

A Study on Scattering Characterization of Water Steam Aerosols for Smoke Detector

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Abstract

Small water droplets which can float in the air (such as water steam aerosols or water mist) are common disturbing aerosols to photoelectric detectors. These small water droplets generally have bigger particle sizes than fire smoke particles which makes it possible for the discrimination between water droplets and fire smoke aerosols only by common optical solutions, i.e. by measuring the scattered light intensity. Then the false alarm rate of detectors can be reduced to some degree. According to the previous works, multi-wavelength, multi-angle and polarized light scattering technologies are feasible measures used to distinguish different types of particles.

In this paper, the asymmetry ratio is studied. For different types of aerosols, the asymmetry ratios are different to some extent. However, the differences are close in some cases. Therefore, a parameter $P(\lambda)$ is proposed according to the definition of polarization ratio. The calculated results show that the $P(\lambda)$ values are negative for water steam aerosols and water mist whereas the $P(\lambda)$ values are positive for smouldering cotton and flaming n-heptane particles when the wavelength λ of light source is 405 nm or 850 nm.

Keywords: Smoke detector, false alarms, water steam aerosols, light scattering, asymmetry ratio

Introduction

Water steam aerosols is one of main interference sources for photoelectric detectors which are designed by Mie theory, i.e. light scattering [1]. Water vapour or water steam is water in gas phase. Detectors cannot response to it because of its invisibility. However, water droplets, such as water steam aerosols, water fog, and water mist, can scatter the light beam which may cause the detectors to produce false alarms.

Generally, when water vapour encounters cold air, it will liquefy into small visible water droplets to form water steam aerosols. This situation usually occurs in kitchens and bathrooms. And also when the environmental pressure drops, the water vapour will liquefy to form water mist or water fog. This situation is likely to occur in the aircraft cargo compartments where the environmental pressure and temperature can be changeable. Therefore, in the SAE AS8036A, a test named 'Combined Temperature, Pressure and Humidity Cycling' is specified to simulate the environment of aircraft cargo compartments [2]. No alarm shall occur during the test. Tobera et al. [3] designed a test apparatus which provides a simple way for studying the effects of high humidity environmental on smoke detectors.

In this paper, we aim to study the asymmetry ratio R (the ratio of scattering light intensities at 40° to scattering light intensities at 140°) for the discrimination between water droplets (water steam aerosols and water mist) and two types of fire (smouldering cotton and flaming n-heptane) smoke particles. Two laser diodes with single wavelength at 405 nm and 850nm respectively were used as light sources. And the effects of vertical and parallel polarised directions of light sources were also analysed.

Theory

The asymmetry ratio R can be calculated:

$$R(\lambda) = \frac{I(40^\circ, \lambda)}{I(140^\circ, \lambda)} \quad (\text{Eq. 1})$$

where $I(40^\circ, \lambda)$ or $I(140^\circ, \lambda)$ is the scattering light intensity or the photocurrent of photodiode when the scattering angle is 40° or 140° and the wavelength is λ because the photocurrent is proportional to the light intensity.

By referring to reference [4][5], the polarization ratio can be used as an indicator for water droplets. According to Loepfe's results, similarly, a parameter $P(\lambda)$ can be defined as follows:

$$P(\lambda) = \frac{R_{VPD} - R_{HPD}}{R_{VPD} + R_{HPD}} \quad (\text{Eq. 2})$$

where R_{VPD} is the asymmetry ratio at vertical polarization direction (VPD) and R_{HPD} is the asymmetry ratio at horizontal polarization direction (HPD).

Note that both R_{VPD} and R_{HPD} are independent of the concentration of scattering particles which means the R_{VPD} and R_{HPD} don't have to be acquired simultaneously. And the most important is that $P(\lambda)$ can be used to distinguish between different aerosols.

Experimental test platform

Figure 1 (a) shows the simple experimental test platform for the present work. A small combustion chamber made of stainless steel was served as space for smoke production. There was a vertical cylindrical pipe with 20 mm diameter on the top of combustion chamber which allowed the airflow containing particles to flow out. An adjustable speed fan can be used to accelerate the flow to get a stable airflow. A rotating breadboard was placed above the combustor. Therefore, a light beam emitted from laser diode can be scattered by the particles in the airflow as shown in Figure 1 (b). The remaining light intensities were collected by a photodiode on the opposite side of light source which was able to calculate the extinction indexes. Two photodiodes were arranged at angle 40° and 140° for receiving the scattering light of corresponding scattering angles. These three photodiode receivers were connected to three photodiode amplifiers independently for the acquisition of photocurrent signals.

