ABSTRACT

The aim of this study is systematically to provide evidence about the interaction between the water droplet stream and the flame, and explain how it affects the ability of the gasoline pool fire extinction by water sprays. Two different purposed built gasoline pools were used to generate open fires. A mono-dispersed water droplet stream with droplet size in the range of hundreds microns and water sprays with droplet size ranging from decades to hundreds microns were used as the fire-fighting agent. One of the pools was elaborately fabricated to allow the mono-dispersed water droplet stream vertically passing through the fuel pan’s center hole without impinging the gasoline in the pan to make sure that the mechanism of extinction is purely the action of the droplet stream on the flames involving heat transfer between flames and the droplets as well as the entrained air current. The passing direction and the position of the mono-dispersed water droplet stream related to the gasoline surface were systematically varied. One simple-hole nozzle was used to generate water sprays with larger droplet size. The other was a long narrow oil groove pool whose length can be adjusted to expend the fire size to make sure that the evaporation of water droplet definitely occurs. The macro lenses and CCD camera assembled with a computer were used to acquire the process of extinguishing in the experiment. The simple-hole nozzle assembled with a net was used to generate water sprays with smaller droplet size. The results clearly show two modes of extinguishing; one is to obstruct the interaction of the gasoline vapor and the air, and the other is to reduce the flame temperature lower than the point of combustion resulting in fire extinction.

