design of the burn cup could be compared and conclusions could be drawn. This first series of control tests were evaluated using a full can of gel fuel, allowing for simulation of a recently filled and ignited gel fuel cup.

4.4.2 Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date:	21-Feb-13	**Time:** 3:30 PM	**Test ID:** Control 3
Participants:	Ryan Ismirlian	......Y.................	
	Joan Keyes	......Y.................	
	Dan Mello	......Y.................	
	James Miller	..............N........	
	Ryan Rangle	......Y.................	
Pre-Ignition	**Force of Push:**	**2.97 Newtons**	
	Height of Table:	**31.5 in**	
	Weight of Opened Can	**154.05grams**	
3min Ingition	**Peak Width of Flame:**	(0.5 in	
	Base Width of Flame:	2 in	
	Height of Flame:	4 in	
	Flame Temperature:	610.03 C	
	Flame Color:	blue base, orange ring, yellow flame	
	Fire Sound:	gentle crackle	
Testing Results	**Min. Distance:**	*see attached sheets*	
	Max. Distance:	*see attached sheets*	
	Extinguish Time:	19:30.8	
	Remaining Weight:	73.10grams	

Figure 30: Control Test 3 Data

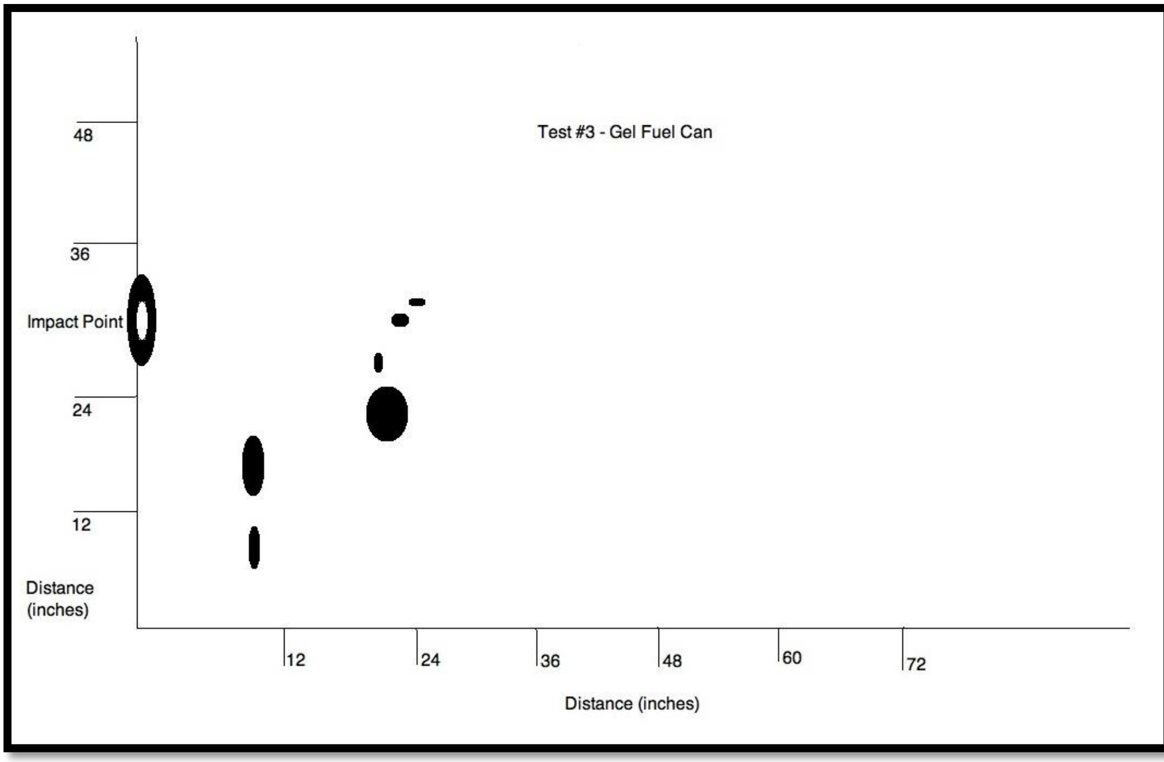


Figure 31: Resulting Spill Data for Control Test 3

4.4.3 Key Experimentation Aspects of Note

In this individual testing, there was not a very large area of spillage that occurred when the actuation mechanism was used to tip over the gel fuel. Most of the gel fuel was confined an area from the impact point of about 24 inches, and occurred mostly in two large sections. The burn cup spun in the air as it was falling, and landed with the open face of the burn cup facing the initial site. This meant that the gel fuel was projected back from the final landing spot of the burn cup. However, much of the gel fuel was spilled out of the burn cup, resulting in a very intense and long lasting flame where the gel burned.

4.4.4 Interpretation of Experimental Data

From this sample of experimentation, it can be seen in Figure 31 how the simple opened gel fuel canister can lead to spillage of the gel fuel upon impact with the floor. Though the gel fuel did not spill as far as expected, this may be due to the material onto which the can was tipped. However, most of the gel fuel spilled out of the can upon impact, and there were several large puddles of the burning gel fuel that burned for a notable duration. Furthermore, the gel fuel spilled backwards towards the impact point, which could lead to potential danger to the user of a firepot in the case that the individual accidently spilled the substance which in turn poured towards them. In the case of a real spillover of gel fuel, an unattended firepot could result in serious damage due to the large amount of gel fuel that was ignited.

4.5 Control Test of Half-Full Gel Fuel Containers, Take 1

This portion of the experimental procedure was designed so as to allow for testing of a gel fuel can that has been in use for some period of time and is accidently spilled over. As in the previous testing, the gel fuel can is to be tested using no alterations to the gel fuel compound itself, as well as to the burn cup the gel is housed in. This test will be conducted as a level basis to see if proportional quantities of gel fuel are expelled from the canister upon impact as when there is the full amount of gel fuel in the initial control test.

4.5.1 Experimentation Goals

The goal of this experimentation is to see how the unaltered gel fuel reacts when the half full can is tipped over and spilled to the ground. This is to simulate a more realistic usage of the gel fuel, and can offer data pointing towards the need for new designs to the gel fuel canister. These results can be compared to those of modified gel fuels and the accompanying burn cups, allowing for proper conclusions on the safety of these products and the feasibility of new iterations.

4.5.2 Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date:	21-Feb-13	**Time:** 4:00 PM	**Test ID:** Control 4
Participants:	Ryan Ismirlian	......Y................	
	Joan Keyes	......Y................	
	Dan Mello	......Y................	
	James Miller	..............N........	
	Ryan Rangle	......Y................	
Pre-Ignition	**Force of Push:**	**2.97 Newtons**	
	Height of Table:	**31.5 in**	
	Weight of Opened Can	**80.39grams**	
3min Ingition	**Peak Width of Flame:**	0.25 in	
	Base Width of Flame:	2 in	
	Height of Flame:	5.5 in	
	Flame Temperature:	595.0 C	
	Flame Color:	blue base, orange ring, yellow flame	
	Fire Sound:	light crackle, periodic loud cracks	
Testing Results	**Min. Distance:**	*see attached sheets*	
	Max. Distance:	*see attached sheets*	
	Extinguish Time:	N/A (self-extinguished)	
	Remaining Weight:	63.71grams	

Figure 32: Control Test 4 Data

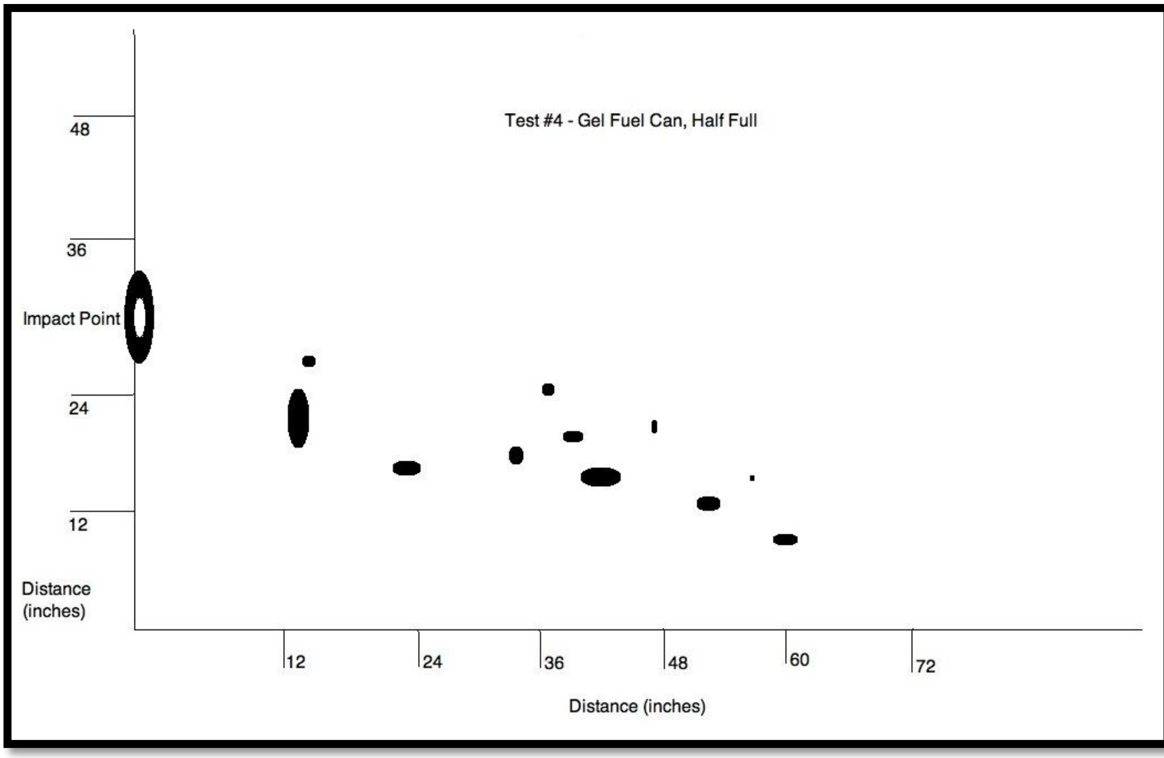


Figure 33: Resulting Spill Data for Control Test 4

4.5.3 Key Experimentation Aspects of Note

In this experiment, the first test using half of the gel fuel can produced a series smaller spots, yet managed to propel the gel fuel a much further distance. The gel can landed about an equal distance away from the platform after launch, despite the fact that the same force was being applied to a lighter object. As noted on the FRED sheet in Figure 32, the remaining weight of the gel fuel can was less, as more of the gel fuel flew from the can. More importantly of note, the gel fuel reached a distance of over 60 inches, or 5 feet away from the impact point.

4.5.4 Interpretation of Experimental Data

From this sample of experimentation, it can be seen in Figure 33 how the half-filled gel fuel container can be just as dangerous as gel fuel canister with a full load of fuel. Perhaps this is due to the gel fuel being able to build up a higher momentum due to the impact, as an effect of the lighter weight of the gel fuel can. In summary, such a test proves that even minimal amounts of the alcohol-based gel fuels requires the further care and safety features outlined to potentially make for a safer product.

4.6 Control Test of Half-Full Gel Fuel Containers, Take 2

4.6.1 Experimentation Goals

This portion of the experimental procedure was designed so as to allow for testing of a gel fuel can that has been in use for some period of time and is accidently spilled over. As in the previous testing, the gel fuel can is to be tested using no alterations to the gel fuel compound itself, as well as to the burn cup the gel is housed in. This test will be conducted as a level basis to see if proportional quantities of gel fuel are expelled from the canister upon impact as when there is the full amount of gel fuel in the initial control test.

4.6.2 Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date:	21-Feb-13	**Time:** 4:00 PM	**Test ID:** Control 5
Participants:	Ryan Ismirlian	......Y...............	
	Joan Keyes	......Y...............	
	Dan Mello	......Y...............	
	James Miller	.............N........	
	Ryan Rangle	......Y...............	
Pre-Ignition	**Force of Push:**	**2.97 Newtons**	
	Height of Table:	**31.5 in**	
	Weight of Opened Can	**81.06grams**	
3min Ingition	**Peak Width of Flame:**	0.25 in	
	Base Width of Flame:	2 in	
	Height of Flame:	5 in	
	Flame Temperature:	629.0 C	
	Flame Color:	blue base, orange portions, yellow top	
	Fire Sound:	slightly crackling	
Testing Results	**Min. Distance:**	*see attached sheets*	
	Max. Distance:	*see attached sheets*	
	Extinguish Time:	07:47.5	
	Remaining Weight:	51.68grams	

Figure 34: Control Test 5 Data

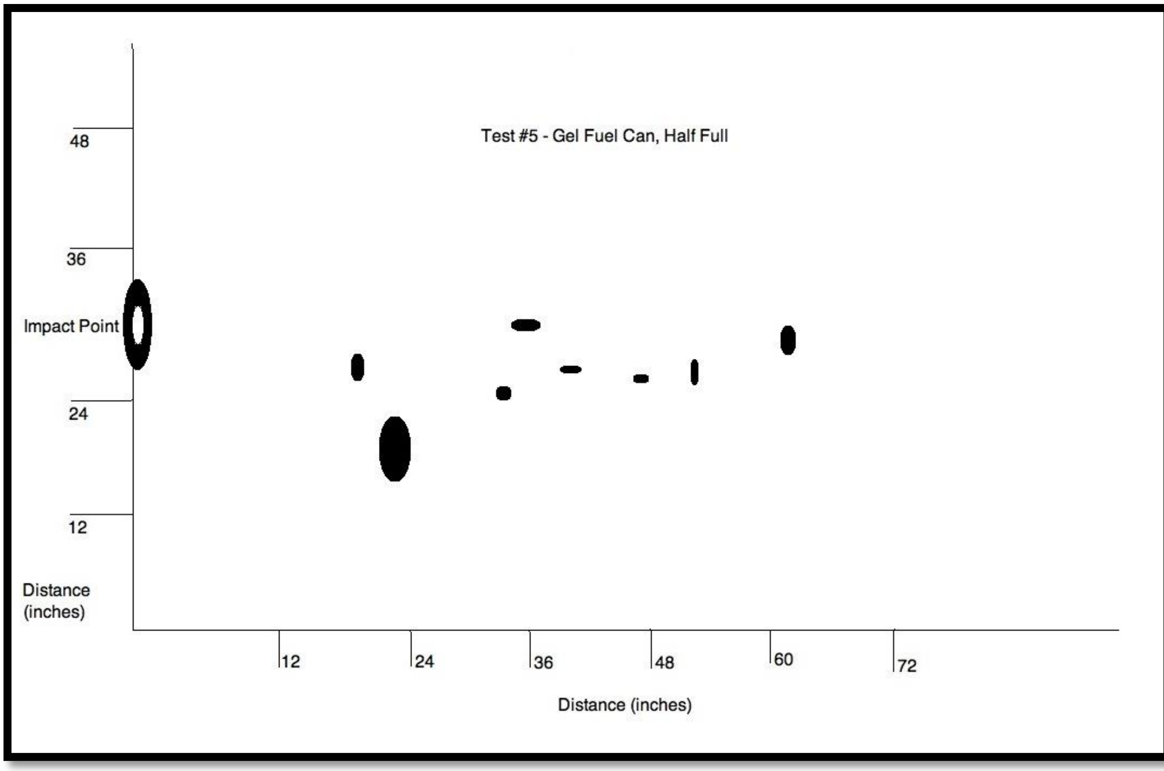


Figure 35: Resulting Spill Data for Control Test 5

4.6.3 Key Experimentation Aspects of Note

In this experimentation, the half-filled gel fuel container spilled a good chunk of the gel into the testing area. The can itself impacted about 17.5 inches away from the actuation mechanism, and the gel fuel spilled up to an additional 5 feet away from the actuation mechanism. The gel also spilled sporadically, with individual splotches that were ignited upon release from the container. These individual patches did not stay lit for long periods of time, as seen by the total time for extinguishing of 7 minutes and 48 seconds in Figure 34. However, these areas of spilled gel fuel all were ignited for varying amounts of time, and could burn further upon igniting another flame source.

4.6.4 Interpretation of Experimental Data

From this experimentation, it can be seen in Figure 35 how the control testing with even half of the gel fuel can has the potential to lead to a dangerous spillage, even without the quantity of gel that is contained within a full gel fuel canister. Even with less gel fuel present, the spillage created by the actuation mechanism created an even further spill. This could lead to a much more potentially dangerous situation in that there is a larger radius of spill area. In summary, such a test proves that even minimal amounts of the alcohol-based gel fuels requires the further care and safety features outlined to potentially make for a safer product.

4.7 Control Test of Half-Full Gel Fuel Containers, Take 3

4.7.1 Experimentation Goals

The goal of this experimentation is to see how the unaltered gel fuel reacts when the half full can is tipped over and spilled to the ground. This is to simulate a more realistic usage of the gel fuel, and can offer data pointing towards the need for new designs to the gel fuel canister. These results can be compared to those of modified gel fuels and the accompanying burn cups, allowing for proper conclusions on the safety of these products and the feasibility of new iterations.

4.7.2 Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date:	21-Feb-13	**Time:** 4:30 PM	**Test ID:** Control 5
Participants:	Ryan Ismirlian	......Y...............	
	Joan Keyes	......Y...............	
	Dan Mello	......Y...............	
	James Miller	..............N........	
	Ryan Rangle	......Y...............	
Pre-Ignition	**Force of Push:**	**2.97 Newtons**	
	Height of Table:	**31.5 in**	
	Weight of Opened Can	**80.70grams**	
3min Ingition	**Peak Width of Flame:**	0.5 in	
	Base Width of Flame:	2 in	
	Height of Flame:	5.5 in	
	Flame Temperature:	605.4 C	
	Flame Color:	blue base, orange layers, yellow top	
	Fire Sound:	slightly crackling	
Testing Results	**Min. Distance:**	*see attached sheets*	
	Max. Distance:	*see attached sheets*	
	Extinguish Time:	09:17.0	
	Remaining Weight:	49.5grams	

Figure 36: Control Test 6 Data

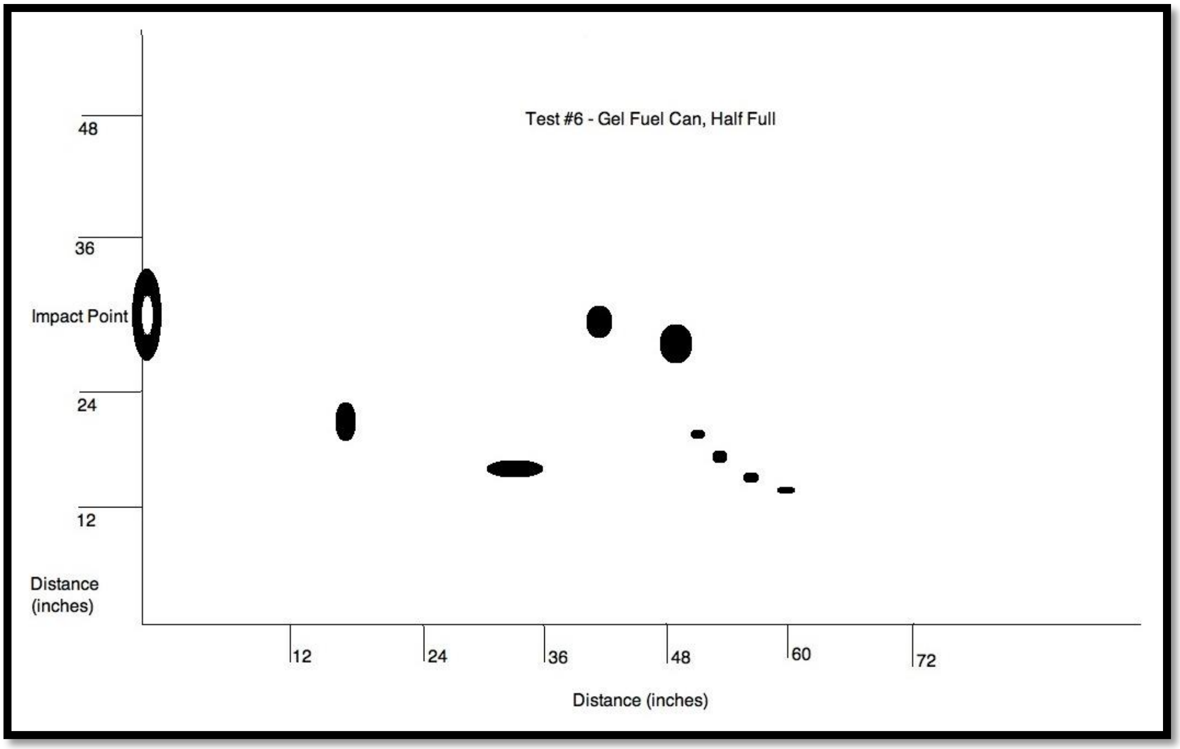


Figure 37: Resulting Spill Data for Control Test 6

4.7.3 Key Experimentation Aspects of Note

In this experimentation, the half-filled gel fuel container spilled the majority of the gel into the testing area. The can itself impacted about 15 inches away from the actuation mechanism, and the gel fuel spilled over an additional 5 feet away from the actuation mechanism. The gel also spilled sporadically, with individual splotches that were ignited upon release from the container. These individual patches did not stay lit for long periods of time, as seen by the total time for extinguishing of 9 minutes and 17 seconds, shown in Figure 36. However, these areas of spilled gel fuel all were ignited for varying amounts of time, and could burn further upon igniting another flame source. Furthermore, there was a short series of additional specks of gel fuel, which all impacted the ground while ignited; only taking several minutes to extinguish.

4.7.4 Interpretation of Experimental Data

From this experimentation, it can be seen in Figure 37 how the control testing with even half of the gel fuel can has the potential to lead to a dangerous spillage, even without the quantity of gel that is contained within a full gel fuel canister. Even with less gel fuel present, the spillage created by the actuation mechanism created an even further spill. This could lead to a much more potentially dangerous situation in that there is a larger radius of spill area. In summary, such a test proves that even minimal amounts of the alcohol-based gel fuels requires the further care and safety features outlined to potentially make for a safer product.

4.8 Test of Meshing Covered Full Gel Fuel Containers, Take 1

4.8.1 Experimentation Goals

These series of tests in this experimental procedure are aimed towards the implementation of a layer of meshing over the top of the gel fuel can in order to create a more sealed and safer product. This meshing, made of an 18 gage standard spacing stainless steel mesh, will be tested to see if it can properly act as an inhibitor of the flow of gel fuel in the case of a tip over of the firepot or the ignited flame source. These modified gel fuel containers, with the meshing welded near the top of the cup, will be tested by use of the actuation mechanism as in the case of the previous full and half-full control tests.

4.8.2 Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date: 22 March 2013 **Time: 12:00pm** **Test ID: Mesh 1**

Participants:

	Ryan Ismirlian	......Y................
	Joan Keyes	......Y................
	Dan Mello	......Y................
	James Miller	......Y................
	Ryan Rangle	......Y................

Pre-Ignition

Force of Push: 297 Newtons

Height of Table: 31.5 in

Weight of Opened Can: 155.2g

3min Ingition

Peak Width of Flame: .25 in

Base Width of Flame: 2 in

Height of Flame: 4.25 in

Flame Tempera 615.3 C

Flame Color: blue base, orange ring, yellow peak

Fire Sound: slight crackle

Testing Results

Min. Distance: 14 in

Max. Distance: 25 in

Extinguish Time: 4:19.6

Remaining Weight: 96.5 grams

Figure 38: Floating Mesh Test 1 Data

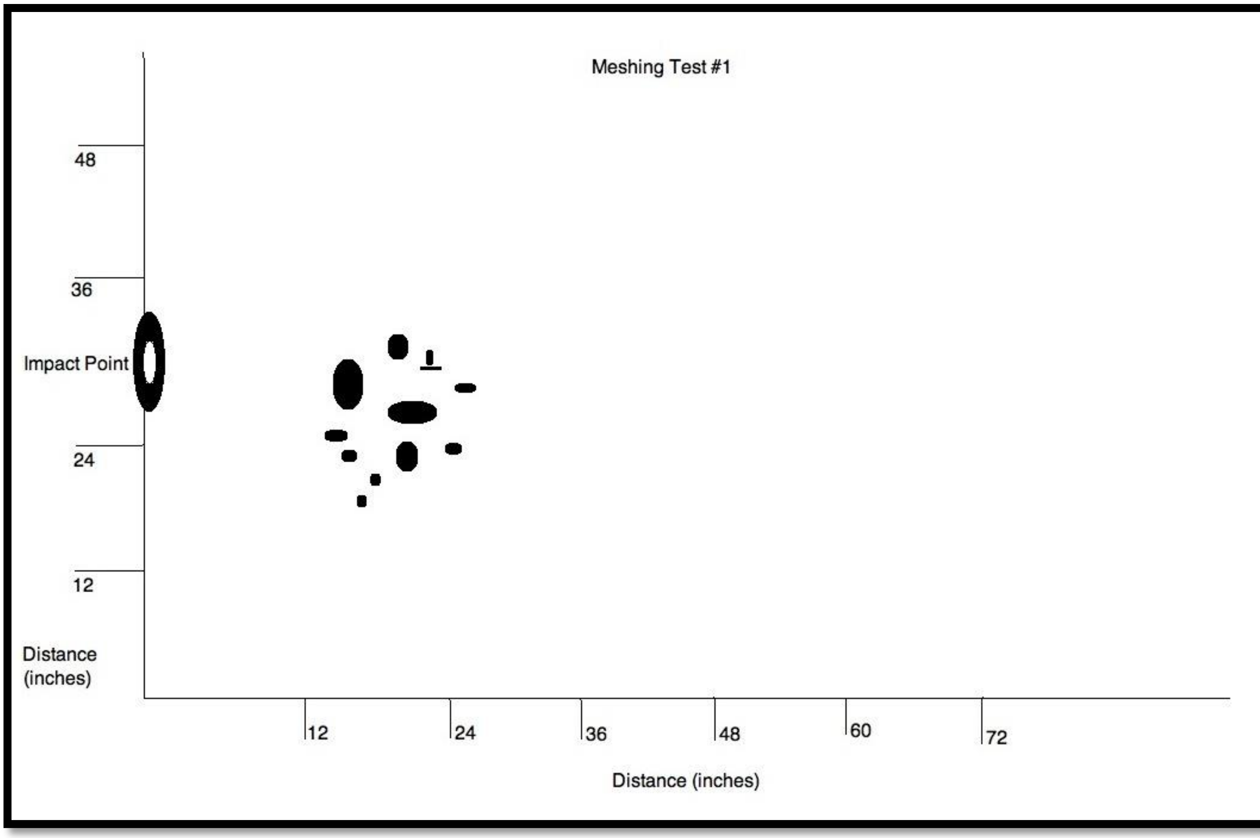


Figure 39: Resulting Spill Data for Floating Mesh Test 1

4.8.3 Key Experimentation Aspects of Note

In this experimentation, it can be seen how the addition of a layer of stainless steel meshing worked to truly prohibit the flow of the gel fuel out of the canister upon impact of the floor. The area of spillage was held mostly to a 12-14 inch radius, with very few spots large enough to burn for a considerable time. This was evidenced by the total burn time of only 4 minutes and 20 seconds, as seen in Figure 38, a drastically reduced time from that of the initial control tests. It is to be noted that there are many smaller gel fuel patches, yet not all of these spots were even ignited at the point of contact with the floor, and did not subsequently catch fire. Furthermore, a much higher majority of the gel fuel remained within the can, with the gel fuel can with the meshing layer weighing in at 96.5 grams.

