SPRINKLER PROTECTION FOR BARREL STORAGE OF DISTILLED SPIRITS

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ABSTRACT
This paper describes a method of discharging water directly upon the burning surfaces of alcohol-water mixture by means of thermovalves installed in the diked areas on the floor of the barrel storage, and tests conducted to confirm the relationship between the water discharge density and the extinguishing time.

1. Introduction
According to the Japanese Fire Service Law, alcohol-water mixtures having alcoholic contents of below 59 per cent alcohol by volume (59 vol.%) and being stored are not treated as dangerous materials. Therefore, distillers store raw spirits with alcoholic content of 59 vol.% in barrels.\(^1\) This barrel storage falls into the category of rack storage defined by the Fire Service Law, which calls for mandatory installation of an automatic sprinkler system in the premises. Accordingly, the existing standard for automatic sprinkler systems for rack storage provides that sprinkler heads be installed on the ceiling and in the racks. However, there is no specific provision regarding installation of sprinkler heads and water discharge on the floor surfaces or in diked floor areas.\(^1\)-\(^4\)

The barrel storage presents a greater danger of alcohol fire which is caused by ignition of spilled raw spirits than other fires in ordinary combustibles in the warehouse building or in related installations. Barrels fell off the racks due to earthquake or accidentally dropped while they are being moved in or out of storage may be damaged, and consequent leakage of contents might take fire
from some ignition source. If the alcohol in the spilled raw spirit starts burning on the floor surface, water should be first discharged upon the burning surfaces to extinguish the fire, and then over the racks on which the barrels are piled and the hoops of the barrels to prevent collapse of the barrels by cooling action of the water.

If concrete dikes arranged in the form of grille are provided on the floor of the barrel storage, the spilled raw spirit from the damaged barrels does not spread over the floor but remains within the diked areas where it has directly flowed in, thus the fire area is confined by the dikes. Therefore, it would remarkably increase the effect of the automatic sprinkler system if the fire in the diked area is detected in its early stage and discharge of water is concentrated on this fire zone.5-9)

This paper describes tests conducted to confirm fire extinguishing effects of different methods of discharging water and quantities of water discharged into the diked area, and introduces a sprinkler protection with thermovalves installed in the diked areas as a sprinkler system suited for extinguishing fire in the barrel storage.

2. Tests
2.1. Purpose

It is well known that extinguishment of fire in raw spirit is accomplished by dilution of alcoholic content in the raw spirit and decrease in solution temperature. Nevertheless, when designing a fire extinguishing system, one must know if any difference in fire extinguishing effect would be made depending upon methods of discharging water, or what relationship exists between the extinguishing time and the water discharge density. In order to obtain data which may be used as bases for designing a sprinkler system for the diked areas of the barrel storage, fire extinguishing tests were conducted by using ethanol and methanol with alcoholic content of 59 vol.%.  

2.2. Test arrangement

Two liquid vessels of different sizes were used. The large vessel of 2,250 mm x 3,900 mm (8.775 m²) is nearly the same size as one diked area in the average barrel storage.10) To simulate the actual installation a catwalk with a sprinkler
head underneath was installed above the vessel so that the operating time of the sprinkler head under the lowest tier in case of fire may be known. Another sprinkler head with a baffle was installed 2,400 mm above the sprinkler head so that operation of the sprinkler head to be located under the intermediate catwalk may be known. Thermocouples were installed in the alcohol - water mixture and above the vessel to measure the solution temperature and plume temperature respectively. (Fig.1).

The small vessel of 1 m dia\textsuperscript{11} was mainly used for tests related to studies of water discharge densities, method of discharging water and fire extinguishing time. Thermocouples were installed for measuring the solution temperature and plume temperature. Sprinkler head, spray head and discharge nozzle with single orifice were arranged as shown with Fig.2.

2.3. Test results\textsuperscript{11-13} The sprinkler head installed 1.3 m from the bottom of the vessel and simulating the one located under the catwalk in the lowest tier in the rack operated in 52 seconds while the other one installed at the height of 3.7 m operated in 1 minute 58 seconds. This indicates that it is advantageous to install a sprinkler head under the catwalk in the lowest tier for the purpose of attaining quicker response of the sprinkler head.

Difference in extinguishing time due to different methods of discharging water was hardly noted both in the discharge of water upon the solution surface through the sprinkler head, the spray head and in the gentle application of water from a single orifice nozzle. On the other hand there were great differences in solution temperatures measured at different depths during the fire fighting, i.e. the temperature differences were 5 \textdegree C and 10 \textdegree C between 3 mm and 8 mm, and 8 mm and 18 mm below the solution surface respectively. The solution temperature at the depth of 18 mm rose by some 3\textdegree C until the fire was extinguished (Fig.3). This indicates that particles of water discharged upon the solution surface through the sprinkler head, etc. had an effect only on the surface of the solution.

