Flame Arrestors for Gelled Alcohol Containers

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Background

The recent popularity of fire display devices and fire pots has dramatically increased the number of injuries caused by combustion in alcohol containers. The vapor space in an alcohol container is in the explosive range at room temperature at the time of purchase. This is unlike gasoline. The vapor space in a gasoline container is too rich to combust when new – no evaporation or aging has occurred.[1] **This paper describes pour and explosion testing and analysis performed on gelled alcohol containers with and without flame arrestors at Berkeley Engineering And Research, Inc. (BEAR).** This research shows that flame arrestors can be used on gelled alcohol containers without inhibiting flow and that flame arrestors are effective in preventing injuries to users by inhibiting ignition inside an alcohol or gelled alcohol container such as shown in Figure 1 below:

Figure 1. Vapor space inside a gelled alcohol container ignited by an external flame producing a dangerous jetting action. Testing performed at BEAR.

The tests described also indicate that transport velocity (velocity of the air being pulled into a container from squeezing and releasing) has an effect on the required flame arrestor hole size to stop a flame. Flame arrestor designers should take caution in using the methods currently described in the open literature which do not take transport velocity into account.[2,3] Continued testing and analysis is currently being conducted to characterize the effects of transport velocity.

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[1] Stevick, G.R., Rondinone, D., Sagle, A., and J. Zicherman "Fire Incidents and Explosions Involving Portable Plastic Gasoline Containers And Their Prevention", *J. Failure of Failure Analysis and Prevention,* Aug 2011.
[2] Grossel, S., "Deflagration and Detonation Flame arresters, American Institute of Chemical Engineers, (2002).
[3] ASTM Standard F l 273, 1991, "Standard Specification for Tank Vent Flame Arresters," 2007.

Cap Modification to include a Flame Arrestor

Caps from two gel container manufacturers, Manufacturer A and Manufacturer B, were modified to include a flame arrestor with 36 one mm diameter holes. The flame arrestors were machined and deburred to fit within the underside of the gel container caps, and installed into the gel container caps. The caps in Figures 2 and 3 are identical in configuration except for the color and main hole size. Identical flame arrestors were installed in the underside of both.

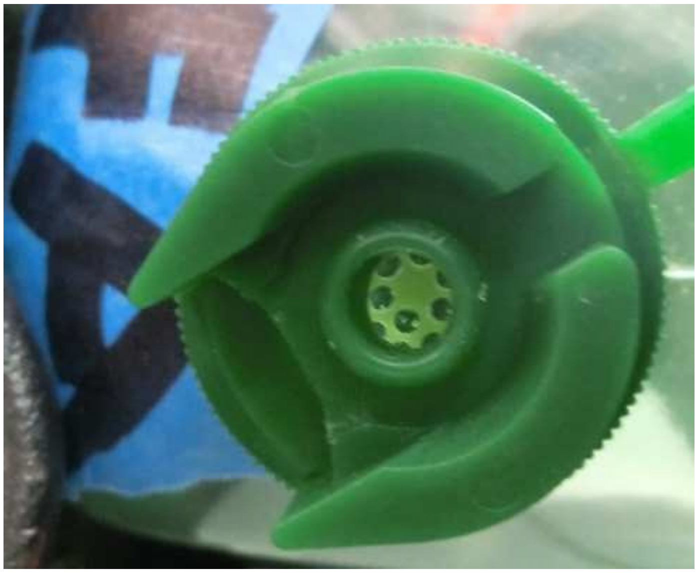

Figure 2. Topside of a cap from Manufacturer A. The flame arrestor is installed in the underside of the cap.

Figure 3. Underside of a Manufacturer B cap with a flame arrestor installed.

Pour Testing

Two side-by-side pour tests were performed using a pair of Manufacturer A containers and a pair of Manufacturer B containers. Within each pair, one container had an unmodified cap, and the other had a cap modified by the addition of a flame arrestor as described in Section 1 above. Each pair was assembled using a wood block spacer and plastic zip-ties so that they could be poured together as shown in Figure 4.

