**Interflam 2019: Large Outdoor Fires**

**Fire safety of alcoholic beverages in retail stores**

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**Summary**
A fire test series to study pool fires of ethanol-water mixtures in the small, intermediate, and large scale has been performed. Additionally, demonstration tests of piles of PET plastic 0.5-L liquor bottles (39 vol%) in retail store arrays were carried out to illustrate their burning behaviour. On the basis of the test results, the burning of pool fires of different alcoholic beverages and the fire load due to alcohol can be evaluated for the purpose of performance-based fire safety design. The fire tests of retail store arrays showed that these fires grow slowly, and their heat release rate maxima are relatively low taking into account the mass of the fire load. The estimated heat release rate maxima of four-layer retail store arrays were ca. 1.5 MW and their growth times were over 600 seconds. Design fires generally used for the fire safety design of shopping centres are typically much more severe than the fire test results of retail store arrays of alcoholic beverages in this study.

**KEYWORDS**
alcohol fires, design fires, fire testing, heat release, performance-based fire safety design, pool fires

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**1 | Introduction**

In 2015, the Finnish Safety and Chemical Agency (Tukes) published a guideline concerning the storage of flammable liquids in retail stores. The interpretation of this guideline raised questions about the fire safety of liquor stores, especially related to the storage of alcoholic beverages with an alcohol content of 20 vol% or more. Fire authorities considered that further clarifications and studies were needed, in order to ensure the fire safety of liquor stores.

Motivated by these concerns, and given that very little information is available in the literature, an experimental study of the fire behaviour of ethanol-water mixtures was performed. The study included pool fire experiments in the small, intermediate, and large scale, and a series of demonstrative fire tests of retail store arrays of polyethylene terephthalate (PET) plastic bottles containing strong (39 vol%) alcoholic beverages. The focus of the study was in products with ca. 40 vol% of alcohol. Also stronger alcoholic beverages are sold in liquor stores in Finland, but typically in glass bottles and with lesser sales volume.

Heat release rates measured or estimated for pool fires can be directly used for heat release from different ethanol-water mixture pools, for example, in a situation where the mixture spread on the floor during a compartment fire. For example, a pool fire can be used as a design fire in performance-based fire safety design. The threat scenario could be ignition of a pool formed by the liquid spread on the floor.

The main goal of this study was to find answers to the following questions:

1. Is a spill collection tray under a retail store array of PET plastic liquor bottles beneficial for fire safety?
2. Shall the spill collection tray be shallow or deep?
3. How easily does a retail store array of PET plastic liquor bottles ignite?
4. What is the heat release rate of the retail store array?
5. How does a PET plastic liquor bottle behave in fire?

Small-scale pool fire experiments using the cone calorimeter apparatus have been previously reported. The goal of the small-scale tests was to produce data on the heat release rate and effective heat of combustion of ethanol-water mixtures for estimating the heat release and fire load which can be caused by alcoholic beverages in liquor stores. It was concluded that a significant fire load is not formed until the ethanol percentage of the alcoholic beverage is ca. 20 vol% or more. The small-scale data can also be used as an input to simulations of ethanol-water mixture pool fires in the performance-based fire safety design.

This paper introduces the intermediate and large-scale pool fire tests performed, as well as the demonstration tests of retail store arrays.

2 | EXPERIMENTAL

2.1 | Intermediate-scale pool fire tests

Nineteen intermediate-scale tests were performed using a square pool fire tray, made of steel, with an area of $0.44 \times 0.44 \, \text{m}^2$ ($0.19 \, \text{m}^2$) and a depth of 100 mm. In these tests, the volume percentages of the ethanol-water mixtures varied in the range of 20-96.1 vol% and the layer thicknesses in the range of 5-25 mm. The tests were carried out using the Single Burning Item (SBI) test apparatus, normally used for testing construction products in vertical position according to the EN 13823 standard. The test series of ethanol-water mixtures was run deviating from the EN 13823 standard. In practice, only the hood collecting the exhaust gases, the exhaust duct with its instrumentation, and the data acquisition system were utilised in these tests. A stand for a scale was built on the specimen trolley. The pool fire tray for the liquid specimen was positioned on top of the scale. The specimen was ignited with a hand-held gas burner. During the test, heat release rate and mass loss were measured. This data was needed for estimating the heat release rate in the large scale tests on the basis of mass loss data. In addition, gas temperatures at five heights from the bottom of the pool fire tray were measured (results not presented in this paper). The experimental arrangement is illustrated in Figure 1.