4.8.4 Interpretation of Experimental Data

As shown by the results of this trial in Figure 39, the stainless steel meshing layer greatly reduced the overall danger of the product by reducing the amount of gel fuel that spilled from the canister. Because of this, the smaller patches of gel fuel were not able to travel as far, or even remain lit for an equal duration. Though a portion of gel fuel was still able to escape from the burn cup upon impact with the floor, the significant increase in laboratory performance provided proof of the potential for a much safer product.

4.9 Test of Meshing Covered Full Gel Fuel Containers, Take 2

4.9.1 Experimentation Goals

These series of tests in this experimental procedure are aimed towards the implementation of a layer of meshing over the top of the gel fuel can in order to create a more sealed and safer product. This meshing, made of an 18 gage standard spacing stainless steel mesh, will be tested to see if it can properly act as an inhibitor of the flow of gel fuel in the case of a tip over of the firepot or the ignited flame source. These modified gel fuel containers, with the meshing welded near the top of the cup, will be tested by use of the actuation mechanism as in the case of the previous full and half-full control tests.

4.9.2 Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date: 22 March 2013	**Time: 12:20pm**	**Test ID: Mesh 2**

Participants:

Ryan Ismirlian	……Y……………
Joan Keyes	……Y……………
Dan Mello	……Y……………
James Miller	……Y……………
Ryan Rangle	……Y……………

Pre-Ignition

Force of Push: 297 Newtons

Height of Table: 31.5 in

Weight of Open 157.0 g

3min Ingition

Peak Width of Flame: .25 in

Base Width of Flame: 2 in

Height of Flame: 4.75 in

Flame Tempera 605.5 C

Flame Color: blue base, orange ring, yellow peak

Fire Sound: slight crackle

Testing Results

Min. Distance: 12.5 in

Max. Distance: 28 in

Extinguish Time: 5:49.9

Remaining Weight: 102.6 grams

Figure 40: Floating Mesh Test 2 Data

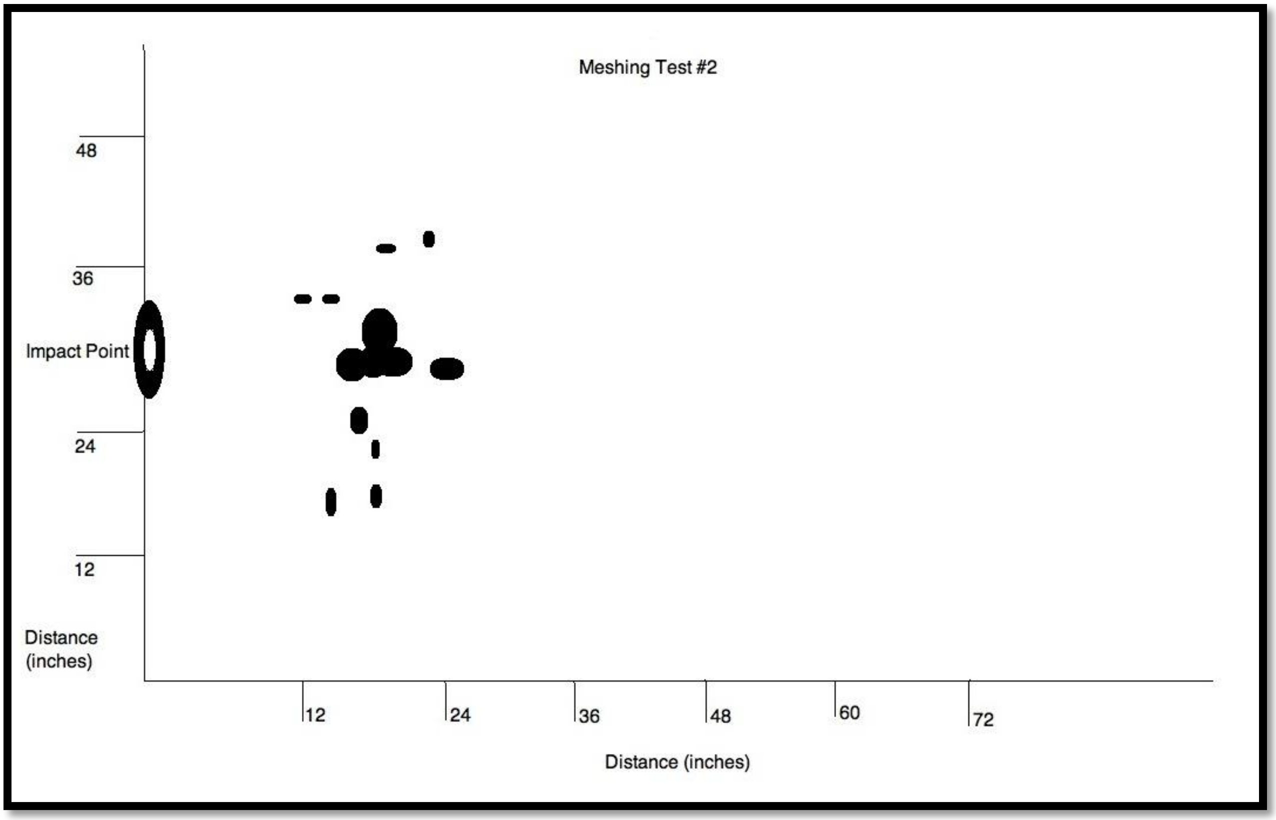


Figure 41: Resulting Spill Data for Floating Mesh Test 2

4.9.3 Key Experimentation Aspects of Note

In this experiment, it can be seen how the addition of a layer of stainless steel meshing worked to truly prohibit the flow of the gel fuel out of the canister upon impact of the floor. The area of spillage was held mostly to a 12-18 inch radius, with very few spots large enough to burn for a considerable time. This was evidenced by the total burn time of only 5 minutes and 50 seconds as shown in Figure 40, a drastically reduced time from that of the initial control tests. It is to be noted that there are many smaller gel fuel patches, yet not all of these spots were even ignited at the point of contact with the floor, and did not subsequently catch fire. Furthermore, a much higher majority of the gel fuel remained within the can, with the gel fuel can with the meshing layer weighing in at 102.6 grams.

4.9.4 Interpretation of Experimental Data

As shown by the results of this trial in Figure 41, the stainless steel meshing layer greatly reduced the overall danger of the product by reducing the amount of gel fuel that spilled from the canister. Because of this, the smaller patches of gel fuel were not able to travel as far, or even remain lit for an equal duration. Though a portion of gel fuel was still able to escape from the burn cup upon impact with the floor, the significant increase in laboratory performance provided proof of the potential for a much safer product.

4.10 Test of Meshing Covered Full Gel Fuel Containers, Take 3

4.10.1 Experimentation Goals

These series of tests in this experimental procedure are aimed towards the implementation of a layer of meshing over the top of the gel fuel can in order to create a more sealed and safer product. This meshing, made of an 18 gage standard spacing stainless steel mesh, will be tested to see if it can properly act as an inhibitor of the flow of gel fuel in the case of a tip over of the firepot or the ignited flame source. These modified gel fuel containers, with the meshing welded near the top of the cup, will be tested by use of the actuation mechanism as in the case of the previous full and half-full control tests.

4.10.2 Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date: 22 March 2013 **Time: 12:45pm** **Test ID: Mesh 3**

Participants:

Ryan Ismirlian ......Y...............
Joan Keyes ......Y...............
Dan Mello ......Y...............
James Miller ......Y...............
Ryan Rangle ......Y...............

Pre-Ignition

Force of Push: 297 Newtons

Height of Table: 31.5 in

Weight of Open 153.3 g

3min Ingition

Peak Width of Flame: 0.25 in

Base Width of Flame: 2 in

Height of Flame: 4 in

Flame Tempera 589.4 C

Flame Color: blue base, orange ring, yellow peak

Fire Sound: slight crackle

Testing Results

Min. Distance: 12 in

Max. Distance: 30.5 in

Extinguish Time: 4:40.3

Remaining Weight: 92.1 grams

Figure 42: Floating Mesh Test 3 Data

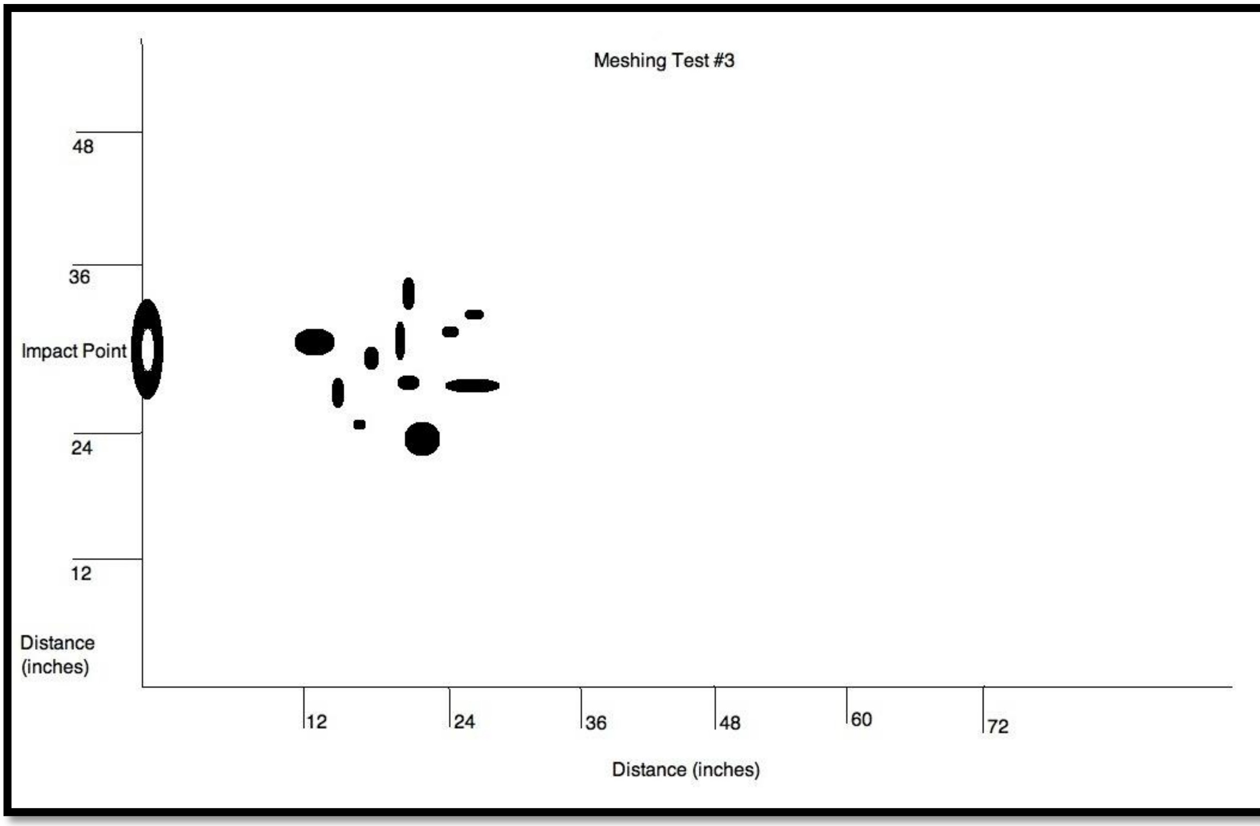


Figure 43: Resulting Spill Data for Floating Mesh Test 3

4.10.3 Key Experimentation Aspects of Note

In this experiment, it can be seen how the addition of a layer of stainless steel meshing worked to truly prohibit the flow of the gel fuel out of the canister upon impact of the floor. The area of spillage was held mostly to a 14-16 inch radius, with very few spots large enough to burn for a considerable time. This was evidenced by the total burn time of only 4 minutes and 40 seconds as shown in Figure 42, a drastically reduced time from that of the initial control tests. It is to be noted that there are many smaller gel fuel patches, yet not all of these spots were even ignited at the point of contact with the floor, and did not subsequently catch fire. Furthermore, a much higher majority of the gel fuel remained within the can, with the gel fuel can with the meshing layer weighing in at 92.1 grams.

4.10.4: Interpretation of Experimental Data

As shown by the results of this trial in Figure 43, the stainless steel meshing layer greatly reduced the overall danger of the product by reducing the amount of gel fuel that spilled from the canister. Because of this, the smaller patches of gel fuel were not able to travel as far, or even remain lit for an equal duration. Though a portion of gel fuel was still able to escape from the burn cup upon impact with the floor, this significant increase in laboratory performance proves that there is the potential for a much safer product.

4.11 Test of Full Lipped Gel Fuel Containers, Take 1

4.11.1 Experimentation Goals

The goal of this series of experimental testing was to establish the possibility of a new mechanical design to the single-use gel fuel canisters as a feature to increase the safety of the product. Using a steel ring, the lip of the canister will be augmented with the welding on of such a product to allow for a decrease in the overall area of opening on the top of the gel fuel container. This is to be experimented in the hopes that the decreased area opening will inhibit the flow of the gel fuel in the burn cup in the case of a spill or tip over. These tests will be conducted in the same fashion as the controls and differing variables tests.

4.11.2: Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date: 15 April 2013 | **Time: 2:45pm** | **Test ID: Lip Test 1**

Participants:	Ryan Ismirlian	......**Y**...............
	Joan Keyes	...............**N**......
	Dan Mello	......**Y**...............
	James Miller	......**Y**...............
	Ryan Rangle	...............**N**......

Pre-Ignition

Force of Push: 2.97 Newtons

Height of Table: 31.5 in

Weight of Opened Can: 154.5 grams

3min Ingition

Peak Width of Flame: 0.25 in

Base Width of Flame: 1.25 in

Height of Flame: 3.5 in

Flame Temperature: 582.1 C

Flame Color: blue base, orange flames, yellow tip

Fire Sound: slight crackle

Testing Results

Min. Distance: 11.5 in

Max. Distance: 62.25 in

Extinguish Time: 9:28.4

Remaining Weight: 79.14g

Figure 44: Lip Test 1 Data

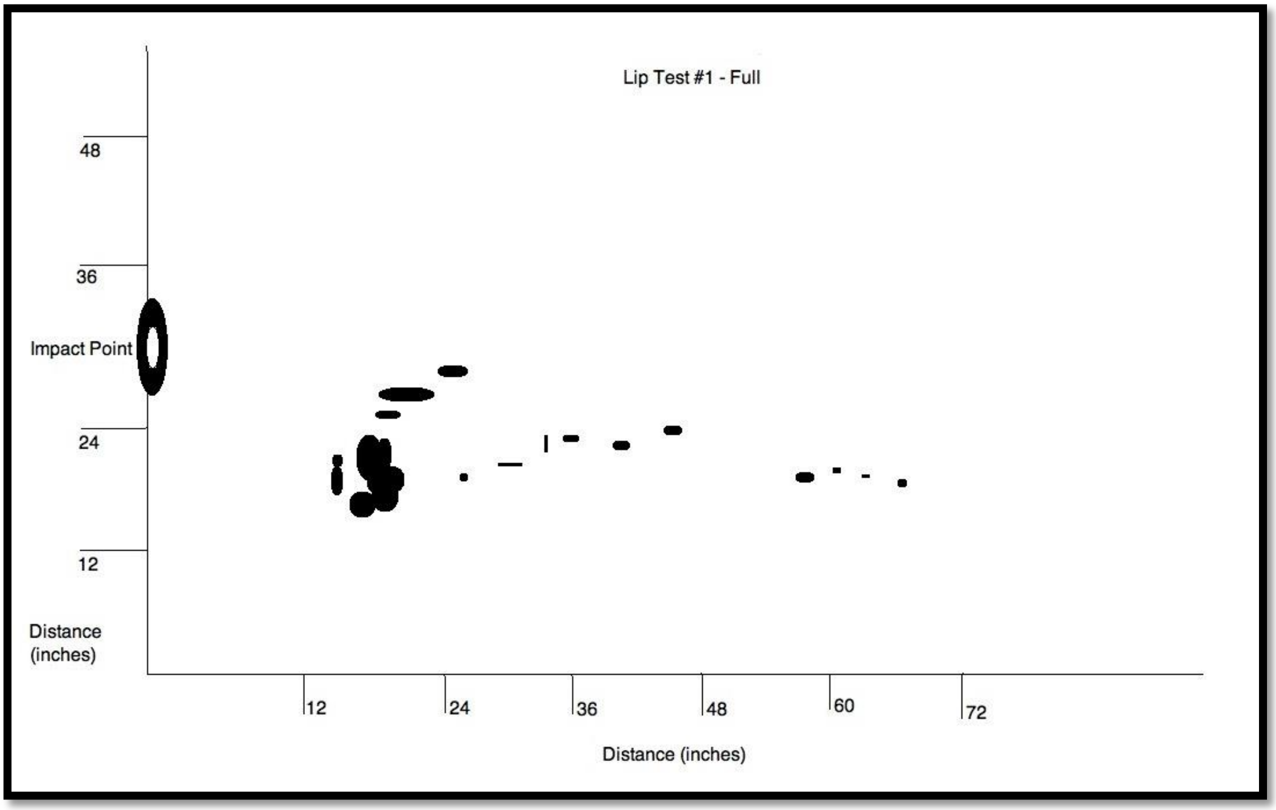


Figure 45: Resulting Spill Data for Lip Test 1

4.11.3 Key Experimentation Aspects of Note

This experimental testing showed the extent to which the gel fuel can spill. In this rendition of experimentation, the gel fuel canister landed a little over a foot away from the actuation mechanism. As seen in the Figure 45, all of the gel fuel spilled forward from this point of impact with the ground. As such, the gel fuel spilled forward forcefully, in distances up to 66-68 inches. Though this was only a minimal amount of gel fuel, many of these small speckles were still ignited and remained so for several minutes. The majority of the gel fuel, however, remained within a 12 inch radius or so of the impact location on the ground.

4.11.4 Interpretation of Experimental Data

This trial of the experiment clearly shows how the gel fuel can be just as dangerous with the addition of the stainless steel lip around the edge of the canister. In concert with the impact on the floor at a straight-forward angle, the lip actually acted as a nozzle which only worked to direct the gel fuel straighter and further. This experiment resulted in the furthest spreading of the gel fuel yet, as shown in Figure 5, though most of the spillage was contained to a small area around the initial impact point on the ground. This test shows that even with a safety modification, the gel fuels can still be a dangerous material.

4.12 Test of Full Lipped Gel Fuel Containers, Take 2

4.12.1 Experimentation Goals

The goal of this series of experimental testing was to establish the possibility of a new mechanical design to the single-use gel fuel canisters as a feature to increase the safety of the product. Using a steel ring, the lip of the canister will be augmented with the welding on of such a product to allow for a decrease in the overall area of opening on the top of the gel fuel container. This is to be experimented in the hopes that the decreased area opening will inhibit the flow of the gel fuel in the burn cup in the case of a spill or tip over. These tests will be conducted in the same fashion as the controls and differing variables tests.

4.12.2 Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date: 15 April 2013 **Time: 2:45pm** **Test ID: Lip Test 2**

Participants:

Ryan Ismirlian ......Y...............
Joan Keyes ....N......
Dan Mello ......Y...............
James Miller ......Y...............
Ryan Rangle ....N......

Pre-Ignition

Force of Push: 2.97 Newtons

Height of Table: 31.5 in

Weight of Opened Can: 153.8 grams

3min Ingition

Peak Width of Flame: 0.25 in

Base Width of Flame: 1.5 in

Height of Flame: 4 in

Flame Temperature: 602.1 C

Flame Color: blue base, orange flames, yellow tip

Fire Sound: slight crackle

Testing Results

Min. Distance: 10 in

Max. Distance: 49 in

Extinguish Time: 11:13.7

Remaining Weight: 80.46g

Figure 46: Lip Test 2 Data

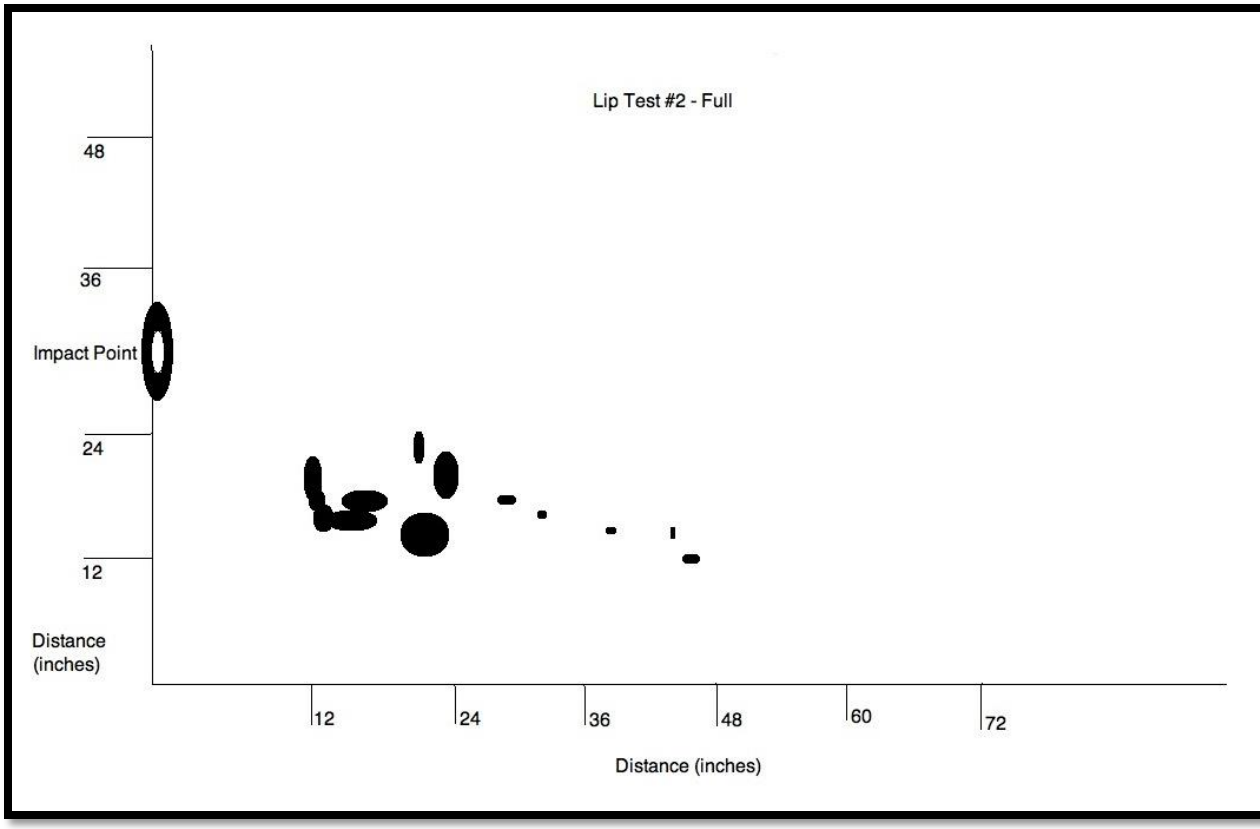


Figure 47: Resulting Spill Data for Lip Test 2

4.12.3 Key Experimentation Aspects of Note

This experimentation rendition of the lipped gel fuel container saw considerable improvement over the previous test. The gel fuel can landed a similar distance from the actuation mechanism, about 12 inches away. Also, much of the gel spill was located in a foot radius around this impact point, as depicted in Figure 47. However, the trail of smaller patches of gel was noticeably smaller, with a maximum distance of 49 inches recorded. Important to note, however, is that large amounts of gel fuel spilled within this initial impact area, again spilling over half its contents onto the floor upon first impact.

