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UV 화염감지기의 감지성능에 대한 분진분위기의 영향

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Influence of Dust Environment on the Detection Capability of Ultraviolet Flame Detector

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요 약

UV 화염감기의 분진분위기에서의 성능저하를 고찰하기 위하여 세제분말, 탄진 및 분말 소화약제의 분진운을 형성하였고 LPG 및 가솔린 화염을 사용하여 UV 화염감지기의 감지 성능을 고찰하였다. 분진 분위기 하에서의 UV 화염감지기의 성능을 분진의 농도와 분진 층의 거리가 증가함에 따라 뚜렷한 증가를 보였으며, 분진의 화학적, 물리적 특성에 커다란 영향을 받았다. 따라서 UV 화염감지기를 분진 분위기에서 사용한 경우 특별한 주의를 기울일 필요가 있는 것으로 사려된다.

Abstract - The detection capability of UV flame detector in dust environment would be impaired. In this study, an experiment was conducted, in an effort to further understand the behavior of UV flame detector and to evaluate its detection capability in industry dust environment. Detergent powder, coal powder and dry extinguishing agent were selected as dust sources. Flaming sources include propane and gasoline flame. Experiment results indicate that dust can cause remarkable attenuation of UV flame radiation. The concentration of dust and the length of air layer where dust dispersed determine the reduction of radiation intensity. On the other hand, the attenuation of UV radiation also depends on the chemical and physical properties of dust.

Key words : Ultraviolet flame detector, Response time, Dust concentration, Propane and gasoline

1. INTRODUCTION

Industries involved in manufacturing, processing, storing or transportation of flammable material are constantly in need of reliable and fast response fire detection systems. It is evident that the smaller the fire, when detected, the easier it is to extinguish. Generally, fire detection system, especially optical flame detectors, are the most powerful apparatus in fire fighting due to their ability of remote detection of a small size fire at a high speed.

Most of heat released in the flame is carried away by the hot combustion products, but a significant proportion is lost by radiation. This may be as high as 30%-40%, depending on the fuel, the size of the flame and on the characteristics of the burning process. This energy serves as a major factor in fire detection analysis. It is dissipated in the form of electromagnetic radiation at various spectral ranges, such as ultraviolet, visible, infrared bands. The flame radiation spectral pattern, being unique, allows several spectral ranges bands. The flame radiation spectral pattern, being unique, allows several spectral ranges to be employed in the various detection devices. Flame detector is designed and produced according to this principle.

In the families of flame detectors, ultraviolet(UV) flame detector has comparatively better properties than that of the other types due to its special characteristics. Background radiation from the sun at sea level, especially at wavelengths shorter than 280nm, is absorbed almost completely by the surrounding atmosphere, while UV flame detector only senses the ultraviolet radiation at wavelengths less than 260nm. Hence, solar radiation would not cause false alarm of UV flame detector. It is "solar blind". Therefore, it can be used to detect ultra-violet radiation emitted by a flame even out of doors. This advantage makes it very suitable for the protection of large indoor space such as aircraft hangars, workshop, and outdoor risks such as chemical plant and oil rigs[1]. Its other advantages include high speed, high sensitivity, wide angle, etc.

However, there are a few specific conditions that should be recognized. Flame detector often operates in complicate industrial environments that contain many nuisance sources that could impair detector performance. It is necessary to assess the effect of flame detector when there are nuisance source existing between flame and detector. It would provide practical basis for improving the performance of UV flame detector.

2. FLAME RADIATION

Stefan-Boltzmann Law states,

$$\Psi = \sigma T^4$$

Where Ψ is the total energy radiated by an object across all wavelength, T is the absolute temperature of the object, σ is the Stefan-Boltzmann constant[2]. It indicates that the intensity of flame radiation mainly depends on the flame temperature. Generally, the flame radiation includes various spectral ranges, such as infrared, visible light and ultraviolet bands. The yellow luminosity associated with the flame of most fires is the energy that is radiated within the visible region of the electro-magnetic spectrum. However, this represents only a small proportion of the total; most is emitted in the near and far infrared regions. An extremely small amount is to be found in the ultraviolet region. Therefore, the attenuation of UV radiation during transmission should have remarkable influence on the effect of detector.

