A STUDY ON DETERIORATION OF VISIBILITY DURING FIRE FIGHTING IN AN ENCLOSURE

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ABSTRACT

Deterioration of visibility during fire fighting occurred after water injection is a problem in the development of a pneumatic nozzle system. A series of experiments had been carried out to investigate the effect of the water injection on the temperature field in a test enclosure. The process of the deterioration of visibility was recorded with video and infrared cameras. The deterioration of visibility occurred before the cooling of the hot zone in the enclosure. The movement of the smoke layer in the enclosure was determined by processing the recorded video images. The volumetric increase of the smoke layer was estimated with the obtained movement of the smoke layer.

KEYWORDS: Visibility, Fire fighting, Enclosure

INTRODUCTION

To minimize the damage caused by fire fighting, the quantity of water injected to the fire area has been reduced using a pneumatic nozzle system[1]. The observation of the fire area during fire fighting activity is needed to achieve the extinction with minimum water quantity. During a series of fire extinguishing experiments, the visibility in the fire enclosure deteriorated after the water injection. The deterioration of visibility may occur by 1) the reduction of the light emission from the fire area and/or 2) the screening of the light emission with the smoke layer.

The pneumatic nozzle system has been developed to minimize the water injected to the fire area for reducing the gas volume generated by the vaporization of water. The reduction of water injection is also expected to avoid cooling the hot zone and preventing the mixing of the hot and cold zones to maintain good visibility through the cold zone in the fire enclosure. However, the deterioration of the visibility in the fire enclosure occurs in the early stage of the fire fighting in experiments. In this study, the thermal conditions in the fire enclosure have been examined with the visible and infrared images.

EXPERIMENT

A model fire enclosure was built in a test room. The test room was 25 m wide, 25 m long, 22 m high. The test room has an opening of 6.5 m wide and 2 m high. The test room was exhausted at 90,000 m^3/hr.

The model enclosure was 6 m wide, 6 m long, 2.3 m high as shown in Fig. 1. The enclosure was constructed with steel. The ceiling and sidewalls were insulated with ceramic material. The ceramic material was covered with metal sheets to prevent the damage during fire suppression experiment. The enclosure had an opening of 0.9 m wide, 1.8 m high on a corner.

Six thermocouples (TYPE-K, 0.65 mm diameter) were attached to the wall near the opening. Their elevations were 0.5 m, 0.6 m, 0.7 m, 0.8 m, 0.9 m, 1.0 m, 1.1 m, 1.2 m, 1.3 m, 1.4 m, 1.5 m, respectively, above the floor. Three thermocouples (TYPE-K, 1.6 mm diameter) were attached to the fire source along the centerline at the bottom, middle, and top.

A fire source of 50 kg wood crib was set in the enclosure. The wood crib is 0.73 m wide, 0.73 m long, 1.4 m high. 1500 ml of heptane in a 7300 mm square tray was used as an ignition source. The smoke layer in the enclosure formed at 25 s after the ignition. The bottom of the smoke layer lowered to 1000 mm above the floor at 50 s after the ignition. The ignition source burned about 80 s. After burning-out of the ignition source, the bottom of the smoke layer rose to 1300 mm above the floor due to the reduction of the heat release rate. The crib burned for 180 s in the enclosure. During this period, the bottom of the smoke layer rose gradually to 1600 mm above the floor.

A pneumatic nozzle is used to extinguish the fire. The discharge rates of water and air are 40 l/minute, 1000 l/minute, respectively. The pneumatic nozzle was targeted to the fire source for 100 s from the opening. After confirming the temperature conditions in the enclosure for entry, two fire fighters entered the enclosure to apply water to the backside of the fire source.

Water from the enclosure was collected by a trench and measured by a balance of a receiver tray of 1 m square. Subtracting the recovered water from the injected water, the net water consumed during the extinction experiment was determined.