This assembly allowed the pair to be squeezed simultaneously so that the container without the flame arrestor and the container with the flame arrestor would be loaded identically. The viscosity of the gel required that the containers be squeezed in order to allow gel to exit the containers. Thus exact orientation of the containers was not critical as long as they were tipped to allow the gel to cover the cap openings. The containers were approximately full at the start of each pour test, although their volumes were not identical – neither the Manufacturer A nor Manufacturer B bottles contained identical amounts of gelled alcohol at the time of purchase.

It was found that the pour rates for the standard caps (without flame arrestors) and the modified flame arrestor caps (with flame arrestors) were similar. For the Manufacturer A caps and liquid viscosity, the rate of pour was nearly identical for caps with and without a flame arrestor. For the Manufacturer B caps, the rate of pour was approximately 30% slower for the flame arrestor cap compared to the standard cap. This change in pour rate would not significantly affect the use of the product. However, enlarging the central outer hole in the Manufacturer B cap might mitigate the pour rate reduction without compromising the safety afforded by the presence of a flame arrestor.

Figure 4. Manufacturer B Containers showing a difference in pour rate with and without a flame arrestor in the cap.

Flame Arrestor Explosion Testing

The same containers and the same flame arrestor modified caps that used for the pour tests, were then used for a pair of internal combustion or explosion tests. The containers were approximately ½ full of gel at the start of each explosion test. Each container with a modified flame arrestor cap was used for one single test.

The containers were mounted onto a platform that allowed the container to be tipped to various angles. The platform included a pair of squeezing arms that allowed the containers to be squeezed while at any test angle simulating actual use.

For each test, a metal cup was filled approximately ½ full with gel from the container being tested (so the Manufacturer A's container was tested using Manufacturer A's alcohol gel, and the Manufacturer B's container was tested using Manufacturer B's gel). The gel in the cup was then lit, and the gel container tipped so that gel could be poured from the container into and around the cup containing burning gel. Both high definition and high speed videos were taken for each test.

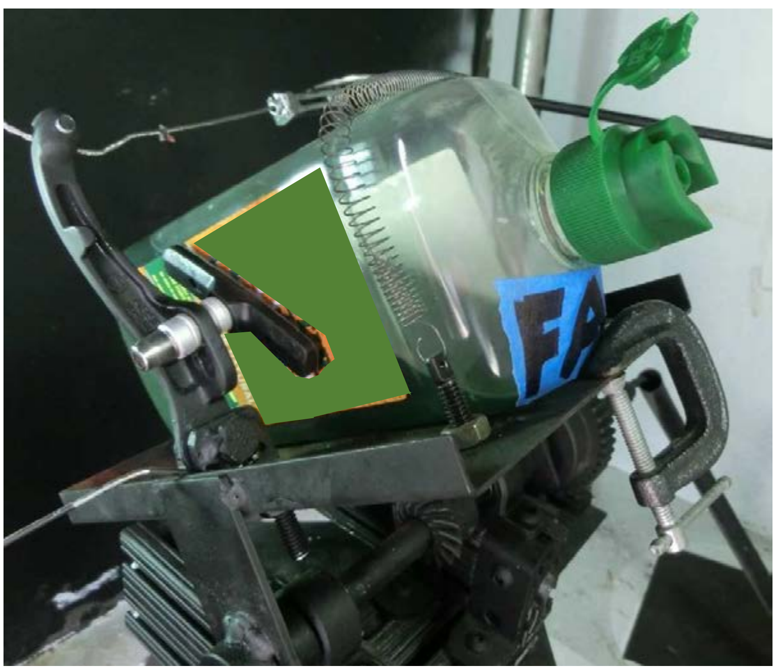

Figure 5. Test Setup – Tipping and Squeezing platform assembly with a Manufacturer A Container mounted for testing.

