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Multi-angle Scattering Characteristic of test Fire Smoke and Typical Interference Aerosol

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Abstract

This paper describes the experiment platform for studying the scattering characteristic of fire smoke and interference aerosols, which was developed independently by the Shenyang Fire Research Institute of the Ministry of Public Security of China. This paper also introduces the constitution, work principle and key technologies of the platform. By real experiment, the ability of this platform on studying the scattering characteristic of fire smoke and interference aerosol was proved. This paper then presents the scattering intensity distribution data yielded out of that the laser (635nm) was scattered by four test fires SH1-SH4 conforming to Chinese National Standard GB 4715, and by typical interference aerosols, such as loess dust, water mist and tobacco burning smoke, at angles of 30o, 90o and 150o. The analysis in the data shows that the scattering intensity distribution of fire smoke and interference aerosol demonstrated a stable characterized law, and by the difference of this characterized parameter, each fire smoke and typical interference aerosol can be identified. Thus, multi-angle detection is an effective way to resolve broad-spectrum response proportionality and false alarm rejection for scatter type photo-electric detectors, and a promising developing direction of intelligent photo-electric smoke detection.

Keywords: multi-angle; scatter; fire smoke; identification

1. Introduction

Currently, scattered photo-electric smoke sensing is the main technology adopted by spot type smoke detectors. However, for many years, this technology has been facing a few problems: 1) not sensitive enough to invisible smoke sized around 10nm generated by alcohol, etc; 2) severe sensitivity difference in responding to grey, white and black smokes, which causes imbalance; 3) as same as ionisation and transmission smoke detection, it has difficulties in rejecting dust, fog and other non fire generating aerosols, and need a better immunity to false alarms. Supported China by Ministry of Science and Technology, this project completed the study in multi-angle scattering characteristics for four test fire smokes specified by Chinese National Standard GB 4715, and for typical

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interference aerosols such as loess dust, water mist and tobacco smoke, as well as white cement. Finally, solution to problem 2) and 3) was achieved.

2. Design of experiment platform

Adequate experiment equipment must be equipped for carrying out this research. In order to obtain an accurate angle distribution characteristic of relative intensity for multi-angle scattering, the equipment and its method of data processing were required to be able to collect light intensity signals scattered from a very small scatter zone at a small enough differential angle synchronously. Moreover, the inconsistency in properties of photo electricity and electrons, the fluctuation of light source intensity and aerosol concentration were required to be eliminated.

Experiment platform was designed such that a multi-angle scatter chamber, a centrifugal fan, an inlet pipe and a computer were incorporated. With the aid of centrifugal fan, the aerosol, through inlet pipe, entered multi-angle scatter chamber, where a set of components providing radiation beam and six independent channels measuring scatter signal were installed. The computer was used to measure and record scattered electrical level signals, and recorded data was processed by special software and a plot of curve was formed.

