Efficiency of Ionizing and Photoelectric Fire Detectors in Dectecting the Combustion of Materials

Nutthajit Onmek[1,*], Wuttichai Kraveepan[1], Apitharn Phetarwut[1], and Khananat Boonkeawjan[1]

A R T I C L E I N F O

Article history:
Received: 23 Februay 2024
Revised: 4 April 2024
Accepted: 11 August 2024
Online: 31 October 2025

Keywords:
Ionizing
Photoelectric
Smoke detector
False alarm
Material combustion

A B S T R A C T

Fire alarms can protect people and property during fires. The sensors and fuel in fire alarms determine their efficiency. The efficacy of fire alarms can be achieved through the careful selection of suitable detectors for the materials in the building. The objective of this study was to conduct a comparative analysis of the performance of ionization detectors and photoelectric detectors, which meet criteria, and test five common building flame-fueling materials. With a 1-kilogram fuel test, paper had the shortest burn-out time, 5.23 minutes. Synthetic fabrics burned out the longest, at 22.6 minutes. In every case, the ionization detector responded faster than the photoelectric detector. Both types of detectors emitted an audible warning when the concentration of carbon dioxide reached a level below 810 parts per million, a threshold deemed non-hazardous. The photoelectric detector was more resistant to cigarette smoke-triggered false alarms than the ionization detector. The ionization detector had a higher detection efficiency compared to the photoelectric type, as evidenced by the findings obtained through the detection of ions generated during combustion. Therefore, the photoelectric detector is better suited for fast-burning or smoky materials.

1. INTRODUCTION

Every year, fire disasters result in significant loss of life and property damage. Data regarding the damages in Thailand can be obtained from the Department of Public Health and Disaster Prevention for the year 2015. The mean number of fatalities resulting from fires was recorded at 1,715, while the cumulative monetary value of losses incurred amounted to 1,350,808,967 baht [1]. United States fire departments reported the number of civilian deaths at 3,655; 15,200 injuries; and an estimated 25.6 billion dollars in direct property loss in the case of fires [2]. 74 percent of those cases were home fires. They record that fires accounted for 8 percent of the 36,746,500 total calls that were false alarms [3]. There are several approaches to preventing and stopping fires, and fire alarm systems help prevent or reduce the damage. The alarms can be based on monitoring smoke or heat [4]. According to prior studies, smoke detectors are more effective than thermal detectors [5]. However, there are still problems with the efficiency and reliability of fire detection. Response times remain slower than the EN54 standard, and there are false alarms from cigarette smoke [6, 7]. In addition, it is also related to the technical problems of fire alarm equipment in detecting fires caused by different types of fuel [8], which affect the sensitivity, efficiency, and errors in the alarm [9]. Delayed fire alarms delay response actions, potentially causing widespread fires and evacuations, while false alarms are a nuisance and degrade belief in the alarm in the real case of a fire. Aside from the type of fire alarm device, the type of material that burns affects the effectiveness of the fire alarm [10]. Accident Statistics of the Office of Safety Technology Department of Industrial Works, Thailand, show that synthetic fiber, paper, synthetic rubber, wood, and polyvinyl chloride are common materials inside buildings that serve as fuel in a case of fire. Therefore, studies that pair the material combusting with the selection of alarm type are important.

Therefore, this study investigated the efficiency of ionizing and photo-sensing smoke detector types with the combusting materials of synthetic fiber, paper, synthetic rubber, wood, and Polyvinyl Chloride and evaluated CO_2 concentration at the alarm time. In addition, test the resistance to false alarms caused by cigarette smoke. This study can guide the selection of fire alarm devices to match the main materials involved in a fire hazard and assess the evacuation time.