When water was poured in such a manner that the alcohol - water mixture would be forcedly stirred, the thermocouple located 3 mm below the solution surface was often exposed to the combustion gas due to movement of the solution
Fig. 1 Test setup with large vessel

Fig. 2 Test setup with small vessel
level. However, the temperatures at the depths of 8 mm and 18 mm below the solution surface were absolutely the same, and this indicated that the alcohol-water mixture has been well stirred (Fig. 3).

There was a five-minute difference in extinguishing time between the two cases, i.e. when water was discharged through the overhead sprinkler without stirring the solution and when the solution was forcibly stirred, and the latter case required a longer extinguishing time (Fig. 3). This indicates that the method of discharging water upon the solution surface has better fire extinguishing effect because it locally cools the burning surfaces and dilutes the solution.

Discharge of water in large quantity brings about a high cooling effect, consequently a large reduction in solution temperature. The tests demonstrated that the discharge of water in large quantity could extinguish the fire in the alcohol-water mixture at a slightly higher alcoholic content than that extinguished with smaller quantity of water.

Fig. 4 shows alcoholic contents in the alcohol-water mixtures and their temperatures measured at the time of extinguishment of the fires, which are very close to the theoretical curves representing the ignition points of the alcohol-water mixtures. In the tests with the ethanol-water mixture having alcoholic content of 59 vol.% and with a preburn time of some 1~2 minutes until operation of the sprinkler head after ignition, the solution temperatures and alcoholic contents measured at the time of fire extinguishment were 55°C and 9 % at the discharge density of 51/min.m², and 46°C and 11 % at 201/min.m². This indicates that alcohol fires can be extinguished if the burning alcohol surfaces are cooled below the ignition point of mixtures diluted with water. Immediately after extinguishment of the fire with water, the solution surface has low alcoholic content as mentioned above, but there still remains alcohol-water mixture with high alcoholic content at the bottom of the vessel.

Immediately after measuring the alcoholic content in the surface of the alcohol-water mixture, it was stirred and the alcoholic content was measured again. The alcoholic content ranged from 15 to 30 vol.%, which may be used as reference to determine an alcoholic content at the time of extinguishment of fires when estimating the relationship between the extinguishing time and water discharge density from the following formula.
Fig. 3 Comparison of extinguishing alcohol fires\(^{13}\)
Fig. 4 Curves for ignition points of alcohol-water mixtures, and measured values of solution temperatures and alcohol contents at the time of extinguishment in the test.

Vessel 1 m dia.
Alcohol content 59 vol.%
Quantity of alcohol-water mixture 18%

- ethanol-water mixture
- methanol-water mixture

--- curve obtained from the formula(1) with alcohol content of 11% at the time of extinguishment of fire in methanol-water mixture

--- curve obtained from the formula(1) with alcohol content of 15% at the time of extinguishment of fire in methanol-water mixture

Fig. 5 Water discharge density and extinguishing time.
The extinguishing time becomes shorter with increase in water discharge density. The test results may be illustrated in terms of the relationship between the extinguishing time and water discharge density which are plotted in Fig. 5. The curves in Fig. 5 illustrate the relationship between the extinguishing time and water discharge density estimated from the following formula (1). As can be seen from this Figure 5 the majority of the actually measured values are included in these curves for the alcoholic contents of 11 vol.% and 15 vol.% at the time of extinguishment.

Therefore, it is possible to estimate the extinguishing time and water discharge density from the formula (1) if the size of the diked area, ethanol content in the raw spirit and capacity of the barrel are determined, and the estimated values can well be used when designing a sprinkler system.

\[
T = \frac{A (1 - K'/K) - v_{\text{o}} (1 - K'/100)}{Q \cdot K'/100 + v(1 - K'/100)}
\]

where: 
- \( T \) (min) extinguishing time
- \( t_{\text{o}} \) (min) preburn time (operating time of sprinkler head)
- \( v_{\text{o}} \) (mm/min) Burning rate during preburn (solution surface falling speed)
- \( v \) (mm/min) Burning rate during water discharge (solution surface falling speed)
- \( Q \) (mm/min) Water discharge density (precipitation)
- \( K \) (vol.% Initial alcoholic content
- \( K' \) (vol.% Alcoholic content at the time of extinguishment of fire
- \( A \) (mm) Initial alcohol quantity (converted into depth of pure alcohol)

3. Application to actual installation

Extinguishment of alcohol fire with water is accomplished by cooling and dilution of alcohol - water mixture. The tests have demonstrated that the time required for extinguishing the fire is most influenced by water discharge density. It has become apparent that the relationship between these factors well corresponds to the estimation from the above formula (1).

