The Detection of Fires and Explosions of Hydrogen by Flame Detectors (Comparison of UV-IR and IR3 detectors)

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Highlights:
Flame spectra are measure from vacuum UV to IR region to check the useful emission of fire sources
Immune test is performed to select useful detector for hydrogen jet flame and explosion
Large size explosion test is carried out to check the performance of detectors
Detector works and monitors the explosion propagation and records in the time lapse video
UV detector react to electric discharges but has difficulty to H2 explosion

Abstract:

Hydrogen flames are nonluminous flame and invisible. Hydrogen flame detectors using ultraviolet light (UV) have been conventionally used at hydrogen-filling stations in Japan, but it is known that false alarms are generated. Therefore, we investigated the effectiveness of various detectors(IR&UV&UV-IR Detector) applied on oil field platforms. We compared the detectors performances against the hydrogen jet flame and explosion. The effectiveness against fire objects that could be false alarm sources are also examined in immune test. UV sensor has normally wide range response from 185-260nm range. But the emission of fire sources in this region is unknown. So we measured spectrum of this range to demonstrate the sources of emission caused by OH and NO spectra. Also IR region of fire spectra are measured. H_2O, CO_2, and CO spectra show the characteristic strong emissions. Performance of IR3 which measure 3 wave lengths in IR region with AI(Artificial Intelligence) excels compare to UV& UV-IR detectors.

Key words: Detectors, Hydrogen Fire, Hydrogen Explosion, Immune Test, False Alarm, IR3

1. Introduction

Recently demand on hydrogen energy without emit carbon has been expanded. Also hydrogen molecule has the minimum ignition energy compare to other gases, the wide combustion limit (4-96%) and the high diffusion constant. The early stages detection of leaked hydrogen gas and small flame from systems is very important in fire safety to avoid hydrogen explosion. Flame detectors is well known to find effectively the fire in plant applications and the car fire in highway tunnel applications. So IR type of flame detectors have been applied to the practical use in petroleum plants and automobile tunnels. Also This system is installed as effective fire detector in large buildings. General high pressure gas safety ordinance illustrative standard 59-2 against Compressed hydrogen station, and also illustrative standard 66-2 related to safety regulations for industrial complexes etc. , are explained the measures to detect fire in compressed hydrogen station. Measures to Detect Fires in Compressed Hydrogen Stations, the generation of hydrogen flames is to be constantly monitored by detecting ultraviolet rays emitted by hydrogen flames. But it is also said that false alarms are frequently issued.

Therefore, in this study, we investigated the responses of 6 flame detectors against various flames in various distance and various fuels. Their response to false alarm sources is examined as immune test. Especially UV sensor react to ultraviolet(UV) emission by flame and the spectra of UV to Infrared(IR) is studied and find typical emission by combustion. UV sensor is prepared and check the output by fire sorce. 6 detectors are prepared to conduct indoor immunity test and combustion test. Also outside immunity test , combustion and explosion test are performed at Kakioka experimental site(Ibaragi Pre., Japan of Tokyo Uni.) and hydrogen jet flame combustion experiment is carried out at Shirosato Indoor site of JARI(Ibaragi Pre., Japan Automobile Research Institute). [1] [2]

2. Material and Method

2-1 Spectra Analysis of hydrocarbon gas

Gaseous flames of hydrocarbons of methane, butane and candle light are created. Spectroscopic measurements of gaseous flame from vacuum ultraviolet region to infrared region are performed. Spectroscopic analysis of ultraviolet region is carried out by Shimazu small spectrometer Spectromate SPG-100S, with side on type photomultiplier tube (Hamamatsu photonics R928-09 type/28mm/multi-alkali). Vacuum ultraviolet spectrum analysis is carried out by Vacuum Optics Co. Ltd. Spectrometer (Hamamatsu photonics R1220 Te-Cs) with MgF2 window. Infra-red spectrum analysis is conducted by SR5000 spectrometer (CI Co.Ltd). Flames are created by gas micro-burner.

2-2 UV sensor

UVtron is famous for UV flame detectors. To know the performance of this sensor, UV counter (electric circuit) is built using UVtron (Hamamatsu photonics R2868) and performance is checked under different applied voltage and different light sources and flames. Geiger Muller tube which has no bandpass filter is applied.

So UVtron has window of quartz glass allow 185nm and more longer wave to penetrate and has the sensitivity from 185-260nm range. There is strong emission of light from hydrocarbon combustion flame about 310nm by OH radical. And UVtron has no sensitivity more than 300nm to avoid 310nm emission from outside circumstances. Fig1

Fig.1 Typical UV sensor （ Sensitivity range185-260nm.UVtron Hamamatsu photonics R2868）

2-3 Flame detector

6 flame detectors are prepared for this test. All detectors are explosion proof.