It can be seen in each test (see Figures 6 through 10) that the flame from the cup of gel and the poured gel reached the cap of each container. In both tests, the caps were melted from this exposure, but this melting did not close the hole and still allowed for gel to exit the containers and air to enter the containers. The tipping angles of the containers were varied so that the case of gel partially covering the cap outlet, and the case of gel not covering the outlet could be evaluated in the same test.

The test results, tabulated in Table 1 below, clearly show that with a flame arrestor present in the cap external flames cannot enter into the container and cause an internal explosion despite vigorous squeezing of the container.

Date	**Time**	**Can Type**	**Cap main hole size**	**Ignition Source**	**Fill %**	**HS Video File**	**Notes**
09/11/13	12:30 PM	PVC	3 mm	Gel	½	9-11-13 Mfg A Gel Can with flame arrestor in Cap 240fps HS.avi	Flame arrestor installed in cap – no combustion
09/11/13	01:00 PM	PVC	6 mm	Gel	½	9-11-13 Mfg B Gel Can with flame arrestor in Cap 240fps HS.avi	Flame arrestor installed in cap – no combustion

Table 1. Test results.

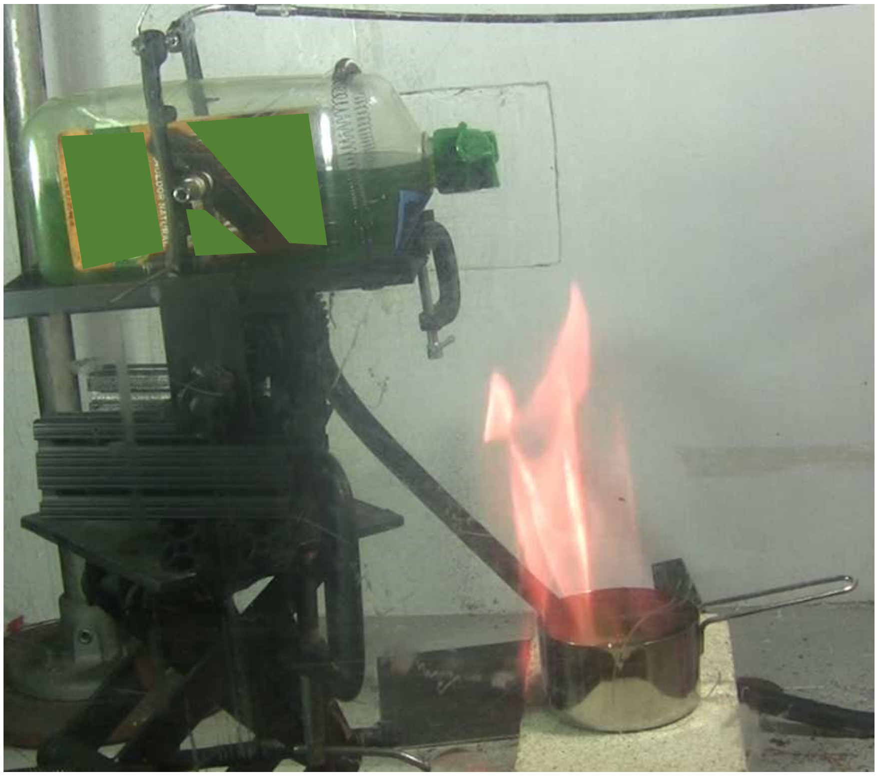

Figure 6. Manufacturer A container with a flame arrestor during testing.