2. MATERIALS AND METHODS

In compliance with the fire alarm testing standard established by the Department of Public Works and Town & Country Planning, provide the following information regarding the room: dimensions, temperature, and relative humidity. The testing setting was maintained at 22–26

[1]*Faculty of Science and Industrial Technology, Prince of Songkla, University, Surat Thani Campus, Muang, Surat Thani 84000, Thailand.*
Corresponding author: Nutthajit Onmek; Email: nutthajit.o@psu.ac.th.

degrees Celsius and 40–60 percent relative humidity. The temperature and quantity of CO2 gas within the room are assessed both prior to and after each experiment to verify their comparability to the surrounding ambient conditions.

2.1 Experimental equipment

Ionization Smoke Detector: Brand A, single-use type; the device can operate normally at 0–45 °C, 0–90% RH, and has an alarm sound level of 85 dB. It has been certified by both BS and CE standards. Made in China.

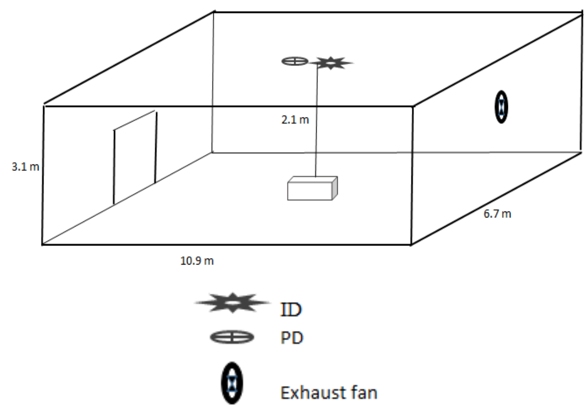

Fig. 1. Testing room.

Photoelectric Smoke Detector: Brand B, single-use type; the device can operate normally at 0–45 °C, 0–90% RH, and has an alarm sound level of 85 dB. It has been certified by the CE standard. Made in China.

2.2 Burn Tests

Each test used 1 kg of fuel with 3 replicates of 5 sample types, for a total of 15 test. Benzene was added (0.04 mL per test) to help ignite the fuel base, which was then allowed to burn out. The following observations were recorded:

1) When the fuel light is on, start the timer and record the time to burn out.
2) When the smoke detector alarms, record the time and the CO_2 level.
3) When the fuel burns out, record the time.
4) After each test run, the test room was ventilated until the CO_2 level was back to a normal background level before the next test run.

2.3 False alarm test with cigarette smoke

A 10-cigarette smoke test was carried out with the cigarettes lined up on a cylinder with drilled holes and connected to an air pump. After all the cigarettes were ignited, the air pump was started, and the smoke detector eventually responded at a time that was recorded. Three replicates were run with each type of smoke detector.

3. RESULTS AND DISCUSSION

3.1 Ignition time

The ignition time refers to the duration between the initiation and flame-up combustion. The ignition time of PVC exhibited the longest duration, with a mean value of 41.33±3.05 seconds. In comparison, wood had a somewhat shorter ignition time of 38.66±1.15 seconds, followed by synthetic fibers with an average ignition time of 27.66±2.51 seconds. Synthetic rubber exhibited a further reduction in ignition time, averaging at 25.66±2.08 seconds. Finally, the paper showed the shortest ignition time among the tested materials, with an average value of 4.66±1.15 seconds. The statistical significance of the data was determined using a one-way analysis of variance (ANOVA) test conducted by Scheffe. The results indicated a significant difference at a significance level of $P < 0.05$, as shown in Figure 2.

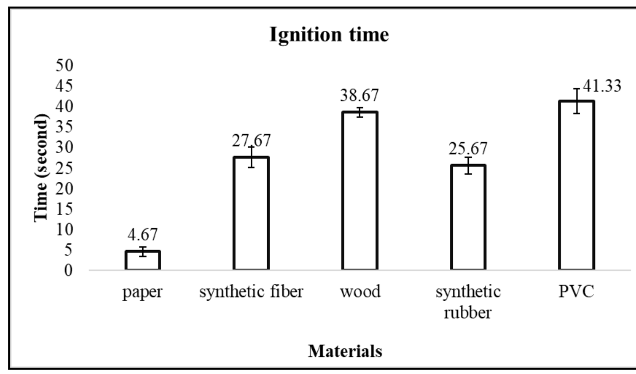

Fig. 2. Ignition time of each material.