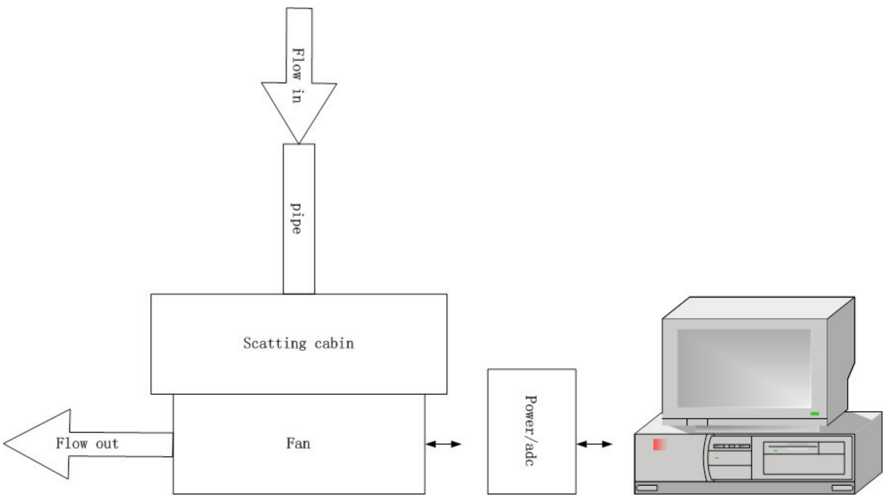


Fig. 1. Schematic of experiment platform

2.1. Scatter chamber

Scatter chamber is the key part of the platform. Radiation beam was provided by a light source component and an extinction component, there were also 6 measuring channels components, which could be slid to required angle, to receive scattered light. All components were installed on the circle of an index plate with angle scales. Such precise structure ensured the radiation beam and six scattered beams are placed in one plane, and their optical axes intersected at the circle center in central scatter zone. Thus, every detection component in different directions can equally detect the signals scattered from the spot on the planar geometric center of optical axes.

An important issue in design of scatter chamber is how to eliminate the effect of divergence of radiation beam on measurement. To complete this, we designed a special optical lens and aperture system, and 635nm divergent beam of semiconductor laser diode were constrained and filtered. Moreover, an extinction component, namely light trap or optical black hole, was also designed to effectively absorb the excitation beam passed through scatter zone. The whole inner surface of scatter chamber is black, providing a dark background for multi-angle scattering.

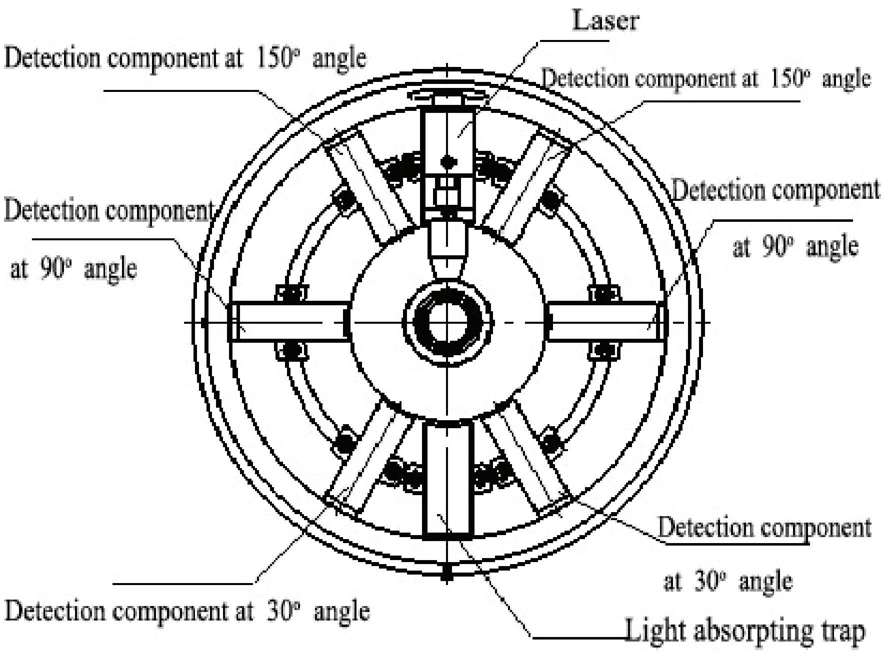


Fig. 2. Plan of multi-angle scatter chamber

Another important issue is how to narrow the common view field of six measuring channels. As a wide view field may cause receiving of scatter signal from different scatter zones and angles, the angle characteristic would then be affected. Thus, we designed receiving optical lens and view field aperture, and the visible scatter zone of detector was narrowed to Ø0.2mm, the differential angle for each measuring channel was 13^o. Then all measuring channels can just receive signals from only one small spot in scatter zone, and the directivity of detection angle was well protected. Additionally, real experiments showed that the maximum deviance of photo-electrical transfer and amplifying circuit responsivity of six channels was less than 3%.

2.2. Collecting and processing data

In order to measure signals of six channels synchronously, the platform used synchronous high speed multi-channel data collecting card with a collecting rate of 100K, 12bit resolution, dynamic input range 0-5V, linear data range 0-2047.