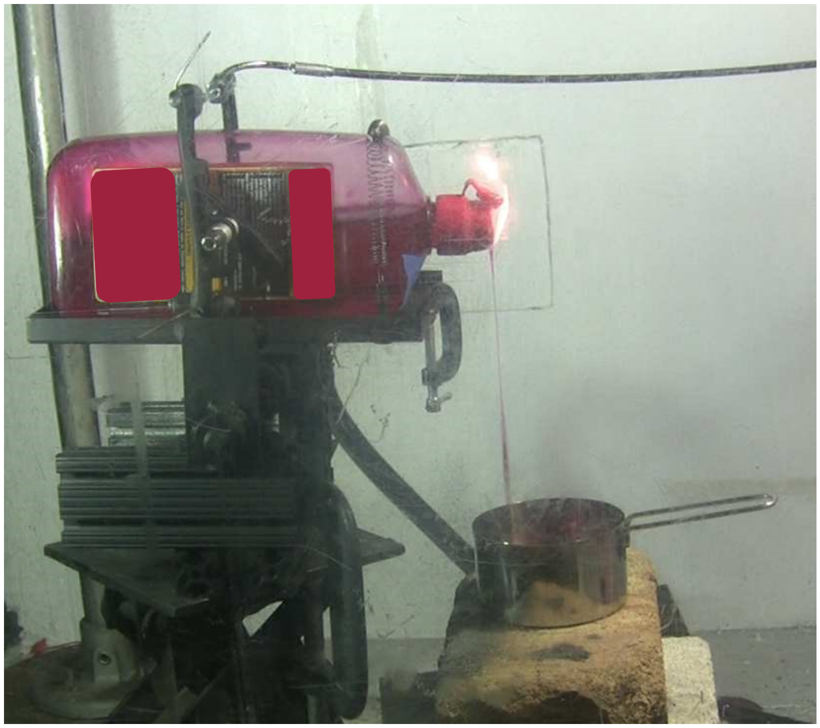

Figure 7. Manufacturer B container with a flame arrestor during testing. Opening covered by alcohol gel.

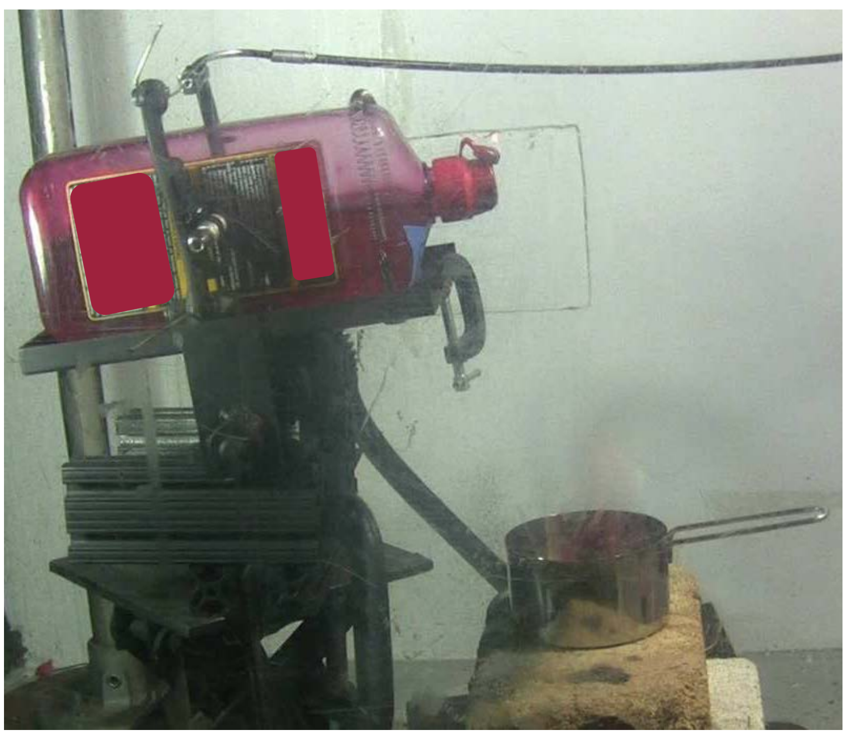

Figure 8. Manufacturer B container with a flame arrestor during testing. Opening exposed, not covered by alcohol gel.