4.12.4 Interpretation of Experimental Data

This trial of the experiment clearly shows how the gel fuel can be just as dangerous with the addition of the stainless steel lip around the edge of the canister. Even with a relatively smooth impact onto the floor upon tipping, the lip ring actually acted as a nozzle which only worked to direct the gel fuel straighter and further. This experiment resulted in a large distance being covered by the flying gel fuel, though most of the spillage was contained to a small area around the initial impact point on the ground, as noted in Figure 46. This test shows that even with a safety modification, the gel fuels can still be a dangerous material.

4.13 Test of Half-Full Lipped Gel Fuel Containers, Take 1

4.13.1 Experimentation Goals

The goal of this series of experimental testing was to establish the possibility of a new mechanical design to the single-use gel fuel canisters as a feature to increase the safety of the product. Using a steel ring, the lip of the canister will be augmented with the welding on of such a product to allow for a decrease in the overall area of opening on the top of the gel fuel container. This is to be experimented in the hopes that the decreased area opening will inhibit the flow of the gel fuel in the burn cup in the case of a spill or tip over. These tests will be conducted in the same fashion as the controls and differing variables tests.

4.13.2 Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date: 15 April 2013 **Time: 3:20pm** **Test ID: Lip Test 3**

Participants:	Ryan Ismirlian	……Y……………
	Joan Keyes	……………N……
	Dan Mello	……Y……………
	James Miller	……Y……………
	Ryan Rangle	……………N……

Pre-Ignition **Force of Push: 2.97 Newtons**

Height of Table: 31.5 in

Weight of Opened Can: 70.4 grams

3min Ingition **Peak Width of Flame: 0.25 in**

Base Width of Flame: 1.2 in

Height of Flame: 3.5 in

Flame Temperature: 598.4 C

Flame Color: blue base, orange flames, yellow tip

Fire Sound: slight crackle

Testing Results **Min. Distance: 1.5 in**

Max. Distance: 26 in

Extinguish Time: 6:17.0

Remaining Weight: 39.46g

Figure 48: Lip Test 3 Data

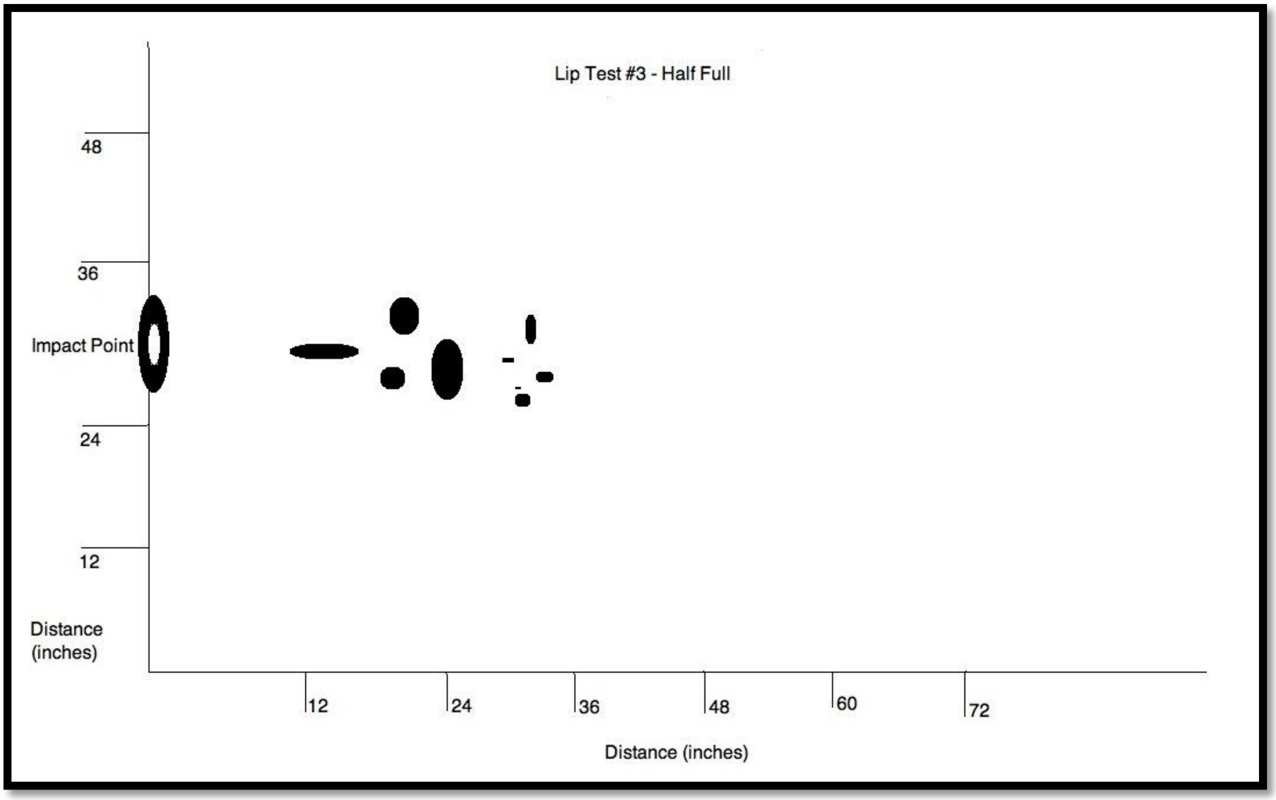


Figure 49: Resulting Spill Data for Lip Test 3

4.13.3 Key Experimentation Aspects of Note

In this half-full trial, it could be seen how the addition of the stainless steel lip helped to minimalize the overall area of burning due to the spill. As can be seen in Figure 49, the gel fuel was contained in an area 12-36 inches from the launch point. However, within this area, the canister still spilled a large quantity of gel fuel that burned for some time. This test resulted in the spillage of about 30 grams of gel fuel, as noted in Figure 48.

4.13.4 Interpretation of Experimental Data

Unlike the previous two experimentations, this trial resulted in a much better outcome for the altered gel fuel container. With only a half full gel fuel container, the spillage of 30g of the gel was a significant reduction from previous tests and was contained to a much smaller area.

Though not a perfect solution to the proposed problem, this is no doubt a vast improvement over the control test involving the use of the half full canisters.

4.14 Test of Half-Full Lipped Gel Fuel Containers, Take 2

4.14.1 Experimentation Goals

The goal of this series of experimental testing was to establish the possibility of a new mechanical design to the single-use gel fuel canisters as a feature to increase the safety of the product. Using a steel ring, the lip of the canister will be augmented with the welding on of such a product to allow for a decrease in the overall area of opening on the top of the gel fuel container. This is to be experimented in the hopes that the decreased area opening will inhibit the flow of the gel fuel in the burn cup in the case of a spill or tip over. These tests will be conducted in the same fashion as the controls and differing variables tests.

4.14.2 Charted / Graphical Results of Experimentation

Firepot Report of Experimental Data (F.R.E.D.)

Date: 15 April 2013 | **Time: 3:35pm** | **Test ID: Lip Test 4**

Participants:

Ryan Ismirlian	......Y...............
Joan Keyes	...............N......
Dan Mello	......Y...............
James Miller	......Y...............
Ryan Rangle	...............N......

Pre-Ignition

Force of Push: 2.97 Newtons

Height of Table: 31.5 in

Weight of Opened Can: 80.46 grams

3min Ingition

Peak Width of Flame: 0.6 in

Base Width of Flame: 1.5 in

Height of Flame: 4.5 in

Flame Temperature: 604.2 C

Flame Color: blue base, orange flames, yellow tip

Fire Sound: slight crackle

Testing Results

Min. Distance: 9 in

Max. Distance: 18 in

Extinguish Time: 7:27.3

Remaining Weight: 40.12g

Figure 50: Lip Test 4 Data

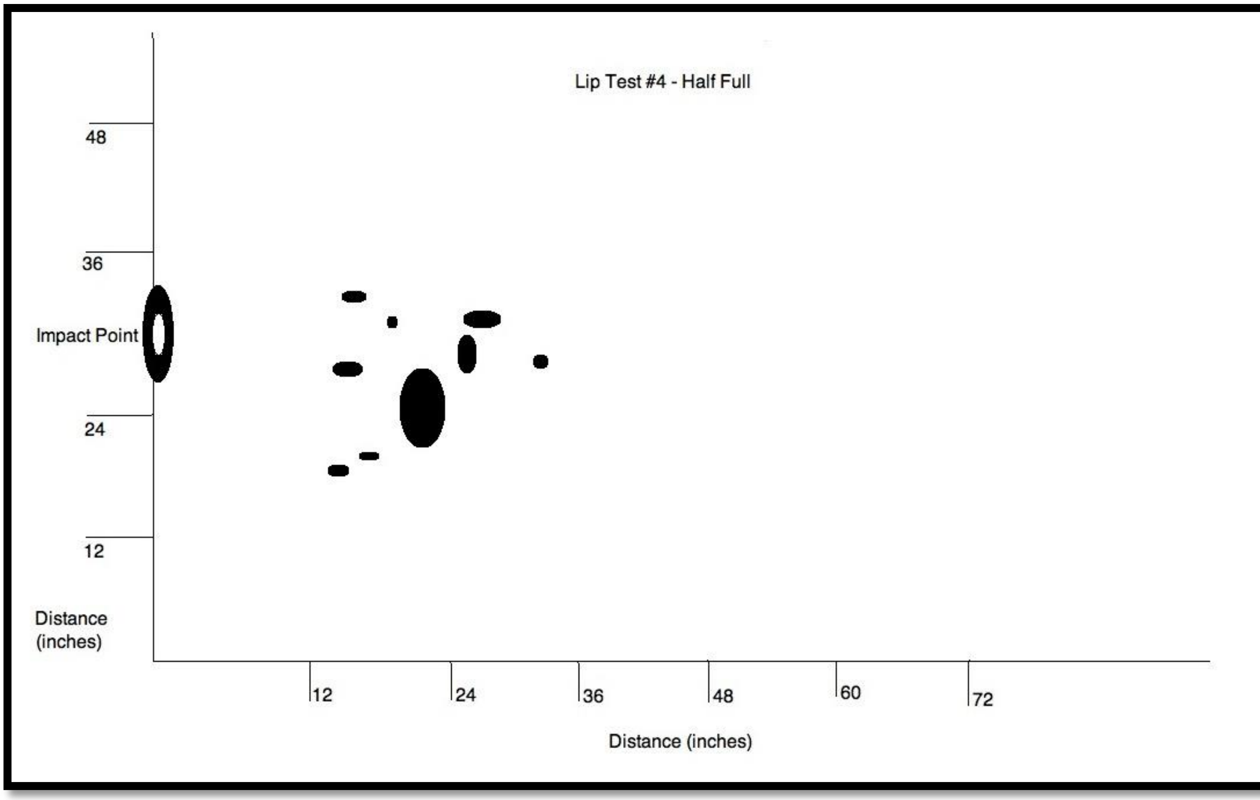


Figure 51: Resulting Spill Data for Lip Test 4

4.14.3 Key Experimentation Aspects of Note

In this half-full trial, it could be seen how the addition of the stainless steel lip helped to minimalize the overall area of burning due to the spill. As can be seen in Figure 51, the gel fuel was contained in an area 13-35 inches from the launch point. However, within this area, the canister still spilled a large quantity of gel fuel that burned for some time. This test resulted in the spillage of about 40 grams of gel fuel.

4.14.4 Interpretation of Experimental Data

Unlike some of the previous experimentations, this trial resulted in a much better outcome for the altered gel fuel container. With only a half full gel fuel container, the spillage of 40g of the gel was a moderate reduction from previous tests and was contained to a much smaller area, as noted in Figure 50. Though not a perfect solution to the proposed problem, this is no doubt a vast improvement over the control test involving the use of the half full canisters. However, other avenues to increase the safety of the product are to be looked into in order to find the safest possibly solution.

4.15 Testing of Pectin, Molasses, and Polyvinyl Alcohol Additives

This series of experimental testing involves the use of additional substances to the mixture of the gel fuel itself. This was done in order to achieve a higher viscosity to the gel fuel – in other words, to make the gel fuel thicker as a whole. This increase in viscosity was is desirable as a safety precaution. In the case of a spill of gel fuel or the tipping of the gel fuel, this will allow for the total volume of gel fuel (and thereby logically the total area) of spillage of the liquid to be reduced. In order to do this, the project group came up with 3 unique additives that could be incorporated into the current fuels in an experimental fashion. The three additives that were decided upon were a pectin powder, molasses, and polyvinyl alcohol. Each of these additives was chosen for their theoretical compatibility with the alcohol-based gel fuels. The following sections will extrapolate on the results of experimentation with the gel fuel in concert with these additives.

4.15.1 Experimentation Goals

The goal of this experimentation was to see whether or not these additives would be beneficial to the increase in viscosity of the gel fuel. The gel fuel is to be mixed with each of these individual additives one at a time and the resting compounds will be tested to see whether or not they succeeded in creating a more viscous compound. If the resulting product is clearly less viscous, then it will be discarded and no testing will be necessary in order to experimentally prove improvements in the results.

4.15.2 Results of Mixing Additives

4.15.2.1 Results of Mixing the Pectin Additive

In this sampling of experimentation, the pectin additive was mixed into the current alcohol-based gel fuels. The powder form of pectin was added to the gel fuel, and was stirred in until the compound was dissolved. In this experimental testing the gel fuel did not increase in viscosity as planned. Rather, the pectin mixed into the gelling agents of the fuel created a thicker sludge that lost its clear hue. However, the alcohol separated from the resulting compound, creating a layer of liquid on top of this newfound sludge. This discovery led to the realization that the gel fuel would in fact be much more dangerous in this state. Any knock over of the firepot or a container of this mixture would no doubt cause further spilling of the alcohol, now returned to its liquid state. As such, this mixture involving the use of the pectin powder was not tested in the manner of the previous tests, as the product failed a test of common logic of desired experimental results.

4.15.2.2 Results of Mixing the Molasses Additive

In this sampling of experimentation, the molasses additive was mixed into the current alcohol-based gel fuels. The common liquid form of molasses was added to the gel fuel, and was stirred in until the two liquids were properly mixed. In this experimental testing the gel fuel did not increase in viscosity as planned. Rather, the molasses mixed into the gelling agents of the fuel, create a thicker sludge that lost its clear hue. However, the alcohol separated from the resulting compound, creating a layer of liquid on top of this newfound sludge. Soon, the alcohol receded back into this compound, creating a much thinner overall liquid than the original gel fuel. This discovery led to the realization that the gel fuel would in fact be much more dangerous in this state. Any knock over of the firepot or a container of this mixture would no doubt cause further spilling of the alcohol, now returned to its liquid state. As such, this mixture involving the use of the molasses was not tested in the manner of the previous tests, as the product failed a test of common logic of desired experimental results.

4.15.2.3 Results of Mixing the Polyvinyl Alcohol Additive

Upon experimental testing of the mixture of both the pectin powders and the molasses into the gel fuels, the group deemed that it would be futile to keep testing a series of products as mixtures into the gel fuel simply to see if the resulting crude compound would in fact become more viscous. It was further noted that the quantity of isopropanol or ethyl alcohol in the current gel fuels was high enough, and that added yet more alcohol to the flammable and explosive mixture would be counterproductive and unsafe. Due to this, the group decided that it was unnecessary to test any further products as additives to the gel fuel mixture.

4.15.3 Interpretation of Experimental Data

As previously noted, the addition of these compounds to the existing gel fuels was not a successful endeavor. These resulting mixtures were not even tested, as the clearly increased liquid nature of the gel fuel would no doubt make for a more dangerous product. The group instead decided to turn back to the mechanical aspect of alterations to the canister of the fuel itself, as changes to these structures had shown much improved results to the overall performance of the product in safety testing.

4.16 Conclusion

The experimental procedures followed in these laboratory tests showed a great promise to several of the iterations of possible design implementations for an overall safer product. As shown in the control tests of full and partially full gel fuel containers, the product as is can fall from the height of a simple table or countertop, spraying ignited fuel across an entire room. The simple implementation of a layer of stainless steel meshing, rather inexpensive to incorporate and relatively unobtrusive to the overall performance of the product, can work to greatly reduce the volume and distance of the spillage. A second series of altered tests showed less promise. The addition of a steel lip to the canisters, in an attempt to decrease the area of the opening on top of the unit to decrease volumetric flow rate in case of a spill, worked only to project the gel further upon impact with the floor. From the results gained in this series of trials, the group decided such an implementation would not be beneficial to the product. Yet another series of alterations were made to current gel fuels – this time, to the formula of the compound itself. These ideas were instantly quenched, as the resulting mixture was nothing but less viscous and much more dangerous. However, the results of these tests showed an important factor. The recognition of a potential solution, in the form of the meshing layer, presents itself as a low-cost, reliable, and safety-increasing addition to the current gel fuels that merits a closer look for its viability in mass production. Furthermore, this success leads to the potential for yet more design possibilities and the formation of regulations to which firepots and their respective alcohol-based gel fuels can be held to.

Chapter 5: Conclusion

5.1 Discussion of Single-Fill Cans

The most prominent firepot related incident scenario was the refueling of the firepot gel fuel container. The scenario which is caused by an attempt to refuel the container and a subsequent fireball or explosion was the cause of 64% of all reported firepot related incidents, 61 of 86 injured victims, and both firepot related fatalities. Also, there have been two incidents which included two injured victims in which the gel fuel storage container exploded after the gel fuel was poured. Due to the large numbers of incidents related to firepots, the CPSC launched their investigation which eventually led to the voluntary recall of millions of gel fuel containers by all companies that were producing the refillable gel fuel. After this operation was executed, the only remaining means of obtaining gel fuel would be through disposable gel fuel containers that are not intended to be refilled or reused after the gel fuel has been completely depleted. These "single-fill cans", still sold today by companies such as Pacific Flame, would have eliminated 67% of all firepot related incidents had they been the only marketed option since firepot gel fuels were first introduced to consumers if used as the manufacturers intended. It also would have prevented 63 of 86 injuries and two deaths. While these single-fill cans may not eliminate other incident scenarios such as firepot tip-over incidents, metal burn cup ejects, and explosion while snuffing, they are an excellent alternative to refillable burn cups and gel fuel storage containers. It may very well be possible to engineer alternative, more economical solutions to these issues that may include a safer way to refill the gel fuel container and a safer gel fuel storage container; however, a very simple way to eliminate two-thirds of all firepot related incidents is to manufacture and distribute only single-fill cans and eliminate gel fuel storage containers all together. The group highly recommends that the CPSC only permits single-fill cans, whether altered to prevent additional incident scenarios or not. This is the first and most important step to regulating gel fuel and the current market has already realized this which is why single-fill cans are the only means to replace firepot gel fuel today.

5.2 Recommendation of Mandatory Standards and Regulations

A large reason why firepots may have been so dangerous was due to the fact that there was a clear lack of standards for firepots and their gel fuels. Had there been sufficient standards and regulations for firepots and their gel fuels, the CPSC may have been able to mitigate a large bulk of the risks associated with firepots.

5.2.1 Recommended Standards Proposed by Bird Brain Inc.

In December of 2011, the CPSC began proposing solutions such as mandatory performance standards, mandatory labeling, voluntary standards, banning, or no action and eventually this led to a voluntary recall. Shortly after on February 21, 2012, the President, CEO, and notable others of Bird Brain Inc. and Sterno, met with members of the CPSC in order to propose their own standards. They proposed single-use cans with an adapter ring which allows the can to be secured to the firepot. Some other standards, regulations, and tests for firepots proposed by Bird Brain Inc. that the Firepot Reliability and Engineering Design group supports are the following:

- Firepot must remain standing when subjected to a 15 degree tilt from all directions with and without gel fuel in place
- Firepot exhibits no observations of damage after burning through four gel fuel cans with an hour in between burns
- Establish maximum surface temperatures measured one hour into the burn cycle
- Subject firepot to four cycles of two hours at room temperature then three hours at 150 degrees Fahrenheit in addition to a freeze-thaw test
- Firepot subjected to 24 hours in a 1% salt spray bath with no observable damage
- Clear and concise instructions for proper use
- Label warning statements consistent with ASTM 2058

- Emergency warnings in case of a fire and directions for extinguishing media
  (Khanna 2012)

Some other standards, regulations, and tests for gel fuel proposed by Bird Brain Inc. that the Firepot Reliability and Engineering Design group supports are the following:

- No spillage at a 90 tilt for 30 seconds
- Test 24 single-use cans for flaming material ejections or other unsafe events
- Clear and concise instructions for proper use
- Label warning statements consistent with 16 CFR 1500 and FHSA
  (Khanna 2012)

5.2.2 Recommended Standards Proposed by F.R.E.D.

The group agreed with many standards and regulations proposed by Bird Brain Inc. to the CPSC, but would also like to extend additional suggestions for standards and regulations to the CPSC for consideration. Additional or modified Bird Brain Inc. standards, regulations, and tests for firepots that the Firepot Reliability and Engineering Design group proposes are the following:

- No observed structural damage if dropped from six inches onto any wood or smooth mineral surface

  The purpose the first proposed firepot standard is to increase the resistance to breakage. If the firepot can withstand a drop from six inches without damage, it should be able to withstand being tipped over without breaking and dislodging the gel fuel can.

- Gel fuel can must fit securely into firepot with no possibility of unintended dislodge

  The purpose of the second proposed standard is to mitigate the risk of the metal burn cup ejecting while in use. This scenario has six recorded incidents which included three injuries.

- The bottom surface must have a higher coefficient of friction than the rest of the ceramic exterior
- The circumference or perimeter of the base must be greater than ¾ of the largest circumference or perimeter of the rest of the exterior

The purpose of the next two standards is to reduce the risk of a tip over if the firepot or surface that the firepot is placed upon is bumped into.

Additional or modified Bird Brain Inc. standards, regulations, and tests for gel fuel that the Firepot Reliability and Engineering Design group proposes are the following:

- <u>No spillage if dropped from any angle or any angular velocity while airborne</u>
- <u>Container must not have any spillage past one foot of where the container lands if tipped from a height of five feet</u>
- <u>No spillage if subjected to a 180 degree tilt for five seconds</u>

  During testing, the group discovered that a large amount of the gel fuel ejects while the container is airborne and more so upon contact with the ground. Any engineering solution that does not allow spillage while airborne and limits spillage upon contact will reduce the spread of the fire if knocked over and the possibility of flaming gel landing on a person or animal.

- <u>Container must withhold at least 50% of the gel fuel contained if laying still at a 90 degree angle for 24 hours</u>

  The can is most likely to land on its side if knocked over alone or in a firepot dependant on the design. If the fuel can is able to contain at least half of the gel fuel while on its side, it will limit large pooling around the can when knocked over.

- <u>Container must be sold with a snuffing device that keeps human skin at least one foot away from the flame while snuffing</u>

  There has been one recorded incident where there was an explosion while snuffing. If the firepot or gel fuel containers are sold with a snuffing device that keeps humans away from the flame, it may reduce burns should this incident scenario occur again.

- <u>Container must be re-sealable in such a way that no gel fuel will spill when subjected to a tilt of any angle for 24 hours</u>

If the cans are marketed as single-fill as opposed to single-use, the storage of the remaining gel fuel if not expended completely must be done in a safe manner where the gel fuel will not spill.

- Must be labeled with emergency warnings to include extinguishing flame on human skin

  Due to the fact that the gel fuel spreads instead of becoming snuffed upon a person conducting a "stop, drop, and roll" maneuver, the gel fuel containers must have appropriate instructions to extinguish flaming gel on skin to limit the exposure time to decrease the severity of burns.

5.3 Viable Mechanical Gel Fuel Can Solutions

The group has managed to come up with a number of possible solutions to mitigate the dangers of firepots and their gel fuels by augmenting only the single-fill can design. While it would be possible to explore the possibilities of designing a safer way to refuel a gel fuel can and improving the safety of the gel fuel storage containers, the group chose to stick with the single-fill cans and modify them to inhibit incident scenarios in addition to refueling incidents and gel fuel storage container incidents.

5.3.1 Tested Solutions

The group tested two possible solutions that may improve the safety of the single-fill gel fuel cans.

5.3.1.1 Fixed Mesh Solution

The first modification of the single-fill gel fuel cans was to fix 18 gauge stainless steel mesh at the lid of the gel fuel can. The purpose of the mesh is to reduce the spillage of gel fuel upon initial contact, while airborne, contact with the ground, and pooling around the can. This solution was by far superior to the control test and the lipped gel fuel container test. There was no notable difference in the aesthetic nature of the flame. The flame height, width, color, smell, and sound stayed generally the same. However, the difference between the control and the fixed mesh solution would be in the spillage of the gel fuel when knocked over from a height of 31.5 inches. As seen in the results section, the containers with a fixed meshing on top would only allow spillage between a 12-18 inch radius, all of which extinguished often in less than five minutes. This is a dramatic decrease from the control test which allowed droplets of gel fuel to spread over five feet and pools remaining lit for nine minutes or more. Due to the vast decrease in distance and volume of spillage without hindering the aesthetic appeal of the flame, the group strongly recommends this solution.

5.3.1.2 Lipped Edge Solution

The second modification of the single-fill gel fuel cans was to add a lip on the inner circumference of the gel fuel can in order to make the inner diameter significantly smaller than the outer diameter of the can. The purpose of constricting the diameter was to limit the initial flow rate of the gel fuel from the can. Another practicality of this solution is that when the can is on its side, the gel will only seep out until the level of the gel fuel matches at the same height as or below the inner diameter of the lip in the top of the can. This method was much less successful than anticipated. The gel fuel spilled in distances in excess of five feet from the impact point showing little to no reduction in spillage distance. The lip of the can also failed to prevent large amounts of gel fuel from spilling after landing on its side and pooling around the can. In addition to the lack of spill prevention, despite the data being similar, the flame was substantially hindered by the lipped edge. The flame was shorter for longer time periods, narrower for longer time periods, and did not “dance” as much. Due to the lack of added safety and reduction in aesthetic appeal, the group has decided that this solution alone is not recommended.