Paper had the fastest ignition time, while PVC was the slowest. Prior research has shown that the rate of combustion depends on material density, shape, and the atmospheric headspace that provides the oxygen for combustion. PVC has a melting temperature of about 212 °C, and the polar chlorine atoms give its polymer chains high molecular rigidity. Therefore, chemical softeners are used to modify its properties, and these also affect its thermal stability [11]. Similarly, the other test materials are only representative of a wide range of products. For example, paper can be made from chemical or mechanical pulp, be filled or unfilled with inorganic pigments, or be coated or uncoated. Therefore, these results do not have a wide generality but only represent the specific cases tested.

3.2 Alarm time

Alarm time was recorded from flame-up to audible alarm. The alarm time of paper, synthetic fiber, wood, synthetic rubber, and PVC was 8±1.0, 42±1.0, 42±2.0, 27±2.51, and 53±0.57 seconds, respectively, for ionization detectors and 19±1.52, 71±1.57, 53±1.15, 88±2.51, and 86±1.52 seconds, respectively, for photoelectric detectors (Figure 3).

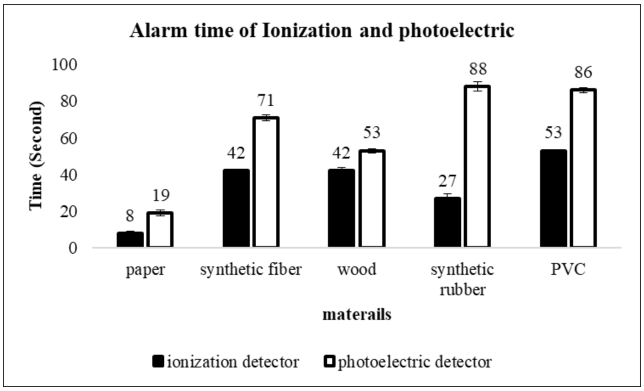

Fig. 3. Comparison of alarm times between ionization and photoelectric detectors of each material.

The results show that the ionization detector was faster alarm than the photoelectric smoke detector, when synthetic fiber, synthetic rubber or wood was burning. The difference was statistically significant ($P<0.05$). However, no significant difference was observed when burning plastic, PVC, or paper (Tables 1-2).

Table 1. The findings of Tukey's honestly significant difference (HSD) post hoc test were presented based on the type of detector

Material	ID	PD
Paper	7.66^a	18.33^a
Synthetic fabric	42^c	70.66^c
Wood	42^c	52.33^b
Synthetic rubber	42.33^c	52.33^b
PVC	26.33^b	87.33^d

Table 2. ANOVA of alarm time in Ionizing smoke detector and photoelectric detector by material

Type of detector		SS	df	MS	F	Sig.
ID	Between Groups	2792.933	4	698.233	158.689**	≤0.001
	Within Groups	44.000	10	4.400		
	Total	2836.933	14			
PD	Between Groups	7927.067	4	1981.767	479.460**	≤0.001
	Within Groups	41.333	10	4.133		
	Total	7968.400	14			

An analysis of variance (ANOVA) was conducted to examine the differences in alarm time between ionizing smoke detectors and photoelectric detectors, with a focus on the effect of material. The amount of visible smoke depends on the amount of soot produced by burning, as measured by photoelectric smoke detectors. [12]. In our experiments, the ionization detectors detected ions from the combustion, which resulted in a faster alarm signal. In contrast, photoelectric smoke detectors could detect the fire faster than ionization types, which was reasonable considering different experimental conditions that could channel or dilute the smoke [13]. However, in that study, the minimum temperature was -1 °C and the maximum was 23 °C, whereas in our study, the room temperature was from 22 to 27 °C. Temperature affected flammability and chemical reaction rates, as well as the evaporation of volatile components that burned as gases to make the visible flame. Further, heat-induced convection in the air depends on the air temperature, as cooler air has a higher density, which affects the channeling and dilution of smoke from combustion [14, 15, 16]. Therefore, the testing temperature may be a factor affecting the results.