2.2 | Large-scale pool fire tests

The large-scale fire tests were performed in the large fire test hall of VTT. In total, 10 tests were run. In these tests, the ethanol concentration was either 40 or 50 vol%, the size of the square steel pool fire tray was $0.44 \times 0.44 \, \text{m}^2$ ($0.19 \, \text{m}^2$), $0.80 \times 0.80 \, \text{m}^2$ ($0.64 \, \text{m}^2$) or $2 \times 2 \, \text{m}^2$ ($4 \, \text{m}^2$), and the fuel layer thickness was 10, 50 or 100 mm. The depth of the smallest pool fire tray was 100 mm, and the depth of the larger ones was 250 mm. The fuel was ignited with a hand-held gas burner. The pool fire trays were positioned on top of a scale, in order to measure the mass loss. Heat release rate was not directly
measured in these tests but it was estimated on the basis of the mass loss measurement by comparing the intermediate-scale and large-scale mass loss data. In addition, gas temperatures at five heights from the bottom of the pool fire tray and at ceiling height were measured (results not presented in this paper). The experimental arrangement is illustrated in Figure 2.

2.3 Demonstration tests of retail store arrays

In addition to the pool fire tests, three demonstration tests of retail store arrays were carried out in the large fire test hall. The solid-pile arrangement used in the demonstration tests is representative of retail store arrays of ca. 40 vol% alcoholic beverages in liquor stores in Finland. These products can also be stored on shelves, but the number of bottles in shelf arrangements is typically smaller than in solid-pile arrangements. As a rule of thumb, popular products with high sales volume are stored in piles, others on shelves.

In the demonstrations tests, the fire load consisted of four layers of PET plastic 0.5-L liquor bottles (39 vol%) in retail store arrays. Each layer had 96 bottles, and there were cardboard sheets between the layers. The arrays were placed on metallic roller supports. Under the roller supports, there was a spill collection tray with an area of 1 m × 1 m (1 m²). The spill collection tray was placed on a larger pool fire tray with an area of 2 m × 2 m (4 m²), positioned on a scale for mass measurement. The ignition source was a pile of porous wood fibre board, size 120 mm × 120 mm × 75 mm, soaked with 500 mL of heptane. The ignition source was placed under the retail store array on the bottom of the spill collection tray (see Figure 3), and it gave a relatively high pro-longed heat exposure on the test array. The measurements in the demonstration tests included mass loss, and gas temperatures at five heights above the pool fire tray and at ceiling height. The results of the temperature measurements are not presented in this paper. Mass loss rate was calculated on the basis of the mass loss measurement results.

The following demonstration tests for piles of PET plastic 0.5-L liquor bottles (39 vol%) in retail store arrays were performed:

- D1: Shallow spill collection tray (depth 10 mm) under the bottle array.
- D2: Deep spill collection tray (depth 100 mm) under the bottle array.
- D3: Shallow spill collection tray (depth 10 mm) under the bottle array, and another bottle array above on a shelf. The upper bottle array consisted of an incombustible shelf, supports made of wooden boards and 40 liquor bottles on the shelf (see Figure 4).

3 RESULTS AND DISCUSSION

3.1 Intermediate-scale pool fire tests

The main goal of the pool fire tests carried out using the SBI test apparatus was to measure the heat release rate of the ethanol-water mixture pools and compare it with the mass loss measured simultaneously. The test arrangement provided comparative data for the pool fire tests carried out in the large fire test hall where mass loss was measured but heat release rate measurement was not possible. Another goal was to study the repeatability of ethanol-water mixture pool fires.

As an example, Figure 5 shows the heat release rate in the intermediate-scale pool fire tests with layer thickness of 15 mm. Replicate tests were performed at concentrations of 30 and 40 vol%, showing good repeatability. To reduce the total number of tests, the most dilute mixture with 20 vol% of ethanol was tested only with the layer thickness of 5 mm. The focus of the study was in higher ethanol concentrations. For 20 vol% of ethanol (layer thickness 5 mm), the repeatability was poorer, due to the poor ignitability of the pool. Ignition using a large hand-held gas burner took a relatively long time

![Figure 3](image1.png) Demonstration test D2, ignition. The retail store array was placed on top of roller supports in the deep spill collection tray (depth 100 mm, area 1 m × 1 m)

![Figure 4](image2.png) Demonstration test D3 shortly after ignition. The retail store array was placed on top of roller supports in the shallow spill collection tray (depth 10 mm, area 1 m × 1 m). On the shelf above the array, there were 40 bottles
(ca. 30 seconds), leading to differences in the pre-heating of the specimens in different tests.

3.2 | Large-scale pool fire tests

To obtain a scaling factor between the heat release rate and the mass loss rate, the results of the 0.44 × 0.44 m² (0.19 m²) pool fire tray tests using the SBI apparatus and in the large fire test hall were compared. Figure 6 shows the results for ethanol-water mixtures with 40 vol% of ethanol. Visual fitting of the curves resulted in a scaling factor of 17.5 kW/(g/s). Similarly, a scaling factor of 18.2 kW/(g/s) was obtained for ethanol-water mixtures with 50 vol% of ethanol.