5.3.2 Conceptual Solutions

The following solutions in Chapter 5.3.2 are intellectual concepts that the Firepot Reliability and Engineering Design group have proposed as possible mechanical means to increase the safety of gel fuel cans. These concepts have not yet been demonstrated as working designs and have no recorded data to go along with them.

5.3.2.1 Halo Floating Ring Design

Utilizing a loose fit ring of mesh, a center guide rod aids this mechanical feature. The floating mesh has two purposes: to hinder the release of gel fuel during an incident and to allow the gel to burn without hindering its performance. The ring sits upon the gel, allowing the gel to slightly penetrate the ring to allow the gel to burn on top of the meshing as opposed to under it like the fixed mesh design. This proposed idea is depicted in Figure 52.

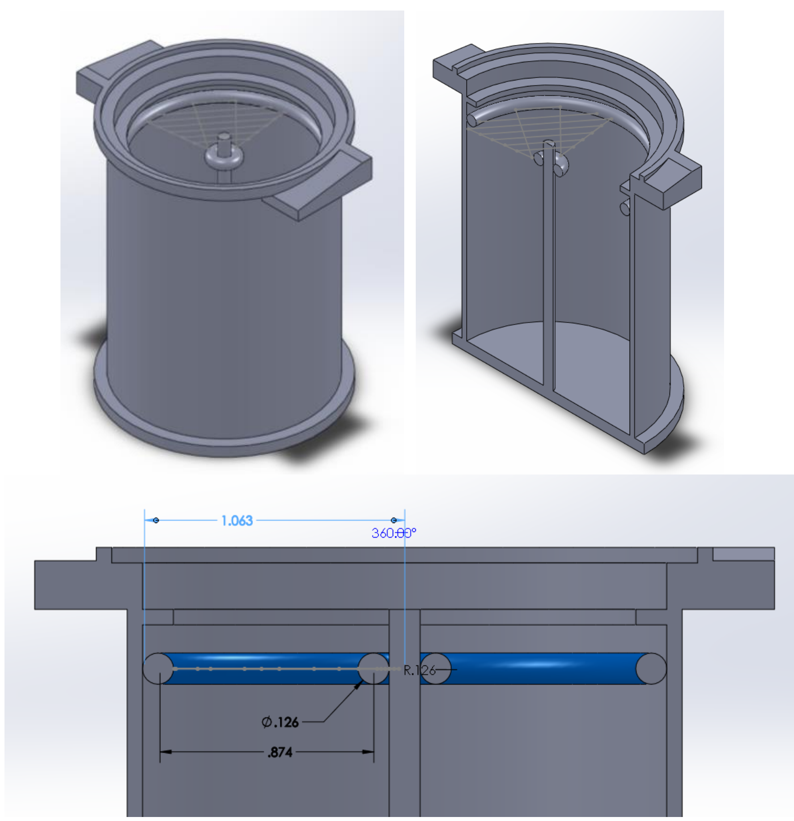


Figure 52: Halo Floating Mesh Canister Design

5.3.2.2 Vertical Axis Ball Stopper Design (V.A.B.S.)

This spill preventer is designed with gravity in mind. The ball is housed in the gel canister and guided by a thin rod down the center. The rod is anchored to the bottom of the can and attached to the overlaying mesh at the top of the canister. The meshing sits low enough to avoid contact with the sealing lid. The initial position of a full gel container would have the ball resting at the bottom. When flipped beyond 90 degrees, the ball will be inclined to shift its position toward the opening by the flow of the gel and gravity. When approaching 180 degrees, gravity acts even greater on the weighted ball causing it to press against the restricting lip, hindering the gel fuel flow through the opening. At 180 degrees, the ball creates a full seal stopping the gel from continuing to flow past the restricting wall. This scenario is designed to prevent excessive spilling and release of the gel fuel during and post incident. The meshing acts as a secondary preventative measure that further lessens the escape of the gel that was beyond the seal. The design would be most effective during a knock over or drop situation more than tipping situations. This proposed idea is depicted in Figures 53 and 54.

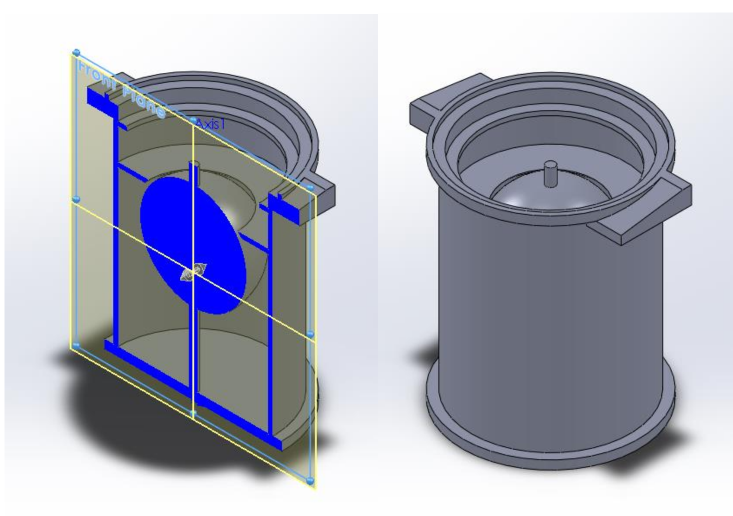


Figure 53: V.A.B.S. Canister Design w/Section View

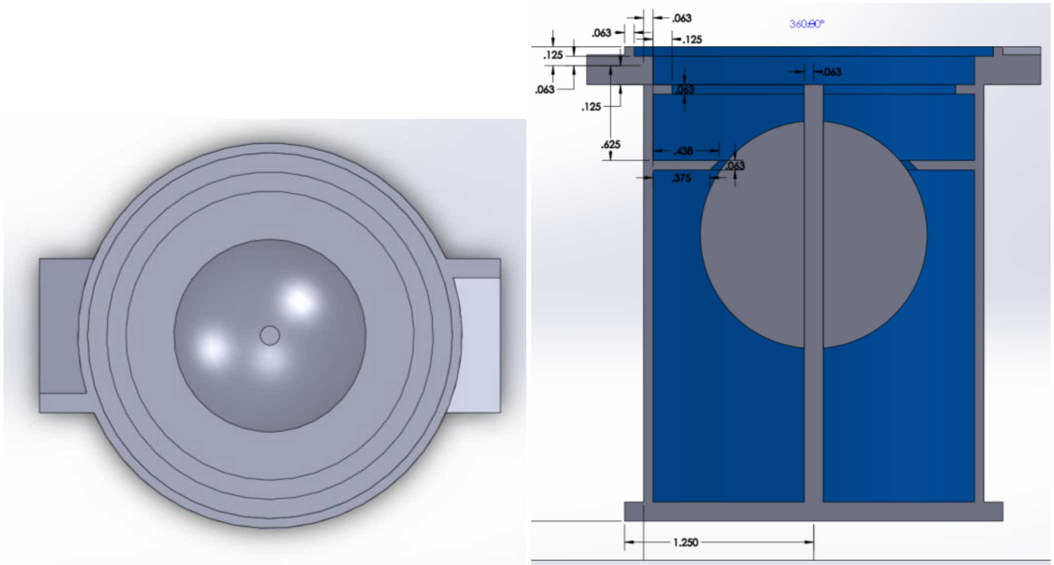


Figure 54: V.A.B.S. Canister Design Top and Interior

5.3.2.3 Fixed Base Design

The locking scenario designed into the single-fill canister will allow for the canister to be anchored to the removable burn cup. In addition to this design, it is suggested that the burn cup have a similar locking scenario that will allow the burn cup to be anchored to the firepot base itself. This will lessen the sporadic behavior of the gel filled canister in the event of a knock over or drop. This proposed idea is depicted in Figure 55.

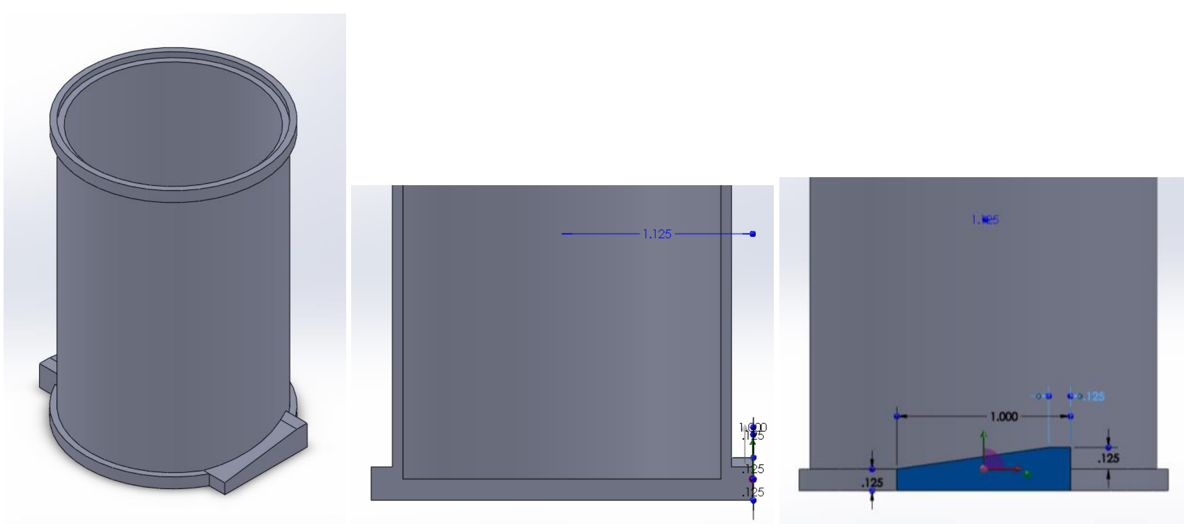


Figure 55: Locking Base Design

5.3.2.5 Flat Cap Design

The device shown here is a snap-on mesh covering. The meshing, depending on the grade, aids in the prevention of excessive spillage or expulsion of the gel fuel in the case of a knock over or drop. The meshing hinders the gel's flow rate, thereby reducing the affected area during and after an incident due to the reduction of the escape area. The grade of meshing is to be determined as to prevent the gel from escaping while not hindering the gel's performance below the meshing (suffocating the flame). This proposed idea is depicted in Figure 56.

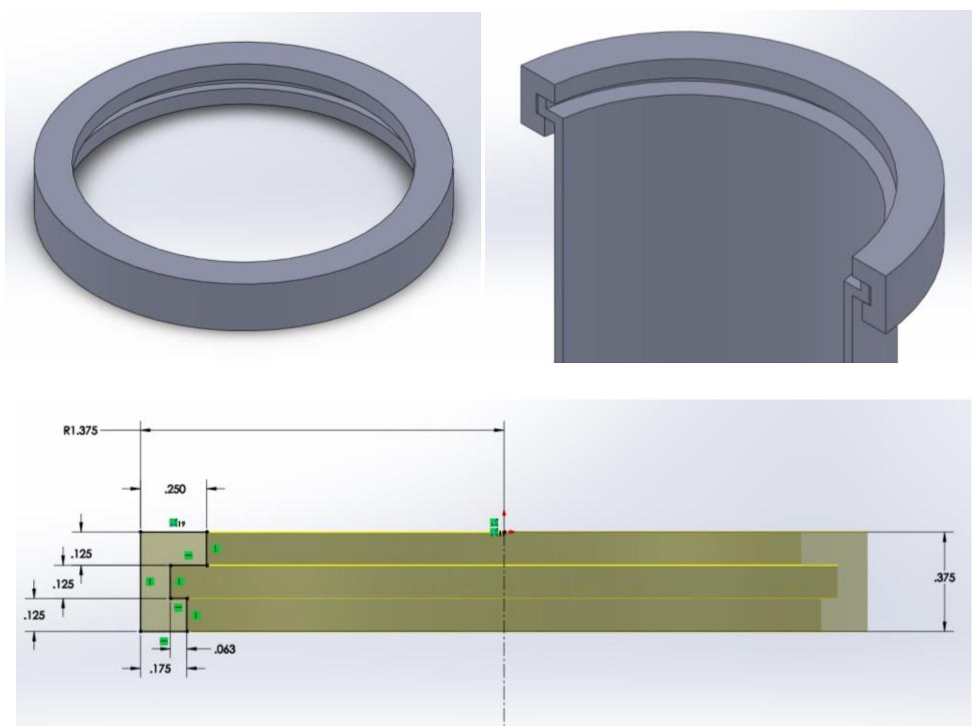


Figure 56: Snap-On Flat Meshing Design

5.3.2.4 Flexed Cap Design

The flexed meshing cap is designed to allow for high grade meshing to hinder fluid flow significantly while allowing air to circulate to the bottom of the container as is burns through the supply. The structure provides more obstacles for the gel fuel and thereby hinders the direction and fluid flow. This design, seen in Figure 57, can also allow for a low grade of meshing to be additionally situated on top to act as a secondary defense that allows for air flow.

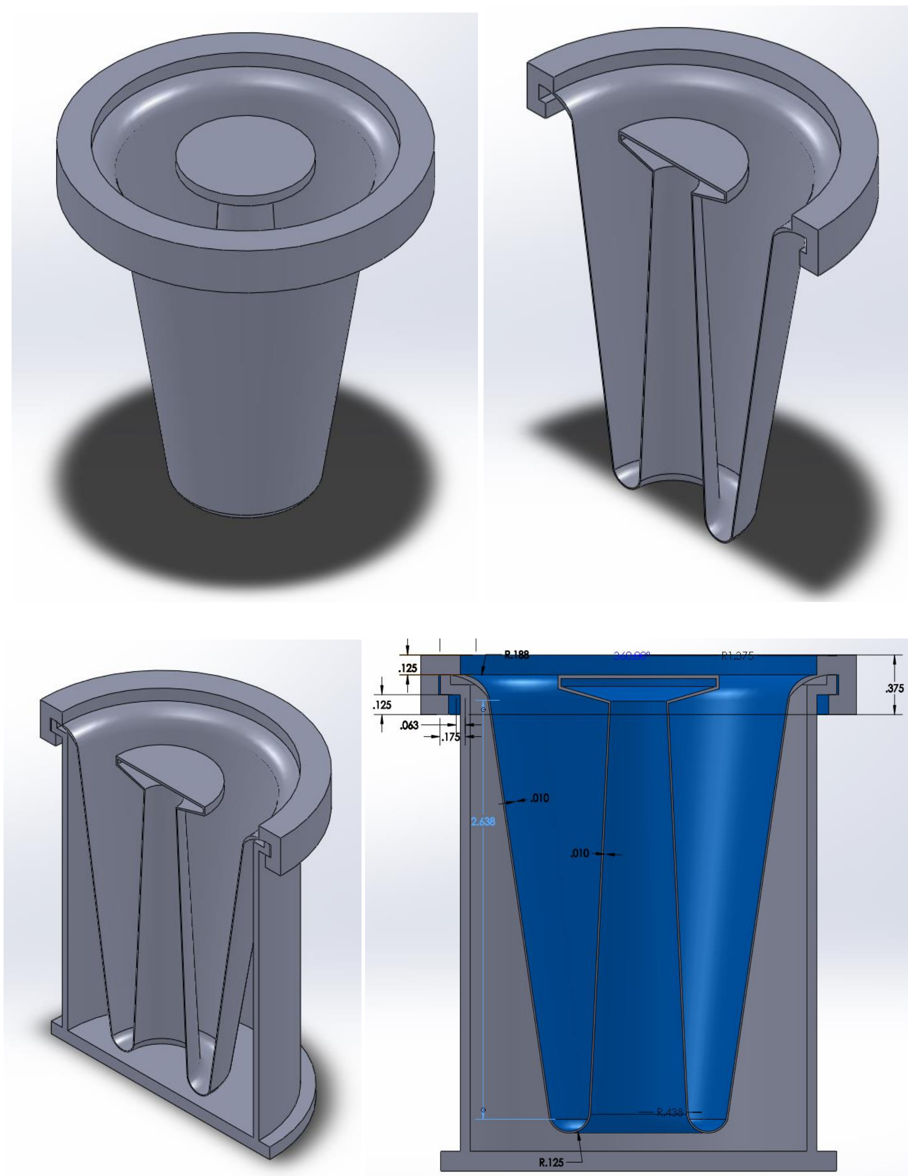


Figure 57: Snap-On Flexed Meshing Design

5.3.3 Chemical Solutions

The group has attempted several different ways to alter the gel fuel chemically. While we have not found a viable solution, it is still a very plausible concept. The thickening of the gel fuel may lower the volume and distance of the spread of gel fuel upon tipping and impact as well as cause the fuel leak at a slower rate when not standing upright. If a thickening agent that does not inhibit the aesthetic appeal of the flame is able to slow the flow rate of the gel fuel, it may create a much safer option to the current gel fuel composition. The group would recommend thickening the gel fuel chemically as long as it does not decrease the aesthetic appeal of the flame. It is also recommended that this option be used in conjunction with a stainless steel meshing.

5.4 Mesh vs. Ball Solutions and Marketability

This project was focused on engineering possible solutions through mechanical and chemical means but did not focus on the manufacturability of the designs or speculations of how they would perform in the current market. The fixed or floating meshing and vertical axis ball stopper designs are rather unique when compared to the others. These are the most reasonable solutions but for different reasons. Dr. Ashok Hingorany of Minuteman International/ACHLA Designs has given these specific solutions merit in terms of being marketable solutions. He explained to the group that it would be unlikely for any manufacturer to begin producing new gel fuel cans due to the negative stigma associated with them. However, a company that is currently still making the gel fuels may be interested because it would keep customers safer and deter lawsuits.

5.4.1 Plausibility of a Mesh Solution

The reason why a manufacturer may be interested in a fixed or floating mesh solution is because it would be extremely cheap to stamp circles out of a mass produced mesh and press them into the cans while they are in production. It may cost less than ten cents per can and would not be complicated to integrate into the production line. The main drawback of this design is that while the group has shown substantial evidence suggesting that a mesh solution is a much safer alternative to the current design, it is not perfect. The tests showed that gel still escaped from the can during tipping and impact and still pooled around the can when on its side or upside down. A manufacturer may adopt this design due to the ease and low cost of production which would lead to a safer gel fuel can that would be marketed at a cost similar to the current design. At the same time, a manufacturer may reject this design because it may be too cumbersome to implement for a design that is still not perfect.

5.4.2 Plausibility of a Ball Solution

The reason why a manufacturer may be interested by the vertical axis ball stopper solution is that, by concept, it will prevent nearly all gel fuel from escaping the can while airborne, upon impact, and tilted between 90 and 180 degrees in addition to a larger possibility of snuffing the flame during a tipping incident. In theory, this makes the vertical axis ball stopper solution much safer than any other solution proposed by the Firepot Reliability and Engineering Design group. The only drawback is that it is a complicated design. It would take more machinery to create a design like this and the entire production line of the gel fuel cans would have to be rearranged. Not only would it be cumbersome to produce this design, it would cost much more in materials and slow down production compared with a meshing solution. Manufacturers may be attracted to this design due to the dramatic increase in safety and potential decrease in liability. They may however, reject this design due to the potential loss of revenue that stems from purchasing new machinery, slower production time, and adding expense to the product which may discourage consumers from purchasing the new style of can.

5.5 FRED Recommendations and Final Remarks

The Firepot Reliability and Engineering Design group has performed extensive background research, intricate testing, and in-depth analysis in order to attempt to refine and propose new standards for firepots and their gel fuels, as well as design conceptual and actual solutions to mitigate the risks associated with firepots and their gel fuels.

First, the group strongly advises the Consumer Product Safety Commission to consider the standards proposed by both Bird Brain Inc. and FRED in Chapter 5.2. If new standards relating to gel fuel cans are implemented, manufacturers that have succumbed to the voluntary recall would be able to reintroduce gel fuel cans to the market with the peace of mind attached to the support of the CPSC.

As long as the manufacturer meets all the standards proposed, the design should be safe enough to market regardless of how they did so. In other words, there are unlimited solutions that would meet all standards set forth and it is up to the manufacturer to decide how to do it.

Of all the solutions proposed in this project, the members of FRED have agreed on what they believe is the best solution. The best solution must increase the level of safety as much as possible while still keeping the cost low. A low cost is critical when considering how a raised price would affect the sales of the gel fuel cans.

FRED would recommend chemically thickening the gel fuel as much as possible without hindering the aesthetic appeal of the flame. This would take place in conjunction with a fixed meshing on the top of the can. The meshing should be as fine as possible, also without hindering the aesthetic appeal of the flame. Finally, implement some sort of mechanical addition to the gel fuel can and firepot so that the gel fuel can is able to be easily fastened securely to the firepot by hand. A slight modification of the gel fuel, exterior of the can, and addition of a meshing would be a relatively cheap and easy change to the current product. This solution would prevent the incident scenarios of refueling the firepot, fuel storage container explosion, spontaneous metal burn cup ejection, and alleviate the severity of a tip-over incident. This suggested solution would alleviate the severity, or eliminate entirely, 79% of all incidents at a very cheap cost.

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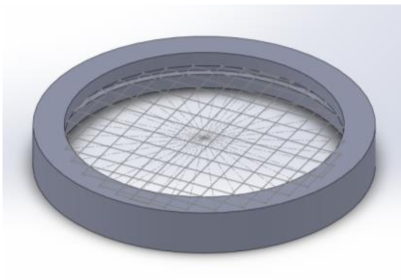
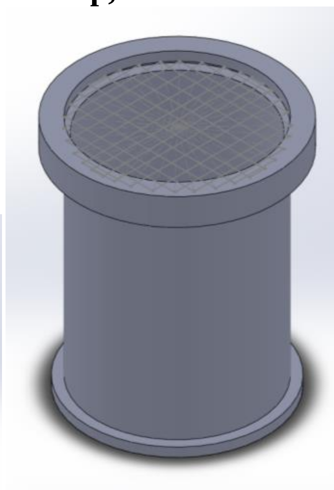
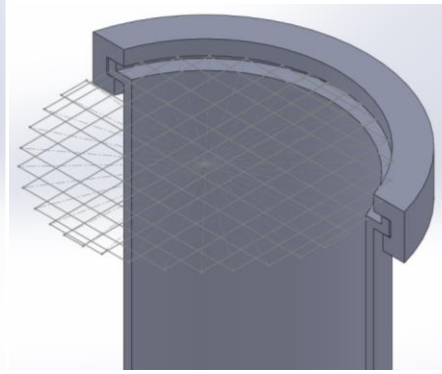
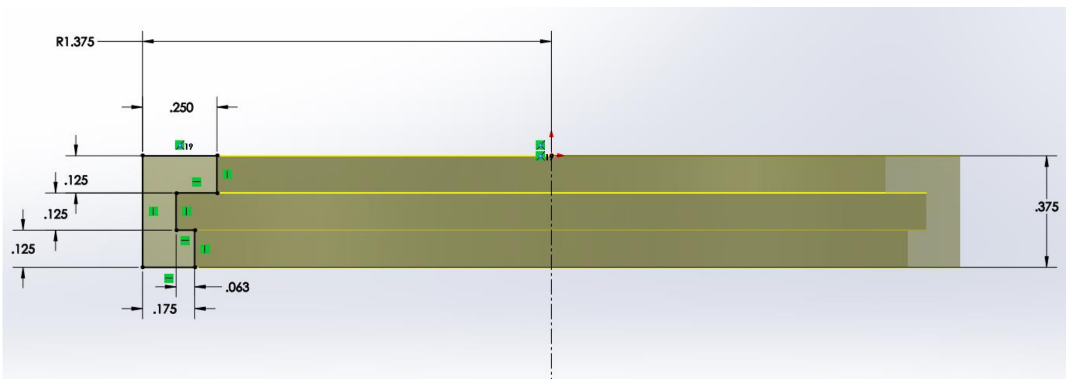
Appendix A: Designs and Descriptions

Single-Use Canister w/Flat Mesh Cap, Modified Can Size



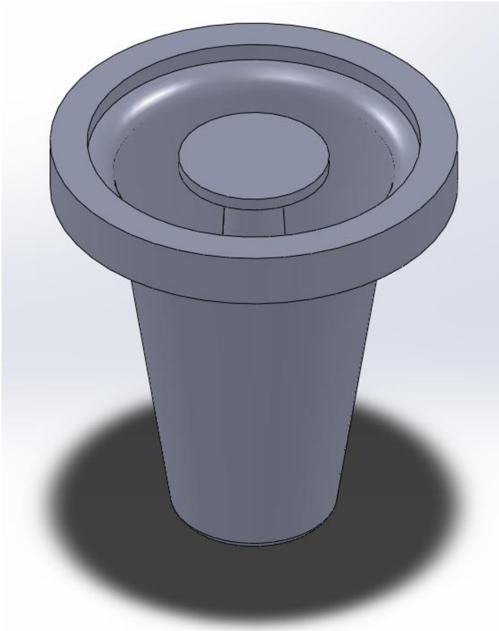


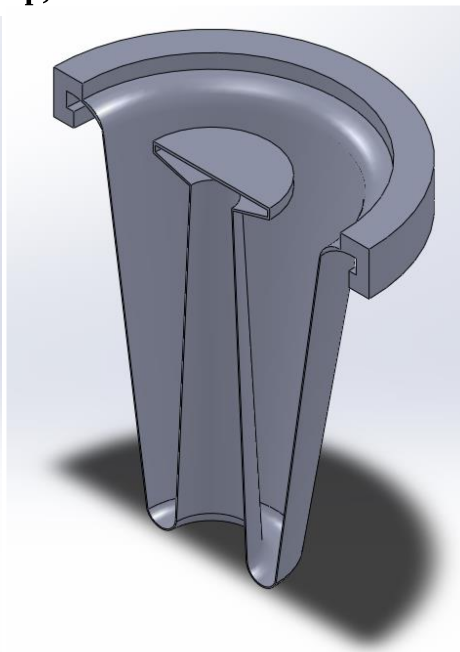


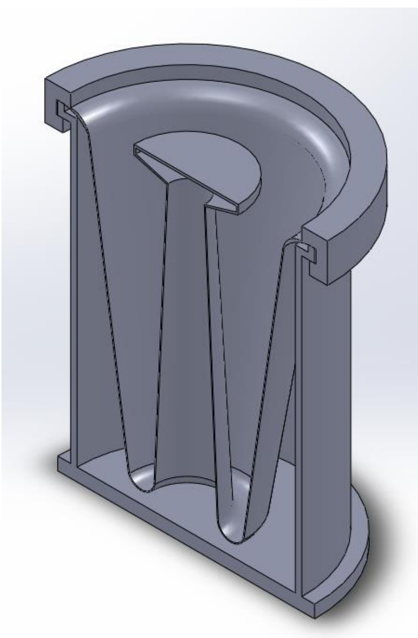


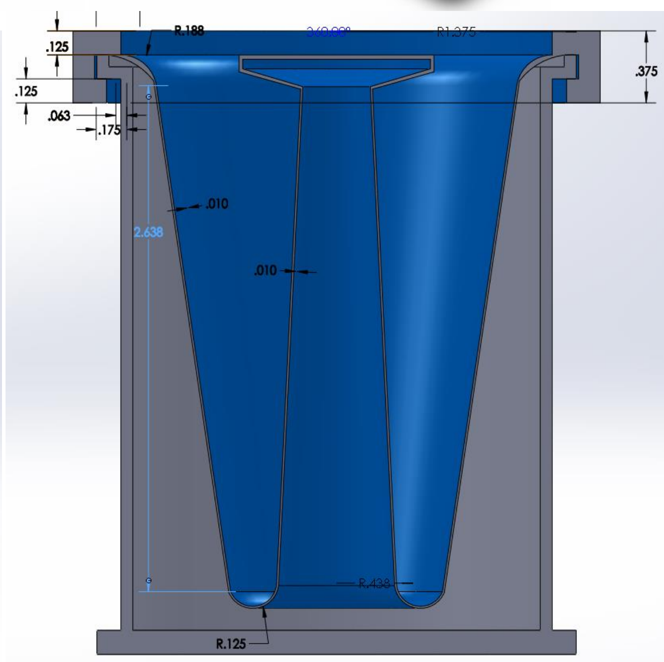
The device shown here is a snap on mesh covering. The meshing, depending on the grade, aids in the prevention of excessive spillage or launching of the gel fuel in the case of a knock over or drop. The meshing hinders the gel's viscous flow rate thereby reducing the affected area during and after an incident due to the reduction of the escape area. Grade of meshing is to be determined as to prevent the gel from escaping while not hindering the gel's performance below the meshing (suffocating the flame thereby snuffing it prematurely).