No1 detector is for the hydrogen applications. The 3 different wave lengths spectra in IR region are monitored and detect fire and explosion by AI to produce signal to initiate fire prevention reaction, also 3 minutes video before and after the event is memorized in silicon chips by Co. A.(①or H2 for abbreviation)

No2 detector is suitable for Hydrogen and Hydrocarbons. We can apply this toward the petroleum complex and combustion of hydrocarbons. The 2 different wave length of spectra in UV and IR are monitored and detect fire and explosion by AI. The event is monitored in black and white CCD camera in real time and memorized in silicone chips by Co. A. (② or UV-IR for abbreviation)

No3 detector is for the petroleum complex and combustion of hydrocarbons. The 3 different wave length of spectra in IR are chosen to monitor and detect petroleum fire by AI. The event is monitored and memorize in silicone chips by Co. A.(③ or IR-3 for abbreviation)

No 4 detector is UV detector from Co. B. (④ for abbreviation)

No 5 detector is UV-IR detector from Co C. (⑤ for abbreviation)

No 6 detector is UV detector from Co. D. (⑥ for abbreviation)

3 detector No1-3 can monitor and event memory of 3 minutes video before and after the event is activated in silicone chips.

Fig 2. Flame detector ①②③ of A Co.

2-4 Immune Test

In the source of false Alarm test the following equipment are applied:1)LED light, 2)Strong Halogen Light , 3)Cigarette Lighter 4) Flash Light 5) Bunsen Burner 6)Pool Fire(300x300x150cm) of methanol, gasoline and kerosene are prepared.

2-5 Tent explosion test at Kakioka Outside experimental site of Tokyo Uni..

Small tent explosion test of 1mx1mx1m is held at outside experimental site.

The concentration of gases in tent explosion test are monitored by Sx Sensor dedicated to real time monitoring of multiple gases in real time. In Fig.3 Schematic diagram of Tent explosion

