EXPERIMENTS ON THE INTERACTION OF WATER SPRAYS WITH POOL FIRES

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ABSTRACT

A series of measurements and visualization to investigate the interaction of water sprays with pool fires is presented. Fire source is a small-scale pool burner with methanol, ethanol and gasoline. Measurements of temperatures, O_2, CO_2, and CO concentrations along the plume centerline are carried out to observe pool fire structures without water sprays. Visualization by the Ar-ion laser sheet shows flow pattern of droplets of the sprays above the pool fires. It is observed that in the case of methanol and ethanol, water sprays continuously penetrate into the center of fuel surfaces. The gasoline pool fire allows intermittent penetration of water sprays because of pulsating characteristics of the gasoline flame. To evaluate the cooling effect of the fuel surface by the sprays, the temperature was measured at the fuel surface. As soon as the mists reach the fuel surface of methanol and ethanol, the temperatures of the fuel surface decrease rapidly below the boiling point, and then the fires are extinguished. Due to the application of mist upon the gasoline fire, though the fuel temperature decrease abruptly at the time of the injection, such a rapid decrease do not continue till the extinction point.

1. INTRODUCTION

The use of water mists for fire extinguishment and control is currently receiving a considerable attention as one of the potential methods for halon 1301 replacement. Advantage of mists for fire extinguishment is the relatively small quantity of water compared with conventional sprinkler systems. It has been known that the fine water droplets extinguish and control fires by several actions; cooling of the flame and fire plume, oxygen displacement by water vapor, and radiant heat attenuation. In order to optimize design of water mists system, the understanding of the interaction between water sprays and fires is very important. The interaction of a water mist with a buoyant methane diffusion flame was studied.[1] A limited number of measurements of temperature and the steady state O_2 and CO concentrations along the plume centerline were carried out. For the conditions tested, the plume-to-spray thrust ratio was large, resulting in negligible direct penetration of the droplets into the fire region.

In recent, studies on the application to the water mists in practical fires have been performed,[2-4] and the extinguishing condition for gasoline pool fires are suggested.[4] It was shown that there were two distinguished regions in the relationship between a distance from a nozzle to a fuel pan and an injection pressure, i.e. a fire extinction region, and a fire enhanced region, and that the direct cause of extinguishment was cooling of the fuel surface rather than of the fire plumes.

The purpose of present work are to investigate interaction between mists and fire plumes and to describe fire extinguishment by the cooling of liquid fuel surface for several fuels. Liquid fuels burn through an evaporation, and the boiling point of most of them is much higher than the ambient temperature. The evaporation of the fuel needs the heat source which might be produced in the combustion process of the fuel. The fire source is a liquid pool burner with a pan of 150mm diameter in an open environment. Direct photos, video recording and measurement of temperature, and gas concentration are used to describe the macroscopic characteristics of pool fires. Visualization by the Ar-Ion laser sheet shows flow pattern of droplets of the sprays above the pool fires. The flow pattern of mists upon the fuel surfaces will be decided by the relationship between the spray momentum and the buoyancy of plumes. To evaluate the cooling effect of the fuel surface from the sprays, the temperature was measured at the fuel surface. The temperature may be one of the most useful property because that is a general and direct quantity based on the mechanism of pool fires extinguishment in an open environment.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

Experiments were performed with a small-scale liquid gasoline, methanol and ethanol pool fire. The configuration of apparatus is given in Fig. 1. The fuel was contained in a circular stainless steel (SUS304) pan, with a height of 40mm and a inner diameter of 150mm. Additional fuel was not supplied fuel during the combustion. The pool was mounted on a steel stand 600mm above the ground to minimize the effects of surrounding ground surfaces on the behavior of the fire. A downward-directed solid cone nozzle with single orifice for the water spray was positioned on a square steel plate. The pool and the nozzle were centered under a natural draft fume hood which provides an open port for the exhaust of combustion products. To shield the fire and the water spray from draughts in the laboratory, the entire system was enclosed by a screen. Even though this configuration does not resemble a truly open space, it may be noted that the required combustion air for the flame is not completely cut off by the screen.