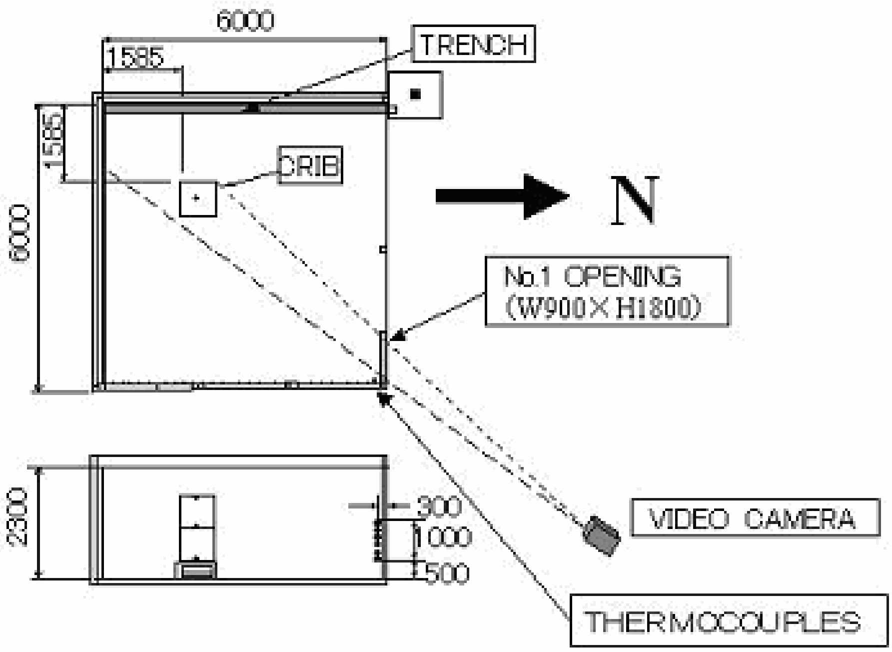

FIGURE 1. Model fire enclosure

RESULTS

The experimental procedure is identical for six cases. Experimental cases are labeled from 9-101 to 9-106 in the figures.

The averaged quantity of water injected is 77 l in these cases. The averaged time period of the water injection is 116 s at the normal discharge rate, 40 l/minute. 86 % of the injected water was discharged at the opening of the enclosure.

Video images after water injection of six cases are shown in Fig. 2. Time after the water injection, t is shown on the left side of the images. These images are sampled at 10 ms intervals. The video camera located behind the fire fighters. The fire source emission is used as the illumination source in the enclosure. The fire source is seen in the middle of images. The upper part of the enclosure is filled with smoke. The burning crib is seen in flame under smoke. The water-air mixture is seen as a dark part near the fire fighters at t = 20 ms. The dark part near the fire fighters moved with the pneumatic nozzle manipulation. The position of the bottom of smoke layer lowered at t = 60 ms. Cone shaped section of smoke layer is seen at t = 60 ms in cases 9-102, 9-103, 9-104, 9-105, 9-106.   The cone shape section is moving toward the stream of the water-air mixture.   The diameter of the cone shape section is about 0.5 m in these pictures.