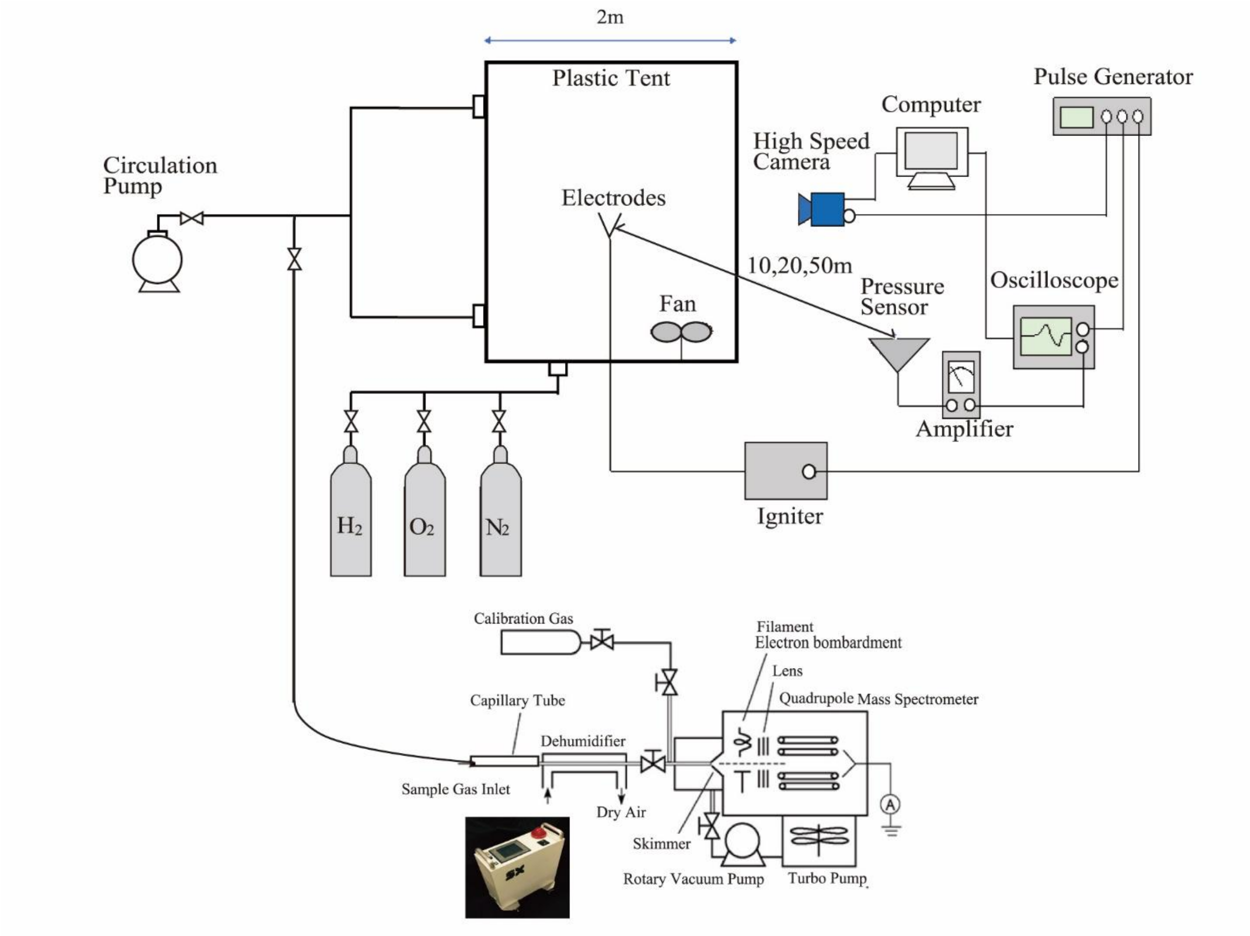

Fig.3 Schematic diagram of Tent explosion test

Fig.4 Mechanism of H_2 Sensor (Sx) multi-gas monitoring in real time

Schematic diagram of Sx is shown in Fig.4. The weight of Sx is 25kg and portable for the outdoor mountain experiment. When Sx measure H_2, alarm red light is on. Liquid crystal touch panel is used to control Sx to start by open valves. Sx has self-calibration system having certain concentration of single to mixed calibration gases. And having these calibration lines for each gas, Sx can monitor and show the concentration of each gas immediately. Real time monitoring is carried out from 2ms. For the real time monitoring system inside volume of Sx is minimized. Sampling inlet of this system is 150-250 µm SUS capillary tube by 1m. Gas sample is introduced from capillary through dehumidifier and skimmer to ionization chamber. This system has the differential pumping stages and ionization system by electron bombardment method (EB). To minimize water product and humidity influence, Sx has dehumidifier with heater. Mass Spectrometer system works up to m/Z=300. [7] [8]

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2-5 Small tent explosion test at Kakioka Out side experimental site of Tokyo Uni..

Small tent explosion test of 1m x1m x1m is held at outside experimental site. The concentration of gases in tent explosion test are monitored by Sx .Sensor is dedicated to measure the concentration of gases in real time monitoring of multiple gases. High speed CCDcamera(VEO710 Vision Research Inc., (USA)1280x800pixcels and 7400fps is also applied to monitor the propagation of flame structure. The measurement by detectors are set by the distance of 30m from the center of tent.

2-6 Large size explosion test is held at the mountain site

Large tent of 2m x 2mx 2m is applied to the tent explosion test. The method is the same as the small tent explosion test.

3. Results

3.1 Flame spectra by candle and gases in UV and IR region

Flame spectra of flame well known but in UV-to IR region of wide spectrum to distinguish fire and false alarm, we challenge to measure spectrum from vacuum ultraviolet region to infrared region in the same circumstances. Candle light emits strong 306,287,281,261nm spectra caused by OH radicals.

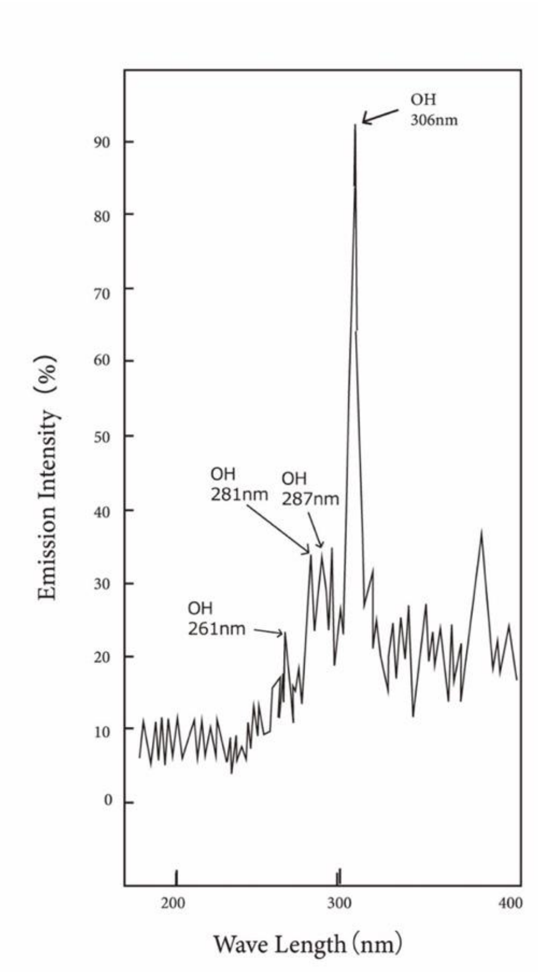

Fig. 5 Flame Spectrum of Candle

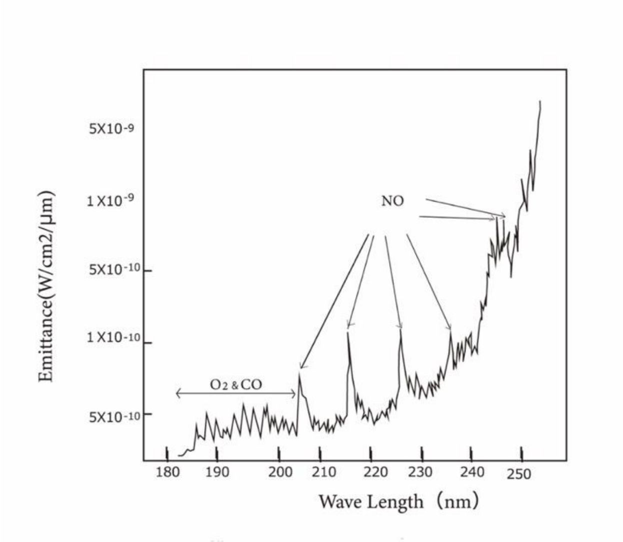

Fig.6 Flame Spectrum of Methane

In methane flame emission by micro burner showed series of NO , O2 and CO based spectra in vacuum ultraviolet region. From 180nm to 200nm, CO of Cameron band and 4th positive band are typical. From 200 to 260nm band caused by NO sigma band is main emission. Also 240-300nm range, OH radical emission is active.