Keywords: Pool fire, Extinction, Sprays, Droplet

1. INTRODUCTION

The pressure to discontinue the use of Halon gas fixed fire protection systems has provided the impetus for a concentrated effort to find alternative agents, which in turn has forced attention and resources to the development of fine water sprays for fire extinguishment and control. It is known that the water is used to extract heat directly from the flames, the hot products of combustion or from the surface of the fuel attributed to its suitable thermal characteristics such as heat capacity and latent heat of vaporization, and the phase change from liquid water to vapor may also contribute to extinction by reducing the oxygen concentration of the surrounding atmosphere. Moreover, the fact that the small-sized droplet in the fine water spray will finally be vaporized is much suitable to the request that the water damage and fire spreading should be avoided. Grant et al. [1] provided a comprehensive summary regarding the use of water sprays for the suppression and extinguishment of typical Class ‘A’ compartment fires in 2000. For the Class ‘B’ hydrocarbon pool fire, about 50 years ago, Rasbash and Rogowski [2] conducted extinction experiments which occurred when liquids burning in open vessels were cooled by water sprays projected downwards on to the liquid surface and correlated the extinction time with the spray and the fire properties. They found that the extinction time was directly proportional to the drop size of the spray and the preburn time and inversely proportional to the rate of flow of water per unit of fire area, and also to the difference in temperature between the fire point and ambient temperature. To develop techniques for the prediction of fire suppression phenomena by using water spray, Alpert [3] numerically analyzed the interaction between water sprays and fire plumes and the water flux which penetrates through the fire plume as well as the cooling effect of the spray were calculated for a simplified axisymmetric problem of a sprinkler spray directly above the center of a constant fire source. Using relatively small amounts of water disintegrated into fine droplets has been proved to be valid for reducing the temperature and levels of toxic and irritant fire products within the cabin, as compared with a conventional sprinkler system which produces coarser droplets by, for example, Ames et al. [4]. To understand the effects of water sprays on fire intensity, Kim et al. [5] conducted experiments by using downward-directed sprays interacting with a small-scale opposed gasoline pool fire in an open environment, and confirmed that the mechanism of fire extinguishment by water sprays is the cooling of the fuel surface, which will lead to the suppression of fuel evaporation, rather than cooling of the fire plume itself. Followed the above work, Kim et al. [6] investigated the extinction limit and enhancement for a gasoline pool fire interacting with a water mist and found that there are two distinct regions in the relationship between the distance from the nozzle to the fuel pan and the injection pressure; a fire extinction region and a fire enhanced region. They also concluded that the water flux is a more useful parameter.
than the injection pressure for the extinction limit and the
larger the spray thrust the larger the burning rate is in the
fire enhanced region. To clarify whether it is still premature
to advocate the use of fine sprays for many fire fighting
application, Jones and Nolan [7] examined the fire
extinguishment researches with the emphasis being on the
use of fine water sprays or mists rather than on the general
use of water sprays by reviewing the means of producing
fine sprays and the major results of some case studies. They
concluded that fine sprays may not universally applicable to
all pool-types of combustion control, especially larger-scale
fire spread. A quasi-steady-state model was developed by
Gerard et al. [8] to predict the effectiveness of a water mist
system for extinguishing fuel spray and pool fires. The
model was able to predict the extinguishment times for a
wide range of fire sizes, but lost accuracy as the fire size
approached the critical value. The limits of the model need
to be explored further since the model was developed for
obstructed fires where extinguishment primarily occurs as a
result of oxygen consumption and dilution and neglects the
effects of the interaction of the mist with the flame. Kondo
et al. [9] conducted an experiment to make clear the effects
of water droplet size, velocity and momentum, and
entrained air velocity on fire extinction of a city gas flame
by water spray. They concluded that the extinction patterns
can be classified into three types, i.e. the blow off, the fade
out and the transient types; the dominant factors for above
regions are the entrained airflow, the momentum of each
droplet and the spray volume flux with large momentum
droplets reaching the burner surface and cooling and
covering it, and the entrained air velocity, respectively,
which controls the transient from blow off to fade out. Kim
[10] provided an overview of some progress in fire
suppression technology which includes halocarbon and
inert gaseous agents, water mist systems, compressed-air-foam systems, and aerosol and gas
generators. He summarized that water mist characteristics,
such as drop size distribution, flux density and spray
momentum, have a direct effect on its fire suppression
effectiveness; and to effectively suppress a fire, a water
mist system must generate a deliver optimum sized droplets
with an adequate concentration to the fire, also there is no
one drop size distribution to fit all fire scenario. From the
previous review of the literature on extinction by water mist,
most of the works are carried out in the situation of directly
letting water mist or sprays interact with the flame and even
impinge the liquid fuel surface. There are few cases which
are conducted in the situation without impinging and being
purely the action of the droplet stream on the flame. It
becomes clear that there is a need to increase our physical
understanding of the interaction of the mist with the flame
in the design of an efficient fire extinguishment system.
More recent studies, by the author of using a fire-fighting
tool named Impulse Fire Extinguisher which releases
high-pressure air to force the plain water out from the gun
with very high discharged velocity to fight the fire in
different directions have showed that the extinguisher can
extinguish fire Classes ‘A’ and ‘B’ with plain water [11];
and the mono-dispersed droplet generator become available
which offers a droplet stream with unique size and can
provide quantitative evidence about the effects of the
interaction of the mist with the flame [12].

This work follows on from these previous experiences
[11, 12]. Two different purposed built gasoline pools are
used to generate open fires. Mono-dispersed water droplet
streams and sprays from a simple-hole nozzle were used as
the fire-fighting agent and were passing through the flame
without impinging the fuel surface. The objective of this
study is to investigate the interaction between the water
droplet stream and the flame, and explain how it affects the
ability of the gasoline pool fire extinction by water sprays.

2. EXPERIMENTAL APPARATUS

A configuration of the apparatus is given in Fig.1.

![Fig.1 Schematic of the experimental apparatus](image)

Experiments were performed with two different purposed
built gasoline pool fires. One pool fire was generated by
using a circular copper pan (shown in Fig. 2) which was
elaborately fabricated with a concentric passage inside and
the gasoline was contained in the pan.

![Fig.2 Schematic diagram of the circular copper pan with a
 concentric passage inside.](image)

The other was generated by using a long narrow groove
pool (shown in Fig. 3) which the gasoline was filled in.