The results of the intermediate-scale tests performed using the SBI apparatus can be generalised to the larger pools with a reasonable accuracy. The tests carried out in the large fire test hall gave practically similar heat release rates per unit area than the tests carried out using the SBI apparatus. In the large fire test hall, the heat release rates per unit area for 50-mm layers of mixture with 40 and 50 vol% of ethanol in the 2 m × 2 m (4 m²) pool fire tray were 240 and 300 kW/m², respectively. In the tests performed using the SBI apparatus in the 0.44 × 0.44 m² (0.19 m²) pool fire tray, the corresponding heat release rates per unit area were 247 and 304 kW/m². For very thin layers, these results are not necessarily valid due to heat losses to the bottom of the pool fire tray, as explained below.

Pool fires of thin liquid layers (less than 5 mm) have been studied in a research project aiming at producing information to support the forensic investigation of, for example, arsons. One of the fuels studied was denatured alcohol. The highest burning rates of pool fires were in the range 14%-55% lower than the burning rate expected of a large pool. The high scattering of the results was explained by the effect of the substrate. Especially the increase of the thermal conductivity of the substrate correlates inversely with heat release rate. The result is clearly valid for thin pools (ca. 1 mm), whereas the effect of the substrate disappears for pools with thickness of over 5 mm. Also Drysdale refers to studies where thin liquid pools have been found to lose heat to the substrate, leading to the decrease of heat release rate.

It is noted that almost all pool fire tests performed in this study had a relatively small layer thickness compared to the brim height of the pool fire tray. In the large fire test hall, a test with the 0.44 × 0.44 m² pool fire tray (depth 100 mm, area 0.19 m²) full to the brim of mixture with 40 vol% of ethanol was carried out. This test showed clearly less intense burning than layer thicknesses of 10 and 50 mm of the same mixture.

Drysdale refers to studies on the effect of the metallic pool edge on the burning behaviour of the liquid. A visible edge of the pool increases convective heat transfer to the surface of the burning liquid, because the turbulence caused by the entrainment of air increases in the proximity of the pool edge.

On the basis of the literature referred above, the heat release rate estimates of the pool fire tests in this study can be assumed to be on the safe side, that is, thin pools spread on the floor can be assumed to burn less intensely as the test results presented would indicate.

3.3 | Demonstration tests of retail store arrays

All three demonstration tests proceeded in a similar manner. At first, the ignition source ignited the cardboard sheets above it, leading to the collapse of the part of the layer on top of these sheets. After that, the fire progressed moderately until the neighbouring parts of the layer collapsed and the fire spread to the whole size of the bottle array. In the tests with the shallow spill collection tray, more liquid and bottles ended up on the bottom of the larger 2 m × 2 m (4 m²) pool fire tray compared to the test with the deep spill collection tray.
Figures 7 and 8 show the demonstration tests D1 and D3 (both with shallow spill collection tray) during advanced fire. It is noted that the smoke production in the demonstration tests was characteristically small. Test D3 exhibited a larger smoke production due to the burning of the wooden supports of the non-combustible shelf.

To estimate the heat release rate of retail store arrays, the scaling factor of 17.5 kW/(g/s) for mixtures of 40 vol% of ethanol was used, since the alcoholic beverage in the bottles of the arrays had ethanol concentration very close to that (39 vol%). Figure 9 shows the estimated heat release rates of the demonstration tests, compared with $t^2$ fires of ultra-fast, fast, medium and slow fire growth rates (growth time $t_g$ of 75, 150, 300 and 600 seconds, respectively). The $t^2$ fires shown grow according to square-law until the heat release rate reaches 1600 kW, after which the heat release rate is kept constant.

Figure 10 shows the heat release rate of the demonstration test D1 with the $t^2$ fires and some design fires found in the literature. (For clarity, only D1 is presented since it is more severe than D2 and of the same order as D3.) The design fires shown in Figure 10 are the following:

- “Shoe storage”: A design fire often used for the fire safety design of shopping centres in Finland.\(^7\) The heat release rate curve describes a shoe storage fire going to flashover, based on fire tests performed in Australia.\(^8\)
- “Clothing rack”: A fire test by NRC, Canada.\(^9\) Total mass ca. 36 kg, with 86, 2 and 12 mass percent of textiles, plastics, and wood and paper, respectively.
- “Clothing store”: A fire test by NRC, Canada, with two clothing racks in a closed room.\(^10\) Total mass ca. 71 kg, with 86, 2 and 12 mass percent of textiles, plastics, and wood and paper, respectively.
- “Potato chips (NIST)”: A fire test by NIST, US, with a fire load of 27.1 kg of potato chips in small bags (33.8 g/bag).\(^11\)
- “Potato chips (SP)”: A fire test by SP, Sweden, with a fire load of 275 kg of potato chip and cheese nibble bags. A 5.4 m-long three-shelf high shelving unit tightly packed.\(^11\)

On the basis of the demonstration tests, retail store arrays containing alcoholic beverages cannot be considered as a major fire safety...
risk. This type of fire load burns moderately and its heat release is rather small compared to many other fire loads in retail stores and groceries (see Figure 10).