Table 1 below indicates water discharge densities required for one sprinkler
head according to the regulations of different countries for sprinkler system for barrel storage, and they range from 6.7 to 20.4 l/min.m².

Table 1. Comparison of water discharge densities per sprinkler head required by regulations

<table>
<thead>
<tr>
<th>Regulation</th>
<th>Discharge density l/min.m²</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire Service Law (Japan)</td>
<td>6.7 ~ 8.9</td>
<td>Rack storage</td>
</tr>
<tr>
<td>Fire Insurance Assoc. (Japan)</td>
<td>9.4 ~ 10.7</td>
<td>&quot;</td>
</tr>
<tr>
<td>NPPA (USA)</td>
<td>14.3 ~ 18.3</td>
<td>&quot;</td>
</tr>
<tr>
<td>FM (USA)</td>
<td>14.3 ~ 20.4</td>
<td>Barrel storage</td>
</tr>
<tr>
<td>FOC (U.K)</td>
<td>7.5 ~ 10.2</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

A study is made regarding water discharge densities in case one barrel of raw spirit (480 l) with alcoholic content of 59 vol.% spilled and burned in a diked area of 8.8 m² in an existing barrel storage. Fire extinguishing time after the sprinkler head has opened is calculated on condition that the raw spirit has alcoholic content of 11 vol.% at the time of extinguishment, and by using the water discharge densities shown in Table 1.¹¹

With the minimum water discharge density (6.7 l/min.m²) the fire extinguishing time is calculated to be 18 minutes, and with the maximum water discharge density (20.4 l/min.m²) the fire extinguishing time is 9 minutes. However, considering the fact that the time actually required for the sprinkler head to open after ignition varies with each case, and some of the discharged water may possibly fall on to area other than the burning surface, it would take a longer time for fire extinguishment.

The earlier the fire fighting starts, the more effectively it would prevent heat from the fire from causing reduction of the rack strength and collapse of the barrels.

Here, a calculation is made to determine the quantity of water required for extinguishing a fire in raw spirit on the assumption that the fire would be extinguished in less time than that required in the case of the water discharge densities shown in Table 1, i.e. less than five minutes and that the average alcoholic content at the time of extinguishment would be 11 vol.%. It was found that water discharge densities of 51.3 l/min.m² or discharge rate of 451 l/min. per
diked area are required as indicated in Table 2.

Table 2. Calculation of discharge density required for 5-minute extinguishing time (from the start of the fire to its complete extinguishment)

| From the start of fire to opening of the sprinkler head | 1 min. |
| From the start of water discharge to fire extinguishment | 4 min. |
| Capacity of one barrel | 480 |
| Alcoholic content in raw spirit | 59 vol.% |
| Average alcoholic content at the time of extinguishment | 11 vol.% |
| Size of the diked area | 8.8 m² |
| Water discharge density required for extinguishing the fire | 51.3 l/min.m² |
| Water discharge rate required for one diked area | 451 l/min. |

It was found that a system which uses a sprinkler head for fire detection and a valve being capable of discharging the required quantity of water upon operation of the sprinkler head, and which is installed in each diked area would effectively extinguish the fire in spilled raw spirit in the diked area in its early stage.

From the above findings, this barrel storage is now equipped with a system comprising ordinary closed sprinkler heads located on the ceiling, attic and barrel racks, plus 1" thermovalves, each comprising a heat sensitive element with operating temperature of 72°C, valve assembly and spray head with a discharge rate of 460 l/min. at 3 kgf/m² (Fig.2) and located in each diked area under the lowest tier of the rack, i.e. under the floor (Fig.6). The thermovalves are installed below the catwalk in the lowest tier.

4. Conclusion

The tests have confirmed that the alcohol fire can be extinguished if the burning alcohol - water mixture is cooled down and diluted below the ignition point curves by discharge of water. It was also found that the required water discharge density can be estimated if the alcohol density and desired extinguishing time are determined.
It is considered that the sprinkler system installed on the basis of these results has further increased its reliabilities for extinguishing the alcohol fire in the diked area.

The method described in this paper is effective if the spilled alcohol-water mixture is collected in the diked areas and the system is designed in such a way that most of the discharged water is sprayed over these diked areas. Therefore, attention must be paid to the fact that if the sprinkler head is near the ceiling, only a small portion of the sprinkler discharge may be able to enter the diked area.
Photo 1. Fire extinguishing test with large vessel

Photo 2. Thermovalve
References:

(1) Fire Service Law of Japan, Enforcement Ordinance (in Japanese)
(2) ibid, Detailed Enforcement Regulations (in Japanese)
(5) NFPA National Fire Code No. 13, Sprinkler System 1975
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(8) Fire Offices' Comittee, Rules of the Fire Offices' Comittee, Automatic Sprinkler Installations 29th Edition
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