![Fig.3 Photographs of the groove pool; the groove’s
dimensions are 3mmx10mmx300mm and
6mmx10mmx300mm, respectively.](image)
A mono-dispersed water droplet stream with droplet size in the range of about 150–300µm and water sprays injecting from a simple-hole nozzle with droplet size ranging from hundreds microns to mini-meters were used as the fire-fighting agent. The mono-dispersed water droplet stream can pass through the fuel pan’s central passage without impinging the gasoline in the pan to eliminate the effect due to cooling of the liquid surface layer by water. The length of the groove pool can be adjusted to expend the fire size to make sure that the evaporation of water droplet definitely occurs. Before each test the pan or the groove pool were filled with fresh gasoline.

A vibrating orifice droplet generator was used to generate a jet by forcing liquid through a small orifice. The liquid jet is naturally unstable and will disintegrate to form droplets with a range of sizes. When a disturbance in the form of a square wave from the function generator at the appropriate frequency is applied to the reservoir in the generator head, the jet exiting out from the nozzle will breakup into uniform droplets at the rate of one droplet per excitation cycle [12-14]. The supplying pressure and vibrating frequency were adjusted to produce the required stream of droplet, and the macroscopic-lens & CCD camera and video recorder were placed in the appropriate position to observe and record the process of fire extinguishing. A 3-D translating stage was used to move the droplet stream to a suitable position and injecting direction relative to the flame. When the gasoline in the pan or pool is ignited and the fire achieves the required size or quasi-steady burning, the droplet stream or spray is then discharged to impinge the flame and the whole process of extinction is recorded. Instantaneous pictures were recorded at 30 frames per second. An image capture interface card and a personal computer were used to capture the required picture. The sizes of the flame and the droplet were estimated by using the software of Intellicam; and the droplet size was also checked up by using the equation of volume flow rate [12, 14], i.e.

\[ D = \left( \frac{6Q}{\pi f} \right)^{1/3} \]  

(1)

where \( D \) is the diameter of the droplet, \( Q \) is the volume flow rate and \( f \) is the vibrating frequency. The droplet velocity was also estimated by the equation of volume flow rate, i.e.

\[ V = \frac{Q}{A} \]  

(2)

Where \( A \) is the cross section area of the hole in the orifice in the generator head. The time duration from beginning of injection to extinction was measured from the video pictures.

3. RESULTS AND DISCUSSION

This experiment was conducted to provide evidence about the interaction between the water droplet stream and the flame. Two different purposed built gasoline pools were used to generate open fires. A mono-dispersed water droplet stream and water sprays were used as the fire-fighting agent. The fire extinction experiments in a gasoline pan flame by using the mono-dispersed water droplet stream is examined first followed by the case in gasoline pools by using the water mono-dispersed droplet stream and spray. The injection directions of the droplet stream were adjusted in three ways, horizontal, vertical and different bevel angles, respectively. The distance between the droplet stream and free surface of fuel was also be adjusted in different height. The schematic of the droplet stream, the flame and the droplet stream above the free surface of fuel are shown in Fig.4.

![Fig.4 The schematic drawing of droplet stream and flame; injecting with a bevel angle.](image)

3.1 Injection In Horizontal

The injection direction of the droplet stream was adjusted in horizontal and the stream passed through the flame from the left to the right hand side. The volume flow rate and droplet generation frequency were set at 1.03x10^{-7} m^3/sec and 15.95 kHz, respectively, which resulted in droplet stream with 230µm diameter. The coherent part of the droplet stream was ascertained during the stream impinging the flame and the distance from the pan surface to the axis of droplet stream was varied. These results indicate that there is a critical distance from the pan surface to the axis of droplet stream for effective extinction in the case of injection in horizontal. The results also show that increasing the distance from the pan surface to the axis of droplet stream will vary the extinction duration. This can be attributed to the fact that the droplet stream and the induced air flow will somewhat cut off the supply of fuel vapor or interrupt the diffusion of fuel vapor and the efficiency of cut off is a function of the intruding way of droplet stream; more details will be given later.