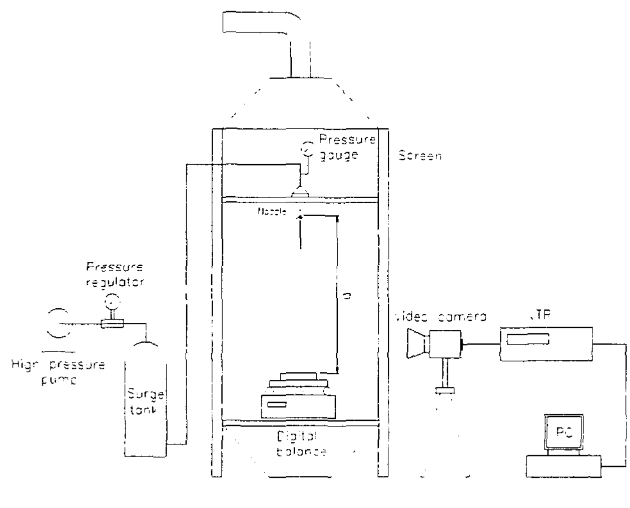
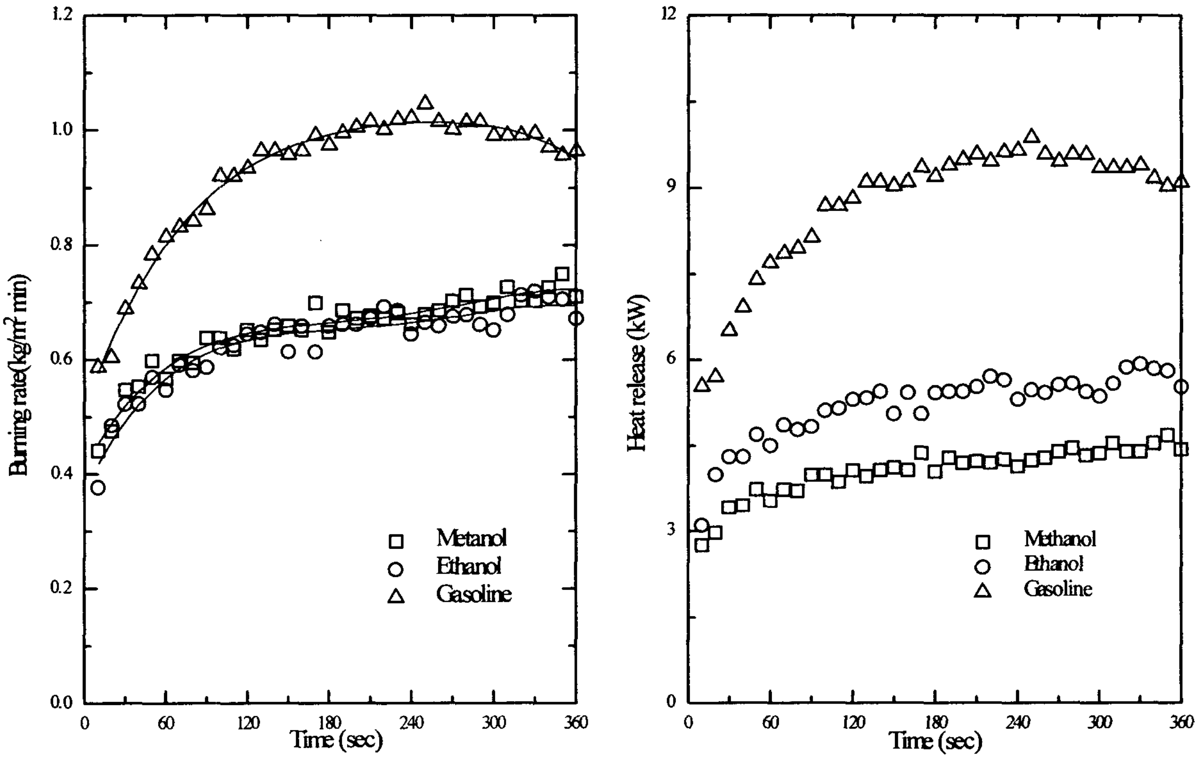


Fig.1 A schematic of the experimental apparatus

Water was pressurized by a high pressure pump, and injected through the nozzle via a solenoid valve to control beginning of injection. A surge tank was installed to diminish some perturbations due to the pumping. A distance from the nozzle tip to the fuel pan was 1m, and the injection pressure of $8kgf/cm^2$ that exceeded the minimum injection pressure for gasoline, in which the fire was extinguished under the given distance. The minimum injection pressure was referred in previous study.[4]

For each test, the pan was filled to 30mm below the pan lip with fresh fuel. The fire was then allowed to burn for 120 seconds to make quasi-steady burning before the water injection. Freely burning rate and heat release rate with time after ignition were shown in Fig. 2. Heat release rate are calculated by burning rate times heat of combustion of each fuel, with considering of combustion efficiency.[5] From the heat release rate diagram, the quasi-steady values of estimated fire sizes were 3.5kW for methanol, 5.0kW for ethanol and 10.0kW for gasoline.