4 | CONCLUSIONS AND IMPACT

The results of the fire tests performed can be used in the assessment of the burning of different alcoholic beverages and the fire load due to alcohol for the purpose of performance-based fire safety design. The fire tests of retail store arrays of alcoholic beverages showed that these fires grow slowly, and their heat release rate maxima are relatively low taking into account the mass of the fire load. The estimated heat release rate maxima of four-layer retail store arrays were ca. 1.5 MW and their growth times were over 600 seconds. The spread of the pool fire formed by liquor leaking from the bottles was limited by the pool fire tray. Without the pool fire tray, the pool would spread to a wider area as a thinner layer, leading to less intense burning and lower heat release rate maximum. Thus, the test results can be assumed to be on the safe side.

On the basis of the test results and the observations during the demonstration tests, the answers to the questions posed (see Introduction) are:

1. A spill collection tray can be beneficial for fire safety, if the bottle layers are piled on top of each other so that there are cardboard sheets between the layers. In this case, the spill collection tray can limit the intensity of fire and sideward fire spread.
2. A shallow spill collection tray is not advantageous, since the bottles falling down from the array end up on the floor. A deep spill collection tray holds the falling bottles better together and reduces the amount of liquid running to the floor, if the pool fire tray has an area larger than the bottle array.
3. A retail store array does not ignite easily. The alcohol does not significantly contribute to fire as long as the bottles keep standing.
4. The heat release rate of the retail store array studied (four layers, 96 bottles per layer) is ca. 1.5 MW at maximum. The growth time \( t_p \) (of \( t^2 \) fire) is larger than 600 s, that is, the fire grows slowly.
5. Of PET plastic bottles, the caps (made of high-density polyethylene [HDPE]) melt first, and then the neck melts partly. Otherwise, the PET plastic of the bottle does not significantly contribute to fire in the early phases of the fire. The bottles do not leak from other parts, since the pressure inside a bottle is released when its cap falls. If the bottles keep standing, the liquid inside them cools effectively the walls of the bottles.

The design fires used in the fire safety design of shopping centres in Finland are typically much more severe than the fires of alcoholic beverage packages can be according to the tests performed. If a liquor store is a part of a shopping centre or in connection of a large supermarket, no additional performance-based fire safety design is needed for it.

As a result of this study, the Finnish Safety and Chemical Agency updated its guideline on the storage of flammable liquids in retail stores.\(^1,^2\) The main difference of the 2015 and 2016 guidelines concerning the instructions for the maximum amount of chemicals in shopping spaces is the following (shown underlined):

- 2015: Alcoholic beverages and cosmetic products, with the exception of aerosols, are not taken into account in the maximum amounts. No protective measures are required of alcoholic beverages containing less than 20% of ethanol.
- 2016: Alcoholic beverages and cosmetic products, with the exception of aerosols, are not taken into account in the maximum amounts. No protective measures are required in the storage of alcoholic beverages.

According to FM Global Property Loss Prevention Data Sheets 8-1, Commodity Classification, “Beer and wine (volume of alcohol 20% or less), considered nonignitable liquid, stored in plastic containers that hold 5 gal (19 L) or less” is classified as a Class 1 commodity.\(^3\) In other words, the fire hazard is similar to noncombustible materials packaged in single-layer corrugated cardboard on wood pallets. This supports the instructions of the Finnish Safety and Chemical Agency dated in 2015. In this study, it was seen that a spill collection tray can be beneficial for fire safety, by limiting the intensity of fire and sideward fire spread. However, the instructions dated 2016 allow the storage of alcoholic beverages in retail stores without protective measures. The demonstration tests showed that typical retail store arrays of ca. 40 vol% alcoholic beverages in plastic bottles cannot be considered as a major fire safety risk, compared to many other fire loads in retail stores.

It is noted that “protective measures” in the quotations above refer to spill collection trays and fireproof cabinets for flammable liquids. Fire safety systems, such as fire alarm and fire extinguishing systems, shall be installed in buildings and premises according to fire safety regulations taking into account their use and fire class.

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