Single-Use Canister w/Flexed Mesh Cap, Modified Can Size



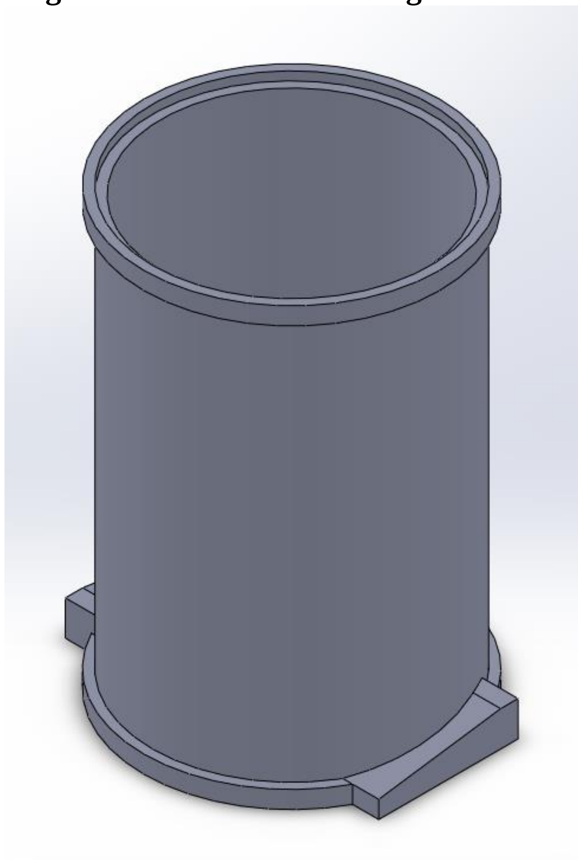


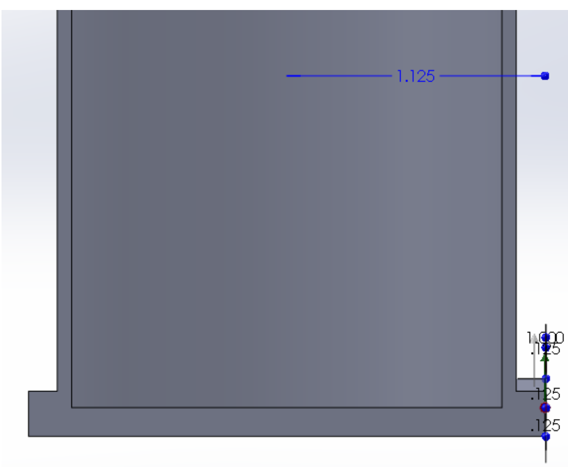


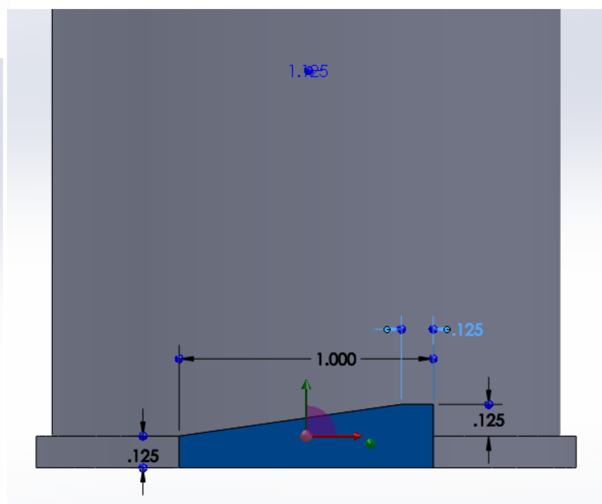


The flexed meshing cap, with snap on intent, is designed to allow for high grade meshing to hinder fluid flow significantly while allowing air to circulate to the bottom of the container as is burns through the supply. The more or less complicated structure provides more obstacles for the gel fuel and thereby hinders the direction and fluid flow. This design can also allow for a low grade of meshing to be additionally situated on top to act as a secondary defense that allows for air flow.

Single-Use Canister w/Locking Mechanism, Original Can Size

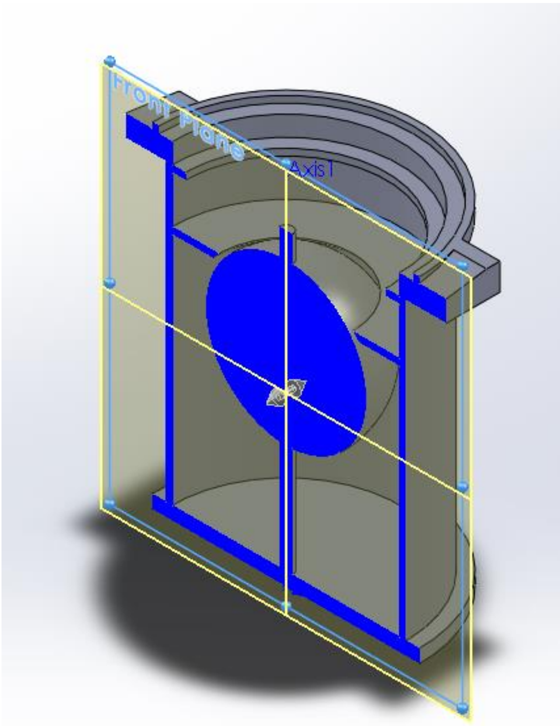


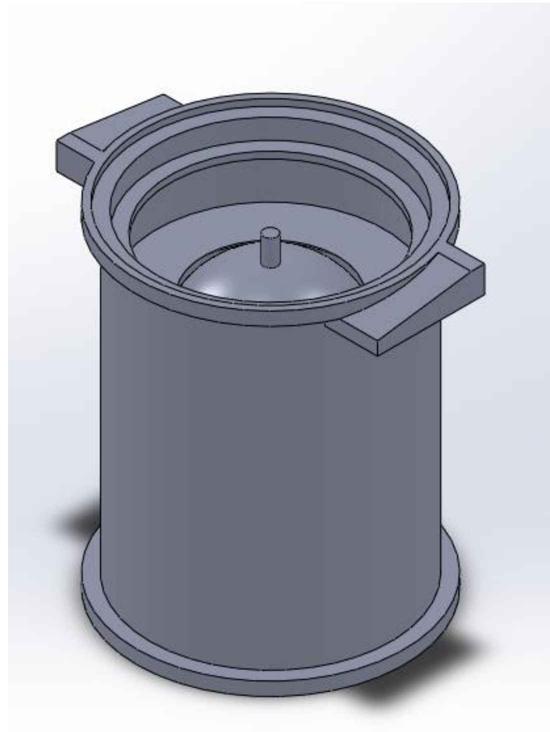


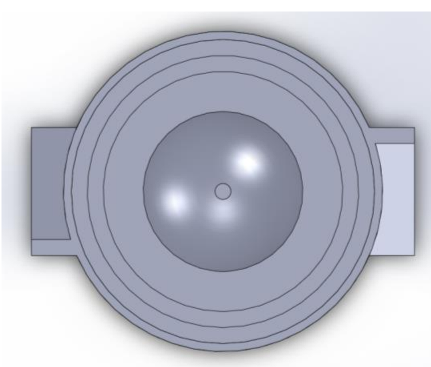


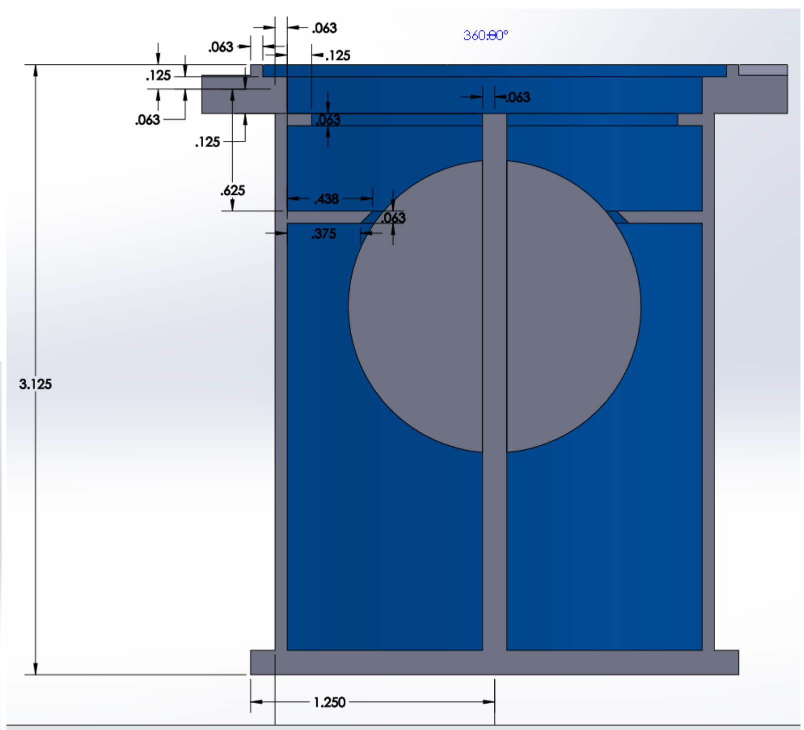
The locking mechanism shown designed into the single-use can will allow for the canister to be anchored to the removable burn cup. In addition to this design, it is suggested that the burn cup have a similar locking mechanism that will allow the burn cup to be anchored to the firepot base itself. Another option is to eliminate the need for the burn cup all together and have the single-use can anchored directly to the pot. This will lessen the sporadic behavior of the gel filled canister in the event of a knock over or drop.

Single-Use Canister w/Ball Preventer, Modified Can Size



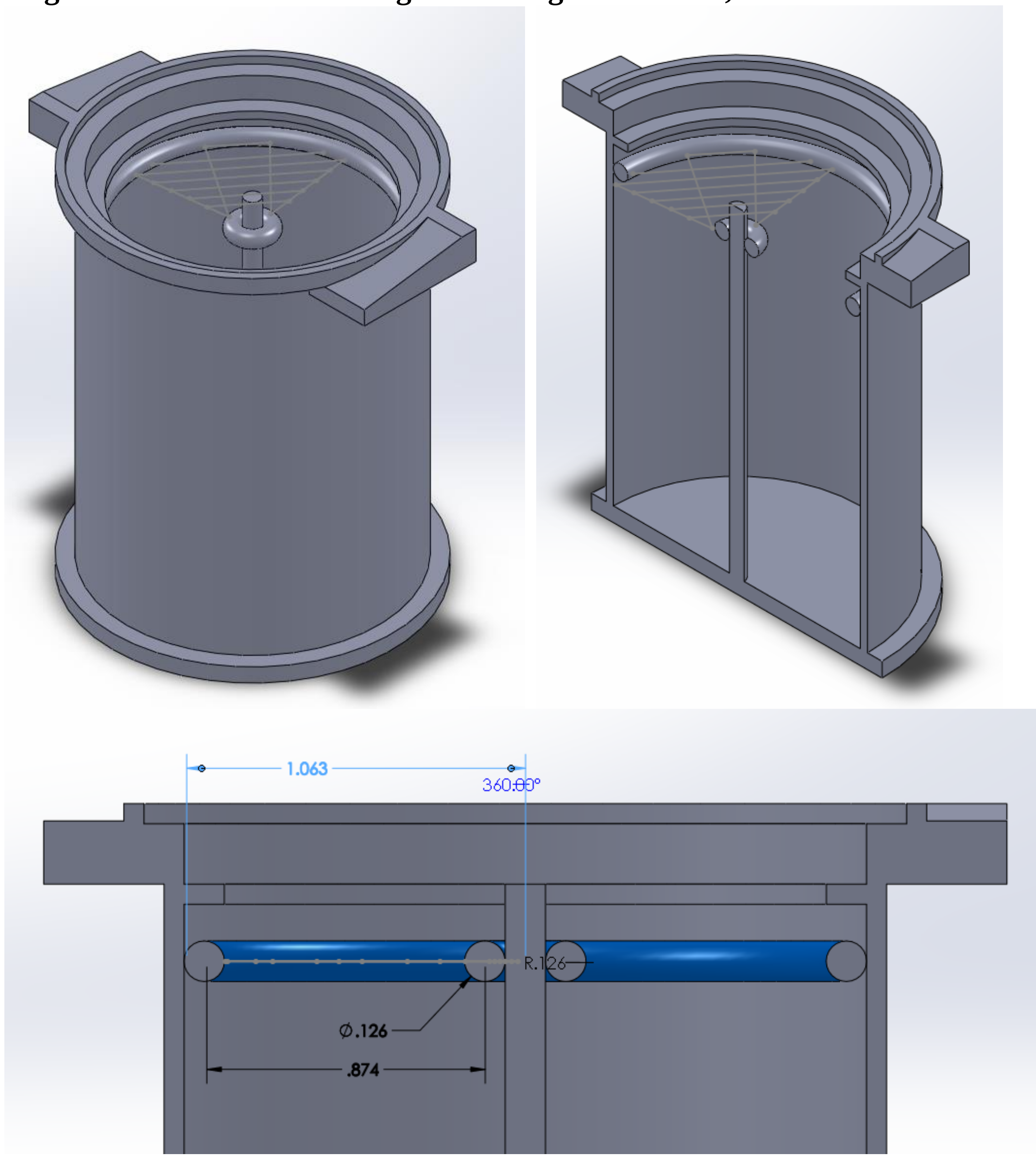






Vertical Axis Ball Stopper, VABS for short, is a mechanically actuated spill preventer that is designed with gravity in mind. The ball is housed in the gel canister and guided by a thin rod down the center. The rod is anchored to the bottom of the can and attached to the overlaying mesh at the top of the canister. The meshing sits low enough to avoid contact with the sealing lid. The initial position of a full gel container would have the ball resting at the bottom. When flipped beyond 90 degrees, the ball will be inclined to shift its position toward the opening with the flow of the gel plus gravity. When approaching 180 degrees, gravity acts even greater on the weighted ball causing it to press against the restricting lip hindering the gel fuel flow through the opening. At 180, the ball creates a full seal stopping the gel from continuing to flow past the restricting wall. This Mechanism is designed to prevent excessive spilling and release of the gel fuel during and post incident. The meshing acts as a secondary preventative measure that further lessens the escape of the gel that was beyond the seal. The design would be most effective during a knock over or drop situation more than tipping situations.

Single-Use Canister w/Floating Mesh Ring Mechanism, Modified Can Size



The Vertical Axis Halo Preventer, or VAHP for short, utilizings a similar design to the ball prevention mechanism, a center guide rod aids the mechanical feature. A floating mesh ring is used in this case and is guided by the rod. The floating mesh has 2 purposes: 1.) to hinder the release of gel fuel during an incident, and 2.) to allow the gel to burn without hindering its performance. The ring sits upon the gel, allowing the gel to slightly penetrate the meshing and burn. Upon tipping, the ring angles and locks itself on the rod and the sides of the canister. If the gel's weight/force overcomes this friction, a sealing (movement limiter) ring towards the top of the can will catch the ring and anchor it as if it were like the fixed meshing design.

Appendix B: List of Proposed Firepot and Gel Fuel Standards

- **FRED Standards**
- *FRED-Modified Bird Brain Standards*
- Bird Brain Standards

Firepot Standards

- **Does not weigh over 5 lbs without gel fuel can**
- **No observed damage if dropped from 6 inches onto any wood or mineral table**
- **Bottom must have a higher friction coefficient than the rest of the ceramic exterior**
- **Circumference or perimeter of base must be greater than ¾ of the largest circumference or perimeter of the rest of the pot**
- *No observed damage if lit for 12 straight hours*
- *Surface temperature not to exceed 120 degrees F if in use for 12 straight hours at an ambient air temperature of 90 degrees F and subjected to sun light*
- *Gel fuel can must fit securely into firepot with no possibility of unintended dislodge*
- Must able to undergo 4 temperature extreme cycles consisting of 1 hour at 0 degrees F to 1 hour at 150 degrees F
- No observed damage if exposed to 24 hours in 1% salt spray
- Will return to upright position if subjected to a tilt up to 15 degrees with or without fuel can in place from any orientation unless symmetrical
- No spillage if subjected to a 15 degree tilt for 24 hours
- No spillage if subjected to 90 degree tilt for 30 seconds
- Must be labeled with instructions for use
- Must be labeled with warning statements consistent with ASTM 2058

Fuel Container Standards

- **No spillage if dropped from any angle or any angular velocity while airborne**
- **Container must not have spillage past 1 foot of where the container lands if "tipped" from a height of 5 feet**
- **Container must withhold at least 50% of gel fuel contained if laying still at a 90 degree angle indefinitely**
- **No spillage if subjected to 180 degree tilt for 5 seconds**
- **Container must be sold with a snuffing device that keeps human skin at least 1 foot away from flame**
- **Container must be re-sealable to a point that it no gel fuel at any angle at any period of time**
- *Must be labeled with emergency warnings to include extinguishing flame on human skin*
- Any observed flame must extinguish within 3 seconds

- Must be labeled with instructions for use
- Must be labeled with warning statements consistent with 16 CFR 1500 and FHSA

Appendix C: Collected Data and Testing Results

Firepot Report of Experimental Data (F.R.E.D.)

Date: 15-Feb-13 **Time:** 3:30 PM **Test ID:** Control 1

Participants:	Ryan Ismirlian	......Y...............
	Joan Keyes	......Y...............
	Dan Mello	......Y...............
	James Miller	......Y...............
	Ryan Rangle	......Y...............
Pre-Ignition	**Force of Push:**	**2.97 Newtons**
	Height of Table:	**31.5 in**
	Weight of Opened Can	**154.5grams**
3min Ingition	**Peak Width of Flame:**	0.5 in
	Base Width of Flame:	2 in
	Height of Flame:	4.25 in
	Flame Temperature:	624.3 C
	Flame Color:	blue base, orange ring, yellow flame
	Fire Sound:	gentle crackle
Testing Results	**Min. Distance:**	*see attached sheets*
	Max. Distance:	*see attached sheets*
	Extinguish Time:	15:58.5
	Remaining Weight:	88.31grams

Firepot Report of Experimental Data (F.R.E.D.)

Date:	21-Feb-13	**Time:** 3:15 PM	**Test ID:** Control 2
Participants:	Ryan Ismirlian	......Y................	
	Joan Keyes	......Y................	
	Dan Mello	......Y................	
	James Miller	..............N........	
	Ryan Rangle	......Y................	
Pre-Ignition	**Force of Push:**	**2.97 Newtons**	
	Height of Table:	**31.5 in**	
	Weight of Opened Can	**153.2grams**	
3min Ingition	**Peak Width of Flame:**	0.5 in	
	Base Width of Flame:	2 in	
	Height of Flame:	3.5 in	
	Flame Temperature:	677.6 C	
	Flame Color:	blue base, orange ring, yellow flame	
	Fire Sound:	gentle crackle	
Testing Results	**Min. Distance:**	*see attached sheets*	
	Max. Distance:	*see attached sheets*	
	Extinguish Time:	19:49.8	
	Remaining Weight:	73.99grams	

Firepot Report of Experimental Data (F.R.E.D.)

Date:	21-Feb-13	**Time:** 3:30 PM	**Test ID:** Control 3
Participants:	Ryan Ismirlian	......Y...............	
	Joan Keyes	......Y...............	
	Dan Mello	......Y...............	
	James Miller	..............N........	
	Ryan Rangle	......Y...............	
Pre-Ignition	**Force of Push:**	**2.97 Newtons**	
	Height of Table:	**31.5 in**	
	Weight of Opened Can	**154.05grams**	
3min Ingition	**Peak Width of Flame:**	0.5 in	
	Base Width of Flame:	2 in	
	Height of Flame:	4 in	
	Flame Temperature:	610.03 C	
	Flame Color:	blue base, orange ring, yellow flame	
	Fire Sound:	gentle crackle	
Testing Results	**Min. Distance:**	*see attached sheets*	
	Max. Distance:	*see attached sheets*	
	Extinguish Time:	19:30.8	
	Remaining Weight:	73.10grams	

Firepot Report of Experimental Data (F.R.E.D.)

Date:	21-Feb-13	**Time:** 4:00 PM	**Test ID:** Control 4
Participants:	Ryan Ismirlian	......Y................	
	Joan Keyes	......Y................	
	Dan Mello	......Y................	
	James Miller	..............N........	
	Ryan Rangle	......Y................	
Pre-Ignition	**Force of Push:**	**2.97 Newtons**	
	Height of Table:	**31.5 in**	
	Weight of Opened Can	**80.39grams**	
3min Ingition	**Peak Width of Flame:**	0.25 in	
	Base Width of Flame:	2 in	
	Height of Flame:	5.5 in	
	Flame Temperature:	595.0 C	
	Flame Color:	blue base, orange ring, yellow flame	
	Fire Sound:	light crackle, periodic loud cracks	
Testing Results	**Min. Distance:**	*see attached sheets*	
	Max. Distance:	*see attached sheets*	
	Extinguish Time:	N/A (self-extinguished)	
	Remaining Weight:	63.71grams	

Firepot Report of Experimental Data (F.R.E.D.)

Date:	21-Feb-13	**Time:** 4:00 PM	**Test ID:** Control 5
Participants:	Ryan Ismirlian	......Y...............	
	Joan Keyes	......Y...............	
	Dan Mello	......Y...............	
	James Miller	..............N........	
	Ryan Rangle	......Y...............	
Pre-Ignition	**Force of Push:**	**2.97 Newtons**	
	Height of Table:	**31.5 in**	
	Weight of Opened Can	**81.06grams**	
3min Ingition	**Peak Width of Flame:**	(0.25 in	
	Base Width of Flame:	2 in	
	Height of Flame:	5 in	
	Flame Temperature:	629.0 C	
	Flame Color:	blue base, orange portions, yellow top	
	Fire Sound:	slightly crackling	
Testing Results	**Min. Distance:**	*see attached sheets*	
	Max. Distance:	*see attached sheets*	
	Extinguish Time:	07:47.5	
	Remaining Weight:	51.68grams	

Firepot Report of Experimental Data (F.R.E.D.)

Date:	21-Feb-13	**Time:** 4:30 PM	**Test ID:** Control 5
Participants:	Ryan Ismirlian	......Y................	
	Joan Keyes	......Y................	
	Dan Mello	......Y................	
	James Miller	..............N........	
	Ryan Rangle	......Y................	
Pre-Ignition	**Force of Push:**	**2.97 Newtons**	
	Height of Table:	**31.5 in**	
	Weight of Opened Can	**80.70grams**	
3min Ingition	**Peak Width of Flame:**	0.5 in	
	Base Width of Flame:	2 in	
	Height of Flame:	5.5 in	
	Flame Temperature:	605.4 C	
	Flame Color:	blue base, orange layers, yellow top	
	Fire Sound:	slightly crackling	
Testing Results	**Min. Distance:**	*see attached sheets*	
	Max. Distance:	*see attached sheets*	
	Extinguish Time:	09:17.0	
	Remaining Weight:	49.5grams	

Firepot Report of Experimental Data (F.R.E.D.)