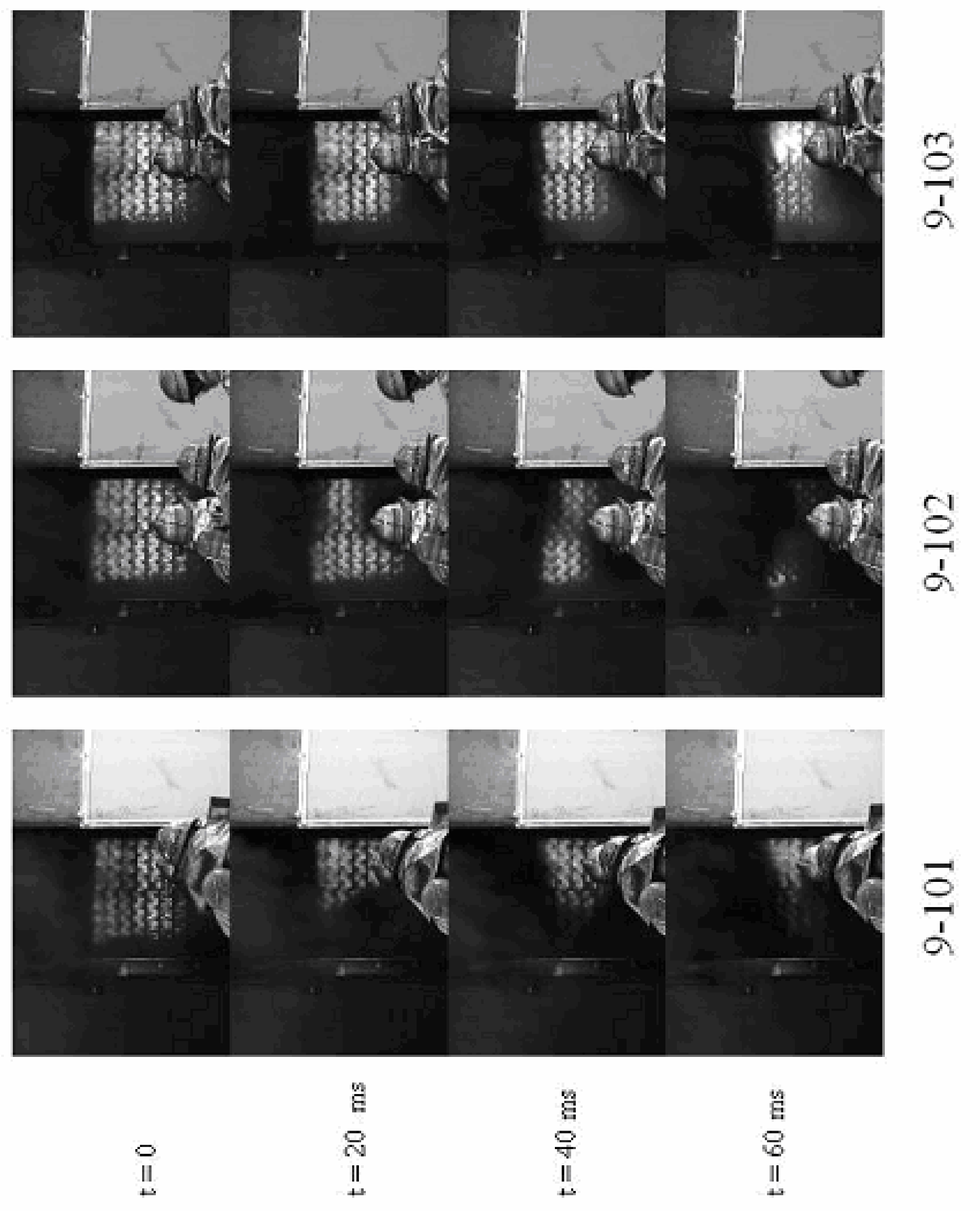

FIGURE 2-1. Video images

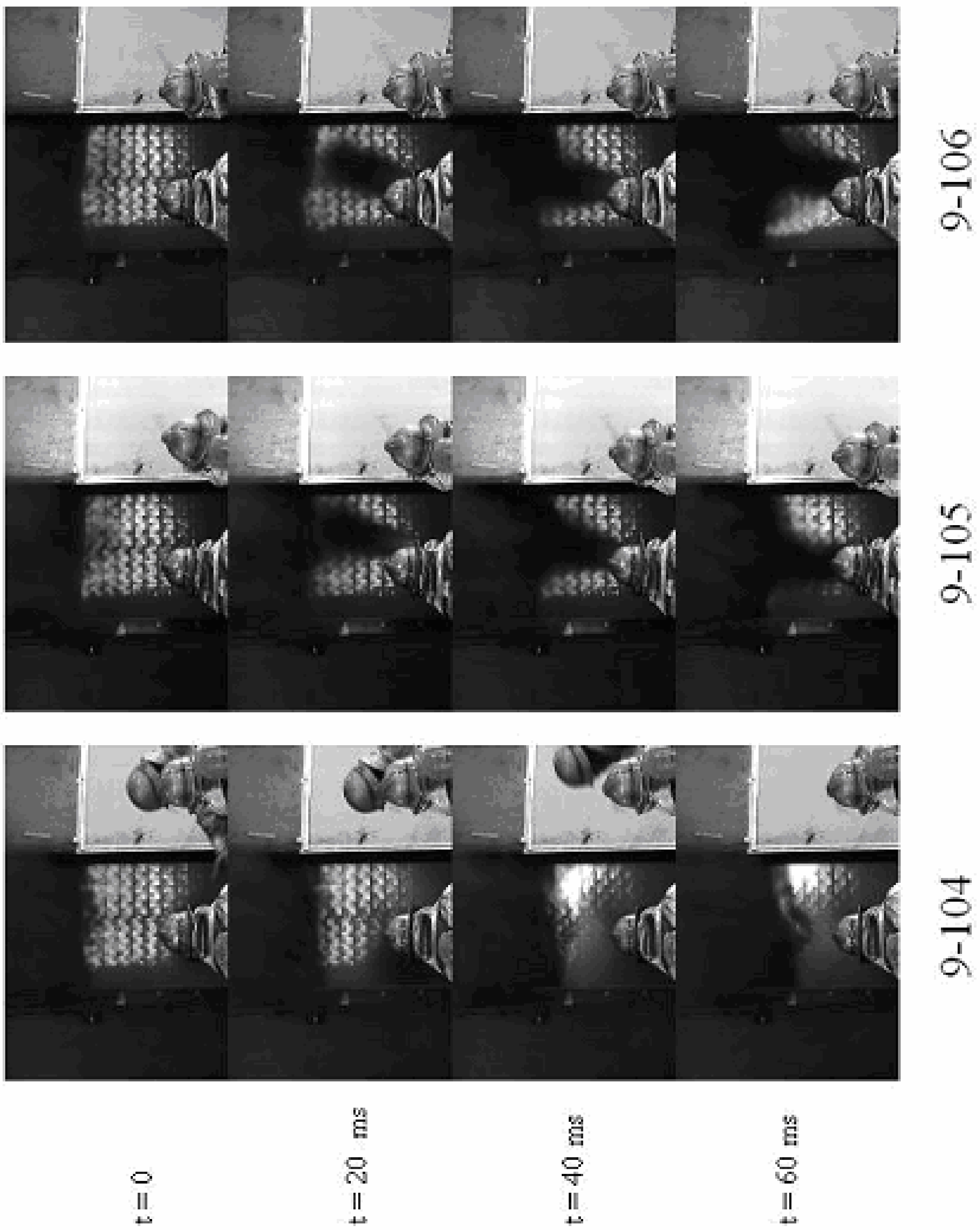

FIGURE 2-2. Video images

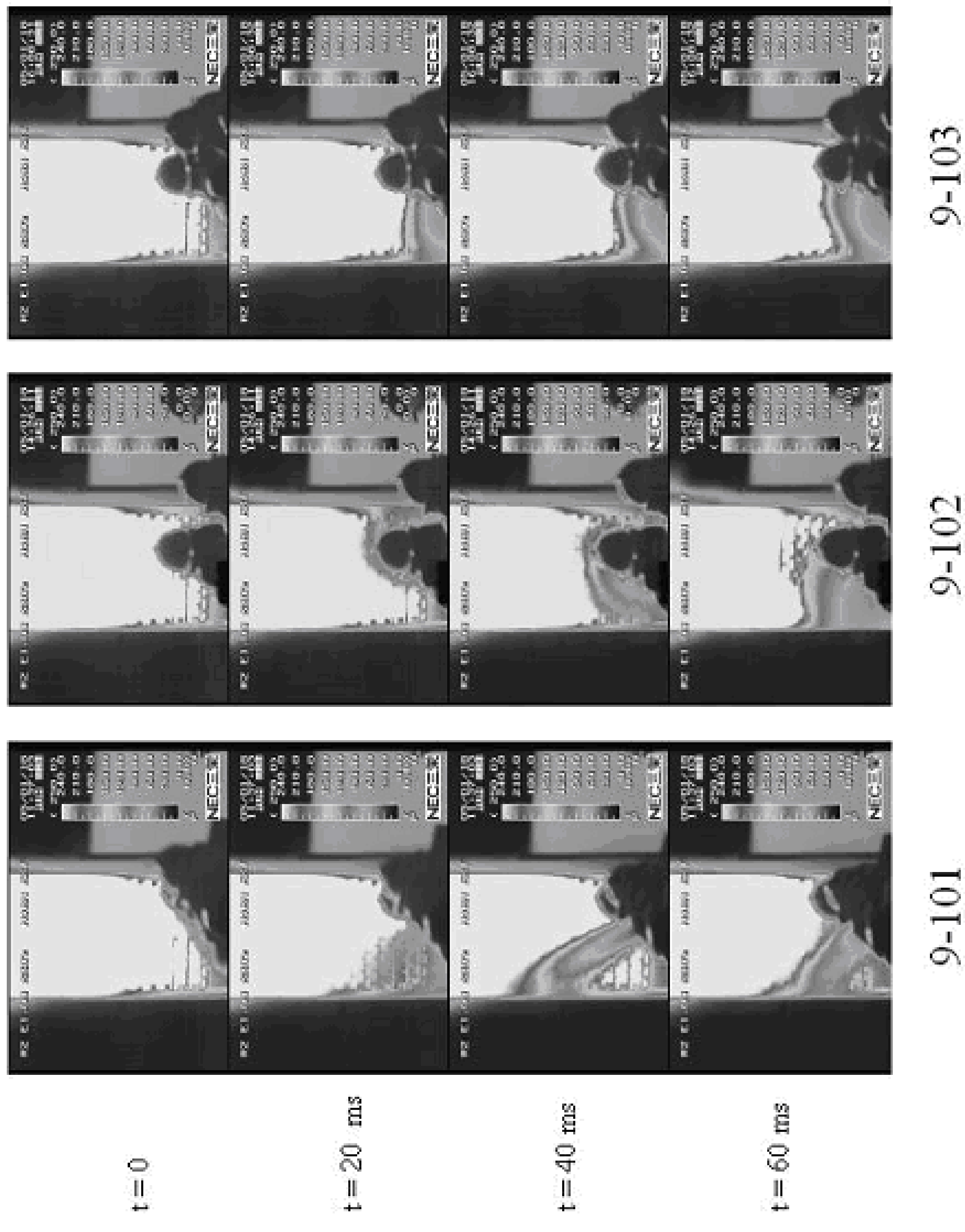

FIGURE 3-1. Infrared images

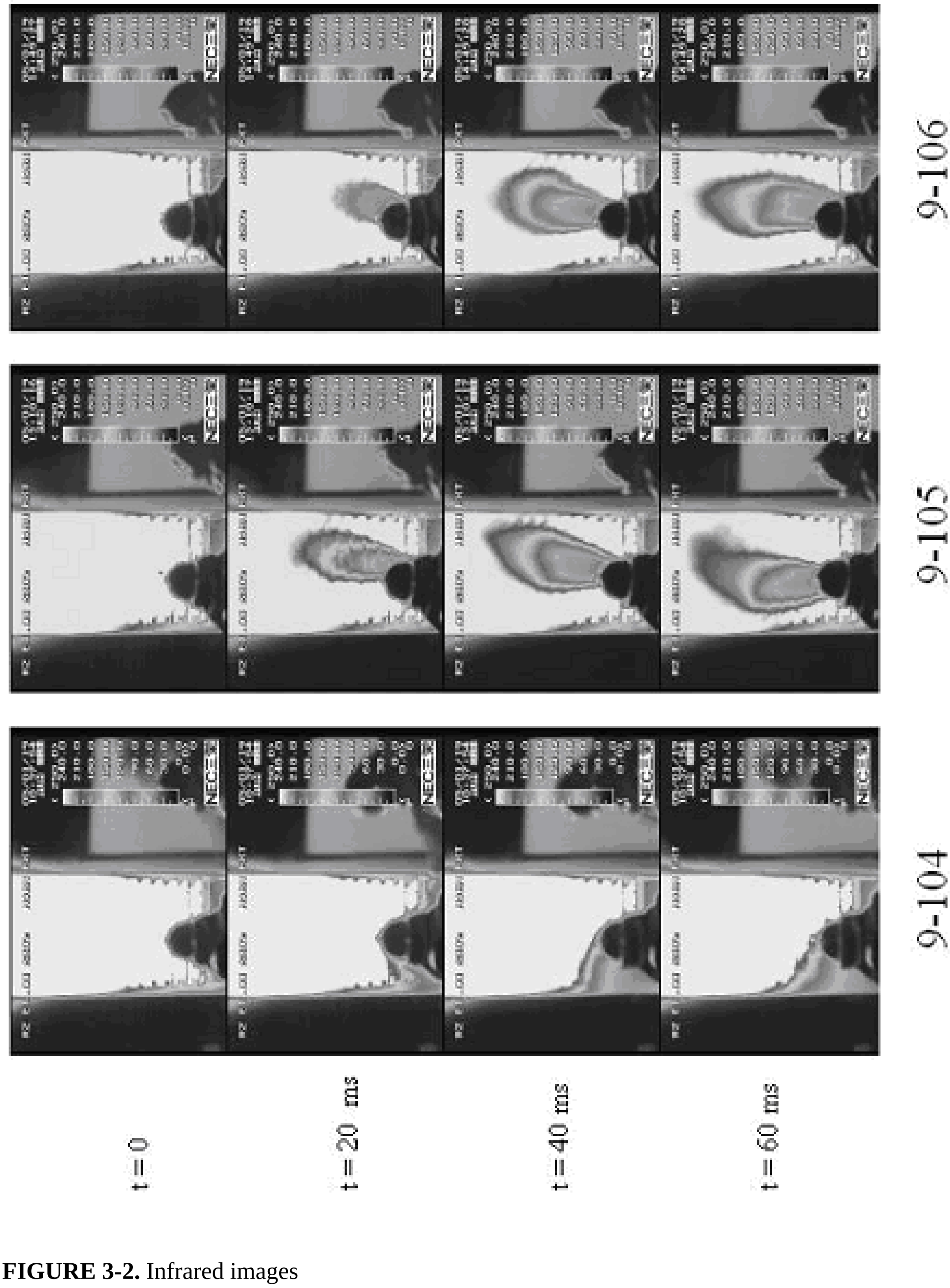

FIGURE 3-2. Infrared images

Infrared images after the water injection are shown in Fig. 3. The infrared camera located next to the video camera. Time after the water injection, t is shown on the left side of pictures. The used wave range is 10 micrometers band where the light penetrates smoke layer in these cases. The infrared image is shown in false color of temperature range from 0 degree Celsius to 250 degree Celsius. The area above 250 degree Celsius is shown in white. The burning crib is seen as white area in the middle of images. The displayed image reflects the equivalent radiation temperature, which is different from the reading of conventional thermometer due to the finite optical thickness and spatial non-uniformity of the object.

The thermal boundary layer of the lower part of the burning crib is seen at t = 0. The water-air mixture is seen near the fire fighters at t = 20 ms. The cooled area of the burning crib is seen at t = 20 ms. The cooled area of the burning crib is moving with the pneumatic nozzle manipulation. Comparing these images with Fig. 2, it is found that the cold water-air mixture is clearly visualized in infrared pictures.

The movement of the bottom of smoke layer is determined from video images by setting a threshold brightness of smoke boundary. The movement of the smoke layer of the case 9-104 is shown in Fig. 4. The time, T after the ignition is shown in seconds. The smoke layer height, H above the floor is shown in meters. The smoke layer height before the water injection was 1.7 m - 1.8 m. The smoke layer lowered after the water injection below the observation range. The transitions of the bottom position of smoke layer occurred within 2 s in this case. The bottom position of smoke lowered about 1 m within 2 s.