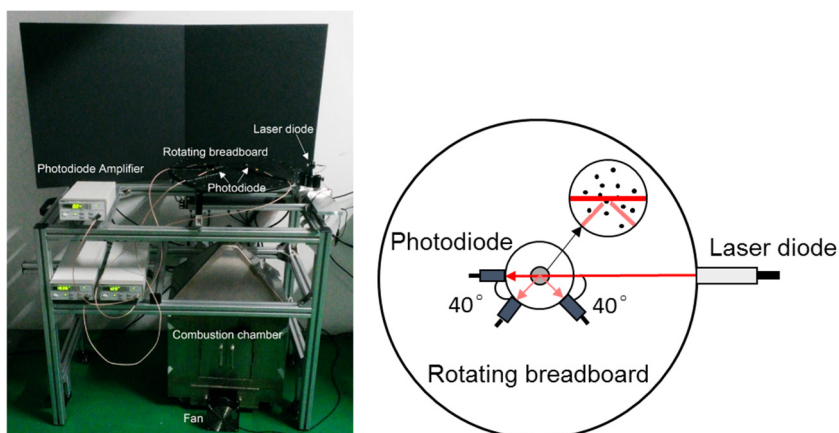


Fig. 1. (a) Experimental platform; (b) experimental schematic diagram.

Two laser diodes at 405 nm (violet) and 850 nm (near infrared) wavelength were used in the experiments. Considering the high polarization extinction ratio (PER) 22 dB of the two laser diode light sources, the effects to the asymmetry ratio of vertical and parallel polarisation directions (i.e. direction of principal axis) with regard to the scattering plane were also studied.

Figure 2 shows the experimental scenes of these aerosols. A 400 Watt boiler with 150 mm in diameter was used to produce water steam aerosols. An airbrush pistol with nozzle 0.15 mm in diameter was used to produce water mist. It was easy to see the water mist and smouldering cotton particles produced by five cotton rope whereas the water steam aerosols and flaming n-heptane particles produced by 25 ml volume can be hardly seen.

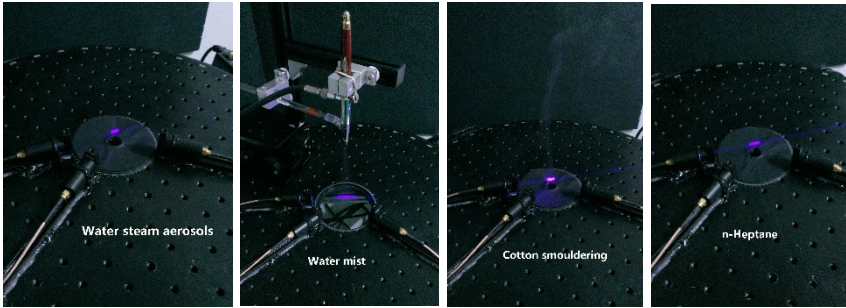


Fig. 2. Experimental scenes: (a) water steam aerosols; (b) water mist; (c) smouldering cotton; (d) flaming n-heptane.

Experimental results of water droplets

Tobera et al. [3] measured the size distribution of water steam aerosols produced by a shower cubicle and got the peak value of measured (volume based) particle size distribution at a diameter of about 15 μm while the fire aerosols are generally under 1 μm [6][7].

Figure 3 shows the results of water steam aerosols. The experimental measurement time is 300 s for each condition. Depending on the calculations, the extinction indexes S of water steam aerosols are very small (only 1 % ~ 2 %) whereas the scattering light intensities are apparent.

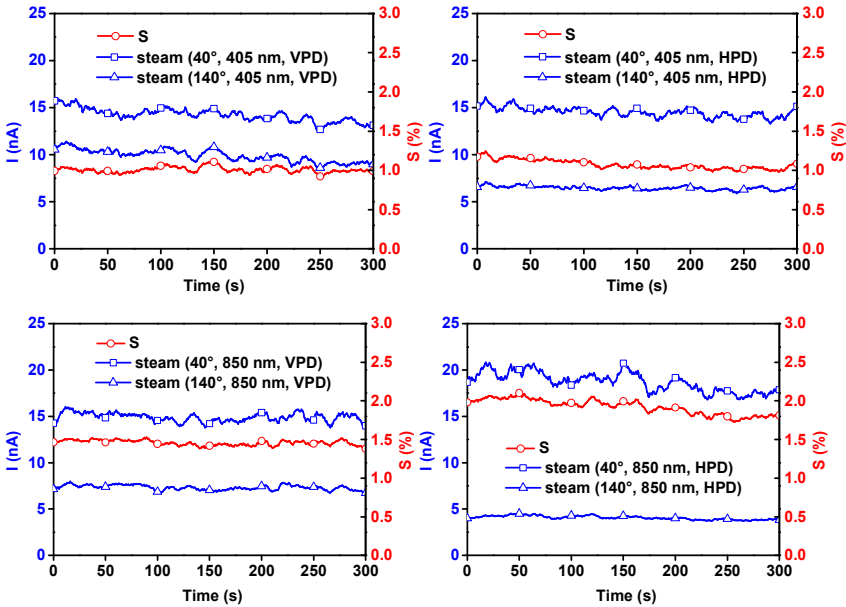


Fig. 3. Experimental results of water steam aerosols.