Date: 22 March 2013 Time: 12:00pm Test ID: Mesh 1

Participants:	Ryan Ismirlian	......Y...............
	Joan Keyes	......Y...............
	Dan Mello	......Y...............
	James Miller	......Y...............
	Ryan Rangle	......Y...............

Pre-Ignition

Force of Push: 297 Newtons

Height of Table: 31.5 in

Weight of Opened Can: 155.2g

3min Ingition

Peak Width of Flame: .25 in

Base Width of Flame: 2 in

Height of Flame: 4.25 in

Flame Tempera 615.3 C

Flame Color: blue base, orange ring, yellow peak

Fire Sound: slight crackle

Testing Results

Min. Distance: 14 in

Max. Distance: 25 in

Extinguish Time: 4:19.6

Remaining Weight: 96.5 grams

Firepot Report of Experimental Data (F.R.E.D.)

Date: 22 March 2013 **Time: 12:20pm** **Test ID: Mesh 2**

Participants:

Ryan Ismirlian	......Y...............
Joan Keyes	......Y...............
Dan Mello	......Y...............
James Miller	......Y...............
Ryan Rangle	......Y...............

Pre-Ignition

Force of Push: 297 Newtons

Height of Table: 31.5 in

Weight of Open 157.0 g

3min Ingition

Peak Width of Flame: .25 in

Base Width of Flame: 2 in

Height of Flame: 4.75 in

Flame Tempera 605.5 C

Flame Color: blue base, orange ring, yellow peak

Fire Sound: slight crackle

Testing Results

Min. Distance: 12.5 in

Max. Distance: 28 in

Extinguish Time: 5:49.9

Remaining Weight: 102.6 grams

Firepot Report of Experimental Data (F.R.E.D.)

Date: 22 March 2013 **Time: 12:45pm** **Test ID: Mesh 3**

Participants:	Ryan Ismirlian	......Y...............
	Joan Keyes	......Y...............
	Dan Mello	......Y...............
	James Miller	......Y...............
	Ryan Rangle	......Y...............

Pre-Ignition	**Force of Push: 297 Newtons**
	Height of Table: 31.5 in
	Weight of Open 153.3 g
3min Ingition	**Peak Width of Flame: 0.25 in**
	Base Width of Flame: 2 in
	Height of Flame: 4 in
	Flame Tempera 589.4 C
	Flame Color: blue base, orange ring, yellow peak
	Fire Sound: slight crackle
Testing Results	**Min. Distance: 12 in**
	Max. Distance: 30.5 in
	Extinguish Time: 4:40.3
	Remaining Weight: 92.1 grams

Firepot Report of Experimental Data (F.R.E.D.)

Date: 15 April 2013 **Time: 2:45pm** **Test ID: Lip Test 1**

Participants:	Ryan Ismirlian	……Y……………
	Joan Keyes	……………N……
	Dan Mello	……Y……………
	James Miller	……Y……………
	Ryan Rangle	……………N……

Pre-Ignition	**Force of Push: 2.97 Newtons**
	Height of Table: 31.5 in
	Weight of Opened Can: 154.5 grams
3min Ingition	**Peak Width of Flame: 0.25 in**
	Base Width of Flame: 1.25 in
	Height of Flame: 3.5 in
	Flame Temperature: 582.1 C
	Flame Color: blue base, orange flames, yellow tip
	Fire Sound: slight crackle
Testing Results	**Min. Distance: 11.5 in**
	Max. Distance: 62.25 in
	Extinguish Time: 9:28.4
	Remaining Weight: 79.14g

Firepot Report of Experimental Data (F.R.E.D.)

Date: 15 April 2013	**Time: 2:45pm**	**Test ID: Lip Test 2**

Participants:	Ryan Ismirlian	……Y…………….
	Joan Keyes	…………….N……
	Dan Mello	……Y…………….
	James Miller	……Y…………….
	Ryan Rangle	…………….N……

Pre-Ignition	**Force of Push: 2.97 Newtons**
	Height of Table: 31.5 in
	Weight of Opened Can: 153.8 grams
3min Ingition	**Peak Width of Flame: 0.25 in**
	Base Width of Flame: 1.5 in
	Height of Flame: 4 in
	Flame Temperature: 602.1 C
	Flame Color: blue base, orange flames, yellow tip
	Fire Sound: slight crackle
Testing Results	**Min. Distance: 10 in**
	Max. Distance: 49 in
	Extinguish Time: 11:13.7
	Remaining Weight: 80.46g

Firepot Report of Experimental Data (F.R.E.D.)

Date: 15 April 2013 **Time: 3:20pm** **Test ID: Lip Test 3**

Participants:	Ryan Ismirlian	......**Y**................
	Joan Keyes	................**N**......
	Dan Mello	......**Y**................
	James Miller	......**Y**................
	Ryan Rangle	................**N**......

Pre-Ignition	**Force of Push: 2.97 Newtons**
	Height of Table: 31.5 in
	Weight of Opened Can: 70.4 grams
3min Ingition	**Peak Width of Flame: 0.25 in**
	Base Width of Flame: 1.2 in
	Height of Flame: 3.5 in
	Flame Temperature: 598.4 C
	Flame Color: blue base, orange flames, yellow tip
	Fire Sound: slight crackle
Testing Results	**Min. Distance: 1.5 in**
	Max. Distance: 26 in
	Extinguish Time: 6:17.0
	Remaining Weight: 39.46g

Firepot Report of Experimental Data (F.R.E.D.)

Date: 15 April 2013 **Time: 3:35pm** **Test ID: Lip Test 4**

Participants:	Ryan Ismirlian	......Y...............
	Joan Keyes	...............N......
	Dan Mello	......Y...............
	James Miller	......Y...............
	Ryan Rangle	...............N......

Pre-Ignition **Force of Push: 2.97 Newtons**

Height of Table: 31.5 in

Weight of Opened Can: 80.46 grams

3min Ingition **Peak Width of Flame: 0.6 in**

Base Width of Flame: 1.5 in

Height of Flame: 4.5 in

Flame Temperature: 604.2 C

Flame Color: blue base, orange flames, yellow tip

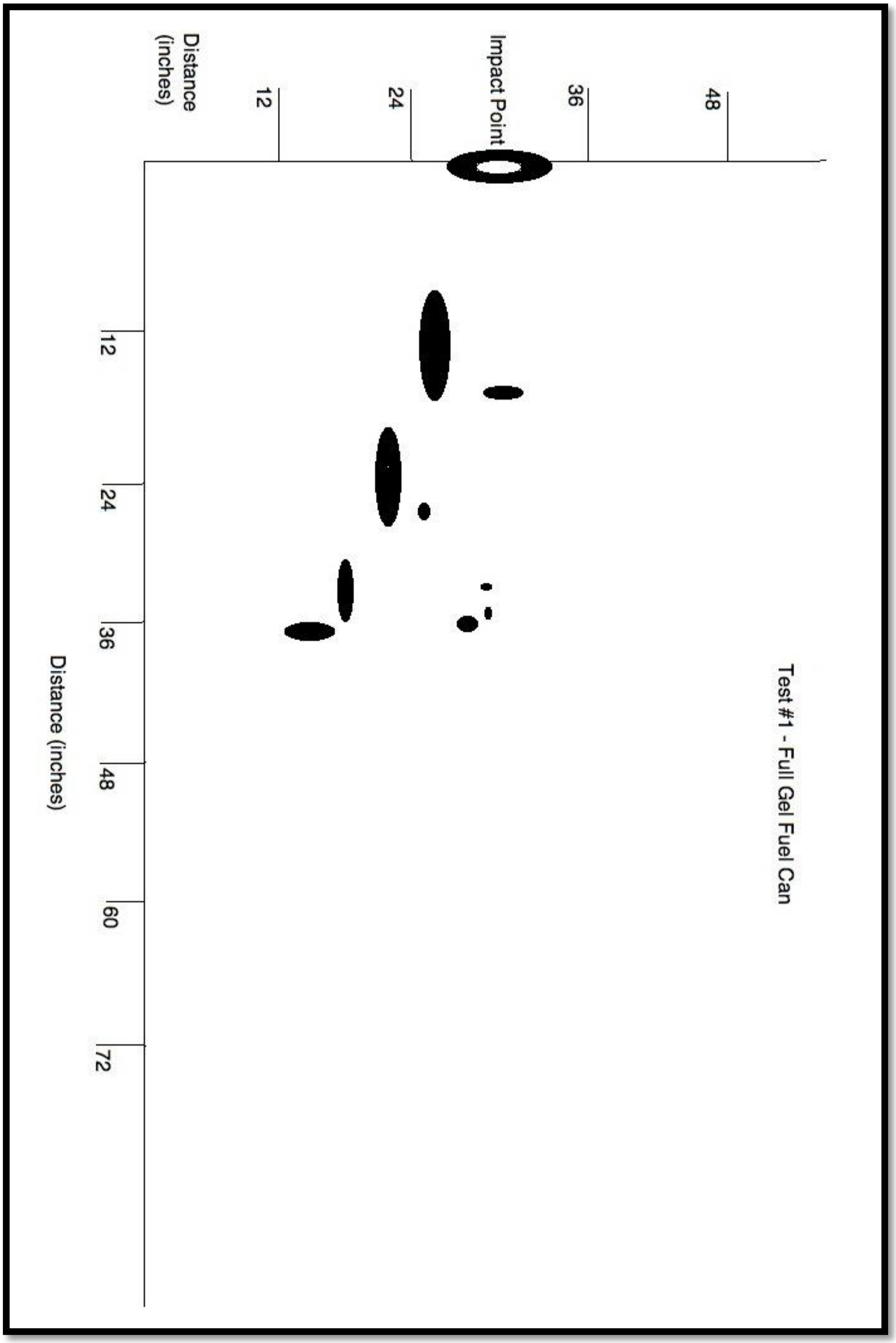
Fire Sound: slight crackle

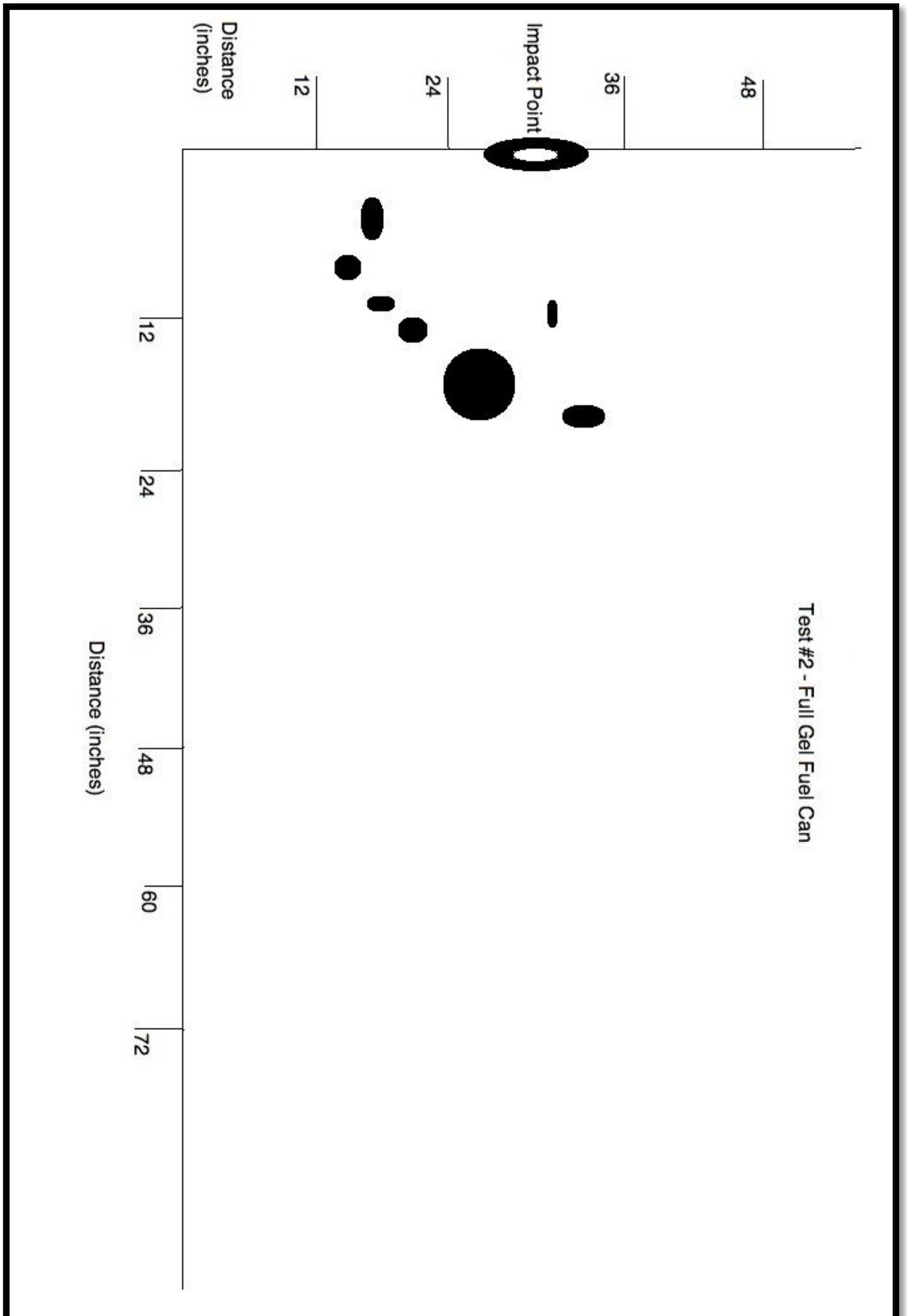
Testing Results **Min. Distance: 9 in**

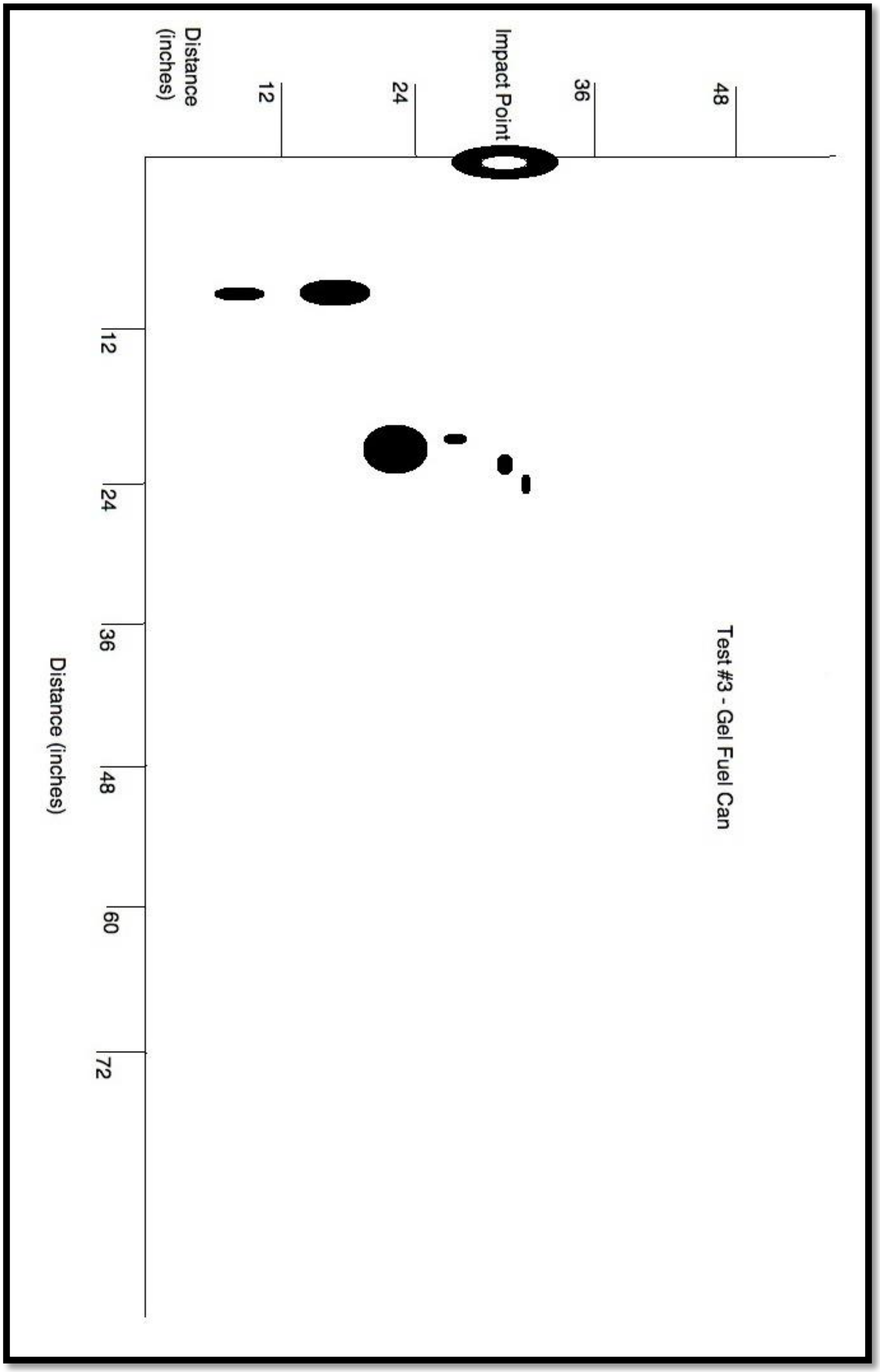
Max. Distance: 18 in

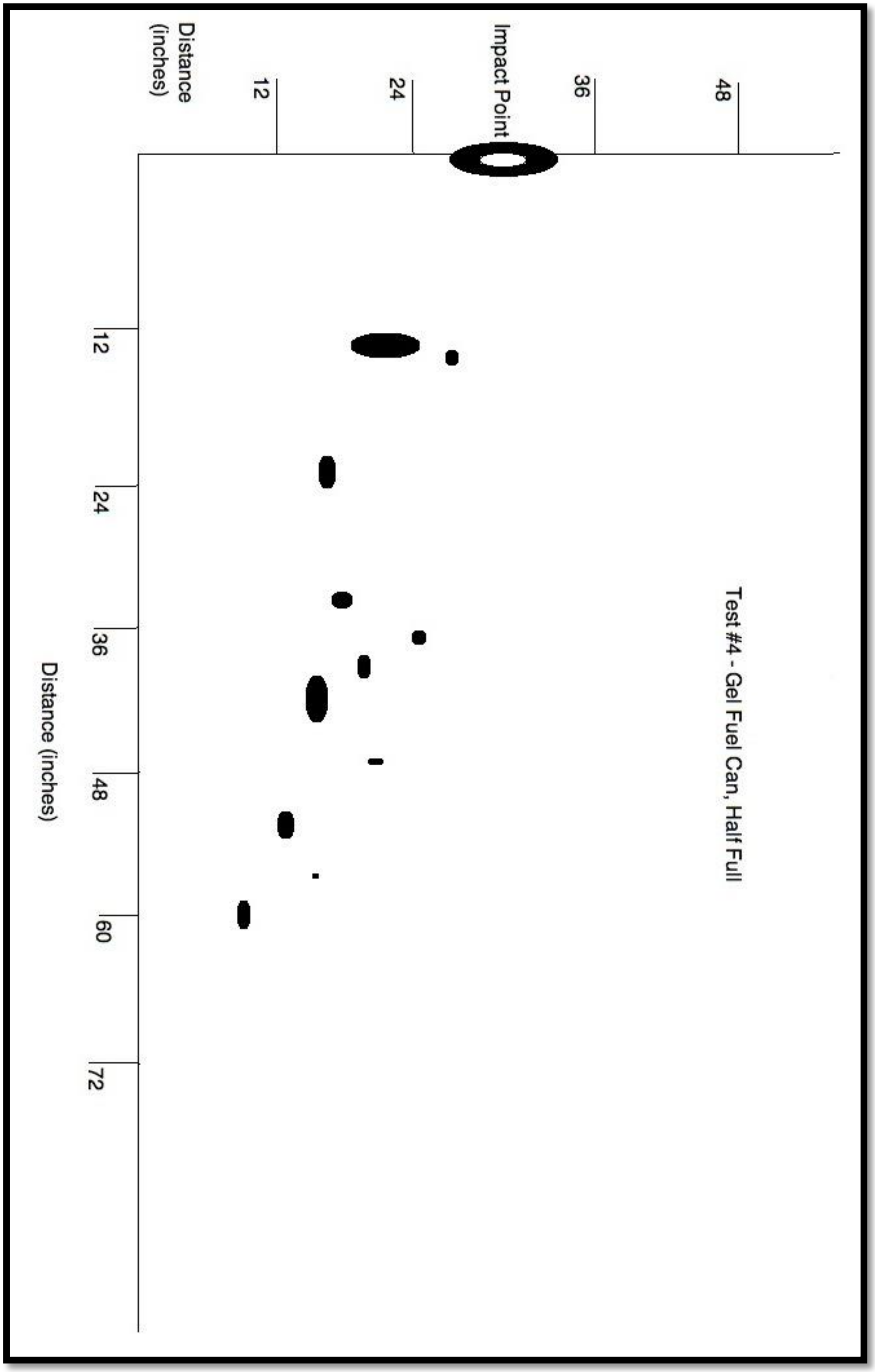
Extinguish Time: 7:27.3

Remaining Weight: 40.12g

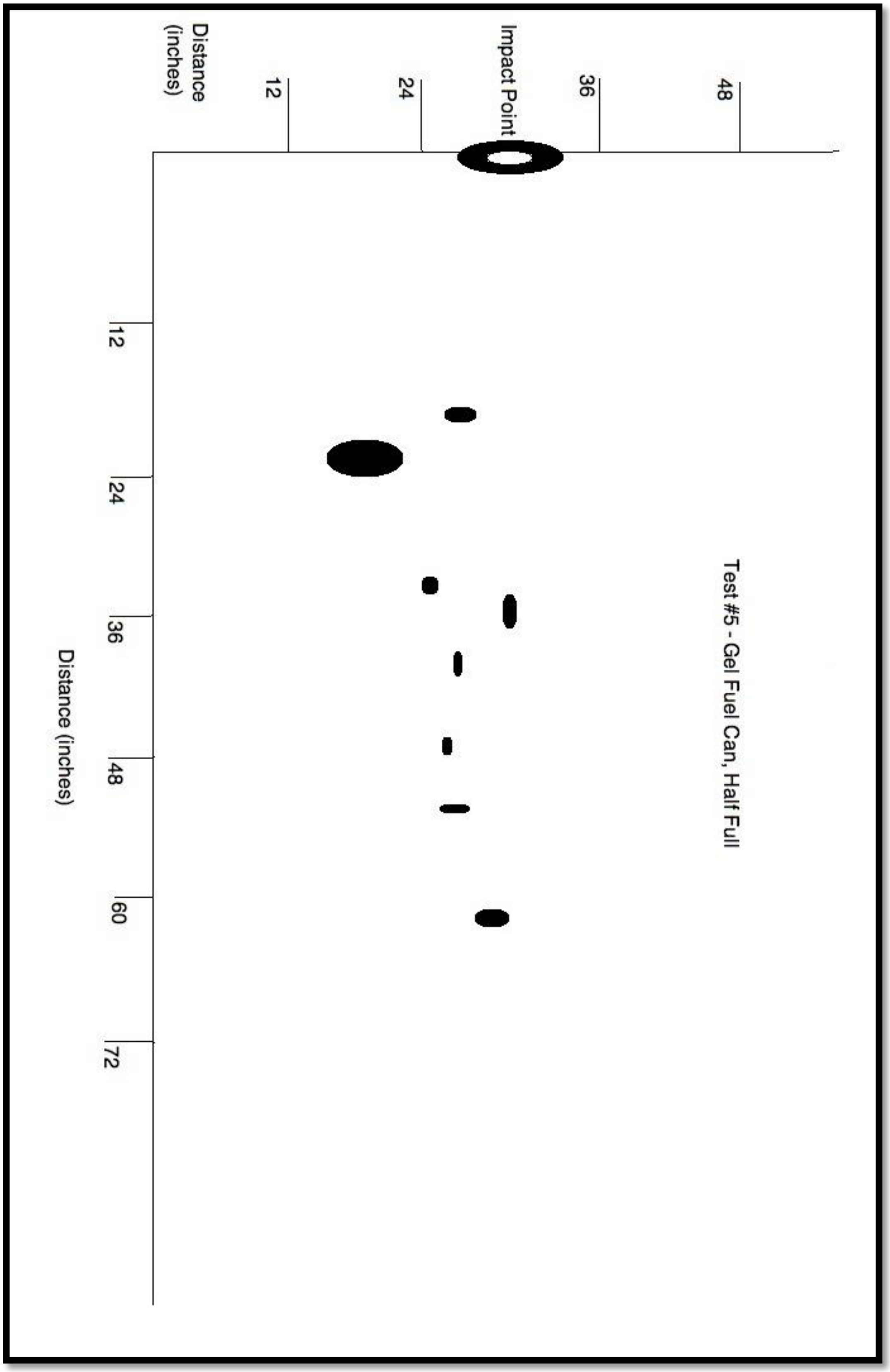

Test #1 - Full Gel Fuel Can
Impact Point
Distance (inches)
12
24
36
48
Distance (inches)
12
24
36
48
60
72