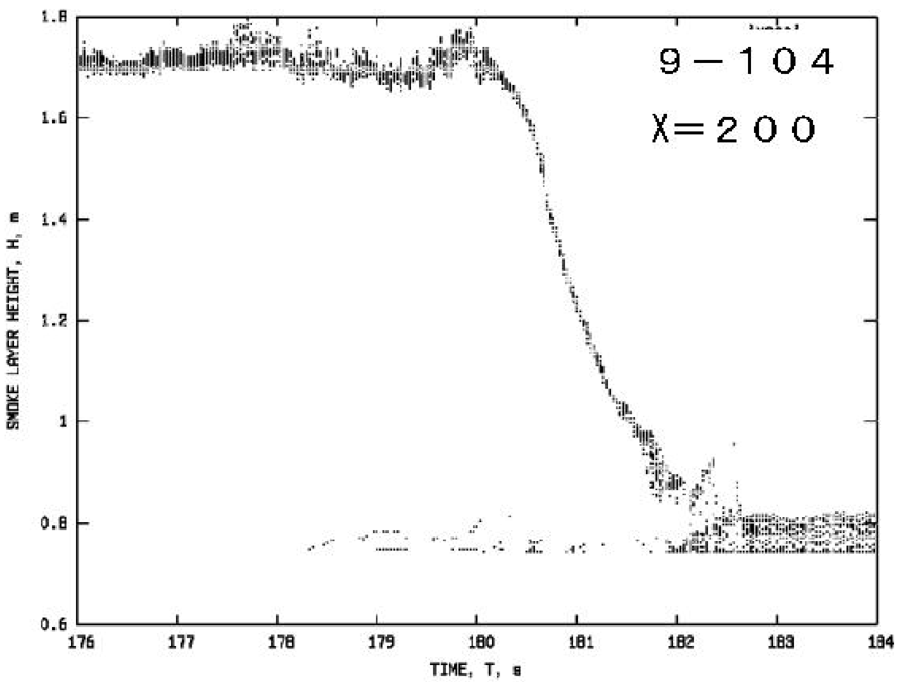

FIGURE 4. Movement of smoke layer

Temperature records near the opening of case 9-101 are shown in Fig. 5. The temperature between 900 mm to 1200 mm above the floor rose slightly after the water injection. This area is the boundary of the hot and cold zones in the enclosure. The time delays of the temperature change among these locations are not seen in this figure. The temperature decrease began 7 s after the water injection from 1300 mm to 1500 mm above the floor, 4 s after the water injection from 900 mm to 1200 mm above the floor. The temperature was constant from 600 mm to 800 mm above the floor. Three zones are formed from 600 mm to 1500 mm above the floor.