(a) Freely burning rate of fuels

(b) Heat release of the fuels

Fig.2 Freely burning rate and heat release rate of fuels

Flame temperature was measured by a R-type thermocouple of 0.025mm diameter 10mm above the initial fuel surface along the pool center. In order to know the temperature behavior of the liquid fuel surface during the water injection to the fire, the K-type thermocouple of 0.1mm diameter located 2mm below the initial fuel surface. CO, CO_2 and O_2 concentrations were measured 40mm above the initial fuel surface. CO and CO_2 gas analyzer of IR type (Signal, Model M2000, U.K.) were calibrated using the standard gas, and the paramagnetic method (Signal, Model M8000, U.K.) for the O_2 analyzer. Ar-ion laser sheet (5W) was applied to visualize the flow pattern of droplets of water sprays above the pool fires. The laser sheet was going through the plume centerline.

3. RESULTS AND DISSCUSSION

3.1 FREELY BURNING

The visible flame shape of pool fires was dependent on fuels, as seen Fig.3. From the video records, the flame shapes of the methanol and the ethanol were dramatically changed with time through a pulsation cycle with the large necking-in regions. A series of thin flame sheets swept radially inward across the fuel surface in what appeared to be waves. Analysis of the methanol and ethanol fires revealed that at steady state the oscillating frequency was about 3Hz, which was consistent with the previous studies.[6] The shape of gasoline fire was not similar to those of the other fuels. Initially gasoline fire was also showed pulsating as the case of methanol and ethanol, but it did not exhibit large necking-in regions in the steady state.

a) methanol b) ethanol c) gasoline

Fig.3 Flame shape of the fuels

The position of the flame sheet will be associated with stoichiometric air-fuel ratio of the fuels.[7] For gasoline having a large stoichiometric air-fuel ratio, since the evaporation rate of fuel is still small during the initial period of the combustion, the amount of the air needed for the combustion is also small, and then the shape flame was similar to those of the other fuels. According as the fuel temperature is increased with the lapse of time, the evaporating rate of fuel is also increased, and then requiring the large amount of the combustion air. Therefore, as shown in Fig.3, the flame was positioned on the rim of pool. For other fuels with the low stoichiometric air-fuel ratio, the flames were being attached very near the fuel surface. The information about the position of flame could be also observed from the flame temperature at 10mm above the initial fuel surface along the pool center. Figure 4 showed that the flame temperature in methanol and ethanol fluctuated to be average temperature about 800 ℃, verified existence of the flame that position. However, the temperature of gasoline was decreasing and began to level out to be about 200 ℃