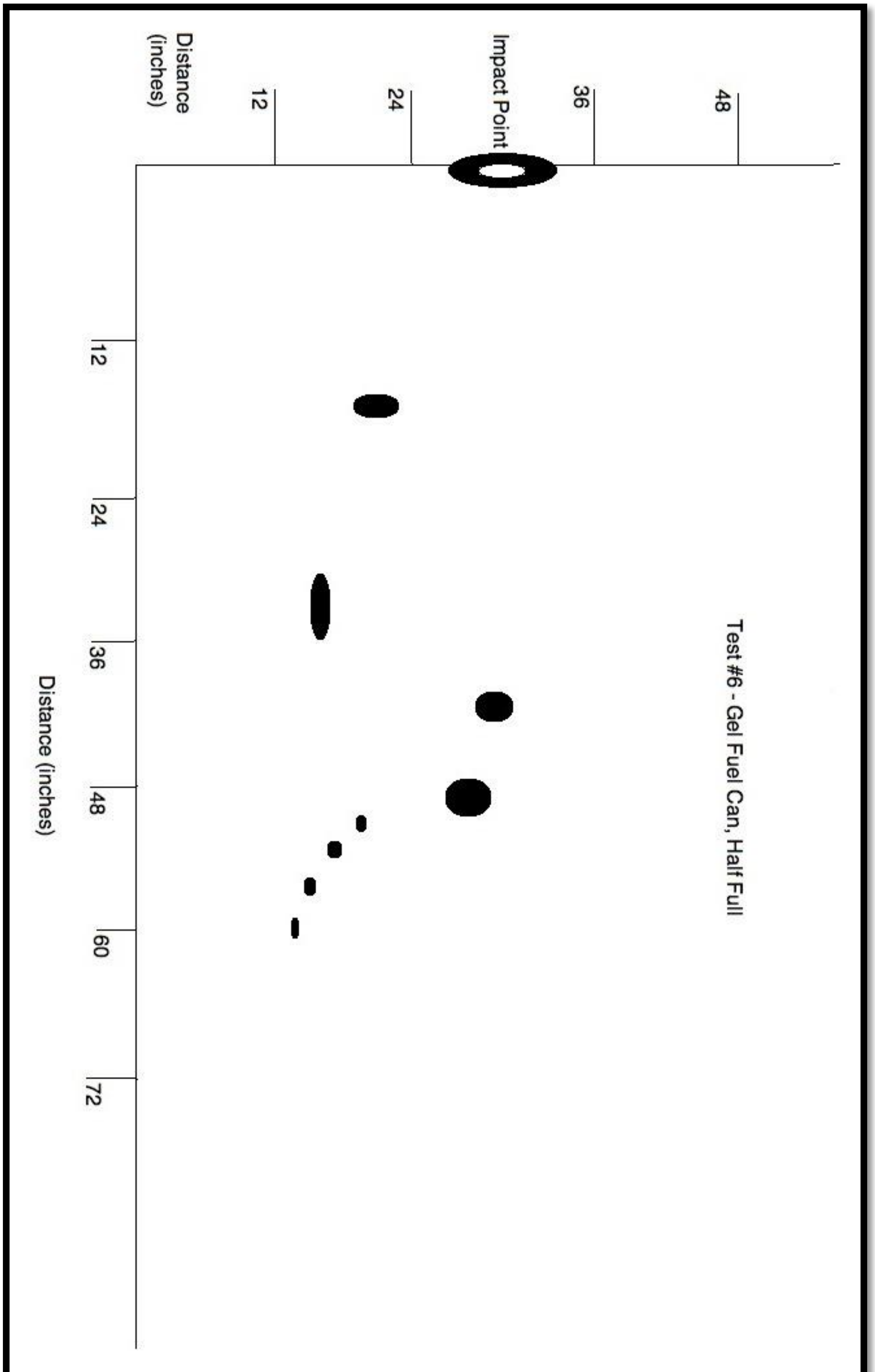

Test #2 - Full Gel Fuel Can
Impact Point
Distance (inches)
12
24
36
48
Distance (inches)
12
24
36
48
60
72


Test #3 - Gel Fuel Can
Impact Point
Distance (inches)
12
24
36
48
Distance (inches)
12
24
36
48
60
72

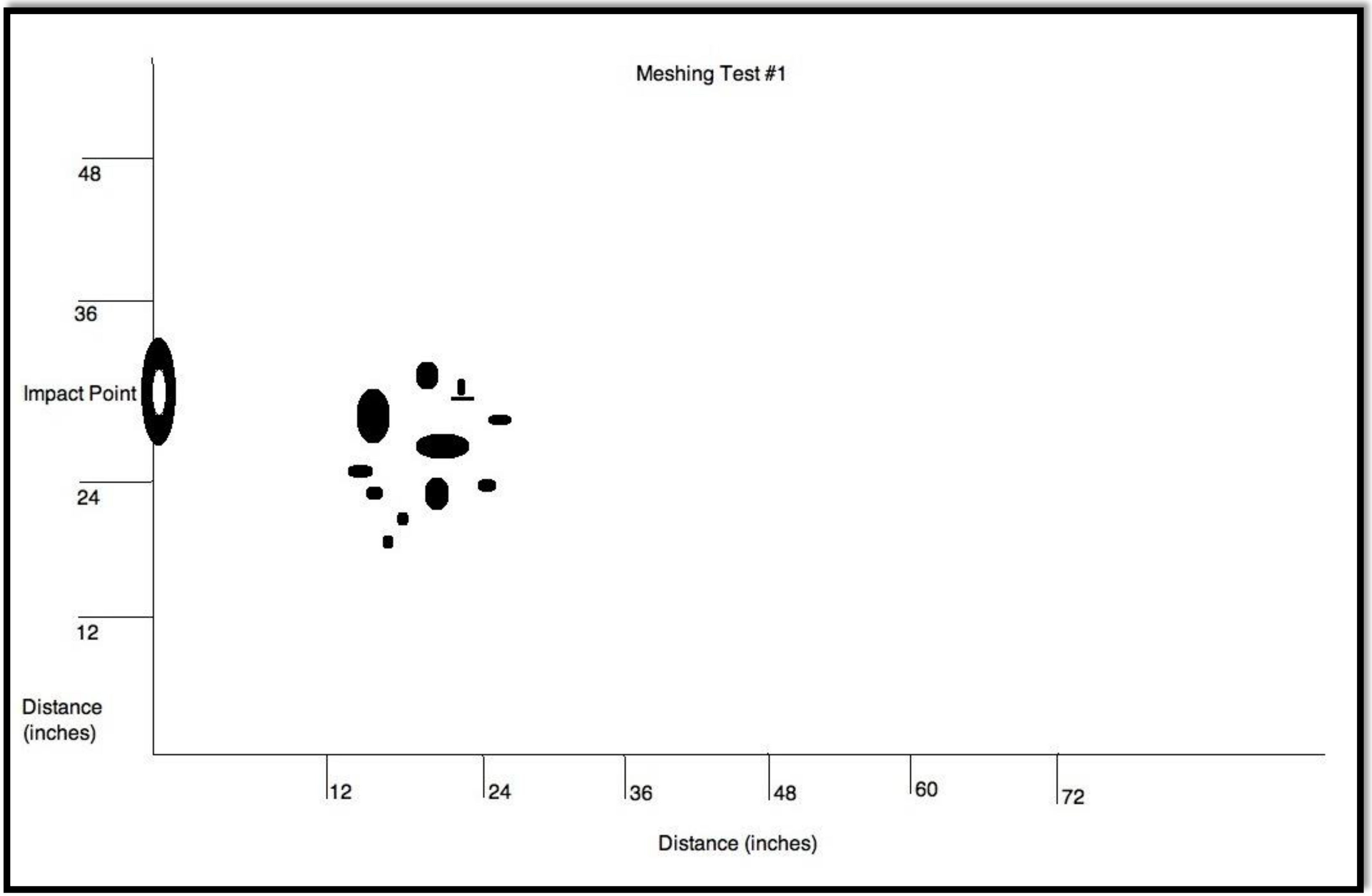


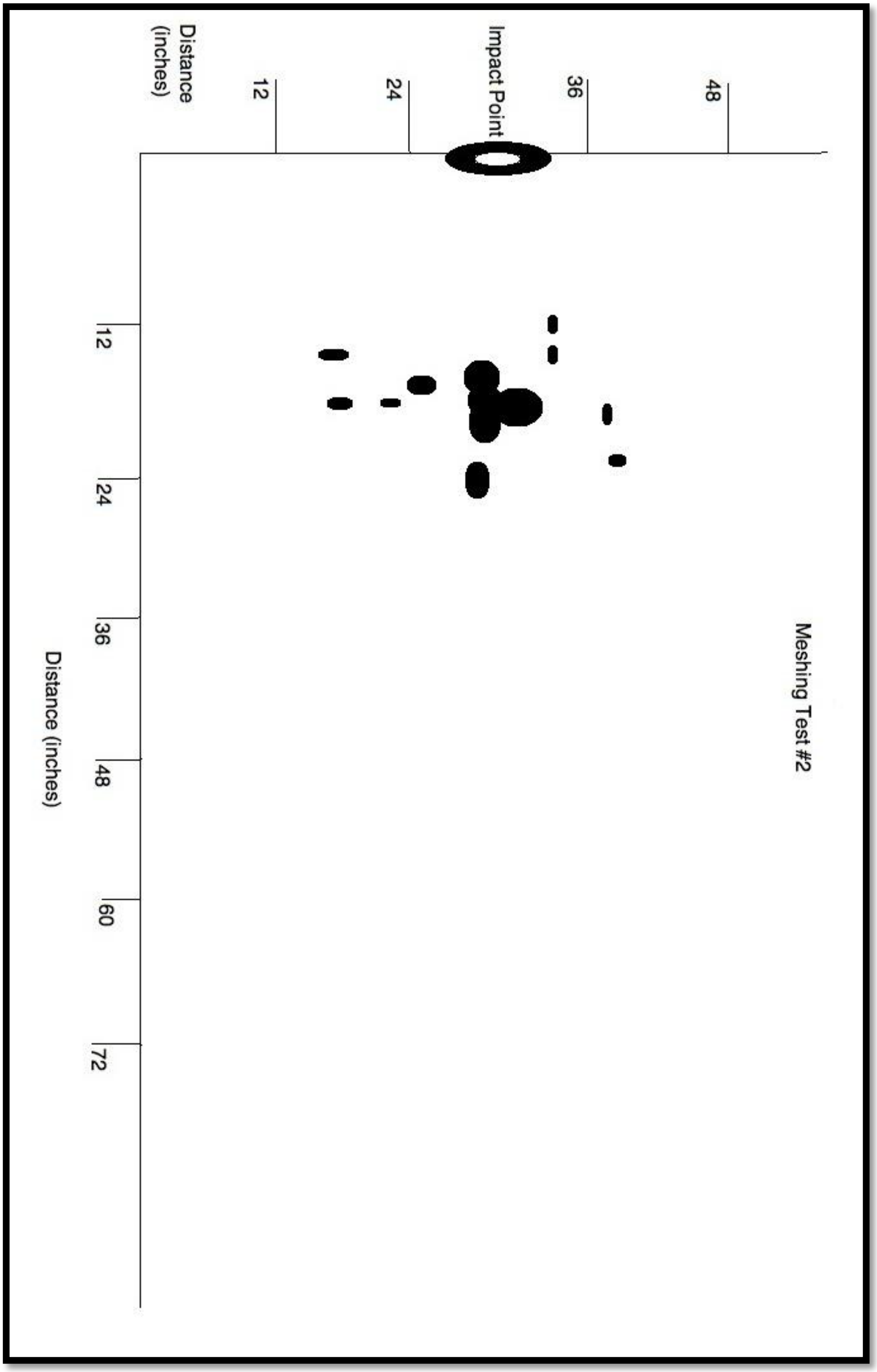
Test #4 - Gel Fuel Can, Half Full
Impact Point
Distance (inches)
12
24
36
48
Distance (inches)
12
24
36
48
60
72

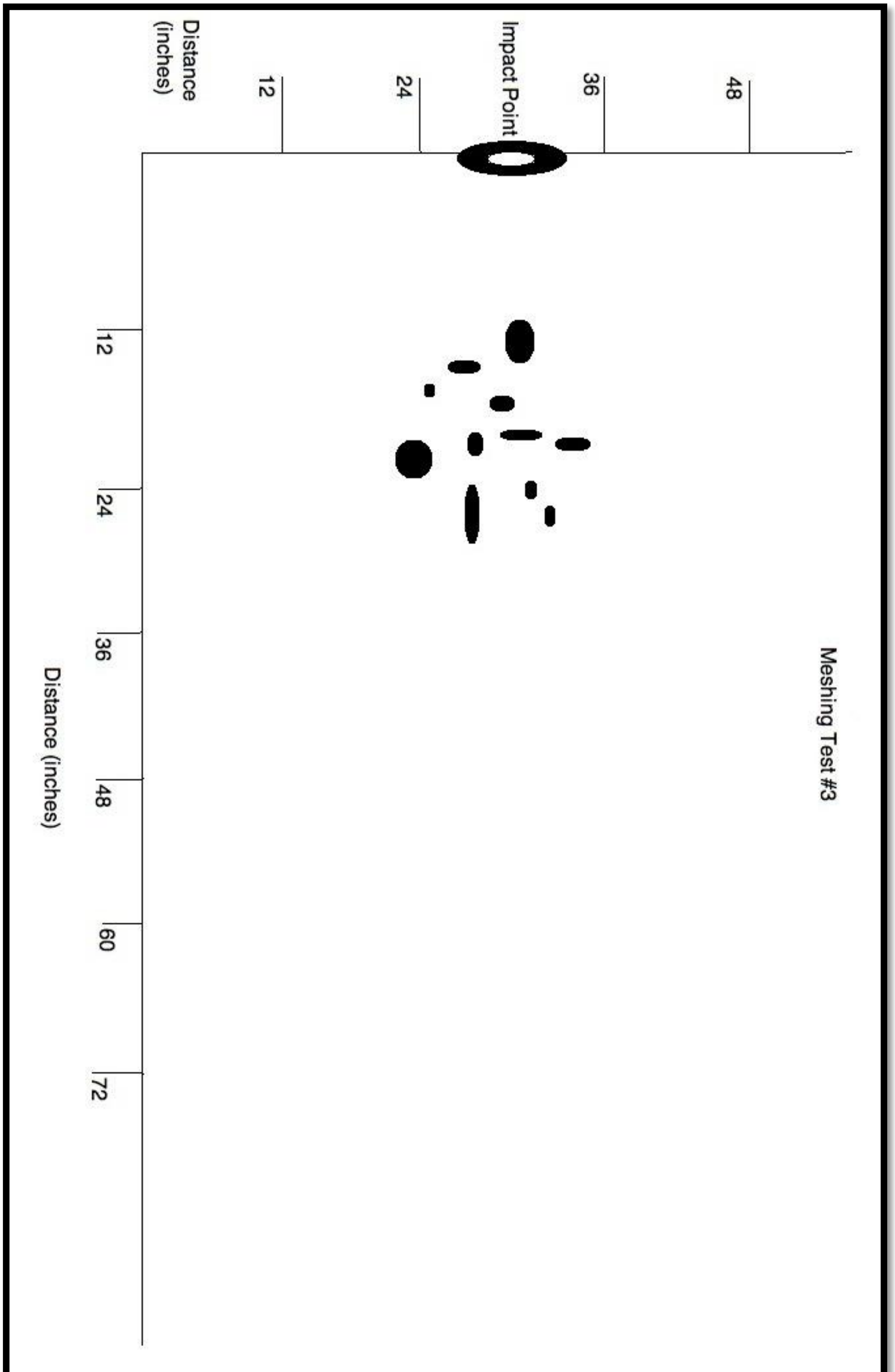

Test #5 - Gel Fuel Can, Half Full
Impact Point
Distance (inches)
12
24
36
48
Distance (inches)
12
24
36
48
60
72



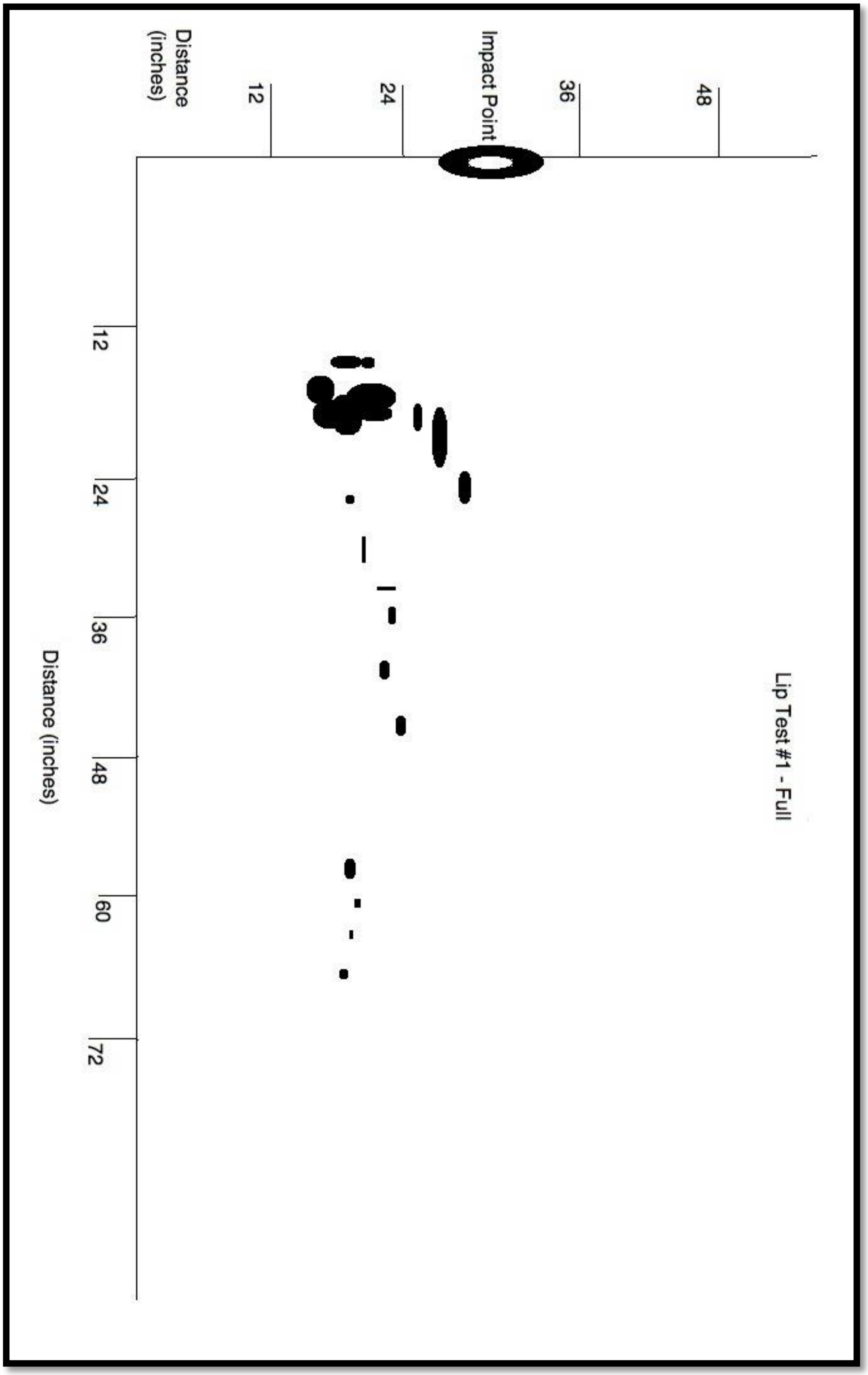
Test #6 - Gel Fuel Can, Half Full
Impact Point
Distance (inches)
12
24
36
48
Distance (inches)
12
24
36
48
60
72


Meshing Test #1
48
36
Impact Point
24
12
Distance (inches)
12
24
36
48
60
72
Distance (inches)
1

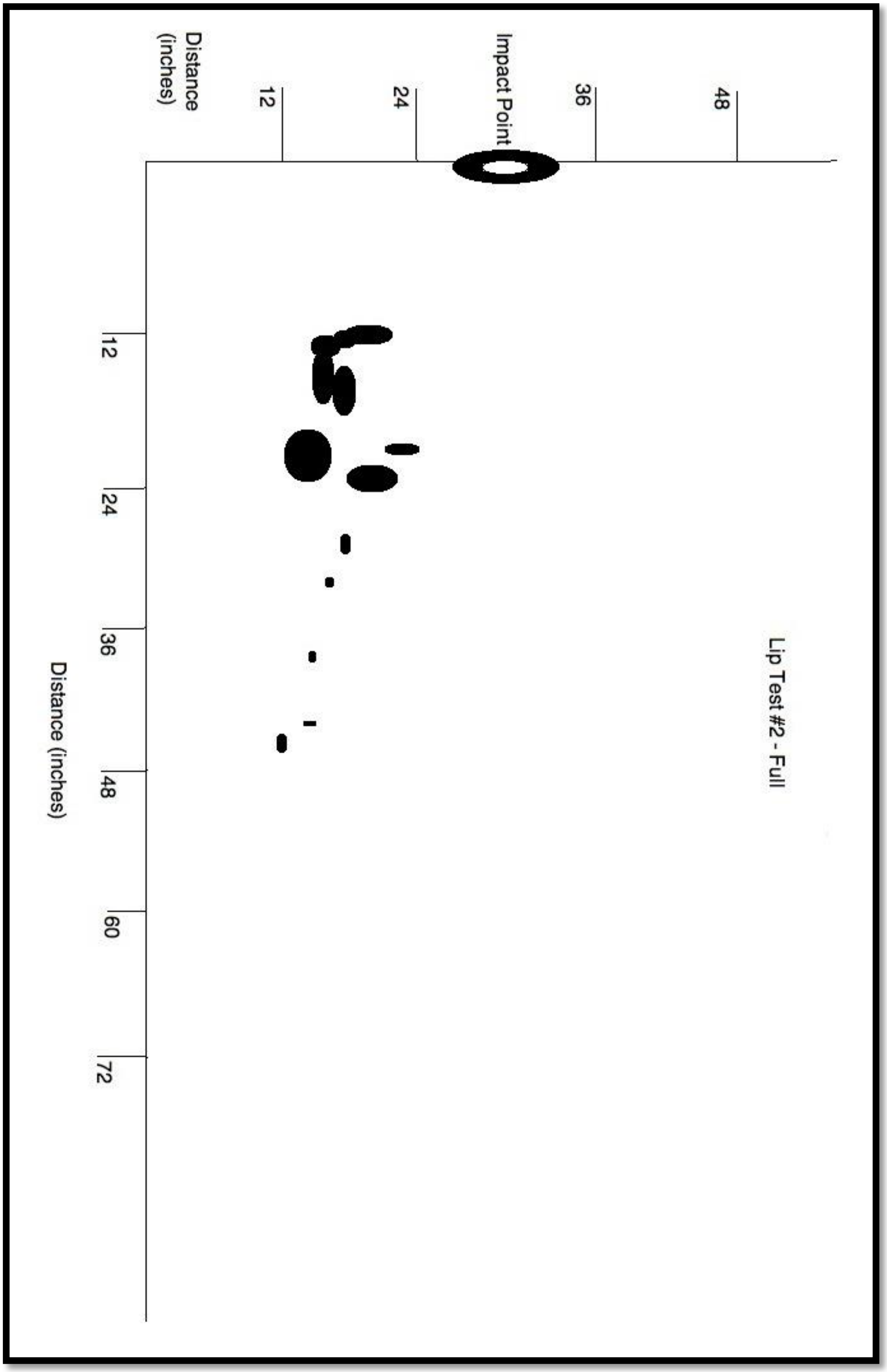

Meshing Test #2
Impact Point
Distance
(inches)
12
24
36
48
12
24
36
48
60
72
Distance (inches)