3. ATTENUATION OF UV FLAME RADIATION

The attenuation of propagating UV radiation occurs by a combination of absorption and scattering. Absorption is defined that energy is absorbed and reradiated again in all directions, and probably over a different range of wavelengths. Scattering is defined that energy is lost by being redirected out of the beam of radiation, but wavelength does not change. Generally, during the transmission of UV radiation from flame to detector, both of these two kinds of energy loss would impair the intensity of UV signal.

3.1. Absorption of UV Radiation

The primary mechanism of absorption by gas and particle can be described as the exchange of a quantum of energy between the molecule and the electromagnetic radiation. The mechanism which molecules absorb energy from incident UV radiation is electronic transitions. It involves promotion of electrons to higher energy orbital for absorption, lower energy orbital for emission. Molecular absorption removes energy from the beam of UV radiation as it travels through the air, and reradiates it uniformly in all directions at different wavelengths.

3.2. Scattering of UV radiation

Particles in the air(whilst smoke, dust, haze) remove energy from the beam of radiation, partly by absorption and partly by scattering radiation in all directions. Scattering changes the direction of propagation only, not the wavelength. Scattering of radiation by particles usually dominates over absorption by particles. Because of the short wavelength of UV radiation, we can describe the scattering of UV light by using Mie Scattering, which occurs when the wave length of the propagating radiation is of the same order as the particles' diameters in the medium the radiation is propagating through. The treatment of Mie Scattering is complicated. It may often be roughly approximated as being proportional to λ^{-1}(λ:wavelength of radiation).

All molecules and particles can both scatter and absorb radiation. The parameter, which describes the relative magnitude of scattering and absorption, is the single scattering albedo, defined as:

$$\omega_0 = \sigma_s / (\sigma_s + \sigma_a)$$

Where σ_s and σ_a are, respectively, the cross sections for scattering and absorption. Extreme values are $\varpi_0 = 0$ for pure absorption and $\varpi_0 = 1$ for pure scattering. Mixture of different gases and particles can result in a range of effective values of ϖ_0 for a given air layer. Generally, molecule primarily reflect the effect of absorption while particle reflect the effect of scattering[3].

The attenuation of radiation intensity caused by absorption and scattering is described by Beer-Lambert Law(Appendix). It gives us a macroscopic explanation of how much light is attenuated by a given layer of sample. According to this law, the energy loss of radiation can be analyzed quantitatively.

4. EXPERIMENT

In this paper, we mainly discuss the situation that UV flame detector works in the environment with industry dust existing. In order to make the experiment convenient to carry out, an UV flame sensor made in Japan was selected to replace the real UV flame detector. But it does not affect the evaluation of detection effect of flame detector, which works in nuisance source environment. We can obtain the real detector signatures though the result of this project.

The spectral band in which the sensor operates ranges from 185 to 260nm. An extremely sensitive sensing device is applied in this sensor. It consists of two electrodes which are maintained at a DC potential of 350 volts. They are contained inside a sealed unit that is filled with low-pressure gas. Ultra-violet radiation falling on the cathode causes emission of the electrons at a rate proportional to radiation intensity. These electrons move rapidly to the anode, causing the release of more electrons in collisions with the gas molecules in their path. This causes an avalanche discharge which amplifies the current flowing between the electrodes by many orders of magnitude. The rate and amount of electrons released and whether they can cause an avalanche discharge are determined by the radiation intensity and the time of radiation accumulation on the cathode. Therefore, the response time of sensor is inversely proportional to the intensity of flame radiation that the sensor received. The detection effect of flame sensor can be evaluated by analyzing the response time of sensor.