Series of No spectra (sigma band) would be depend on the temperature of emitted flame jet and by increase of temperature the intensity change dramatically. [3] [4] [5]

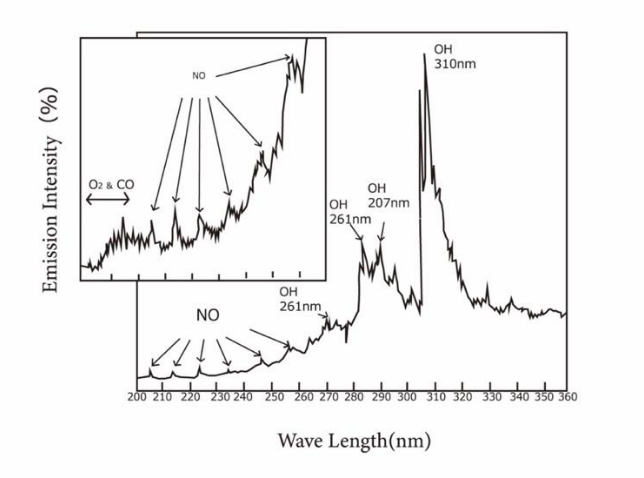

Fig.7 Flame Spectrum of Butane

Ultraviolet region of spectra by Butane is obtained. The result is same methane.

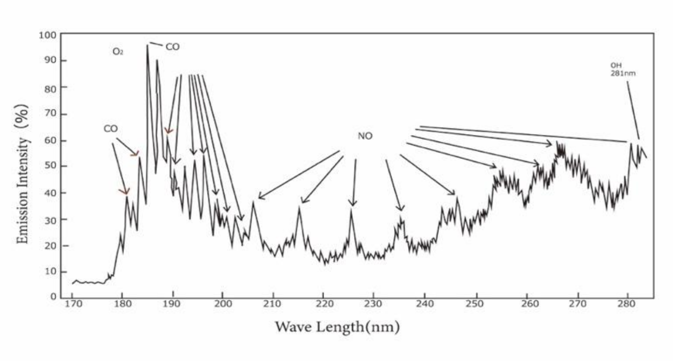

Fig.8 Flame Spectrum of Butane in vacuum ultraviolet region spectrum

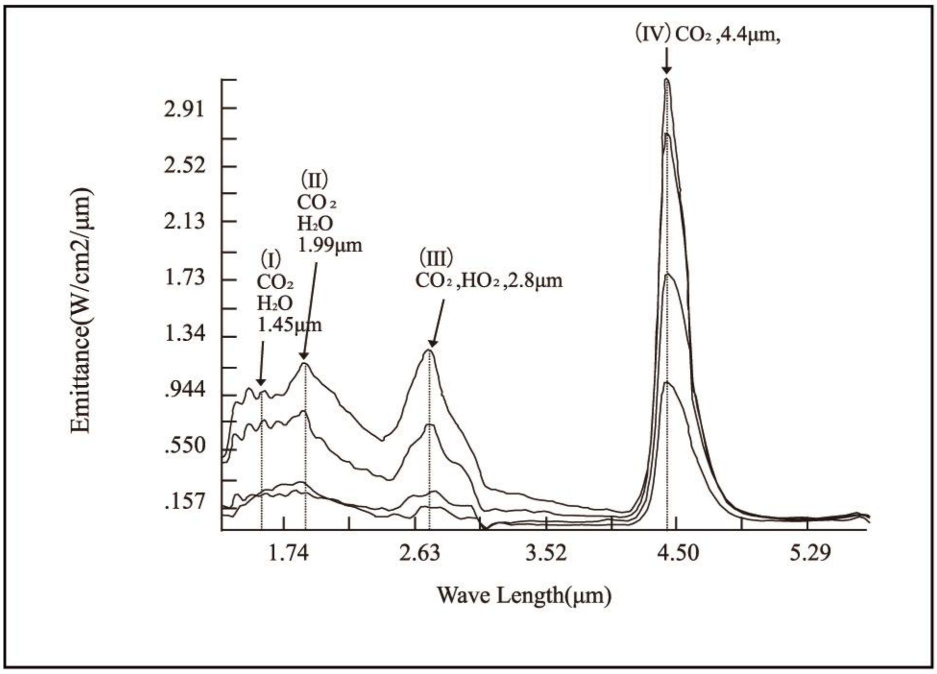

Fig.9 Butane Flame

Fig.9 Flame spectrum of Butane in IR region Butane is

Infrared region of emission spectra is observed. The typical emission from flame showed 1-2μm range of mainly OH and CO based emission spectra. Also 4.4μm CO2 emission is strong.