For both wavelengths, same changing pattern of scattering light intensities is that the scattering light intensities at 40° increase whereas the scattering light intensities at 140° decrease when the polarization direction is changed from vertical polarization direction (VPD) to horizontal polarization direction (HPD). These results are consistent with the Loepfe's results about water vapour that the degree of polarization is negative at 40° and positive at 140° [5].

Figure 4 shows the micrograph (X-200) and the size distribution of water mist produced by an airbrush pistol. The water mist was collected by silicone oil. Lognormal distribution can be used to fit the size distribution and the geometric mean diameter is about 8 μm .

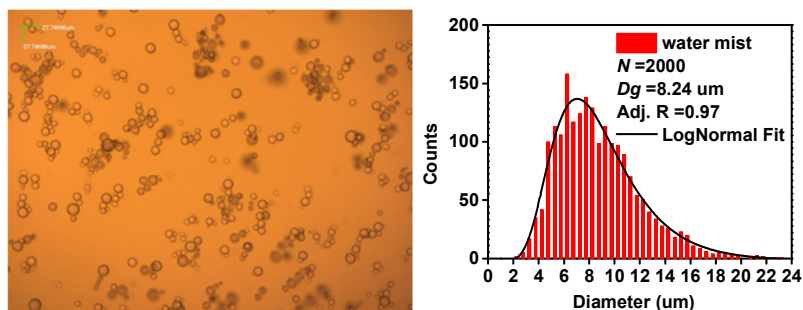


Fig. 4. (a) Micrograph (X-200); (b) size distribution of water mist.

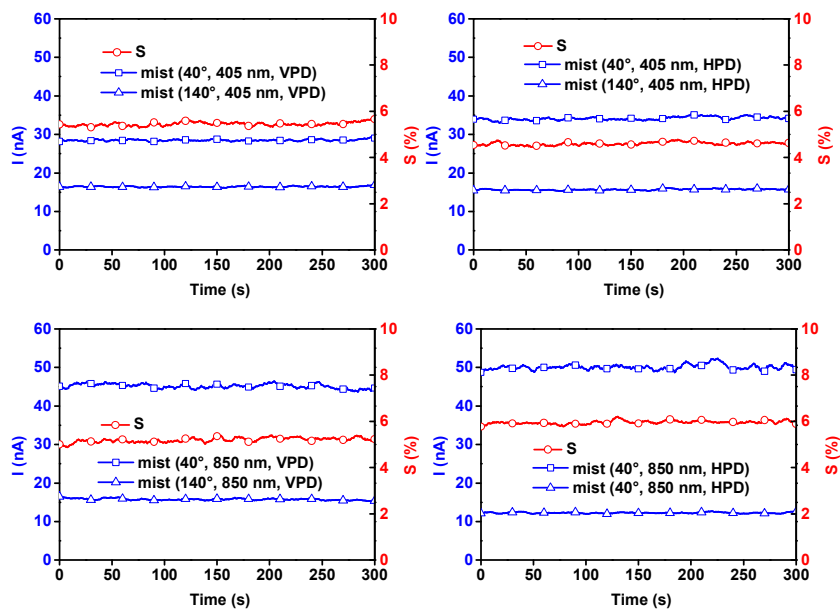


Fig. 5. Experimental results of water mist.

Figure 5 shows the results of water mist. Both the extinction indexes and scattering light intensities increase obviously compared with the water steam aerosols. And when the polarization direction of both wavelengths is changed from VPD to HPD, the changing pattern of scattering light intensities is similar with the water steam aerosols.

Experimental results of cotton and n-heptane

Figure 6 shows results of smouldering cotton and flaming n-heptane. Taking into account the length of the paper, only the results of 405 nm wavelength and vertical the polarization direction are given. Comparing with the results of flaming n-heptane particles, the extinction indexes and scattering light intensities of smouldering cotton particles have obviously fluctuations over time. It can be inferred that the concentration changed greatly over time.

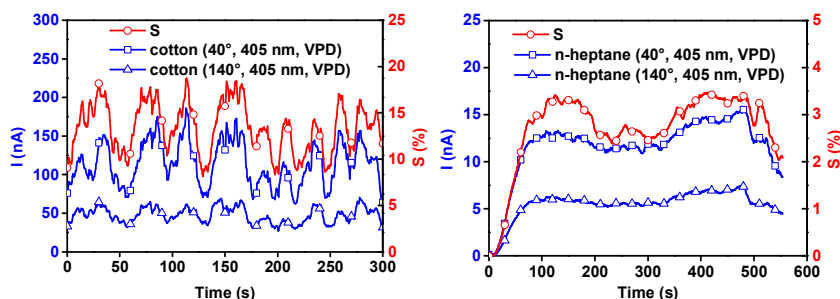


Fig. 6. (a) Smouldering cotton; (b) flaming n-heptane.