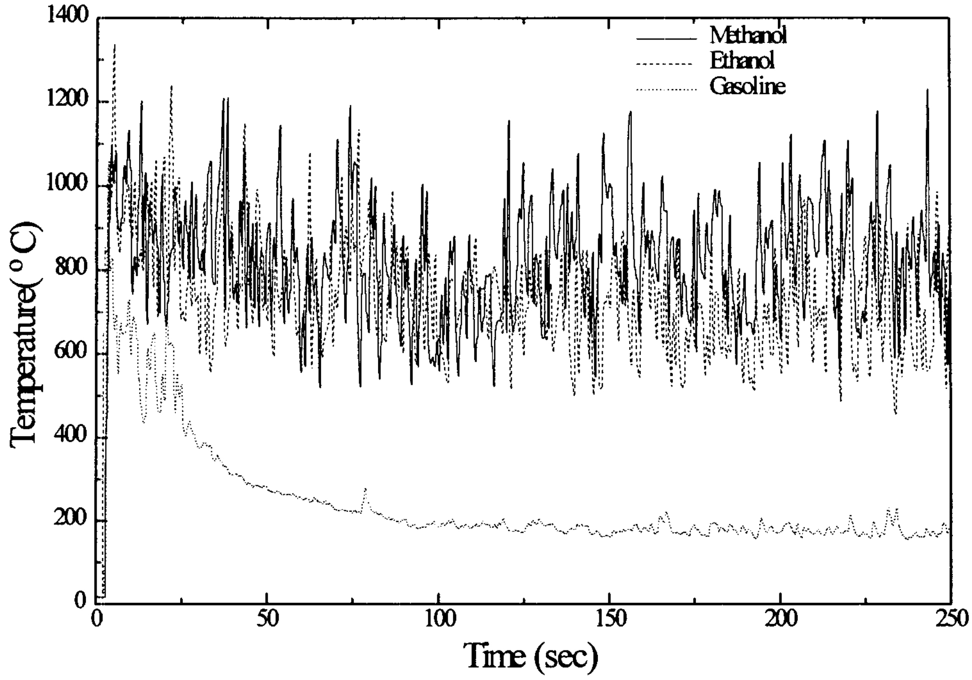
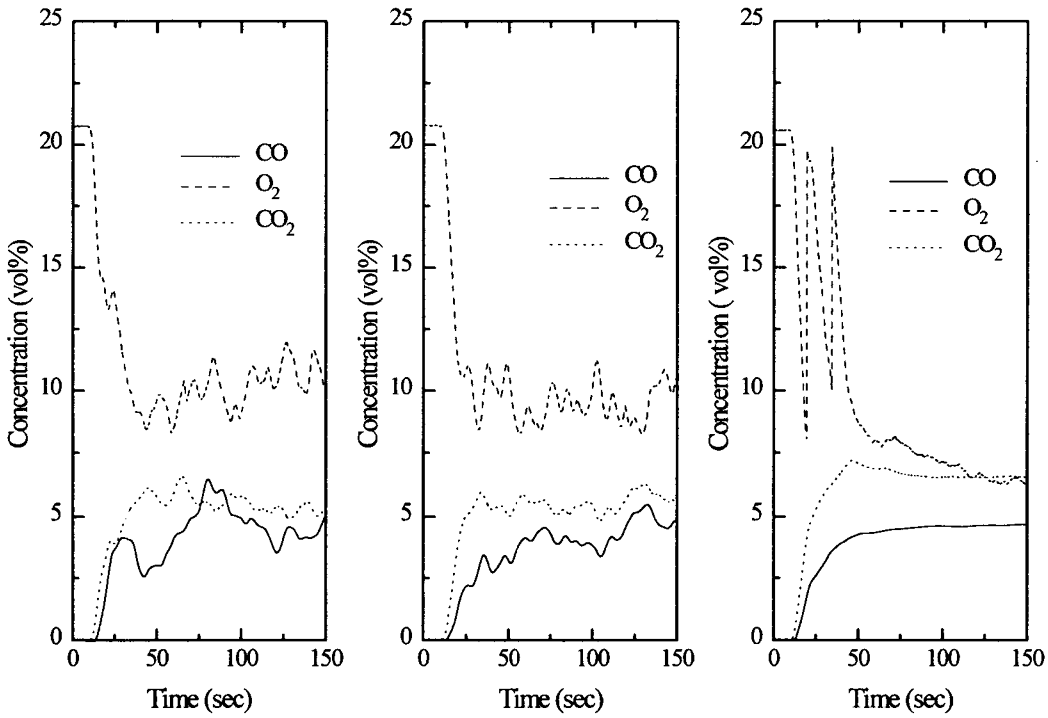