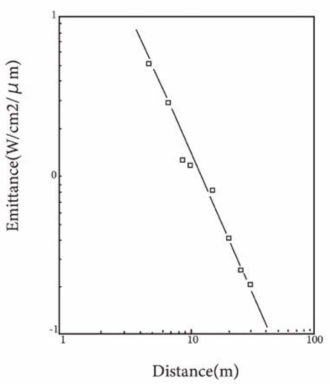

Fig. 10 Emittance of Butane Flame at 4.4μm vs Distance(m)

The dependency of distance of 4.4μm spectrum by distances are measured. Square law is applied to recognize the dependency of distance.

3-2 UV sensor sensitivity test for heptane flame by pool fire test

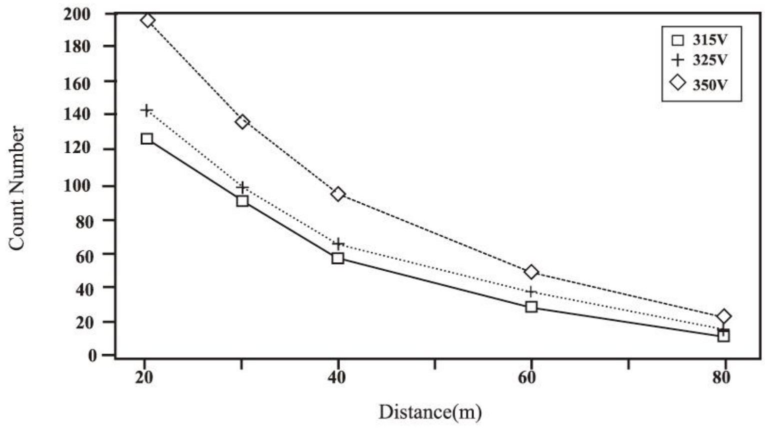

Fig.11. UVtron Count Numbers by Heptane Flame
By different Distances and different applied voltages

Fig11 UVtron Count Numbers by Heptane Flame by different distances and different applied voltages.

The counter circuit built by UVtron is used to measure light source and fire sources.

Heptane is applied to pool fire of 33cmx33cmx15cm pool and change the distance. The out put count numbers are plotted against distance by changing applied voltages

Sensor output decrease dramatically by distance and also decreased by applied voltages from 315 to 350V.This is tube amplifier and the increase of voltage increase of amplification factors. And large amplification factor can create false alarm. Cosmic ray also react to UV sensor and how to avoid the false alarm is difficult and sophisticated business.

3-3 Immunity Test

Light sourse(Distance)	①A Co. IR-H2	②A Co. UV-IR	③A Co. IR3	④A Co. UV	⑤A Co. UV-IR	⑥A Co.UV
LED light (3m)	×	×	×	×	×	×
Halogen lamp(3m)	×	×	×	×	×	×
Cigarette lighter(4m)	×	×	×	○	×	×
Cigarette lighter(3m)	×	×	×	○	×	×
Cigarette lighter(2m)	×	○	×	○	×	○
flash light (3m)	×	×	×	×	×	×
LPG bunsen burner(3m)	×	×	○	○	×	○

○:Response, ×:Non-response

Table 1 Immunity test for various kinds of light source.

The distance between noise sources and detectors are 30m.Table 1 showed the result of immunity test against various noises . UV sensor react against electric discharges sometimes and also bunsen burner from 3m distance .The position of noise cause the different results caused by field of view for each sensor. According to the information FlameSpec IR3-H2 – Datasheet, detection capabilities and false alarmimmunity of the FlameSpec IR3-H2-HD and FlameSpec UV-IR are described. This results based on FM approval tests and reports conducted for certification according to the FM 3260 standard for flame detectors. Detection distance and speed as well as false alarm immunity data are listed for the FlameSpec IR3-H2-HD and FlameSpec UV-IR detectors catalogue information. These are indicative also for the FlameSpec IR3-H2 and FlameSpec UV-IR-HD (respectively). [6]

3･4 Hydrocarbon pool fire, jet fire and small tent explosion test of out side experiment

Pool fire and small gas explosion test of tent size 1mx1mx1m is performed at Kakioka campus. Various flame detectors are located at the 30m distance from fire source. The immunity test also conducted at the same position using strong LED light, Arc discharge, and Strobe light. Jet flame test is conducted by hydrogen, methane and propane. For hydrocarbon, jet flame and pool fire are detected most of flame detectors but hydrogen. Explosion is hard to detect for all detectors except ①detector. Out put voltage of each detector are monitored and separate into 3 categories. x stands for output voltage 0V, △ stands for output 2.5V or less and ○ stands for output voltage of 5V or more. Result is shown Table 2.