On the basis that spatial correlation and time correlation of multi-angle measurement were assured, when pre-processing, electronic background were subtracted from real time measurement data for each channel, which further reduced error. At the same time, in order to eliminate the error caused` by assembly, six channels were arranged symmetrically at the angle of 30^o, 90^o and 150^o, respectively; and two groups of signals from six channels were conducted synchronous fitting of arithmetic average and moving average; after that, with the reference of 90^o data curve, calculate the signal ratio of $30^o / 90^o$ and $150^o / 90^o$, respectively; at last the relative intensity of every angle were obtained. Above processing method can eliminate the influence of light source intensity and fluctuation of aerosol concentration assuming that the optical parameter and electrical parameter of each channel are uniform.

3. Capability proof

Theoretically, if the platform is able to collect scatter signals in each direction from same scattering zone at the same time, the raw data of each channel ought to show consistency in detailed characteristics of changing in height simultaneously. As fig. 3 shows, the raw data obtain from smouldering cotton proved that the platform was provided with required performance. 3 pairs of curves proximately coincided with each other, which showed a good consistency in optical paths and electrical circuits, and that it’s necessary to carry out the average calculation to eliminate systematic or assembly error.

NOTE: In all experiments, in order to ensure enough dynamic range, signals in 30^o channels were attenuated by -10db.