3.3 Resistance to false alarm

In the 3 replicates of the false alarm test with cigarette smoke, the ionization detector had delays of 12, 8, and 15 seconds, while the photoelectric detector had delays of 23, 17, and 21 seconds, as shown in Figure 4. The paired t-test shows a significant difference ($p < 0.05$), with the ionization detector being more sensitive to cigarette smoke and false alarms. The components of a cigarette consist of the paper covering and the tobacco, which have the components that cause the chemical reaction to ignite and burn quickly. The quick release of ions from chemical reactions makes the ionization detector more sensitive than the photoelectric detector, which has the same result as paper combustion [17].

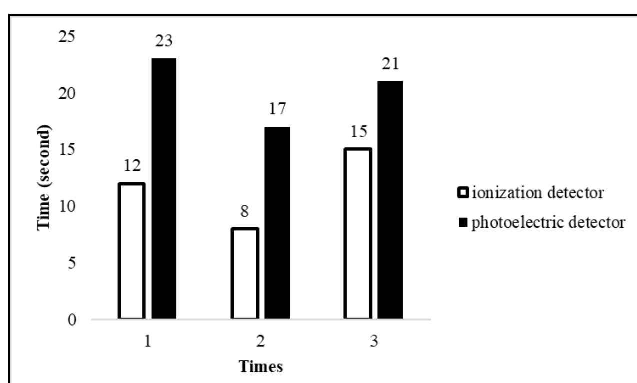

Fig. 4. Time to resist a false alarm in a three-time test of each detector.

3.4 The CO2 levels at alarm time.

For paper, synthetic fiber, wood, synthetic rubber, and PVC, the CO_2 levels at alarm time by an ionization detector were 809.67±28.01 ppm, 712±17.0 ppm, 690.33±10.50 ppm, 738±64.83 ppm, and 742±61.14 ppm, respectively, and with a photoelectric detector, the levels were 817.33±28.29 ppm, 746±2.0 ppm, 709±30.26 ppm, 764±67.86 ppm, and 792.67±70.68 ppm, in the same order (Figure 5).

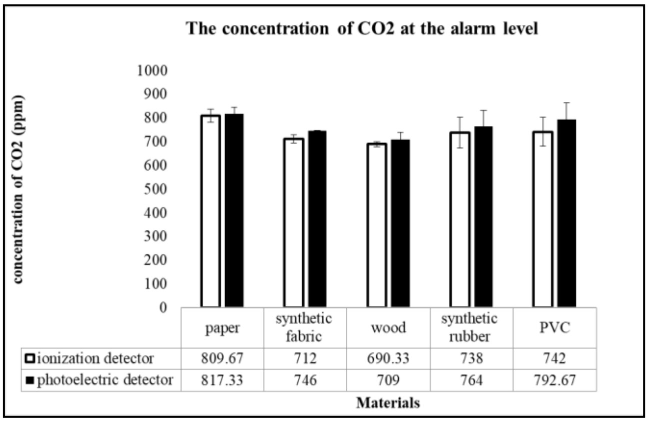

Fig. 5. The concentration of CO2 at the alarm time.

The levels of CO_2 at the alarm time of the ionization detector were consistently slightly lower for synthetic rubber and PVC than the photoelectric detectors. Overall, the CO_2 level at alarm time was lower than 800 ppm in all cases. CO_2 levels more than 10% can cause unconsciousness or loss of life, while before this there could be nausea, vomiting, a severe headache, elevated blood pressure, and an increased heart rate as symptoms. The CO_2 levels could be around 8000 ppm for extended periods without affecting the functionality of personnel [18]. Clearly, the CO_2 levels observed at alarm time were not a health risk to humans. Therefore, people inside the building could be evacuated without danger when there was a smoke detector to start the alarm.