① detector is the only one detector to sense hydrogen jet flame and explosion.
② Detector has UV-IR sensor and weak reaction toward hydrogen jet flame and strong reaction toward gasoline and kerosene pool fire.
③ is typical detector applied to petroleum industry shows the strong reaction against pool fire and jet flame of hydrocarbon gas except hydrogen.
④ & ⑥ is the typical UV sensor of different sensitivity. ⑥ has more sensitive to ④. The result toward false alarm sources of Reference lamp, High brightness LED and Arc discharge show the weakness of these detectors.
⑤ react to gasoline and kerosene pool fire, but has less sensitivity.

Result showed ①detector is the only one detector to react towards hydrogen jet flame and explosion. So that ①,② and③detectors are selected for further comparison experiments below. Immunity test shows UV detectors ④and ⑥ give false alarm to the electric discharge of the arc discharge and the cigarette lighter.

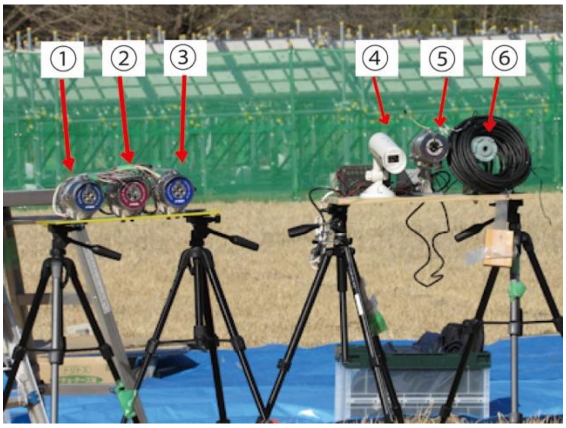

Fig 12 -1 Outside experiment of immunity test

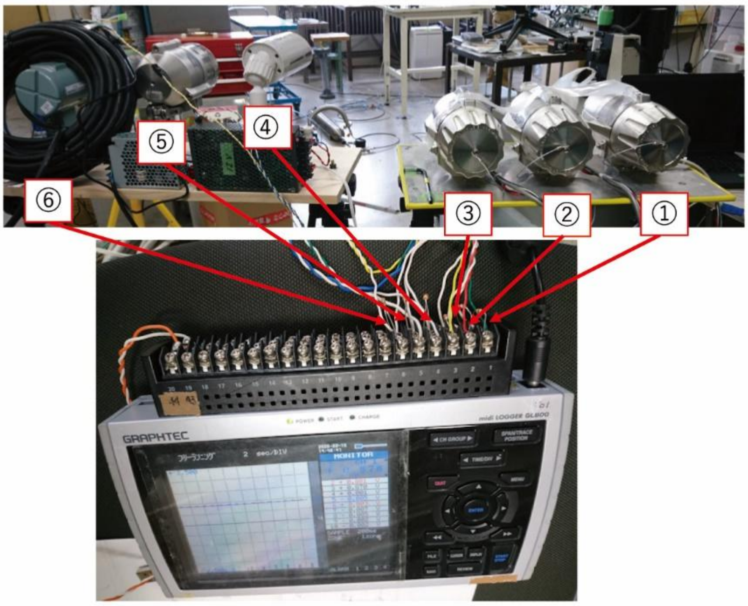

Fig.12-2 Indoor experiment of immunity test

Fig 13 Tent for explosion test

Fig. 14 Pool fire of gasoline

Table 2 Field test for various fire and gas explosions.

Exp.NO.	Flame or source immunity	①	②	③	④	⑤	⑥
1	Propane gas explosion	○	○	○	○	×	×
2	Gasoline pool fire	○	○	○	○	○	○
3	Propane jet fire	×	△	○	○	×	○
4	Reference lamp	×	×	×	×	×	○
5	Methane gas explosion	○	×	○	×	×	×
6	Kerosene pool fire	×	○	○	○	○	○
7	Methane jet fire	○	△	○	○	×	○
8	LED light	×	×	×	×	×	×
9	Hydrogen gas explosion	○	×	×	×	×	×
10	Ethanol pool fire	○	×	○	○	×	○
11	Hydrogen jet fire	○	△	×	○	×	○
12	High brightness LED	×	×	×	×	×	○
13	Propane gas explosion(2nd)	○	×	○	×	×	×
14	Are dischange(15kV)	×	△	×	○	×	○

○:Fire detected alarm level exceed 5V.

△ : Fire alarm level 2.5V 50% of alarm level.