3.2 Injection In vertical

The injection direction of the droplet stream was adjusted in vertical and the stream passed through the concentric circle of the pan without landing on the fuel. The coherent part of the droplet stream was also ascertained during the stream impinging the flame. Figure 5 shows the flame extinction process by the water droplet stream with droplet size of 230µm and droplet generation frequency of 15.59 kHz and the extinction takes about 14.37 seconds, which indicates that the flame extinction is not effective as we define above because the duration is more than 0.5 second.
3.3 Injection With Different Bevel Angles

In order to identify how the intruding way of droplet stream with different bevel angle affects the extinction duration, the injection direction of droplet stream was adjusted in a bevel angle and the stream passed through the flame. The coherent part of the droplet stream was also ascertained during the stream impinging the flame and the distance from the pan surface to the intersection of the axis of droplet stream and the center line of the copper pipe was measured. Figures 6 show the typical interaction processes; one is the case of effective extinction and the other is not effective.

3.4 Effect Of Droplet Size On The Oil Pan Fire Extinction

To identify how the droplet size affects the extinction duration, the volume flow rate and droplet generation frequency were adjusted to generate 200µm and 300µm diameter droplet, respectively, but in the same volume flow rate. The injection direction of the droplet stream was adjusted in horizontal and the height was varied. The experimental results show that the flame extinguishing with large droplet stream (300µm) is better than that with small droplet stream (200µm). Closer examination in the interaction of droplet stream and flame reveals that the stream with larger droplet (300µm) induces larger extent of entrained air current (2.8mm) than that with smaller droplet (200µm) shown in Fig. 8. This effect results in that the critical height of former is larger than that of later and this is consistent with the previous result [12].

3.5 Examination Of Vaporization In The Droplet Stream

It is worthy to examine how much the water droplet vaporize in the extinction duration. The droplet size was estimated by using the software of Intellicam and the results show that there were not differences on the size before and after impinging flame for all the cases in our experiment, which indicates that it did not vaporize in the extinction duration. This fact can be checked from the heat transfer point of view, i.e. the heating energy transferred to the droplet from the flame can be estimated by using the equation of convection heat transfer rate:

\[ q = h \cdot A \cdot (T_\infty - T_1) \]  

where \( q \) is the heat transfer rate from the flame to the droplet (Watt), \( h \) is the coefficient of the heat convection, \( A \) is the surface area of the droplet, \( T_\infty \) is the flame temperature and \( T_1 \) is the droplet temperature. The coefficient of the heat convection about 880 W/(m²°C) was
estimated based on the reference [15]. Finally, the temperature rise was estimated as only about 1°C, which could not vaporize the water droplet at all. The estimation is suitable for all the cases mentioned above. The other oil groove pool fire whose size can be adjusted to make sure that the evaporation of water droplet definitely occurs will be described later.

### 3.6 Extinguishment By Droplet Stream With Random Droplet size

The final goal of the experiment is to find out the efficiency of the fine water spray on the pool fire extinguishment, therefore a droplet stream with random size was generated by switching off the function generator which can supply a disturbance to the mono-dispersed droplet generator head. Two orifices with 100µm and 50µm hole diameter, respectively, were assembled in the generator head. Two orifices with 100µm and 50µm hole diameter, respectively, were assembled in the generator head, generating two different volume flow rates, 8.44x10^{-8}m^3/s and 2.58x10^{-8}m^3/s, two different mean droplet diameters, generating two different volume flow rates, 8.44x10^{-8}m^3/s and 2.58x10^{-8}m^3/s, two different mean droplet diameters, generating two different volume flow rates, and 9.17m/s, respectively, could not vaporize the water droplet at all. The estimation is based on the reference [15]. Finally, the temperature rise was estimated as only about 1°C, which could not vaporize the water droplet at all. The estimation is suitable for all the cases mentioned above. The other oil groove pool fire whose size can be adjusted to make sure that the evaporation of water droplet definitely occurs will be described later.

