NIST Technical Note 1791

Evaluation of Firepots and Gel Fuels

Nathan D. Marsh

http://dx.doi.org/10.6028/NIST.TN.1791

National Institute of
Standards and Technology
U.S. Department of Commerce

NIST Technical Note 1791

Evaluation of Firepots and Gel Fuels

Nathan D. Marsh

Fire Research Division
Engineering Laboratory

http://dx.doi.org/10.6028/NIST.TN.1791

March 2013

U.S. Department of Commerce
Rebecca Blank, Acting Secretary

National Institute of Standards and Technology
Patrick D. Gallagher, Under Secretary of Commerce for Standards and Technology and Director

National Institute of Standards and Technology Technical Note 1791
Natl. Inst. Stand. Technol. Tech. Note 1791, 8 pages (March 2013)
http://dx.doi.org/10.6028/NIST.TN.1791
CODEN: NTNOEF

Abstract

The U.S. Consumer Product Safety Commission (CPSC) has identified a fire and burn hazard associated with a class of products often referred to as "firepots", which has been associated with 2 deaths and 114 injuries as of August 31, 2012. The objective of this report is to define the firepot safety problems and to identify potential technical mitigation approaches that would benefit from further study. The essential feature of this class of products, relative to the burn hazard, is the open-ended design of the fuel reservoir, which is both the location for adding fuel and the intended location of the flame. An exacerbating factor in firepot accidents is the fuel viscosity, which in some fuels is increased artificially (to create "gel fuel"). A typical spill of ethanol from a firepot could have a heat release rate on the order of 130 kW and a mean flame height on the order of 1 m, based on pool fire theory. The safety of alcohol-fueled heat and light sources could be improved if they were subject to performance standards similar to those for candles. In addition, alcohol-based fuels could be separated into two categories: a high-viscosity fuel for non-refillable fuel containers, and a low-viscosity pourable fuel with a required integral flame arrestor on the fuel storage container.

1. Introduction

The U.S. Consumer Product Safety Commission (CPSC) has identified a fire and burn hazard associated with a class of products often referred to as "firepots" [1], which has been associated with 2 deaths and 114 injuries as of August 31, 2012 [**2**]. The objective of this report is to define the firepot safety problems and to identify potential technical mitigation approaches that would benefit from further study.

Firepots are usually marketed as decorative heating and lighting items for the home. They typically, but not necessarily, consist of an outer ceramic housing similar in size and shape to a vase or flower pot, and a small metal insert-cup similar in size and shape to a typical coffee mug (without the handle) with a volume of 200 mL to 500 mL. In its intended use, the metal insert is filled with an alcohol-based fuel, which is then ignited and burns across the open surface of the cup.

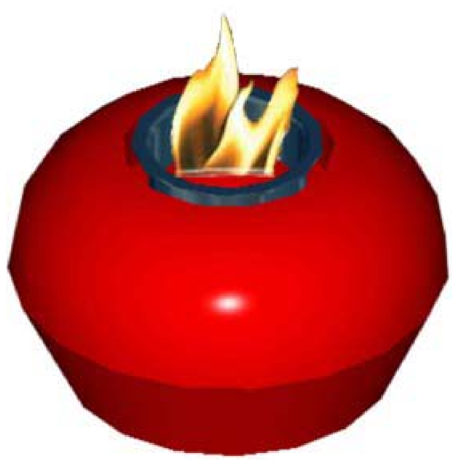

Figure 1. Rendering of a firepot (source: CPSC Briefing Memorandum)

Based on the CPSC investigation [1], the majority of accidents occurred when the firepots were being re-fueled. The CPSC analysis determined the likely course of events leading to these accidents: the fuel had burned down, but not out; the fuel vapor and air mixture inside the fuel storage container was within the flammability limits; and when fuel was added to an existing flame, this vapor mixture was ignited. The resulting rapid increase in pressure caused an expulsion of burning fuel from the fuel container. Figure 2 shows a schematic of this scenario. Given the combination of the flammability of the air / fuel vapor mixture with the open flame located on the fuel reservoir of the firepot, this accident scenario is likely to continue to occur.