×:Non-response

3-5 Indoor experiment of hydrogen flame

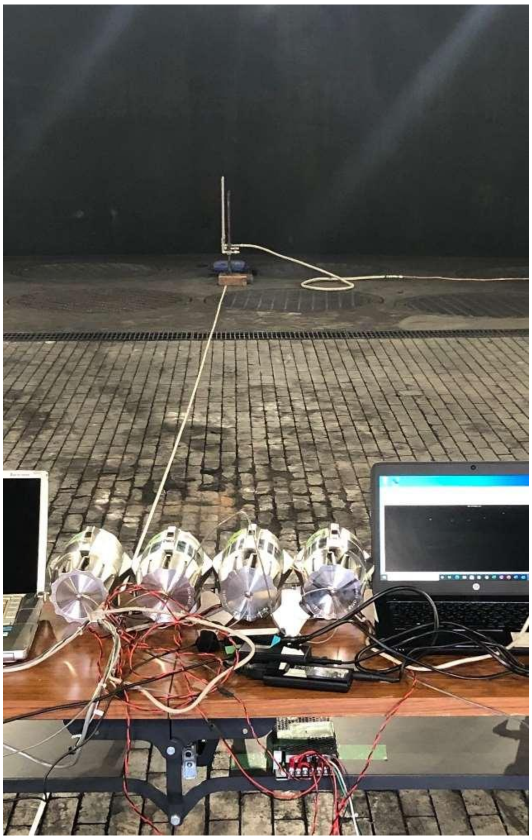

Fig.15 Indoor experiment of gas jet flame (nozzle 3/4inch, H_2 flow rate of 300NL/min, 300fps,F4, Open shatter)

Fig.16 H_2 flame by high speed color CCD camera

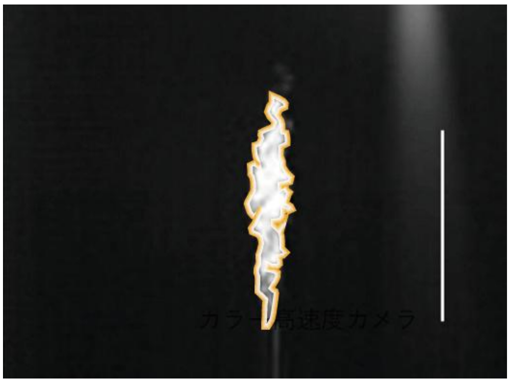

Fig.17 H2 flame by high speed monochrome camera

Color high speed camera and high speed monochrome camera are applied to the discrimination test of hydrogen flame. Hydrogen cannot be discriminated by a color monitor because it cannot be seen with visible light.

Table 3 Datection of H2 jet flame

Distance:10 m

Flow Rate(NL/min)	① H2	②UV-IR	③IR-3	①H2	②UV-IR	③ IR-3	①H2	②UV-IR	③ IR-3
Flame Length(m) /Pipe Diameter(inch)	1/4			1/2			3/4		
15	×	×	×	×	×	×	×	×	×
30	×	×	×	×	×	×	×	×	×
50	×	×	×	×	×	×	×	×	×
100	×	×	×	×	×	×	×	×	×
125	×	×	×	×	×	×	×	×	×
150	×	×	×	○	×	×	○	×	×
175	×	×	×	○	×	×	○	×	×
200	×	×	×	○	×	×	○	×	×

Distance:18 m

Flow Rate(NL/min)	① H2	②UV-IR	③IR-3	①H2	②UV-IR	③ IR-3	①H2	②UV-IR	③ IR-3
Flame Length(m) /Pipe Diameter(inch)	1/4			1/2			3/4		
225	—	—	—	×	×	×	×	×	×
250	—	—	—	×	×	×	×	×	×
275	—	—	—	×	×	×	×	×	×
300	—	—	—	×	×	×	×	×	×
325	—	—	—	×	×	×	×	×	×
350	—	—	—	×	×	×	×	×	×
375	—	—	—	×	×	×	○	×	×
400	—	—	—	×	×	×	○	×	×
450	—	—	—	×	×	×	○	×	×
500	—	—	—	×	×	×	○	×	×

Three detectors of ① ② ③ are chosen to check the reaction toward H2 jet flame by indoor large explosion test facilities at JARI. H2 Jet flames are produced by different diameters of pipe by different flow rate of H2 indicated in Table 3. Flow rate of H2 increase by using 1/4 to 3/4 inch diameter stainless pipe. The flame length of H2 jet flame differ from 15cm to 500cm. Out put voltage is observed and the result is shown in Table 3. ① detector is able to find sensitively the H2 jet flame of flame length more than 150 cm at 10m distance. And H2 jet flame of more than 375cm at 18m distance.

3-6 Out door experiment for large scale H2 explosion test at mountainside

Experiment site for the large scale H2 explosion test is mountain side.(Fig.18)

Large scale tent of 2mx2mx2m is used for H2 explosion test. 3 detectors of A Co(① ② ③) are applied to examine the performance toward explosion of H2. Detector catch the flame and output alarm of red line and monitor using monochrome camera in real time before and after the event for 3minuites. Result showed the flame propagation in explosion and route of film trajectory. ① and ② react to hydrogen explosion but ③.