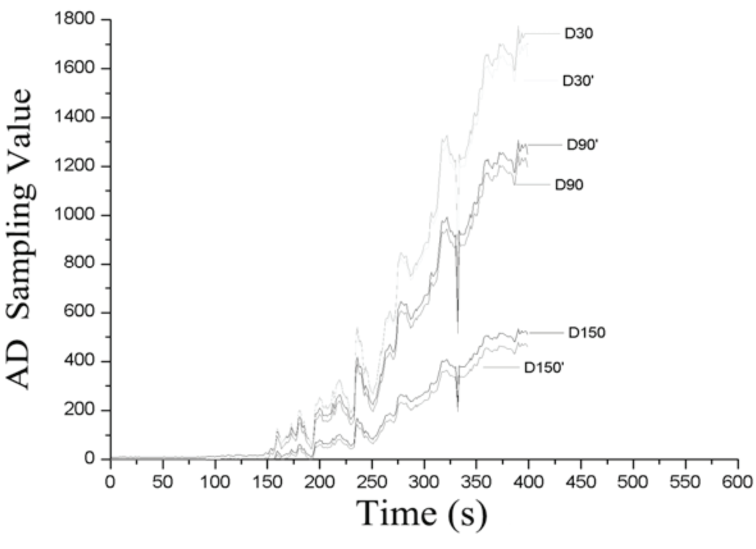


Fig. 3. Raw data for smoldering cotton of six channels

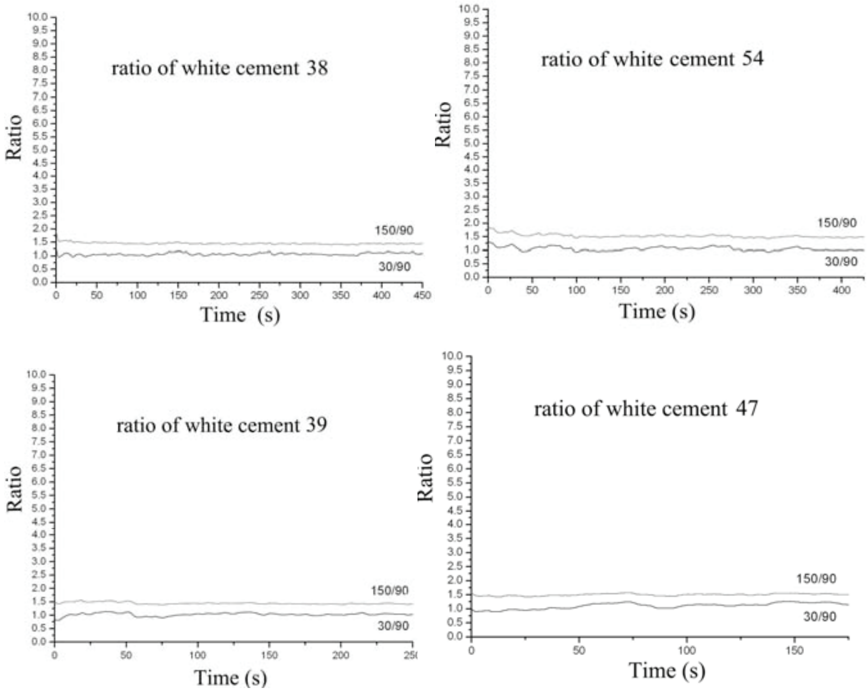


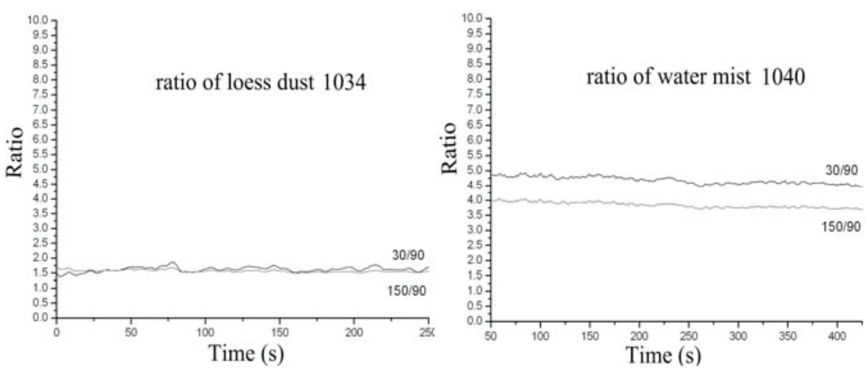
Fig. 4. Four pairs of ratio data for white cement

Assuming that the distribution of scatter relative intensity has stable regularity, if the platform has the ability to eliminate the influence of light source intensity and fluctuation of scatter intensity caused by fluctuation of aerosol concentration, then, theoretically, the obtained ratio curves shall be two straight lines parallel to time axis. The four groups of scatter ratio curves for white cement in different time, as in fig. 4, showed an ideally stable parallelism, which proved the spatial distribution of scatter intensity had a stable characteristic law, and this platform can eliminate intensity interference; hence independent measurement of scatter data from light source intensity and aerosol concentration could be achieved.

Experiments show that multi-angle scattering platform can eliminate various affecting factors and properly conduct the study on scatter characteristic of fire smoke and typical interference aerosols.

