An Experimental Study of the Diffusion Flame Characteristics for the Gas Fueled Torch System

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Abstract

Currently, a gas fueled diffusion flame is used for the relay torch system. It could be burned cleanly but should be stable at severe weather condition such as rain of up to 55 mm/h, winds of up to 70 km/h and also produce a highly bright yellow visible flame. This paper presents torch diffusion flame characteristics on the various wind speeds and rainfall conditions. From the results, flame lengths are controlled by the momentum flux ratio of fuel and ambient air flow and flame stability is much influenced by the mixing characteristics with air flow. Flame is fluctuated above than 200 mm/h rainfall and blow out is occurred about 300 mm/h rainfall condition.

Key Word : Gas Fueled Torch System, Diffusion Flame, Flame Stability, Blow out

Introduction

In the old days, firebrand, magnesium oxide and gunpowder were used as a relay torch system. But such torch systems are not matched with Olympic spirit and generate harmful smoke. So, it is necessary to use environmentally clean gas fuel as a torch system. In the current Olympic game such as Athens 2004, relay torch flame had to travel long distance without flame out.

The modern relay torch should be stable in severe weather condition such as rain up to 55mm/h, winds of up to 70km/h. Also the fuel should be burned cleanly without producing toxins or smoke and the combustion system has to produce a bright yellow flame. To meet these requirements, 80% butane and 20% propane blended gas was used for torch fuel. The torch combustion system has to produce stable jet flame by using turbulent mixing with ambient air. However it is very difficult to predict the flame behavior[1,2,3]. To verify diffusion flame characteristics of torch system, we used wind tunnel which can produce winds of up to 200km/h and rainfall simulation system which can make raindrops of up to 700mm/h. The main combustion system was designed and manufactured by EOS design company in Korea.

In this research, we would like to present flame characteristics with several wind speeds and rainfall conditions.

EXPERIMENTAL APPARATUS

The compressed liquefied butane and propane mixture was used as a torch fuel. The fuel is injected about 40 minutes at the 1m/s velocity. The torch system is composed of fuel cartridge, fuel tube and injection nozzle. The fuel cartridge was installed in the bottom side of torch system.

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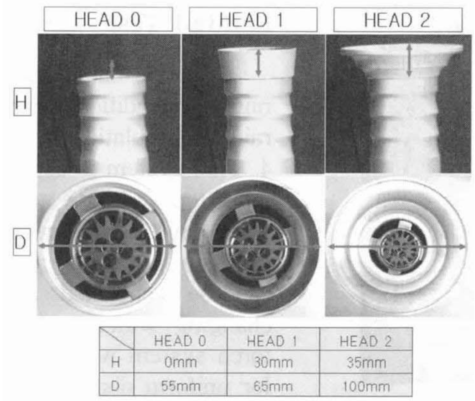

Fig. 1. Torch combustion system

The gas fuel which was injected from fuel nozzle is ignited from external flame source and sustained diffusion flame. Three types of torch heads were used for combustion test as shown in Fig. 1. The first one is without head(HEAD 0),second is cylinder type head(HEAD 1) and last one is bowl type(HEAD 2).

Wind Tunnel Test

To understand flame characteristics with wind speed, we performed wind tunnel test. The basic requirement of torch combustion system is that flame has to be stable at the wind speed of above 70km/h. To verify wind effect on the flame, we used low speed wind tunnel. This wind tunnel can produce wind speed up to 200km/h and test section area is 400×600 mm^2. Fig. 2 shows photograph of wind tunnel test. The wind speed is measured by the velocity probe located at the entrance of the test section. The torch system was installed in the test section and it could be rotated with desired measuring angle. Between the fuel supply and torch combustion system, fuel control valve and pressure measuring system are installed. The pressure is measured by piezoelectric type gauge and the flame temperature was measured by five R-Type thermocouples which interval is 10cm distance. The measured thermocouple voltage signal was transferred to TC-2095 terminal and goes to amplifier SCXI-1102 module. This signal was processed by SCXI-1600 module and transferred to the computer for recording and display by Labview.