### 3.7 Extinguishment Of Pool Fire By Using The Water Mono-Dispersed Droplet Stream And The Spray

In the second part of the experiment, the object is to investigate the effect of droplet vaporization on the extinction. The long narrow groove pools (shown in Fig. 3) with 3 or 6mm in width and 10mm in depth were used to generate a fire and its length can be adjusted in different settings. The mono-dispersed droplet stream whose droplet size can be varied was generated as the fire-fighting agent and it passed through the fire in horizontal. The result reveals the extinction of discussion, there is a critical height for effective extinction in the case of injection in horizontal, therefore the narrow groove pool with the dimensions of 6x10x300mm and the measured droplet diameter can be reduced, from 210 to 180µm in the duration of passing through the fire with 2.5mm height, while the droplet generation rate, volume flow rate and droplet velocity are 13.6 kHz, 6.2x10^{-8}m^3/s and 7.9m/s, respectively.

### 3.8 Critical Height Of Effective Extinction By Using The Water Mono-Dispersed Droplet Stream

As mentioned in the section of injection in horizontal of discussion, there is a critical height for effective extinction in the case of injection in horizontal, therefore the narrow groove pool with the dimensions of 6x10x300mm and the measured droplet diameter can be reduced, from 210 to 180µm in the duration of passing through the fire with 2.5mm height, while the droplet generation rate, volume flow rate and droplet velocity are 13.6 kHz, 6.2x10^{-8}m^3/s and 7.9m/s, respectively.

<table>
<thead>
<tr>
<th>Height of stream from the pool surface (mm)</th>
<th>Mean extinction time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>x</td>
</tr>
<tr>
<td>3.5</td>
<td>x</td>
</tr>
<tr>
<td>3.2</td>
<td>6.57</td>
</tr>
<tr>
<td>2.8</td>
<td>2.57</td>
</tr>
<tr>
<td>2.5</td>
<td>1.23</td>
</tr>
<tr>
<td><strong>2.2</strong></td>
<td><strong>0.30</strong></td>
</tr>
<tr>
<td>1.7</td>
<td>1.03</td>
</tr>
<tr>
<td>1.4</td>
<td>3.70</td>
</tr>
<tr>
<td>1.1</td>
<td>6.23</td>
</tr>
<tr>
<td>0.7</td>
<td>7.93</td>
</tr>
<tr>
<td>0.4</td>
<td>x</td>
</tr>
<tr>
<td>0.1</td>
<td>x</td>
</tr>
</tbody>
</table>

x : extinction time over 10 seconds

It should be mentioned that the test in the pool fire extinction was carried out ten times for each case and the mean extinction time was taken since the flame with about 8 mm in height was more unstable than that in the pan case. The results show that not only the extinction time is affected by the height but also there is an optimum height (2.2mm) for extinction. It should be mentioned that the vaporization of droplet can not be found out in this case, which implies that the extinction is mainly due to the supply of fuel vapor being cut off by the stream flow and induced air current.

### 3.9 Effect Of Droplet And Pool Sizes On The Fire Extinction

Figure 9 shows the results of mean extinction time on the groove pool fire by using two different measured droplet sizes (143 and 204µm) streams injecting in horizontal with 2.5mm in height; the length of pool was varied from 5mm to 35mm, while the droplet generation rates, volume flow rates and droplet velocities are 38.0 and 13.0 kHz, 6.2x10^{-8}m^3/s and 7.9m/s, respectively.