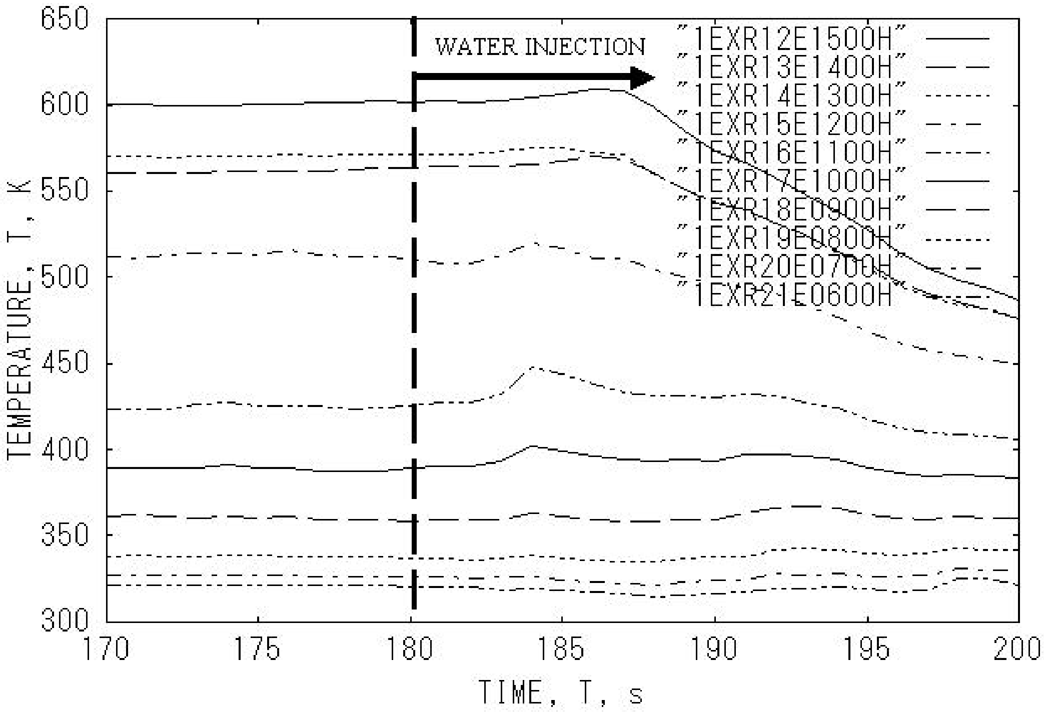

FIGURE 5. Temperature records near opening

DISCUSSIONS

The visibility in the enclosure deteriorated within 2 s in these cases. Considering the water injection duration at the opening, the fire fighters discharged water into the enclosure based on the image before the water injection.

The observed temperature decrease occurred at 4 s after the water injection. The smoke layer was not cooled within 2 s after the water injection, while the smoke layer moved downward in this period. The smoke layer movement occurred in uniform manner excluding the nozzle flow region in video images.

The mixing in the layer from 900 mm to 1200 mm with hot gas after the water injection is seen in the temperature records in Fig. 5. Flame was seen in several cases through the lowered smoke layer. These facts indicate that the cooling of the fire source surface below the visible light emission temperature is achieved within 2 s and the heated gas flows into the layer from 900 mm to 1200 mm.

The constant temperature from 600 mm to 800 mm indicates that this area is in the inflow region where is free from the fire source.

The heat release rate of the used crib under free burning is estimated about 2.0 MW[2]. The weight of the consumed air[3] is about 0.7 kg/s, which volumetric consumption rate at the normal temperature is about 0.5 m^3/s. Presuming the air heated to 1000 K in the fire source, the volumetric flow rate is estimated to be 1.7 m^3/s.

The volumetric feed rate of air of the pneumatic nozzle is 1.7x 10^{-2} m^3/s. The mass feed rate of water of the pneumatic nozzle is 0.7 kg/s. Presuming the water vapor heated to 1000 K in the fire source, the volumetric flow rate is 2.8 m^3/s.

The volumetric increase rate due to the water injection is 2.8 m^3/s while the volumetric increase rate of the smoke layer is estimated 18 m^3/s by presuming the uniform movement of the bottom position of the smoke layer. Six times of volumetric increase is triggered by the water injection. The volumetric increase due to the water injection to the fire source is not large enough to cause the observed smoke layer movement. This result indicates that the lowering of the smoke layer occurred in small area. Non-uniform lowering of hot zone is seen in previous studies[4, 5] of model enclosure fires. The enhanced natural convection may push the smoke layer downward locally due to the increase of the volume of the heated gas from the fire source.

The visibility in an enclosure is evaluated with the video and infrared images. The selected fire scenario in this study was developed using fire cases of Yokohama City Fire Bureau. The fundamental conditions of the size of the enclosure, the free burning period, the burning materials, the fire-fighting procedure, etc. may differ with the selected area. The presented results may be specific for the area in Yokohama Fire Bureau while the procedure to analyze the visibility in the fire enclosure could be applicable for cases in other fire authority.

CONCLUSIONS

This study demonstrated detailed time resolved observations of smoke layer movement during fire extinguishing with water-air mixture. The experiments reveal:

1. The smoke layer movement is captured by a two-dimensional image processing under hand line operation.
2. The velocity of the downward movement of the smoke layer after the water injection is about 0.5 m/s. The smoke layer movement is uniform excluding the nozzle flow region in the video images.
3. The smoke layer movement is faster than the temperature changes in the enclosure.
4. The estimated volumetric increase of the smoke layer is much larger than that expected with the water vapor due to the water injection.

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