4. Smoke and aerosol scatter experiments

4.1. Scatter characteristics experiment data for typical interference aerosols



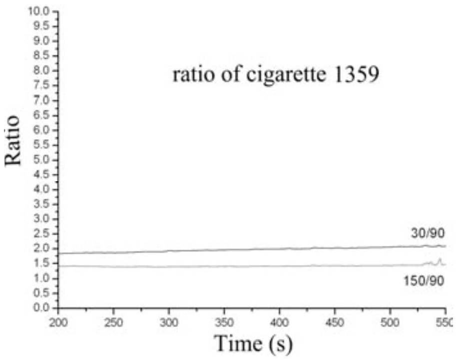


Fig. 5. Experimental data for loess dust, water mist and cigarette respectively

4.2. Scatter characteristic experiment data for fire smoke SH1-SH4

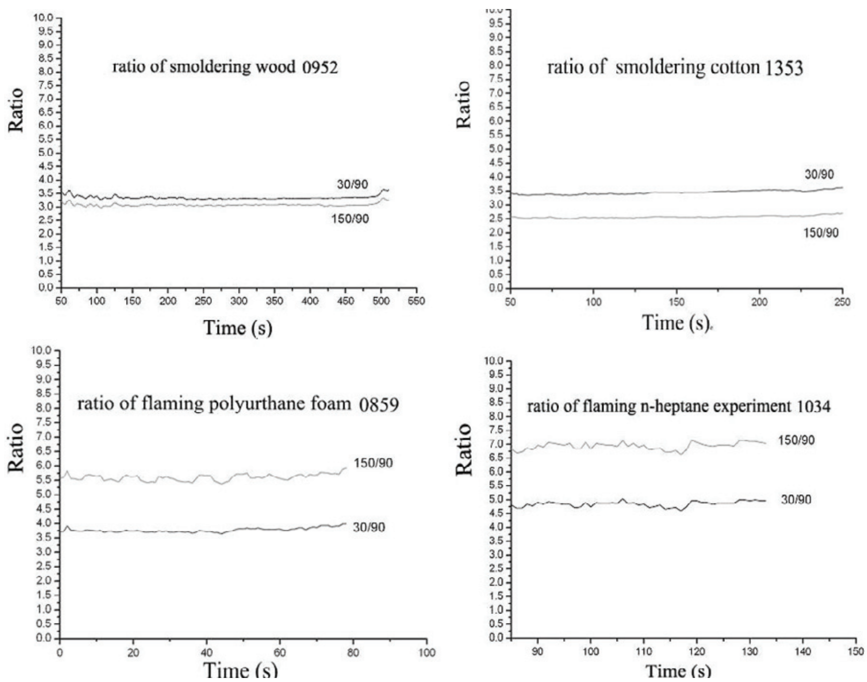


Fig. 6. Experimental data for smoldering wood fire SH1, smoldering cotton fire SH2, plastic (PU) fire SH3, and n-heptane fire SH4

4.3. Scatter proportionality experiment data for fire smoke SH1-SH4

The experimental study in response proportionality for fire smokes SH1-SH4 was carried out, with the measuring reference of extinction coefficient m. Then response proportionality data for fire smoke SH1-SH4 at 30^o, 90^o and 150^o angles was obtained when m=0.5 and 1.0, respectively.

5. Data analysis

Data shows that, typical interference aerosol (loess dust, water mist and tobacco smoke) and fire smoke SH1-SH4 have remarkable difference in scatter characteristic. In fact, for identification systems that can make this essential law demonstrable, there will be an actual limit of identifiable rate for each system, for the existence of intrinsic stability of characteristics and characteristic differences. As far as the various aerosols identified in this work, actual identifiable rate is 100%. Thus, an accurate identification of above fires and interference aerosols can be fully achieved by the parameter of multi-angle scattering characteristic.

The data also shows that, the relative standard deviance for detection response to four test fire smokes at 30^o, 90^o and 150^o angle were about 72% 100%and 61%, respectively. Although the response proportionality of 150^o angle is better than that of 30^o, but the advantage is still far from solving the problem. According to theoretical analysis and experimental studies, the scatter angle with best proportionality may appear at 0^o or 180^o.

The method that scattered smoke detectors adopted to solve response proportionality is to implement different fire criterion strategies for SH1-SH4; at least, SH1-2 and SH3-4 are required to be differentiated. As fig. 6 shows, depends on their scattering nature, SH1-2 and SH3-4 are distinguishable.

Table 1. Proportionality data for multi-angle smoke detection SH1-SH4

obs / item	30^0		90^0		150^0	
	m=0.5	m=1.0	m=0.5	m=1.0	m=0.5	m=1.0
Smoldering wood	1061	1974	409	1076	953	1974
Smoldering cotton	807	1877	285	907	677	1786
PU	139	426	1	28	200	601
n-heptane	134	331	0	11	183	440
mean（X）	535.3	1152	178.8	505.5	503.3	1200.3
σ	408.7	775	173.7	489.7	326.7	685.4
σ/X	76.4%	67.3%	103%	97%	64.9%	57.1%
mean（σ/X）	72%		100%		61%	

6. Conclusion

Following conclusions can be summarised in this study:

- the aerosols have stable characteristic between scattering relative intensity and angle distribution;
- the characteristic parameter of scattering relative intensity for 7 aerosols involved in this study shows remarkable differences, the theory identifiable rate is 100%;
- for SH1-SH4, backward scattering shows a better proportionality than forward scattering, but the advantage is not significant;
- no single angle scattering solution is applicable to response proportionality problem, but identification based on multi-angle scattering can solve this problem very well.