Figure 9. Manufacturer B container with a flame arrestor during testing. Flame Partially Visible During Test – Very Faint Flame Color.

Discussion and Conclusions

Prior testing of both alcohol and gelled alcohol containers with a single hole opening larger than 2 mm, resulted in internal combustion and explosions with the container. In most cases a jetting occurs (see Figure 10a below) which can cause serious injury if someone is in the line of fire. In some cases, the container ruptures (see Figure 10b); injuries can be significantly more serious in these cases.

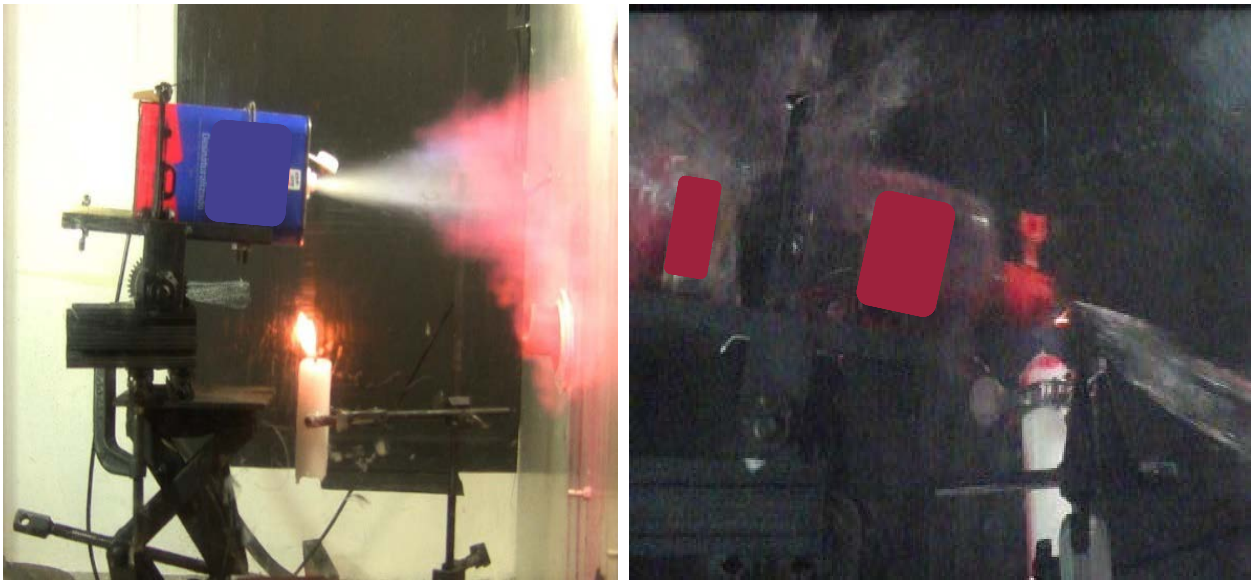

Figure 10. (a) Combustion testing of alcohol container and (b) a gelled alcohol container which ruptured.

This testing clearly shows that flame arrestors can be used on gelled alcohol containers without inhibiting flow and that the flame arrestors are effective in preventing explosion of the container and injuries to users.

Testing is continuing at BEAR for the safe storage of alcohol, gasoline and other fuels. Tests indicate that transport velocity (velocity of the air being pulled into a container from squeezing) has an effect on the flame arrestor hole size required to stop a flame. Flame arrestor designers should take caution using the standard methods currently in the open literature[4,5] which do not take transport velocity into account. Transport velocity is currently a primary focus of the combustion testing at BEAR.

[4] Grossel, S. "Deflagration and Detonation Flame arresters, American Institute of Chemical Engineers, (2002).
[5] ASTM Standard F l 273, 1991, "Standard Specification for Tank Vent Flame Arresters," 2007.