Table 1. Summary of instrumentation

Experiment Equipment	Manufacturer	Type No.
Flame Sensor	Hinsyou Company, Japan	R2868
Amplifier Circuit	Hinsyou Company, Japan	C3299-01
Response Time Indicator	Electric safety Lab, Hoseo University, Korea	
Air Compressor	Kyungwon Company, Korea	AC-102P
Spot Thermometer	MINOLTA, Japan	IR-630

During the test scenarios, this sensor was respectively applied to detect the luminous

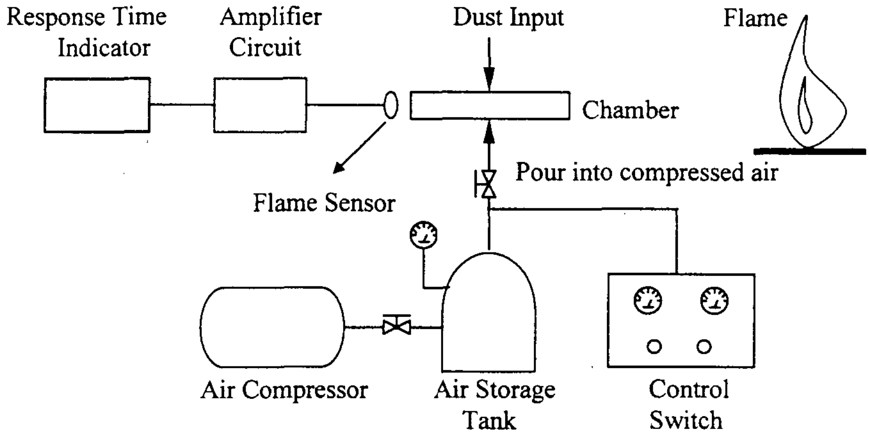


Fig 1. Schematic diagram of testing apparatus for experiment in dust environment

diffusion flames produced by the combustion of different fuel in pure air environment and nuisance source environment. The sensor was tested at different detection distance. Its response time was recorded to analyze the attenuation of flame UV radiation. When the sensor was tested in environment with the dust existing, three kinds of powder were selected to simulate the industry dust environment and were respectively poured into a chamber, which was placed between flame and sensor to enclose the dust. Compressed air of adjustable pressure is simultaneously injected to make the dust dispersed uniformly and form a dust cloud in chamber. In order to set the concentration of dust cloud, the powder of known weight is quantitatively poured into chamber at every turn. Since the dust distributes uniformly in the chamber, the concentration can be simply calculated in such a way that it equals the weight of dust divided by the volume of chamber. The length of chamber and dust concentration were varied to examine the influence on flame radiation[4]-[6]. The schematic view of the test section is shown in Fig.1.

The selection of equipment used to perform this experiment was based on availability and cost. The instrumentation is summarized in Table 1. The test source is shown in Table 2.

Table 2. Summary of environment source and fuel source applied in test

Environment Source	Flaming Source
Pure Air	Propane
Detergent powder (particle size 74um, white color)	
Coal powder (particle size 65um, black color)	Gasoline
Dry extinguishing agent ($NH_4H_2PO_4$ Powder particle size 84um, pink color)	

5. RESULT AND DISCUSSION

Measurements of the sensor signatures from tests involving propane and gasoline flame in pure air environment are presented in Fig. 2. It is seen that the response time of sensor prolongs with the increase of detection distance. The reason is that the air composition causes the attenuation of UV flame radiation. In atmosphere, ozone and oxygen are strong absorber of UV radiation. Although there are little ozone molecules in atmosphere at sea level, oxygen and a few other atmospheric gases, especially nitrogen dioxide and sulfur dioxide, have a potential for attenuating UV radiation. However, this kind of attenuation is limited because of the low concentration of the specific gas and wavelength dependant

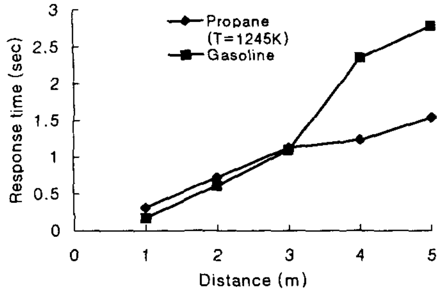


Fig. 2. Response time change of sensor involving propane and gasoline flame in pure air environment as a detection distance variation