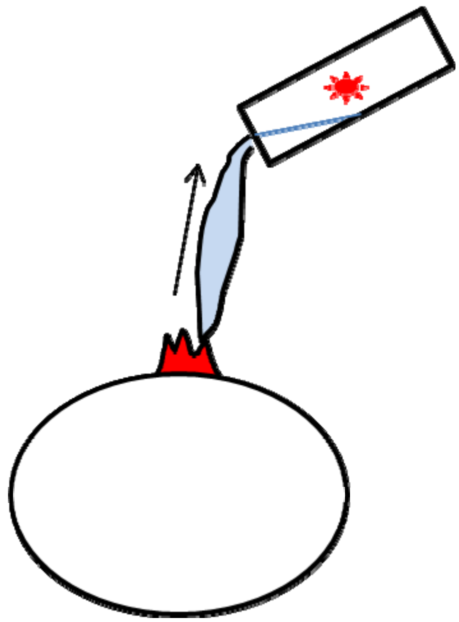

Figure 2. Schematic of primary incident scenario

An exacerbating factor in these accidents is the fuel viscosity, which in some fuels is increased artificially, to create a "gel fuel". The intent behind increasing fuel viscosity may be to increase safety - by preventing the fuel from being confused with a beverage or by reducing the area of a spill (and therefore the severity of a resulting fire). While increasing the viscosity may address these concerns, it also introduces a new hazard, in that the more viscous fuels may result in a greater mass of fuel adhering to the victims; and, anecdotally, the high-viscosity fuels are more resistant to attempts to smother the flames. There may be alternative solutions to concerns regarding ingestion and spill, including adding a colorant or odorant, and increasing the mechanical stability of the appliance.

The rest of this report is broken into three parts. In the next section, key characteristics of firepots that impact fire safety are reviewed. In Section 3, the potential fire hazard from a firepot fuel spill is estimated. In Section 4, firepot design improvements are considered. In Section 5, firepot fuel characteristics and safety considerations are discussed. The last section concludes with recommendations for future research, emphasizing the need to study the effectiveness of flame arrestor designs and to develop a qualifying safety test method.

2. Characteristics of firepots

The essential feature of this type of product, relative to the burn hazard, is the open-ended design of the fuel reservoir, which is both the location for adding fuel and the intended location of the flame. This may be problematic and warrants further study. Firepots do not have a wick or a perforated cap, the features of products such as outdoor torches and camp stoves. An alternative design may improve safety by separating the location for adding fuel from the flame. In addition, firepots tend to be relatively small and light (under 10 kg [3]) which means they can be accidentally tipped over, resulting in a fuel spill, although this is not the most common accident scenario.

3. Estimation of fire hazard from a spill

In the event of a fuel spill, the fire hazard can be estimated from pool fire theory for a flat and level non-porous surface. The size of the spill is a function of the volume of the fuel and its viscosity, given by: [4]

$$D = 0.373\ (\sigma Vt/\mu)^{1/4}$$

where D is the pool diameter (m)

σ is the surface tension of the fuel (N/m)

V is the volume of fuel spilled (L)

t is the time after the spill (sec)

μ is the viscosity of the fuel (Pa s)

Alternately, an empirical estimation of relatively small typical fuel spills under 95 L finds their average depth to be 0.7 mm [5]. In the case of a typical firepot with a capacity of 0.25 L, this would result in a spill area of 0.3 m^2 or a diameter of 0.7 m. Higher viscosity fuel gels would result in smaller spill areas, varying in the above equation by $(1/\mu)^{1/4}$. Viscosity is a function of temperature and the fuel in a burning firepot can be expected to have a lower viscosity than a non-burning firepot.