The torch combustion system requires bright yellow flame. To measure the flame color, we used Color chroma meter(Minolta CS-100A) which was shown in Fig. 3. By using this device, we measured flame color on the form of standard CIE XY index.

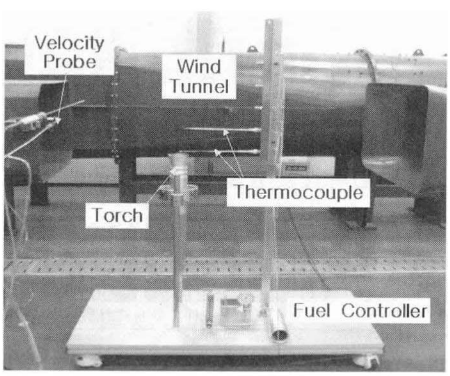

Fig. 2. Wind tunnel test rig

Fig. 3. Color chroma meter

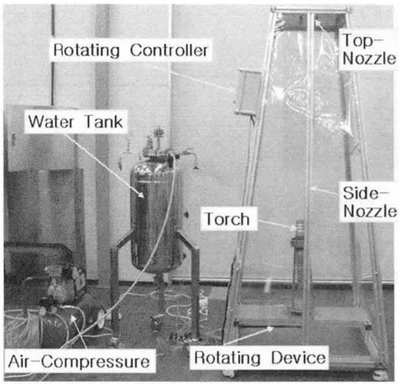

Fig. 4. Rainfall simulation system

Rainfall Test

Torch flame has to be stable above 55mm/h rainfall condition. For this purpose, we devised rainfall simulation system which was shown in Fig. 4. This system is composed of air-compressor, water tank, top and side nozzles and rotating device. Nine water injection nozzles are placed on top and one injection nozzle is placed on side location. Rainfall can be controlled from 0mm/h to 700mm/h by changing water tank pressure. During rainfall test, torch system was rotated on 10rpm by electric motor for uniform distribution of rain drops.

RESULTS AND DISCUSSION

Wind Tunnel Test

Fig. 5 shows flame shape variation with cross wind. On the zero wind speed, flame color is bright yellow and flame height varies from 25cm to 35cm. Up to 1m/s wind speed, flame color is sustained yellow but flame height rapidly shrink to smaller than 10cm and is inclined to downstream flow direction. In this wind speed range, the flame height is directly affected by the wind speed. In the velocity range of more than 1m/s, flame becomes blue color and flame is almost attached on the top of torch head. From wind tunnel test, blow out wind speed is 39 m/s at HEAD 0, 17m/s at HEAD 1 and 17m/s at HEAD 2. In these results, we could understand that interaction area between air and fuel flow plays very important role for flame stability.

Fig. 6 shows flame shape at inclined angle 30°case. Comparing with perpendicular case, flame is thicker than perpendicular case. Yellow flame is observed at 1.6m/s of HEAD 0, 2.0m/s of HEAD 1 and 4.0m/s of HEAD 2 case. The flame blow out wind speed is at 6m/s of HEAD 0 and 25m/s of HEAD 1 and 24m/s of HEAD 2. These results are somewhat different with perpendicular case. The main difference is air flow angle. So, it could be explained that air guiding device as HEAD 1 and HEAD 2 can enhance mixing with air.

Fig. 7 shows flame height with wind speed. In this graph, flame height is decreased with increasing wind speed. The flame height is largely changed from 0m/s to 1m/s wind speed range. After that flame height is almost same and kept constant below than 5m/s. We would like to compare this result with momentum flux ratio of air and fuel streams.