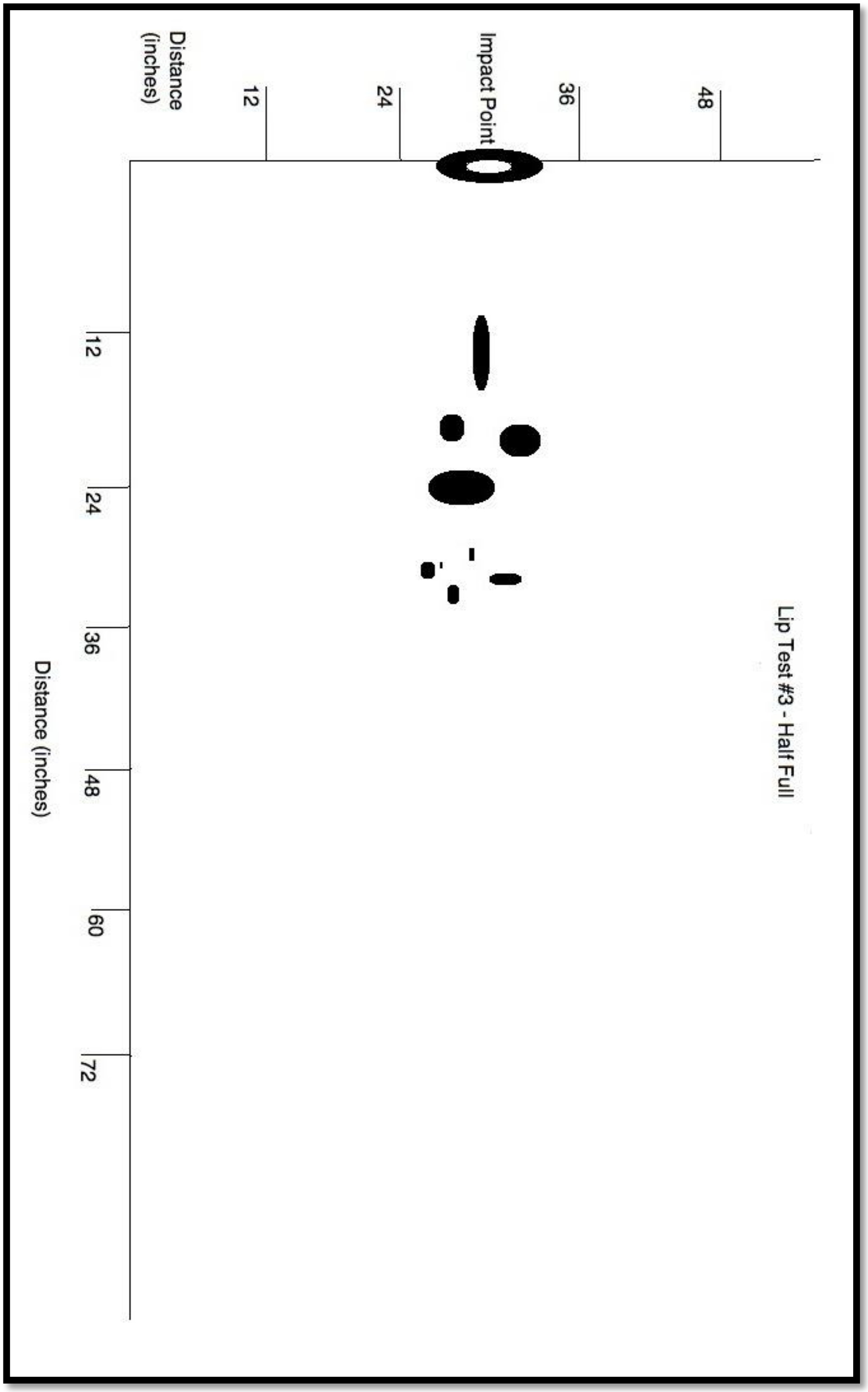


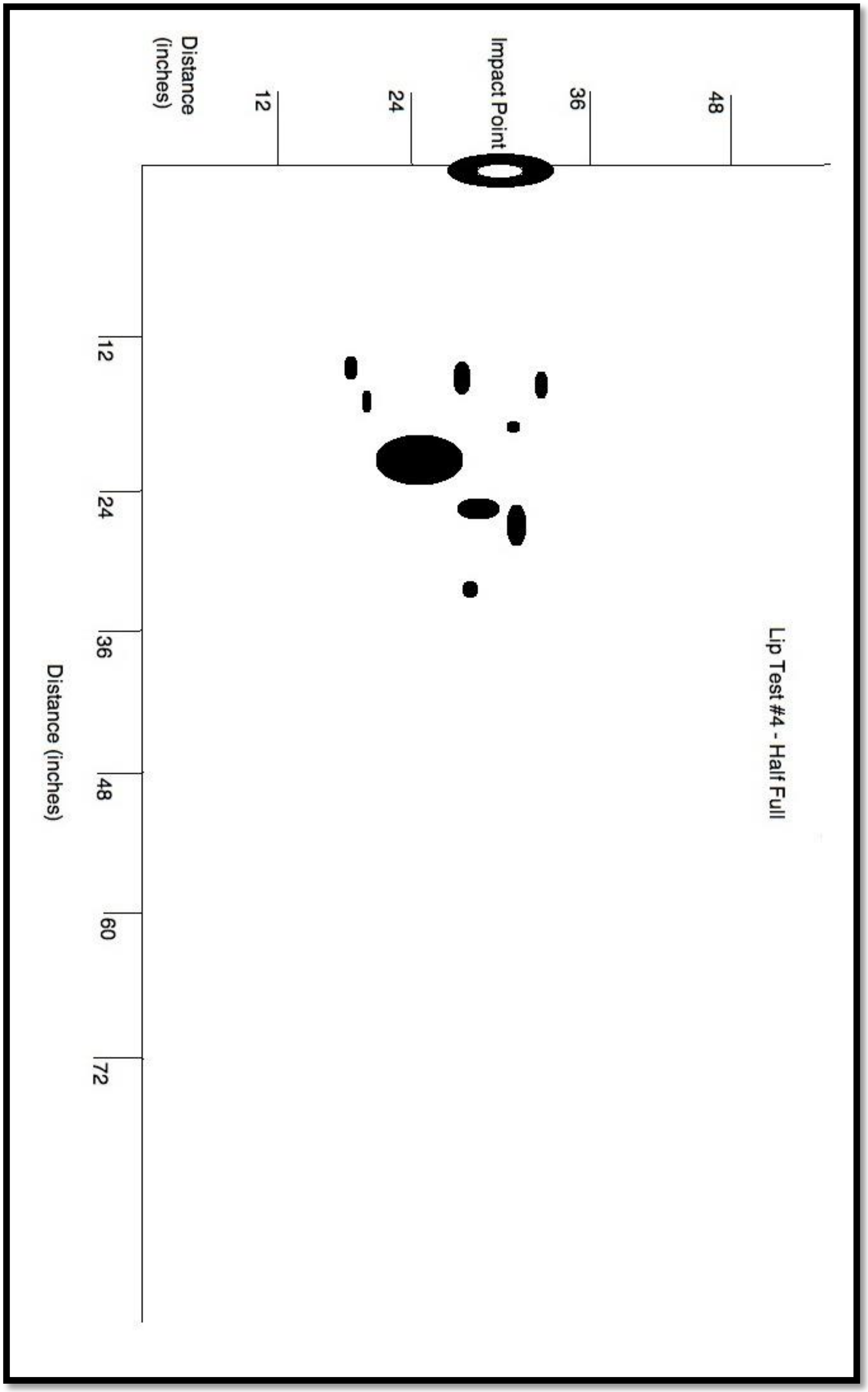
Meshing Test #3
Impact Point
Distance (inches)
12
24
36
48
Distance (inches)
12
24
36
48
60
72



Lip Test #1 - Full
Impact Point
Distance
(inches)
12
24
36
48
12
24
36
48
60
72
Distance (inches)


Lip Test #2 - Full
Impact Point
Distance (inches)
12
24
36
48
Distance (inches)
12
24
36
48
60
72


Lip Test #3 - Half Full
Impact Point
Distance
(inches)
12
24
36
48
12
24
36
48
60
72
Distance (inches)


Lip Test #4 - Half Full
Impact Point
Distance
(inches)
12
24
36
48
12
24
36
48
60
72
Distance (inches)

Appendix D: CPSC Gel Fuel Recall Documents

Bird Brain Recalls Pourable Gel Fuel Due to Burn and Flash Fire Hazards

WASHINGTON, D.C. - The U.S. Consumer Product Safety Commission, in cooperation with the firm named below, today announced a voluntary recall of the following consumer product. Consumers should stop using recalled products immediately unless otherwise instructed. It is illegal to resell or attempt to resell a recalled consumer product.

Name of Product: Bird Brain Firepot Fuel Gel, Bird Brain Firepot Citronella Fuel Gel and Bird Brain BioFuel Fuel Gel

Units: About 1.6 million bottles and cans

Distributor: Bird Brain Inc. of Ypsilanti, Mich.

Hazard: The pourable gel fuel can ignite unexpectedly and splatter onto people and objects nearby when it is poured into a firepot that is still burning. This hazard can occur if the consumer does not see the flame or is not aware that the firepot is still ignited. Gel fuel that splatters and ignites can pose fire and burn risks to consumers that can be fatal.

Incidents/Injuries: Bird Brain is aware of 20 reports of incidents, resulting in 11 injuries that involved first-, second- and third-degree burns.

Description: This recall involves pourable gel fuels packaged in 16-ounce 32-ounce and 64-ounce plastic bottles and sold with or without citronella oil. The labels on the container say "Bird Brain Firepot Fuel Gel" or "BioFuel Fuel Gel." The bottles were sold as single bottles and in multiple-bottle packages. The gel fuel is poured into a stainless steel cup in the center of ceramic firepots or other decorative lighting devices and ignited. The following products are affected by this recall:

Size	Model Name	Item Number	UPC
16 oz. Bottle	Firepot Clear Fuel Gel	11820010	03913803231-7
16 oz. Bottle	Firepot Citronella Fuel Gel	11820011	03913802866-2
32 oz. Bottle	Firepot Clear Fuel Gel	11820001 11820006 11820007 11820008 11820013 11820024	03913805081-6 03913805081-6 03913805081-6 03913805081-6 03913803591-2 03913807473-7
32 oz. Metal Can	Firepot Clear Fuel Gel	11820014 11820018	03913803160-0 03913803160-0
32 oz. Bottle	Firepot Citronella Fuel Gel	11820002 11820009 11820028	03913805082-3 03913805082-3 03913803592-9
32 oz. Metal Can	Firepot Citronella Fuel Gel	11820020 11820019	03913803161-7 03913803161-7
32 oz. Bottle	BioFuel Gel	11820016	03913803322-2
64 oz. Bottle	Firepot Clear Fuel Gel	11820022	03913803304-8
64 oz. Bottle	Firepot Citronella Fuel Gel	11820023	03913803305-5

Sold at: Sears, K-Mart, Target and other major retailers; Amazon.com, Target.com, Buy.com and various online specialty, home and garden, pet and gift shops and independent retailers from October 2008 through August 2011. Individual units were sold for between $8 and $18. Multi-packs were sold for between for between $18 and $136.

Manufactured in: U.S. and China

Remedy: Consumers should immediately stop using the pourable gel fuel and return the gel fuel to the company for a full refund.

Consumer Contact: For additional information, contact Bird Brain toll-free at (877) 414-0842 anytime (live operators available between 8:30 a.m. and 5:30 p.m. ET, Monday through Friday) or visit the company's website at www.birdbrainrecall.com

Release #11-336 CPSC Media Contact: (301) 504-7908

Note: The following press release provides consumers with safety information that was originally announced on September 1, 2011 in release #11-315.

Bond Manufacturing Recalls Pourable Gel Fuel Due to Burn and Flash Fire Hazards

WASHINGTON, D.C. - The U.S. Consumer Product Safety Commission, in cooperation with the firm named below, today announced a voluntary recall of the following consumer product. Consumers should stop using recalled products immediately unless otherwise instructed. It is illegal to resell or attempt to resell a recalled consumer product.

Name of Product: Bond Firebowl Pourable Gel Fuel Bottle and Jugs

Units: About 16,500 bottle and jugs

Manufacturers/Distributors: Bond Manufacturing Co., of Antioch, Calif.

Hazard: The pourable gel fuel can ignite unexpectedly and splatter onto people and objects nearby when it is poured into a firepot that is still burning. This hazard can occur if the consumer does not see the flame or is not aware that the firepot is still ignited. Gel fuel that splatters and ignites can pose fire and burn risks to consumers that can be fatal.

Incidents/Injuries: None

Description: This recall involves pourable gel fuel packaged in 32-ounce and 64-ounce plastic bottles and one-gallon plastic jugs and sold with or without citronella oil. The label on the containers says "Firebowl Gel Fuel" or "Firebowl Gel". The brand name "Bond" is on some versions of the label. The fuel is poured into a stainless steel cup in the center of ceramic firepots or other decorative lighting devices and ignited. This recall also includes a ceramic fire pot set of two bowls. The box says "2 pack Tabletop Gel Firebowls." The following products are included:

Size	Model Name	Item Number	UPC
32 oz.	Firebowl Gel Fuel	66140	034613661402
32 oz.	Firebowl Gel Fuel with Citronella	66201	034613662010
64 oz.	Firebowl Gel Fuel	66141	034613661419
64 oz.	Firebowl Gel Fuel with Citronella	66202	034613662027
2 pack	Ceramic Firebowl set	66146	034613661464

Sold at: Gordmans, Homeclick, SaveMart Supermarkets, Big R Stores, Hy-Vee and various hardware, garden and online stores nationwide from September 2010 until September 2011 for between $5 and $20.

Manufactured in: China

Remedy: Consumers should immediately stop using the pourable gel fuel in firepots and return all bottles or jugs to the company for a full refund.

Consumer Contact: For additional information, contact Bond Manufacturing toll-free at (866) 771-2663 between 8 a.m. and 4:30 p.m. PT Monday through Friday or visit the company's website at www.bondmfg.com

FOR IMMEDIATE RELEASE
September 28, 2011
Release #11-337

Firm's Recall Hotline: (877) 469-6347
CPSC Recall Hotline: (800) 638-2772
CPSC Media Contact: (301) 504-7908

Note: The following press release provides consumers with safety information that was originally announced on September 1, 2011 in release #11-315

Fuel Barons Recalls Pourable Gel Fuels Due to Burn and Flash Fire Hazards

WASHINGTON, D.C. - The U.S. Consumer Product Safety Commission, in cooperation with the firm named below, today announced a voluntary recall of the following consumer product. Consumers should stop using recalled products immediately unless otherwise instructed. It is illegal to resell or attempt to resell a recalled consumer product.

Name of Product: OZOfire™ Pourable Gel Fuel (Formula 4) and SUREFIRE™ Pourable Gel Fuel (Formula 4) Bottles

Units: About 14,000 bottles and jugs

Manufacturers/Distributors: Fuel Barons Inc., of Stateline, Nev.

Hazard: The pourable gel fuel can ignite unexpectedly and splatter onto people and objects nearby when it is poured into a firepot that is still burning. This hazard can occur if the consumer does not see the flame or is not aware that the firepot is still ignited. Gel fuel that splatters and ignites can pose fire and burn risks to consumers that can be fatal.

Incidents/Injuries: Fuel Barons has received one report of an incident where a man sustained second-degree burns to his hand and wrist.

Description: The recall involves pourable gel fuels packaged in one-quart and one-gallon plastic bottles and plastic jugs and sold with or without citronella. The label on the container says "OZOfire™" or "SUREFIRE™," "Formula 4" and "Pure Bio-Ethanol Fuel Pourable Gel." The fuel is poured into a stainless steel cup in the center of ceramic firepots or other decorative lighting devices and ignited. The following products are affected by this recall:

Size	Model
1 QT	OZOfire™ F4 Pourable Gel Fuel
1 QT	SUREFIRE™ S4 Pourable Gel Fuel
1 GAL	OZOfire™ F4 Pourable Gel Fuel

Sold: Online at Windflame.com as well as other online retailers from January 2010 until August 2011 for between $8.50 and $22.

Manufactured in: United States

Remedy: Consumers should immediately stop using the pourable gel fuel in firepots and call the toll free hotline for instructions on how to receive a full refund.

Consumer Contact: For additional information, contact Fuel Barons toll-free at (877) 469-6347 between 9 a.m. and 6 p.m. ET Monday through Friday or visit the company's website at www.fuelbarons.com

FOR IMMEDIATE RELEASE
September 7, 2011
Release #11-346

Firm's Recall Hotline: (866) 671-7988
CPSC Recall Hotline: (800) 638-2772
CPSC Media Contact: (301) 504-7908

Note: The following press release provides consumers with safety information that was originally announced on September 1, 2011 in release #11-315.

Lamplight Farms Recalls Pourable Gel Fuel Due to Burn and Flash Fire Hazards

WASHINGTON, D.C. - The U.S. Consumer Product Safety Commission, in cooperation with the firm named below, today announced a voluntary recall of the following consumer products. Consumers should stop using recalled products immediately unless otherwise instructed. It is illegal to resell or attempt to resell a recalled consumer product.

Name of Product: TIKI® Brand Gel Fuel and TIKI® Brand Citronella Gel Fuel bottles and jugs

Units: About 217,000 bottles and jugs

Distributor: Lamplight Farms Inc., of Menomonee Falls, Wis.

Hazard: The pourable gel fuel can ignite unexpectedly and splatter onto people and objects nearby when it is poured into a fire pot that is still burning. This hazard can occur if the consumer does not see the flame or is not aware that the fire pot is still ignited. Gel fuel that splatters and ignites can pose fire and burn risks to consumers that can be fatal.

Incidents/Injuries: Lamplight has received one report of an incident in which a consumer poured gel fuel on a fire pot that was still burning, resulting in burns to a bystander's arm that required medical treatment.

Description: This recall involves pourable gel fuels packaged in one-quart plastic bottles. They are sold with or without citronella. The fuel is poured into a stainless steel cup in the center of ceramic fire pots. The label on the container reads "TIKI® GEL FUEL." The following products are included in this recall:

Size	Scent	UPC
1 QT	Natural	086861094105
1 QT	Citronella	086861100455

Sold at: Retail stores nationwide and online from December 2010 through September 2011 for about $10.

Manufactured in: United States

Remedy: Consumers should immediately stop using the pourable gel fuel in fire pots and call Lamplight Farms to arrange for the gel fuel to be returned to Lamplight for a full refund.

Consumer Contact: For additional information, contact Lamplight Farms toll-free at (866) 671-7988 between 8 a.m. and 5 p.m. CT Monday through Friday or visit the company's website at www.lamplight.com

FOR IMMEDIATE RELEASE
September 28, 2011
Release #11-340

Firm's Recall Hotline: (855) 774-2260
CPSC Recall Hotline: (800) 638-2772
CPSC Media Contact: (301) 504-7908

Note: The following press release provides consumers with safety information that was originally announced on September 1, 2011 in release #11-315.

Luminosities/Windflame Recalls Pourable Gel Fuels Due to Burn and Flash Fire Hazards

WASHINGTON, D.C. - The U.S. Consumer Product Safety Commission, in cooperation with the firm named below, today announced a voluntary recall of the following consumer product. Consumers should stop using recalled products immediately unless otherwise instructed. It is illegal to resell or attempt to resell a recalled consumer product.

Name of Product: OZOfire™ Pourable Gel Fuel (Formula 4) Bottles

Units: About 26,500 bottles

Distributor: Luminosities/Windflame Inc., of St. Paul, Minn.

Manufacturer: Fuel Barons Inc., of Stateline, Nev.

Hazard: The pourable gel fuel can ignite unexpectedly and splatter onto people and objects nearby when it is poured into a firepot that is still burning. This hazard can occur if the consumer does not see the flame or is not aware that the firepot is still ignited. Gel fuel that splatters and ignites can pose fire and burn risks to consumers that can be fatal.

Incidents/Injuries: Luminosities/Windflame has received one report of an incident involving the gel fuel. No injuries have been reported.

Description: The recall involves pourable OZOfire™ pourable gel fuel packaged in clear one-quart plastic bottles. The gel fuel does not have citronella. The label on the container include the words "OZOfire™," "Fuel Barons Inc.," "Formula 4," and "Pure Bio-Ethanol Fuel Pourable Gel." The fuel is poured into a stainless steel cup in the center of ceramic firepots or other decorative lighting devices and ignited. The following products are affected by this recall:

Size	Model	UPC
1 QT	OZOfire™ Pourable Gel Fuel (Formula 4)	UPC 804879254133

Sold at: Online at specialty and gift shops, furniture stores and home and garden stores and other stores nationwide, through home and garden catalogs and home decorators and landscape architects and online including www.amazon.com October 2010 through August 2011 for between $4 and $12.

Manufactured in: United States

Remedy: Consumers should immediately stop using the pourable gel fuel in firepots and return all bottles to the retailer where the consumer purchased the fuel for a full refund.

Consumer Contact: For additional information, contact Luminosities/Windflame toll-free at (855) 774-2260 between 8 a.m. and 5 p.m. CT Monday through Friday or visit the firm's website at www.windflame.com

FOR IMMEDIATE RELEASE
September 29, 2011
Release #11-344

Firm's Recall Hotline: (425) 949-7878
CPSC Recall Hotline: (800) 638-2772
CPSC Media Contact: (301) 504-7908

Note: The following press release provides consumers with safety information that was originally announced on September 1, 2011 in release #11-315.

Pacific Décor Recalls Pourable Gel Fuel Due to Burn and Flash Fire Hazards

WASHINGTON, D.C. - The U.S. Consumer Product Safety Commission, in cooperation with the firm named below, today announced a voluntary recall of the following consumer product. Consumers should stop using recalled products immediately unless otherwise instructed. It is illegal to resell or attempt to resell a recalled consumer product.

Name of Product: Pacific Flame Pourable Gel Fuel Bottles

Units: About 3,600 bottles

Manufacturer/Distributor: Pacific Décor Ltd., of Woodinville, Wash.

Hazard: The pourable gel fuel can ignite unexpectedly and splatter onto people and objects nearby when it is poured into a firepot that is still burning. This hazard can occur if the consumer does not see the flame or is not aware that the firepot is still ignited. Gel fuel that splatters and ignites can pose fire and burn risks to consumers that can be fatal.

Incidents/Injuries: None reported.

Description: This recall involves pourable gel fuel packaged in one-quart, white plastic bottles, and sold with and without citronella. The label on the container says "Pacific Flame" and "Premium pourable gel fuel." The fuel is poured into a stainless steel cup in the center of ceramic firepots or other decorative lighting devices and ignited. The following products are affected by this recall:

Size	Model Number	SKU
1 QT	160	095583001605
1 QT (with citronella)	170	095583001704

Sold at: Online, in specialty and gift shops, furniture stores and home and garden stores nationwide, through home and garden catalogs and home decorators and landscape architects from June 2011 through August 2011 for between $10 and $12.

Manufactured in: United States

Remedy: Consumers should immediately stop using the pourable gel fuel in firepots and return all bottles to the retailer where the consumer purchased the fuel for a full refund.

Consumer Contact: For additional information, contact Pacific Décor at (425) 949-7878 between 8 a.m. and 5 p.m. PT Monday through Friday or visit the firm's website at www.PacificDecorLtd.com

FOR IMMEDIATE RELEASE
September 28, 2011
Release #11-338

Firm's Recall Hotline: (866) 918-8766
CPSC Recall Hotline: (800) 638-2772
CPSC Media Contact: (301) 504-7908

Note: The following press release provides consumers with safety information that was originally announced on September 1, 2011 in release #11-315.

Real Flame Recalls Pourable Gel Fuel Due to Burn and Flash Fire Hazards

WASHINGTON, D.C. - The U.S. Consumer Product Safety Commission, in cooperation with the firm named below, today announced a voluntary recall of the following consumer product. Consumers should stop using recalled products immediately unless otherwise instructed. It is illegal to resell or attempt to resell a recalled consumer product.

Name of Product: Real Flame Pourable Gel Fuel Bottles

Units: About 100,000 bottles

Distributor: Real Flame, of Racine, Wis.

Hazard: The pourable gel fuel can ignite unexpectedly and splatter onto people and objects nearby when it is poured into a firepot that is still burning. This hazard can occur if the consumer does not see the flame or is not aware that the firepot is still ignited. Gel fuel that splatters and ignites can pose fire and burn risks to consumers that can be fatal.

Incidents/Injuries: None reported

Description: This recall involves pourable gel fuels sold in 29.9-ounce and 29.98-ounce, one-quart clear plastic bottles and sold with or without citronella oil. The label on the container has a stylized flame and the words "Real Flame" and "Pourable Gel Fireplace Fuel." The fuel is poured into a stainless steel cup in the center of ceramic firepots or other decorative lighting devices and ignited. The following products are affected by this recall:

Size	Model Number	SKU
29.9 ounce	2164	752-370012641
1 QT	2164	752-370012641
29.98 ounce with Citronella	2165	752-370021658

Sold at: Target.com, Meijer.com, JCPenney.com, Sears.com, Amazon.com and Realflame.com from January 2009 through August 2011 for between $10 and $13.

Manufactured in: United States

Remedy: Consumers should immediately stop using the pourable gel fuel and return the gel fuel to the firm for a full refund.

Consumer Contact: For additional information, contact Real Flame toll-free at (866) 918-8766 between 8 a.m. and 5 p.m. ET Monday through Friday, visit the firm's website at www.realflamerecall.com or write to the firm at Real Flame, 7800 Northwestern Ave., Racine, Wis. 53406

FOR IMMEDIATE RELEASE
September 28, 2011
Release #11-339

Firm's Recall Hotline: (813) 343-5770
CPSC Recall Hotline: (800) 638-2772
CPSC Media Contact: (301) 504-7908

Note: The following press release provides consumers with safety information that was originally announced on September 1, 2011 in release #11-315.

Smart Solar Recalls Pourable Gel Fuel Due to Burn and Flash Fire Hazards

WASHINGTON, D.C. - The U.S. Consumer Product Safety Commission, in cooperation with the firm named below, today announced a voluntary recall of the following consumer product. Consumers should stop using recalled products immediately unless otherwise instructed. It is illegal to resell or attempt to resell a recalled consumer product.

Name of Product: Smart Jel Gel Fuel bottles

Units: About 1,400 bottles

Manufacturer/Distributor: Smart Solar Inc., of Oldsmar, Fla.

Hazard: The pourable gel fuel can ignite unexpectedly and splatter onto people and objects nearby when it is poured into a firepot that is still burning. This hazard can occur if the consumer does not see the flame or is not aware that the firepot is still ignited. Gel fuel that splatters and ignites can pose fire and burn risks to consumers that can be fatal.

Incidents/Injuries: None reported

Description: This recall involves pourable gel fuels packaged in 30-ounce plastic bottles and sold with or without citronella. The label on the container says "Smart Garden" and "SmartJel." The fuel is poured into a metal cup in the center of ceramic firepots or other decorative lighting devices and ignited. The following products included in this recall:

Size	Model Number/SKU	Description
30 oz.	SJ3200	SmartJel Citronella Formula IPA Gel Refill
30 oz.	SJ3201	SmartJel Unscented Formula IPA Gel Refill

Sold at: Online and selected specialty stores from January 2011 through June 2011 for between $10 and $20.

Manufactured in: United States

Remedy: Consumers should immediately stop using the pourable gel fuel in firepots and return all bottles to the company for a full refund.

Consumer Contact: For additional information, contact Smart Solar at (813) 343-5770 between 9 a.m. and 5 p.m. ET Monday through Friday or visit the company's website at www.smartsolar.com