Likewise, the mean flame height and heat release rate are directly related to the diameter of the pool:

$$L = 0.23Q^{2/5} - 1.02D$$

where L is the mean flame height (m)

D is the pool diameter (m), and

$$Q = m'' \Delta H_{c,eff} A$$

where Q = pool fire heat release rate (kW)

m'' = mass burning rate of fuel per unit surface area (kg/m^2 sec)

$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

A = surface area of pool fire (area involved in vaporization) (m^2)

A typical 0.25 L spill of liquid ethanol from a firepot could produce a heat release rate on the order of 130 kW and an average flame height on the order of 1 m. Such a large flame could ignite nearby items, including furniture, carpeting, or clothing. (For this example using ethanol, m'' = 0.015 kg/m^2-sec and $\Delta H_{c,eff}$ = 26 800 kJ/kg) Peak heat release rates for spills on nonporous surfaces have been found, experimentally, to be approximately 1/4 to 1/8 of the heat release rates of a pool fires [6].

4. Design Improvements

The safety of alcohol-fueled heat and light sources could be improved if they were subject, as much as is practical, to ASTM F2417 - 11, *Standard Specification for Fire Safety for Candles* [7], and ASTM F2601 - 09, *Standard Specification for Fire Safety for Candle Accessories* [8]. These standards include tests for flame height, secondary ignition, end of useful life (i.e. burnout), and stability. The last category involves placing the tested item on a 10° incline. In the case of alcohol fueled devices, it is important that this test be conducted with the fuel reservoir filled to capacity, as some firepots have been found to be increasingly top-heavy when filled. Also, given the greater hazard posed by the tip-over of an alcohol-fueled device (relative to that from a wax candle), it may be beneficial to consider increasing the severity of the incline to 15°, 20°, or even higher. An additional or alternative performance criteria could limit the amount of fuel spilled, using the equations from the previous section as a guide for defining the desired level of safety.

5. Fuel Characteristics and Safety Considerations

Regardless of the appliance or fixture it is used with, the alcohol-based fuel is a potential hazard. The vapor pressure of alcohol at room temperature results in a fuel-air mixture inside the storage container that is within the flammability limits [9]. This poses an unusual hazard compared to other liquid fuels. At room temperature, gasoline has a high enough vapor pressure that a closed container will be above the upper flammability limit, meaning it will not ignite without the addition of more air. Heavier fuels such as diesel fuel and kerosene are known to be relatively difficult to ignite, because their relatively lower vapor pressure keeps them under the lower flammability limit. However, this same feature makes them impractical for use in a product lacking a wick.

Alcohol-based fuels might be separated into two categories. A high-viscosity fuel, greater than 50 Pa-s (50 000 cP), is essentially not pourable, and therefore is appropriate for non-refillable fuel cans. Fuel cans are familiar to the public as the heat source for chafing dishes at, e.g., a catered buffet meal. A non-refillable can of high viscosity fuel of the appropriate size placed inside the fuel reservoir of a firepot achieves essentially the same heat and light effect as with a pourable fuel. The hazard of a liquid spill resulting in a relatively large fire is greatly reduced. In addition, since gel cans are not normally refilled by consumers but rather simply replaced with new gel cans, the inclination to re-fuel a hot (possibly still flaming) firepot would be greatly reduced. It is possible that a fuel that meets this viscosity level would have a reduced viscosity at elevated temperature (this is one of the hazards of candles). However, without further study it is unknown whether any existing technology could meet the requirement of being a high-viscosity fuel while maintaining this viscosity at high temperatures.

While gel cans may improve the safety of firepots, there is still a need for a pourable alcohol fuel for products aside from firepots. The use of low viscosity fuels, less than 0.01 Pa-s (10 cP), however, can be made more safe by ensuring that appropriate safety technologies are in place. For example, a low viscosity alcohol fuel with a suitable flame arrestor on the fuel storage container[*] could improve safety. At least one manufacturer of an alcohol-based fuel already does this. For containers with flame arrestors, the use of a low viscosity fuel reduces the likelihood that the consumer will feel the need to defeat or otherwise remove the flame arrestor. A low viscosity fuel also has the benefit that in the event of a spill, the mass of fuel to which a potential victim would be exposed may be lower than with a fuel gel, also reducing the apparent difficulty of extinguishing a spill-related fire.