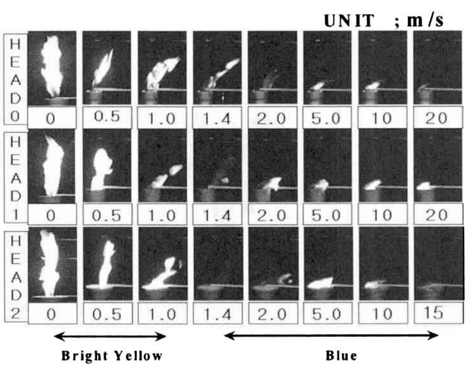

Fig. 5. The torch flame with cross wind

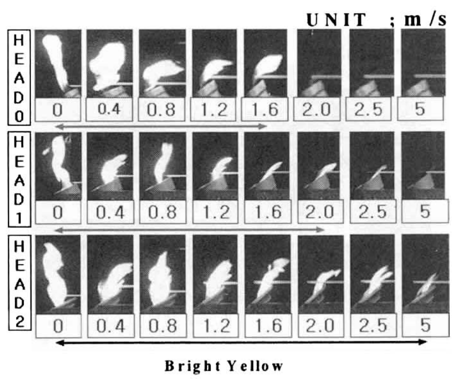

Fig. 6. The torch flame with cross wind at angle 30°

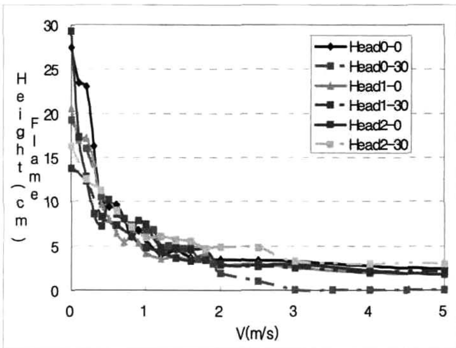

Fig. 7. Flame height with wind speed

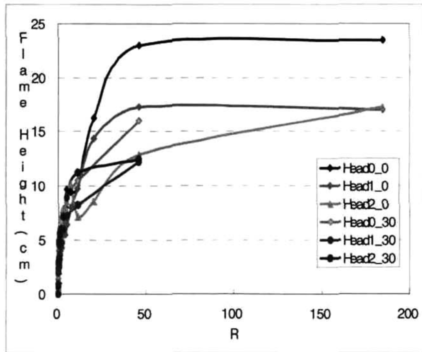

Fig. 8. Flame height with momentum flux ratio

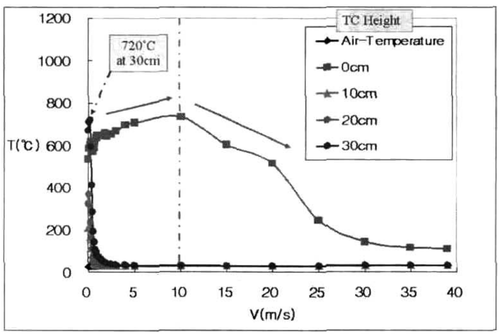

Fig. 9. Flame temperature with wind speed (HEAD 0, Angle 0°)

From Johnson and Kostiuk[4], maximum mean flame length is related to momentum flux ratio (R) of the fuel jet and air flow. The momentum flux ratio (R) defined as below equation.

$$R = \frac{\rho_j V_j^2}{\rho_\infty V_\infty^2} \tag{1}$$

Where ρ is density, V are velocity, and the subscripts j and ∞ designate the fuel jet and ambient fluid respectively. Fig. 8 shows flame height with momentum flux ratio. In this graph, the flame height increases with momentum flux ratio, but the flame height kept almost constant value when momentum flux ratio is over than 50. The momentum ratio 50 corresponds to wind speed 0.2m/s. The flame height and momentum decrease also with increasing air velocity. As a results we could understand that the flame height of torch system is controlled by the momentum flux ratio.

Fig. 9 shows flame temperature with wind speed. The flame temperature has maximum value at wind speed 0.2m/s. The maximum flame temperatures are 720℃ at 30 cm, 315℃ at 20 cm and 165℃ at 10cm location in zero wind speed. The flame temperature is rapidly decreases with air velocity from 0m/s to 1 m/s. At 0cm position, temperature is increased with air velocity range from 0m/s to10m/s. When increasing air speed more than 10m/s, flame temperature decreased to 100℃.