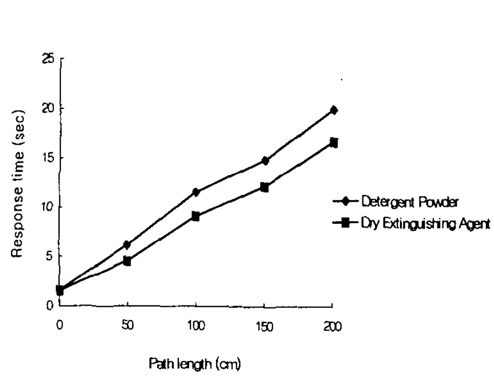


Fig. 4. Response time change of sensor in dust environment as a path length variation(dust concentration = 80mg/l)

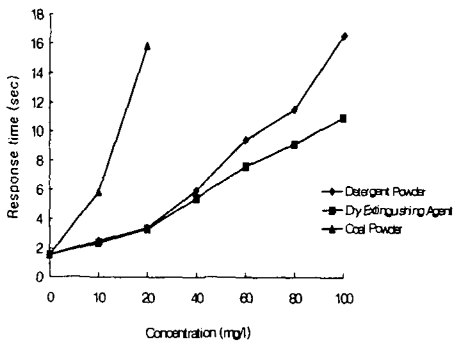
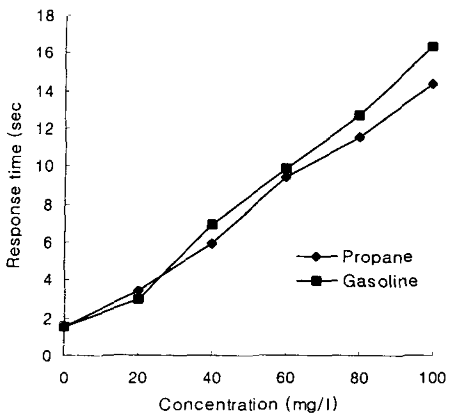


Fig. 3. Effect of dust concentration on the response time of sensor(path length = 100cm)

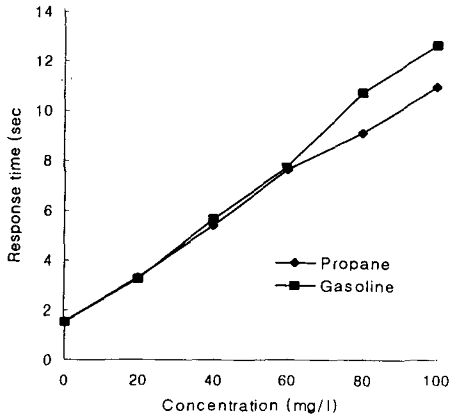
absorption(oxygen only absorbs very short UV radiation at wavelength less than 200nm), it can not cause remarkable reduction of flame radiation. Meanwhile, the sensor has a better effect to detect propane flame at long detection distance. The reason is that the chemical composition of gasoline is more complicated than that of propane. It is proved that hydrocarbon gas like propane which have simple chemical composition can emit relatively powerful UV radiation when it combusts. Therefore, UV flame detector is more suitable to detect such kind of flame that the flame source has simple chemical composition, low molecule weight and small carbon number.

The response time of flame sensor working in different dust environment are presented in Fig. 3 and Fig. 4, where path length is the length of dust layer in chamber that the flame radiation passed through. As expected, the intensity of flame radiation decreased with the increasing path length and dust concentration. Compared with the results in *pure air environment*, the response time of flame sensor increased remarkably. This result accords with Beer-Lambert's Law that the radiation intensity decays exponentially as concentration increases. It states that dust cloud with a certain concentration and thickness can cause outstanding attenuation of UV flame radiation. Fig. 3 also shows that organic powder has more powerful influence on flame radiation that that of inorganic powder. It is owing to the fact that organic dust has much higher cross section($\sigma(\lambda)$) for absorption. In addition, it is found in experiment that the sensor can not detect flame signal when the concentration of coal dust exceeds 20 mg/l. This result and Fig. 3 show that deep color particle like coal dust exerts more powerful influence on radiation than that of light color particle like detergent. It is due to the more strong effect of absorption of deep color particle.