3.5 Duration of burn-out

For the 1 kg samples tested, paper had a total burnout time of 5.23±0.15 minutes, wood 11.05±0.03 minutes, polyvinyl chloride 16.88±0.64 minutes, synthetic rubber 20.46±0.05 minutes, and synthetic fabric 22.6±0.60 minutes. These times differed significantly ($P < 0.05$) shown as Figure 6.

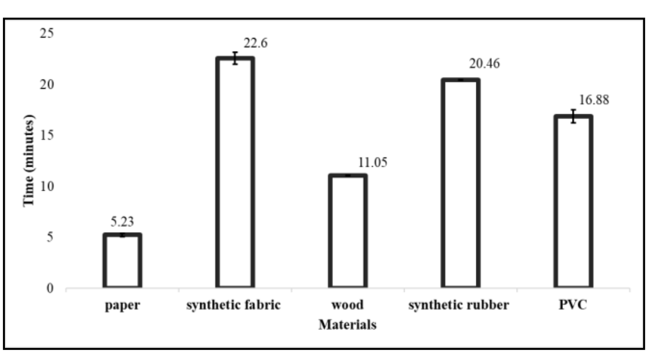

Fig. 6. duration of each material's burnout.

It could be seen that each material had a different combustion ability depending on its composition and chemical properties [19], which was a factor related to pyrolysis index and kinetic parameters [20]. However, the results of this study would not generalize widely to these product categories but would represent the specific cases tested to see the trend duration of burn-out in each kind of material.

4. CONCLUSION

Smoke detectors with ionization and photoelectric sensors were tested for responses to various combustible materials burning as well as for false alarms from cigarette smoke.

Among the materials tested, paper had the fastest burn-out time, while synthetic fabrics were the slowest. Paper materials should be kept away from potential sources of ignition because of their fast burning and easy ignition.

4.1 In terms of time delay until alarm, the ionization detector was the fastest of the tested materials. Nonetheless, the photoelectric detector was more resistant to false alarms caused by cigarette smoke. Therefore, a risk assessment of the combustible materials should be conducted prior to selecting and installing an appropriate kind of detector.

4.2 The CO_2 concentration at the time of the warning was less than 800 ppm for all the materials tested for both detector types, much below the limits that could be dangerous to humans. However, burning materials could release additional harmful substances, and incomplete combustion could produce carbon monoxide, a common cause of mortality even when a fire was generally under control. Because the normal background CO_2 level was around 400 ppm, the low CO_2 concentrations detected were suggestive of the remarkable sensitivity that these low-cost commercial devices had already achieved.

ACKNOWLEDGMENTS

We express gratitude to Prince of Songkla University, Surat Thani Campus, for providing financial support and to Bansomdejchaopraya Rajabhat University for helping in the publication of this article. We express gratitude to Associate Professor Dr. Seppo Karrila for his invaluable contributions to enhancing the quality of the manuscript.

Latif, K., Raza, M. Y., Chaudhary, G. M., & Arshad, A; (2020); Analysis of Energy Crisis, Energy Security and Potential of Renewable Energy Evidence from Pakistan; Journal of Accounting and Finance in Emerging Economies, 6, pp.167-182.

REFERENCE

[1] DPM Reporter. *Department of Disaster Prevention and Mitigation*. Retrieved March 3, 2021, from https://dpmreporter.disaster.go.th/portal/disaster-statistics.

[2] Alves, J. A., Silva, L. T., and Remoaldo, P. C. (2018). Impacts of low frequency noise exposure on well-being: a

case study from Portugal. *Noise & Health*, 20(95): 131–145.

[3] Evarts, B. (2018). *Fire Loss in the United States during* 2017. Quincy, Massachusetts: National Fire Protection Association.

[4] Festag, S. (2016). False alarm ratio of fire detection and fire alarm systems in Germany – A meta-analysis. *Fire Safety Journal*, 79: 119–126.