![Fig.9 Effect of droplet and pool size on extinction time; L: stream with large droplet (200µm), S: stream with small droplet (140µm).](image)

The result indicates that the extinction times by using larger droplet are shorter than those by using smaller droplet for the pool with length less than 25mm, and this is consistent with the result of pan flame extinction. By contrast, the extinction times by using larger droplet are obviously longer than those by using smaller droplet for the pool with length more than 20mm, which implies that the
extinction is not only due to the supply of fuel vapor being cut off by the stream flow and induced air current but also due to the absorption of heat from the flame resulting from the vaporization of water droplet. Figure 10 shows the standard deviation of the extinction time on the above test and indicates that for pool length less than 25mm, the variation in the extinction time for larger droplet size is smaller, which implies that the extinction is more stable.

Fig.10 The standard deviation of extinction time; L: stream with large droplet (200µm), S: stream with small droplet (140µm).

The above results provide a fact that the water droplet will be vaporized by the flame during the large fire fighting and the couple of cutting off the supply of fuel vapor and absorbing heat from the flame is better for fire extinction.

3.10 Extinction Of Pool Fire By Using Water Sprays

Based on the conclusions in the above sub-sections, it is worthy to exam how they exist in the case by using a water spray. The purposed built orifices and nozzle (shown in Fig. 11) assembled with or without a net were used to generate the sprays.

Fig.11 The pictures and schematic of the simple hole nozzle with a net; (a) the nozzle and schematics of orifice, net and washer, (b) the orifice plate and its hole, (c) the SEM micrograph of the net, the mesh number 200, and the space in the net about 80x80µm.

The upstream pressure of the nozzle was 6 kgf/cm²; the diameters of the orifice were 0.5, 0.6, 0.7 and 0.8mm, respectively and the mesh numbers of the net were 200 and 300, respectively. The sprays were injected into the fire in horizontal with the height avoiding the landing of droplet on the fuel surface. Figure 12 shows the pictures of the spray injecting from the 0.5mm hole nozzle without assembling a net.

Fig.12 The pictures of the spray injecting from a nozzle with a hole of 500µm diameter without assembling a net; (a) the liquid jet injecting from the nozzle hole, (b) the water droplets of the spray in the location of 15cm from the exit of nozzle, the scale in the picture 500µm.

The results show that the liquid jet did not integrate at the exit but break up in the down stream and resulting in most of the droplet having a diameter about 500µm. The experimental results show that the fire in the 6x10x500mm groove pool can not be extinguished by this spray in 30 seconds. Figure 13 shows the pictures of the spray injecting from the 0.8mm hole nozzle with a net, which reveals the more turbulence in the liquid jet at the exit and breaking up in the down stream with much smaller droplet (down to about 30µm) than that from the nozzle without a net.

Fig.13 The pictures of the spray injecting from a nozzle with a hole of 800µm diameter with a net; (a) the liquid jet injecting from the nozzle hole, (b) the water droplets of the spray in the location of 15cm from the exit of nozzle, the scale in the picture 500µm.

However, the same fire can be easily extinguished by using the sprays injecting from the nozzle assembled with a net; Figure 14 shows the typical pictures of extinction process and table 2 shows the results of the series of tests.
Table 2 The extinction times of the spray injecting from the nozzle assembled with a net.

<table>
<thead>
<tr>
<th>Hole diameter (mm)</th>
<th>Mesh number</th>
<th>Cross section area of the space (mm²)</th>
<th>Flow rate (10⁻⁶m³/sec)</th>
<th>Mean extinction time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>200</td>
<td>0.097</td>
<td>2.0</td>
<td>1.20</td>
</tr>
<tr>
<td>0.6</td>
<td>200</td>
<td>0.140</td>
<td>2.6</td>
<td>1.17</td>
</tr>
<tr>
<td>0.7</td>
<td>200</td>
<td>0.190</td>
<td>4.0</td>
<td>1.13</td>
</tr>
<tr>
<td>0.8</td>
<td>300</td>
<td>0.146</td>
<td>2.6</td>
<td>0.80</td>
</tr>
<tr>
<td>0.05</td>
<td>300</td>
<td>0.082</td>
<td>1.6</td>
<td>0.87</td>
</tr>
<tr>
<td>0.5</td>
<td>300</td>
<td>0.057</td>
<td>1.0</td>
<td>0.90</td>
</tr>
</tbody>
</table>