Fig. 4 shows the same result on the effect of organic dust as Fig. 3. On the other hand, we can conclude from Fig. 4 that the length of dust layer also has a significant effect to attenuate flame radiation. This result accords



(a) Dust source: Dry Extinguishing Agent



(b) Dust source: Detergent

Fig.5. Effect of dust concentration on the response time of sensor involving different fame source (path length = 100cm)

with Beer-Lambert's Law. Due to the high dust concentration (80mg/1), it is impossible for sensor to detect flame signal. Therefore, the performance of sensor in coal dust environment is not presented in Fig. 4.

Fig. 5 shows the sensor performance with the different flame source and different dust environment. It is seen in Fig. 5 that with the increase of the dust concentration, expecially when it exceeds 60mg/1, the sensor becomes more sensitive to propane flame. It states again that hydrocarbon gas which have simple chemical composition can emit more powerful UV radiation than gasoline with high molecular weight and great chemical complexity when they combust. Moreover, gasoline flame can release large amount of smoke. It also impairs the performance of flame detector. On the other hand, Fig. 5 also shows the same result of organic dust as mentioned above. When the dust source is detergent, the response time of sensor is much longer than the situation in which the dust source is dry extinguishing agent.

Since the coal dust exerts much stronger influence on flame radiation(Fig. 3), a specific test was conducted to measure the maximum limit of dust concentration(coal powder), under which the sensor can not detect flame signal. The result is shown in Table 3. It is seen that the maximum limit of concentration decreases with increasing path length. This result agrees quite well with Beer-Lambert's Law that the concentration is inversely proportional to the length of dust cloud. Compared with the other kinds of dust(Fig. 3), coal dust has quite small limit of concentration because of its chemical and physical properties, which is organic and deep color dust. It states that organic and deep color dust has quite strong influence on UV flame radiation. As a consequence, UV flame sensor is not suitable to be applied in such kind of industry dust environment.

Table 3. The limit of dust concentration(coal powder) at different path length of dust cloud, under which the sensor can not detect flame signal

Path length(cm)	50	100	150	200
Limit of concentration(mg/1)	35	30	25	20

6. CONCLUSION

1. Industrial dust dispersed in the air can cause remarkable attenuation of ultraviolet radiation emitted from flame. The concentration of dust and the length of air layer where dust disperses determine the reduction of radiation intensity.

2. The attenuation of UV radiation also depends on the chemical and physical properties of dust. It is proved that UV detector is not suitable to be applied in industry environment with organic and deep color dust

existing, which include coal, carbon black, coal tar, activated carbon, etc.

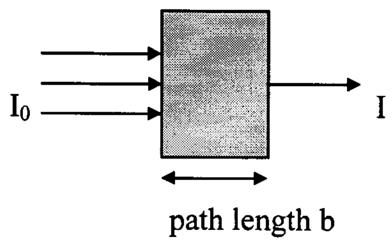
3. UV flame detector is more suitable to detect the luminous flame while flame source has simple chemical composition, low molecule weight and small carbon number.

APPENDIX

Beer-Lambert's Law

The diagram below shows a beam of monochromatic radiation passing through a layer of sample.

Sample of concentration c



The general Beer-Lambert Law is written as:

$$I / I_0 = \exp(\sigma (\lambda) * b * c$$

Where I is the radiation intensity after it pass through the sample and I_0 is the initial radiation intensity, $\sigma (\lambda)$ is a wavelength-dependent cross section for absorption and scattering, b is the path length, and c is the concentration of the absorbing species.

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