Fig.18 Large scale explosion test of H2 at mountain side

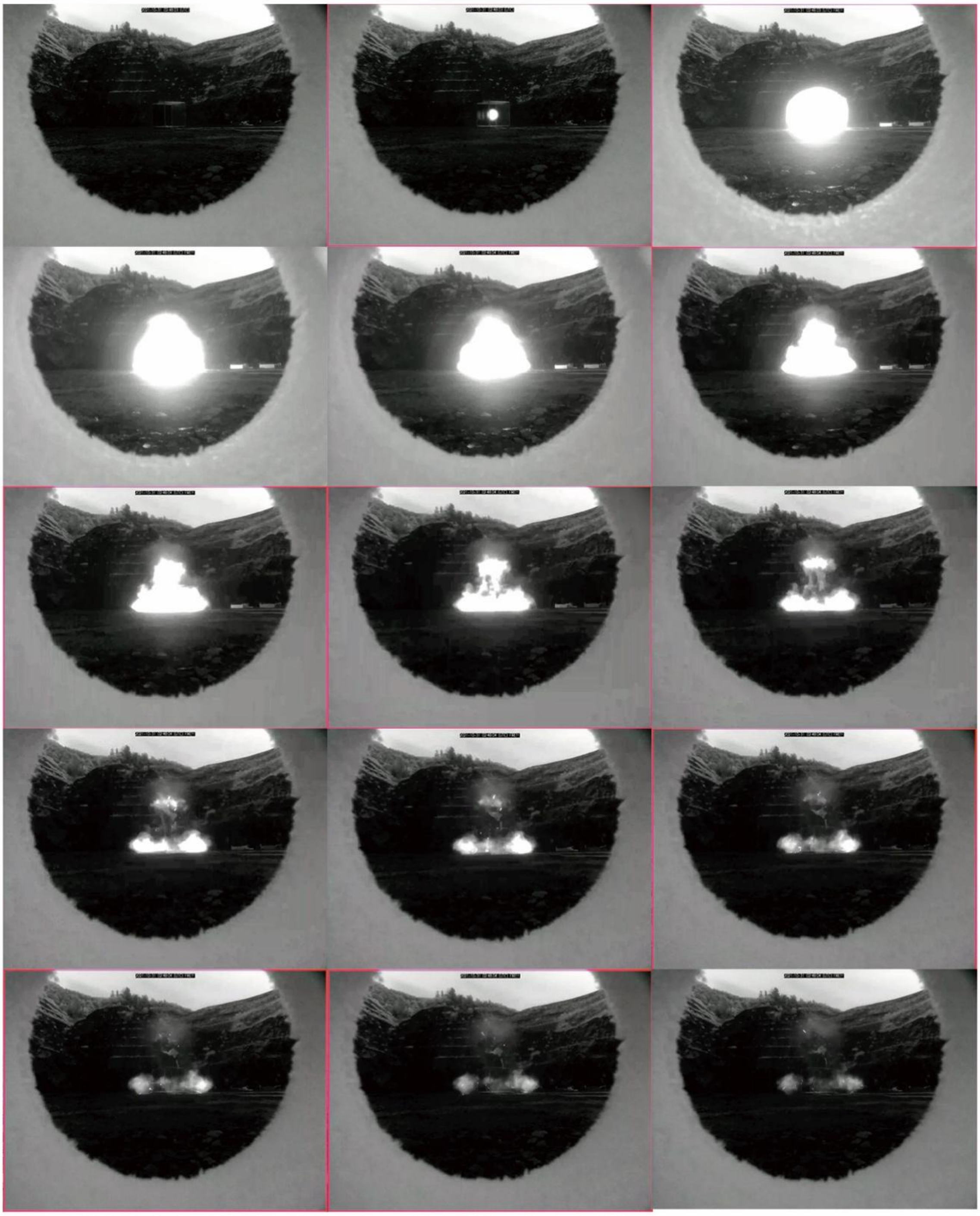

Fig 19 Time lapse monochrome photo by flame detector ①

By analysis of these phots show the ignition of hydrogen fire ball. In the propagation process of fire ball by expansion of tent film, the size of fire ball increase keeping the same center position. The top of square tent film break by expansion and fire ball sprit into two portions. The top of fire ball containing film inside and fly away from tent and finally fly down to the ground. Hydrogen combustion intent also propagate to side directions horizontally and spread. Final fire of hydrogen remain at the ground surface and residual flame is observed at the surface. Residual film fly away from the top of tent and fall down without fire to the ground. The very clear images of explosion process is measured and memorized in the system.

4.Conclusion

Hydrogen stations use flame detectors to monitor fires inside the hydrogen stations. It is necessary to discriminate flames caused by fuel from sun light, arc discharges and spark ignitions for examples by artificial intelligence(AI). Hydrogen flame cannot be discriminated by color monitor because it cannot be seen with visible light. But white and black CCD camera without filter can identify flame H2.

Acknowledgements

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Figure Caption

Fig.1 Typical UV sensor （ Sensitivity range185-260nm.UVtron Hamamatsu photonics R2868）

Fig 2. Flame detector ①②③ of A Co.

Fig.3 Schematic diagram of Tent explosion test

Fig.4 Mechanism of H_2 Sensor (Sx) multi-gas monitoring in real time

Fig. 5 Flame Spectrum of Candle

Fig.6 Flame Spectrum of Methane

Fig.7 Flame Spectrum of Butane

Fig.8 Flame Spectrum of Butane in vacuum ultraviolet region spectrum

Fig.9 Flame spectrum of Butane in IR region Butane is

Fig. 10 Emittance of Butane Flame at 4.4μm vs Distance(m)

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Table

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Table 3 Detection of H2
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