It should be mentioned that the dimension of the space in the net with mesh number of 300 is about half of that in the net with mesh number of 200, and therefore using the nozzle assembled with a net of no. 300 can generate finer spray than that of no. 200. The results list in table 2 reveal that the effect of the droplet size on the fire extinction is more dominant than water flow rate, which indicates again that the couple of cutting off the supply of fuel vapor and absorbing heat from the flame is a better way for fire extinction.

4. CONCLUSION

In this paper, the interaction between the water droplet stream and the flame are investigated systematically to make clear that the effects of impinging way of the droplet stream into the flame and the vaporization of water droplet on the fire extinction. The mono-dispersed droplet generator and single-hole nozzle with/without net were skillfully operated to injecting mono-sized droplet stream and size controllable spray, respectively. The oil pan and groove pool were elaborately fabricated and the injection directions of droplet streams were carefully set to avoid the droplet landing on the fuel surface and the fire size was carefully adjusted to control the vaporization of water droplet. The results of this study are summarized as follows:

For the extinction due to the interruption of droplet stream and entrained airflow resulting from the cutting off the supply of fuel vapor in the reaction zone of flame, the extinction time is affected by the intruding way into the flame. The best way for extinction is that the fire is fought by injecting the droplet stream in horizontal and with an optimum height; by contrast, the droplet stream injecting downward into the flame will enlarge the fire in the beginning of fire fighting. Moreover, the flame extinguishing with large droplet stream is better than that with small droplet stream, which is attributed to the fact that larger droplet can induce larger extent of entrained air current.

For the large-size fire, inversely, the extinction times by using smaller droplet are shorter than that by using larger droplet which is attributed to the fact that the vaporization of smaller water droplet can absorb the heat from the flame and reduce the flame temperature, moreover, the water vapor can also obstruct the way of fuel vapor supply. Therefore, the fire extinction time by using a nozzle assemble a net with higher number mesh is shorter than that with lower number mesh even though supplying fewer flow rate. Finally, the results provide evidence that the couple of cutting off the supply of fuel vapor and absorbing heat from the flame is a better way for fire extinction.

For the case of mono-dispersed droplet stream, the extinguishing mode is dominant in obstructing; and the proceeding and the passing direction of the stream through the flame can affect the performance of fire extinguishing; the best is the direction in horizontal, the second is in bevel and the worst is in vertical. Also, there is an optimum distance from the gasoline surface for fire extinction. Moreover, the ability can be affected by the droplet size; for the same water volume flow rate, the larger of the droplet size is, the more effective the fire extinguishing becomes, which indicates that for the droplet stream with enough momentum passing through the flame can induce a relative cool air flow into the flame, and the effect in fire extinguishing with induced stronger air current is better than that with weaker air current. Contrary to the above, for the water spray passing through the fire in the long narrow oil groove pool, whenever the amount of water vaporization reaches the criterion of the reducing flame temperature mode, the performance of fire extinguishing becomes better contributed by the combination of the effects of the obstruction by spray and extracting heat by water vaporization.

5. NOMENCLATURE

- A: surface area or cross section area [µm²]
- D: diameter [µm]
- f: frequency [1/s]
- h: heat transfer coefficient [W/m² K]
- Q: volume flow rate [m³/s]
- q: heat transfer rate [W]
- Ti: droplet temperature [°C]
- T∞: flame temperature [°C]

6. REFERENCES

1. Grant G., Brenton J. and Drysdale D., Fire suppression by water sprays, Progress in Energy and Combustion

Acknowledgements

This work was supported by the National Science Council, R.O.C. under the contracts NSC 90-2212-E-014-013 and NSC 90-2212-E-014-007.