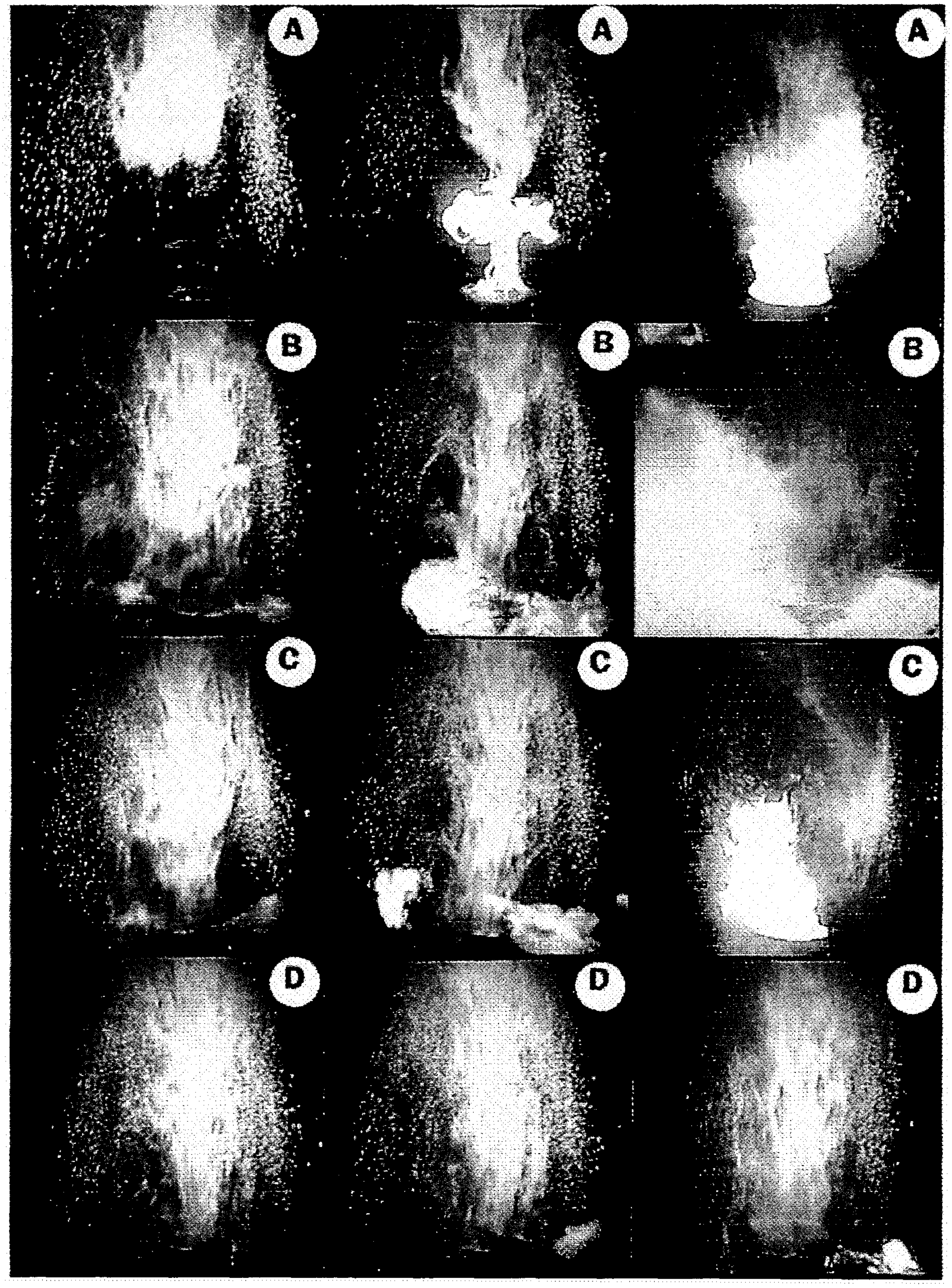