Comparisons of asymmetry ratio

Figure 7 shows the comparisons of asymmetry ratios between the four types of aerosols. Asymmetry ratios were calculated by equation 1. The asymmetry ratios of smouldering cotton particles show obvious fluctuations under all cases which can be explained by the size distribution of smouldering cotton particles also varying with time.

For the flaming n-heptane, the period from 100 s to 400 s which was a relatively stable burning stage was chosen for comparing.

It can be noted that the asymmetry ratios of water mist and n-heptane are very close when the light wavelength is 850 nm and the polarization direction is vertical. The mean values of asymmetry ratios for water mist and n-heptane are 2.86 and 2.67 respectively. In view of this, another parameter is needed for the discrimination of different types of aerosols, such as $P(\lambda)$ which is defined in the previous section.

Table 1 shows the average values of asymmetry ratios within 300 s under four kinds of light source conditions and the comparisons of $P(\lambda)$ calculated by equation 2. With the $P(\lambda)$, water droplets (i.e. water steam aerosols and water mist) can be roughly distinguished from the smoke particles of smouldering cotton and flaming n-heptane, i.e., the

negative P (λ) value indicates that aerosols may be water droplets, while the positive P value indicates that it may be fire smoke aerosols. In addition, it can be seen that the P (850 nm) shows better discrimination than P (405 nm) between these four types of aerosols.

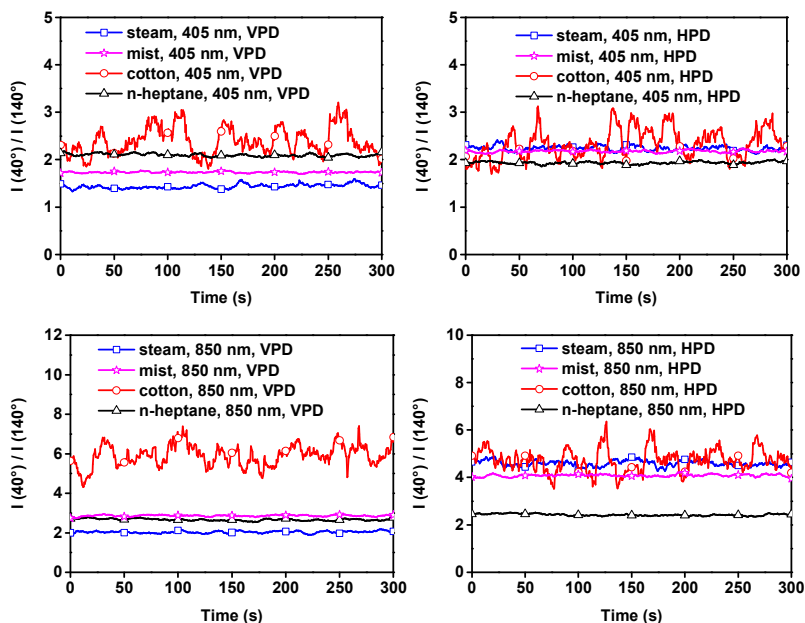


Fig. 7. Comparisons of asymmetry ratio between four types of aerosols.

Table 1. Average values of asymmetry ratio and calculated P (λ).

Aerosols	R_{VPD} 405 nm	R_{HPD} 405 nm	P 405 nm	R_{VPD} 850 nm	R_{HPD} 850 nm	P 850 nm
Water steam aerosols	1.44	2.25	-0.22	2.04	4.59	-0.38
Water mist	1.74	2.18	-0.11	2.86	4.09	-0.18
Smouldering cotton particles	2.39	2.34	0.01	5.91	4.73	0.11
Flaming n-heptane particles	2.10	1.94	0.04	2.67	2.42	0.05

Conclusion

The present work conducted a study on scattering characterization of water droplets, including water steam aerosols and water mist, for smoke detector. Smoke particles of smouldering cotton and flaming n-heptane were used for comparing. A test platform was built for experiments and the scattering light intensities at 40° and 140° can be measured simultaneously. Asymmetry ratios were studied for the discrimination between water droplets and fire smoke particles. The asymmetry ratios between these four types of aerosols show a certain differences. However, the differences are not significant enough for some cases which means the misjudgement can still occur. Based on previous works, the parameter $P(\lambda)$ is defined and can be used for the discrimination between different types of aerosols. According to the experimental results, the negative $P(\lambda)$ value indicates that aerosols may be water droplets, while the positive $P(\lambda)$ value suggests that it may be fire smoke aerosols.

References

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