[5] Abbasi, M., Yazdanirad, S., Habibi, P., Arabi, S., Fallah Madvari, R., Mehri, A., and Ghaljahi, M. (2019). Relationship among noise exposure, sensitivity, and noise annoyance with job satisfaction and job stress in a textile industry. *Noise & Vibration Worldwide*, 50(6): 195–201.

[6] Suindramedhi, S. (2015). Disaster management: Lessons learned from Japan. *GMSARN International Journal*, 9(3): 83–92.

[7] Scorsone, E., Pisanelli, A. M., and Persaud, K. C. (2006). Development of an electronic nose for fire detection. *Sensors and Actuators B: Chemical*, 116(1–2): 55–61.

[8] Nguyen, H., Le, D., Nguyen, H., and Trinh, V. (2020). Thermal behavior of woody biomass in a low oxygen atmosphere using macro-thermogravimetric analysis. *GMSARN International Journal*, 14: 37–41.

[9] Paś, J., and Klimczak, T. (2019). Selected issues of the reliability and operational assessment of a fire alarm system. *Eksploatacja i Niezawodność*, 21(4): 553–561.

[10] Chomanee, J., Tekasakul, S., Tekasakul, P., Furuuchi, M., and Otani, Y. (2009). Effects of moisture content and burning period on concentration of smoke particles and particle-bound polycyclic aromatic hydrocarbons from rubber wood combustion. *Aerosol and Air Quality Research*, 9(4): 404–411.

[11] Liu, W., Zhang, S., Chen, X., Yu, L., Zhu, X., and Feng, Q. (2010). Thermal behavior and fire performance of nylon-6,6 fabric modified with acrylamide by photografting. *Polymer Degradation and Stability*, 95(9): 1842–1848.

[12] Xie, Q., Yuan, H., Song, L., and Zhang, Y. (2007). Experimental studies on time-dependent size distributions of smoke particles of standard test fires. *Building and Environment*, 42(2): 640–646.

[13] Chen, T., Wu, P., and Chiou, Y. (2004). An early fire-detection method based on image processing. *Proceedings of the 2004 International Conference on Image Processing*, Singapore, 24–27 October. IEEE.

[14] Guo, Q., Zhu, H., Zhang, Y., and Yan, Z. (2020). Theoretical and experimental studies on the fire-induced smoke flow in naturally ventilated tunnels with large cross-sectional vertical shafts. *Tunnelling and Underground Space Technology*, 99: 103359.

[15] Ishikawa, T., Kasumi, K., Tanaka, F., and Moinuddin, K. A. M. (2020). Combustion efficiency during fires in tunnels with natural ventilation by vitiated air including descending smoke. *Fire Safety Journal*, 120: 103093.

[16] Bobi, S., and Laoonual, Y. (2022). Evaluation of heat loss to cylinder wall of compression ignition engine by heat transfer models. *GMSARN International Journal*, 16: 240–246.

[17] Dinaburg, J., and Gottuk, D. (2016). Smoke alarm nuisance source characterization: Review and recommendations. *Fire Technology*, 52: 1197–1233.

[18] Jacobson, T. A., Kler, J. S., Hernke, M. T., Braun, R. K., Meyer, K. C., and Funk, W. E. (2019). Direct human health risks of increased atmospheric carbon dioxide. *Nature Sustainability*, 2(8): 691–701.

[19] Leng, E., Ferreiro, A. I., Liu, T., Gong, X., Costa, M., Li, X., and Xu, M. (2020). Experimental and kinetic modelling investigation on the effects of crystallinity on cellulose pyrolysis. *Journal of Analytical and Applied Pyrolysis*, 147: 104863.

[20] Hu, D. H., Chen, M. Q., Huang, Y. W., Wei, S. H., and Zhong, X. B. (2020). Evaluation on isothermal pyrolysis characteristics of typical technical solid wastes. *Thermochimica Acta*, 688: 178604.