Rainfall Test

Rainfall test was conducted by measuring flame lifetime. Before rainfall, 30 seconds preheating was preceded. After preheating, rainfall is started and flame lifetime is measured up to 60 seconds. Fig. 10 shows photographs of flame with rainfall test at 0mm/h, 100mm/h, 200mm/h

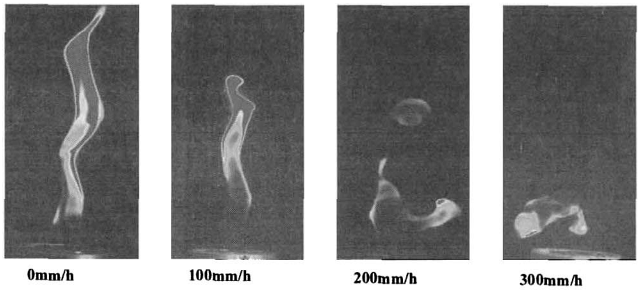

Fig. 10. Flame with rainfall at HEAD 0

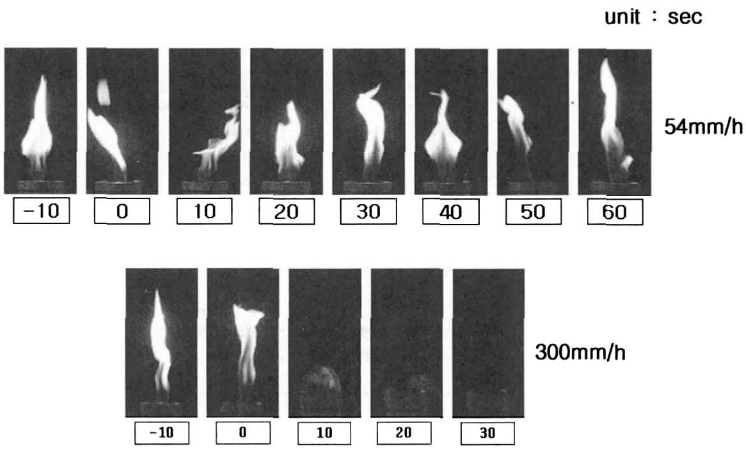

Fig. 11. Transient flame shape with rainfall (HEAD 0)

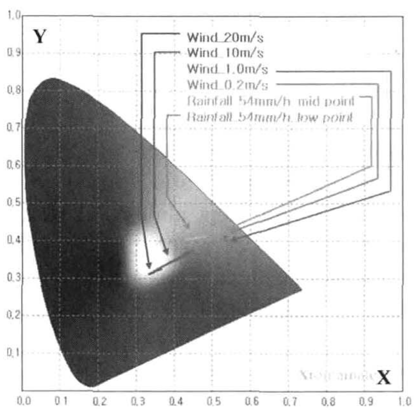

Fig. 12. CIE XY index of flame color

and 300mm/h rainfall. The flame height is decreased with rainfall and flame is separated because of rain drops. After all, blow out is occurred at 300mm/h rainfall condition.

Fig. 11 shows flame shape with time at 54mm/h and 300 mm/h rainfall. In the case of 54mm/h rainfall, flame shapes are slightly affected by rainfall but sustained flame shape. However 300mm/h rainfall case, flame was affected largely by rain drops and blow out is occurred at 20 seconds. This could be explained by two reasons. The one is that addition of an inert water vapor can suppress diffusion flame by reducing the oxygen partial pressure. Another is that rainfall water cools down the flame zone directly and some proportion of the heat of reaction is taken up by heating an inert water droplet. Therefore less thermal energy is available to continue the chemical break-up of compounds in the vicinity of reaction zone.

Flame Color Measurement

Fig. 12 shows CIE XY index for flame. When increasing wind speed, flame color was changed from yellow to blue color. More than 10m/s wind speed, flame color was varied wider range of color index. In the rainfall test, flame fluctuated from yellow to blue with time. It means that flame is very unstable under rainfall condition.

CONCLUSIONS

The torch flame characteristics were investigated by using wind tunnel test and rainfall experiment. The test results are as follows;

1. Flame height was decreased with wind speed.
2. Flame height was increased as increasing momentum ratio of fuel and air.
3. Flame stability was much influenced by torch head shape.
4. As increasing rainfall, flame goes unstable and blow out is occurred at 300mm/h rainfall.
5. Flame color was changed from bright yellow to blue by increasing wind speed.

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