[*] i.e. the container the fuel is in when the user purchases it

The specific design of an effective flame arrestor for low-viscosity alcohol-based fuels in residential applications is uncertain and work is needed in this area. Standards do exist for flame arrestors in industrial and/or petroleum-storage applications [10, 11], but the applicability of these standards to a portable container for the home may be limited. Most useful from these standards is the tabulation of maximum safe experimental gaps, i.e. the maximum pore size in an effective flame arrester, which is 0.9 mm [10] for an alcohol-air mixture. One manufacturer of alcohol-based consumer products crimps a perforated metal cap onto a glass container that is otherwise similar to their other alcohol-containing products. The arrestor has 37 holes placed closely together, each having a diameter on the order of 1 mm. This design is therefore consistent with the ones used in industrial settings, to the degree that a comparison can be made. The materials used in the consumer product container (metal and glass) are compatible with each other and the alcohol-based product.

Therefore, a research project would be useful to study the effectiveness of flame arrestor designs for alcohol-based fuels, and/or to develop a qualifying safety test method. Such a test method would be most effective if it closely resembled an accident scenario, i.e. pouring fuel from the manufacturer’s container on an ignition source. The test method would not require a mechanism for squeezing the container because the low-viscosity requirement for the fuel would make squeezing the container unnecessary. As part of this study, it would be important to develop pass/fail criteria to ensure prevention of accidental fires.

6. Conclusion

Several approaches have been considered for improving the fire safety of fire pots and alcohol-based fuels. First, any design where the fuel is added at the same location where the fire is intended to occur will likely continue to result in accidents. Second, any decorative consumer product incorporating a liquid fuel and an open flame would benefit from a series of performance standards similar to those already under consideration for candles. Given the higher hazard resulting from an alcohol spill, compared to candles, it would be beneficial for the performance test for stability to be more severe. Because a closed container of alcohol falls naturally within the flammability limits, it results in a higher hazard compared to other liquid fuels familiar to consumers. This hazard can be mitigated by separating alcohol-based fuels into two categories: high-viscosity non-pourable fuels in non-refillable cans, and low viscosity fuels packaged in a container with an integral flame arrestor. Research is needed to better understand the requirements of a flame arrestor for a consumer product container (as opposed to one for industrial use) and to develop pass/fail criteria to ensure prevention of accidental fires.

Acknowledgements

This work was sponsored under CPSC-I -12-0015, an Interagency Agreement between the U.S. Consumer Product Safety Commission and the National Institute of Standards and Technology Engineering Laboratory

References

[1] “Fire Pots and Gel Fuel; Advance Notice of Proposed Rulemaking; Request for Comments and Information”, U.S. Consumer Product Safety Commission, 16 CFR Part Chapter II, Billing Code 6355-01-P

[2] Ayers, S. CPSC, Personal communication December 10, 2012

[3] NIST Market research

[4] Barry, J; “Estimating Rates of Spreading and Evaporation of Volatile Liquids” CEP Magazine, January 2005.

[5] SFPE Handbook of Fire Protection Engineering, 4th Edition, 2008.

[6] Putorti, A.D., McElroy, J.A., and Madrzykowski, D., “Flammable and Combustible Liquid Spill/Burn Patterns,” NIJ Report 604-00, National Institute of Justice, Washington, DC, 2001.

[7] ASTM Standard F2417, 2011, “Standard Specification for Fire Safety for Candles,” ASTM International, West Conshohocken, PA, 2011, DOI: 10.1520/F2417-11

[8] ASTM Standard F2601, 2009, “Standard Specification for Fire Safety for Candle Accessories,” ASTM International, West Conshohocken, PA, 2009, DOI: 10.1520/F2601-12

[9] “Staff Briefing Package on Firepots and Gel Fuel” U.S. Consumer Product Safety Commission December 7, 2011

[10] ASTM Standard F1273, 1991, “Standard Specification for Tank Vent Flame Arresters,” ASTM International, West Conshohocken, PA, 2007, DOI: 10.1520/F1273-91R07

[11] UL Standard 525 “Standard for Flame Arresters”, Underwriters Laboratories, Northbrook, IL, 2008.