Fig.4 Flame temperature at 10mm above the initial surface



a) methanol b) ethanol c) gasoline

Fig.5 Concentration of gases at 40mm above the initial fuel surface



a) methanol b) ethanol c) gasoline

Fig.6 Extinguishment process of the fuels with the mists after about 70 seconds. These temperature trends in the case of the gasoline fire will imply that the gasoline flame location has been moving upwards, and gone away. The facts was also justified from measurements of concentration. As shown in Fig.5, O_2 concentration of methanol and ethanol were higher than that of gasoline. For methanol and ethanol, the combustion air was continuously entrained to plumes center by the pulsating motion of the flame as shown in Fig.3. Since fire of gasoline has not the pulsating motion, O_2 concentration was lower than that of the other fuels.

3.2 THE INTERACTION BETWEEN MISTS AND FLAME

Figure 6 shows the extinction process of the pool fires along with mists. Figure 6(a) and (b) showed that the water mists penetrated to reach fuel surfaces, and that then fires of methanol and ethanol were immediately extinguished. The extinction of gasoline pool fire, Fig.6 (c), demonstrated that the path of droplets was extremely distorted which differed from that of methanol and of ethanol. Arrival of mists upon the fuel surfaces will be decided in the relationship between the spray momentum and the buoyant forces of plumes. The buoyant force of fire plumes is therefore the governing factor in determining the penetration of water into the fuel surfaces through the plumes because the spray momentum has not been varied. Since among the fuels used in the experiment the heat release rate of gasoline has the largest value, the buoyant force of the fire also will be the largest. It is therefore understood that in case of gasoline flame such a distorted pattern by the buoyancy affects the penetration of mists to delay the direct cooling of the fuel surfaces, and that finally the fire is extinguished by the accumulation of water droplets in the fuel.

To evaluate the cooling effect of the fuel surface from the sprays, the temperature was measured at 2mm below the initial fuel surface. As seen from Fig.7, the fuel temperatures increased slowly with time, and reached the boiling points. As soon as the mists reached the fuel surface of methanol and ethanol, the fuel temperature decreased rapidly below the boiling point, and then the fires were extinguished. Due to the application of mists upon the gasoline fire, though the fuel temperature decreased abruptly at the time of the injection, such a rapid decrease did not continue till the extinction point.

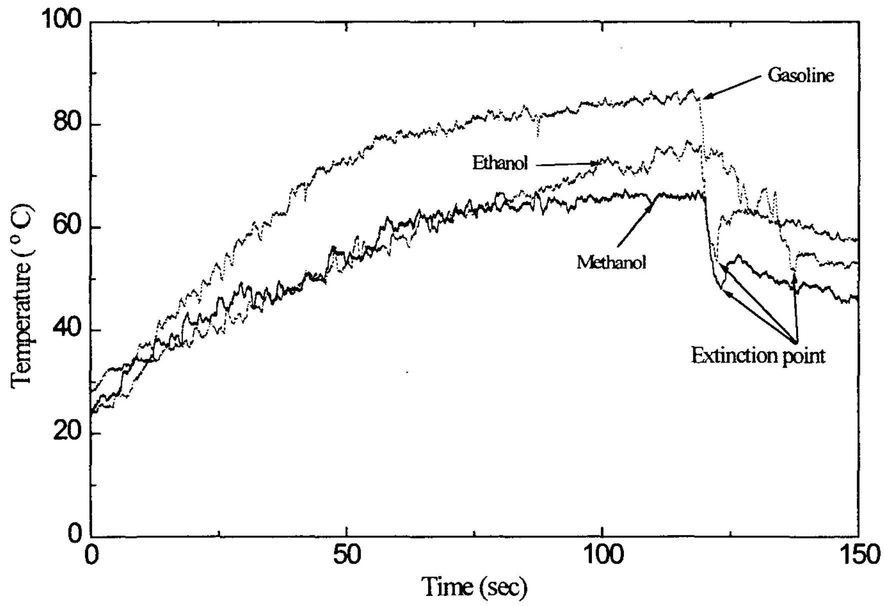


Fig.7 Temperature of the fuel surfaces

Then, by the interaction of the penetration of the mists and buoyancy of the plume, mist intermittently arrive at the fuel surface, and at that time temperature is rapidly decreased. These phenomena show that effective water flux arriving at the fuel surface is a important factor in the pool fire extingushiment and the extinction is done by the cooling of fuel surface. The method of effective water flux using the properties that the mixture of water and gasoline is separated[4] is not applied to mixture of the methanol and the ethanol and water, but from the result of fuel surface temperature measurement, we can verify that the account of effective water flux is different according to the kinds of fuel. Also, in the open environment, the mechanism of pool fires extinguishment is made by cooling of the liquid fuel surface, the fuel surface temperature can be used as a direct and general property representing the extinction efficiency.

4. CONCLUSIONS

A series of measurements and visualization were conducted in 0.15m pool fires with gasoline, methanol and ethanol to investigate the interaction with water sprays. The key conclusions are :

1. The gasoline flames are positioned on the rim of pool, and other flames are being attached very near the fuel surface, which is believed to depend on stoichiometric air-fuel ratio.

2. The state of mists penetration through fire plumes are varied in the heat release of fires from the beautiful visualized pictures.

3. It is clearly observed that the accumulation of water in fuels cools the fuel temperature to suppress the evaporation, leading to the fire extinguishment.

4. As the measure of the extinction efficiency, the fuel surface temperature may be one of the most useful property because that is a general and direct property on the mechanism of pool fires extinguishment in an open environment.

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