Journal of Geoscience and Environment Protection, 2022, 10, 29-44
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

A Review on Mine Fire Disasters and Assessment of Fire Detection Using a Dual-Cab Suppression System

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How to cite this paper: Utip, I. B., Zhang, Y. L., Ren, L., Augustine, A., & Wang, J. F. (2022). A Review on Mine Fire Disasters and Assessment of Fire Detection Using a Dual-Cab Suppression System. *Journal of Geoscience and Environment Protection, 10,* 29-44.
https://doi.org/10.4236/gep.2022.1012003

Received: October 16, 2022
Accepted: December 4, 2022
Published: December 7, 2022

Abstract

The health and productivity of mining operations are negatively impacted by coal mine fires, making them dangerous. It happened everywhere, in both working and abandoned coal mines. This study seeks to review and provide technical analytics of potential mine fires and fire detection in a Dual-Cab suppression system. Analysis was done on potential mine fires like spontaneous combustion, flammable gas explosions, and cab vehicle fires. Additionally, a review of the NIOSH experiment was conducted to assess the performance of smoke and flame detectors in a dual-cab suppression system. This study guides both open-pit and underground mining operations. Additionally, a few ideas and suggestions are presented to assist with on-the-job safety analysis, ensuring creative alterations, and technology advancement for the mining industry's overall safety.

Keywords

Coal Spontaneous Combustion, Mine Fire, Fire Detection, Suppression System, Dual-Cab

1. Introduction

Coal is a combustible carbonaceous material derived from biochemical processes and physiochemical alteration of vegetation. Coal mining methods are classified based on the accessibility of deposits, including surface and underground mining (Abalaka & Aga, 2016; Hansen, 2021; Hansen & Ingason, 2013). Fire outbreak in mines is one of the most challenging safety issues faced by every person working in a mining environment (Kong et al., 2022). Mine fire often grows uncontrollably through the spread of asphyxiating gases and thus exposing the entire workforce, mainly underground miners, to deadly conditions. Mine fires are caused by spontaneous heating, improper fuel storage practices, lighting of gas accumulation, frictional heating and ignitions, the use of long-flame explosives, and mobile equipment malfunctions (Luo, Yuan, Li, Wang, & Yang, 2022). Together with the Mine Safety and Health Administration, the National Institute for Occupational Safety and Health (NIOSH) has been conducting an extensive study programmer (MSHA) (Smith & Thimons, 2009; Trevits, Yuan, Smith, Thimons, & Goodman, 2008; Trevits, Yuan, Smith, & Thimons, 2009). Recently, the main problem with underground mines is the inability to manage smoke and heat spread during a fire incident. However, several methods have been devised to ensure the safety of miners through improved fire prevention, detection, and control measures. Since mine fires occur with alarming regularity, it is critical to recognize and eliminate the potential hazards. Also, this necessitates the development of enhanced fire control and suppression system to ensure the best probable outcome during a mine fire incident.

In retrospect, many death and injuries have been recorded due to mine fire incidents in China, the USA, South Africa, Australia, and Europe. Statistically, more than 95 cases of mine fires were reported in the US from 1990 to 2001. In the United Kingdom, 23 underground mine fires were reported between 1992 and 2002. In 2020, five incidents were reported in South Africa. Also, statistics show an average of 75 fire incidents per year for surface and underground incidents in Sweden (Ingason, Lönnermark, Frantzich, & Kumm, 2010).

The possible sources of these mine fires were spontaneous combustion, equipment malfunction, and others. Recently, South Africa and Mozambique recorded mine fire disasters due to poor safety operations in underground mines, with Cab fires as one of the major incidents.

Cab fires are caused by flammable fumes and mists (balls of fire) that reach the cab during protracted hydraulic fluid and fuel fires, as well as electrical faults involving other combustible materials in the cab. Often, these fires compel the operator to exit the cab under hazardous and critical conditions. Therefore, it is crucial to provide the operator not only with an engine fire suppression system (dry chemical powder) but also with a cab fire protection system, which proves effective in preventing the ignition of flammable vapors in the cab and suppressing cab material fires (Hansen, 2009).

In this paper, the prospective mine fires and the Dual-Cab suppression system's fire detection were investigated. The study included spontaneous combustion, gas explosions, and cab vehicle fires. In addition, the NIOSH experiment was reviewed to evaluate smoke and flame detectors in a dual-cab suppression system. This study is critical because it guides open-pit and underground mining operations and serves as a manual for the mining safety industries in deploying cab fire detectors rather than doing direct testing of fire detectors on the market. It examined the efficiency of two commercially available fire detectors: a Photoelectric Smoke Detector (PSD) and an Optical Flame Detector (OFD), in spotting flame and smoke fires in dual-mode cabs. A few views and proposals are presented to help with on-the-job safety analysis, creative changes, and technological advancements for mining industry safety.

2. Experimental Methods

2.1. Spontaneous Combustion

Figure 1 demonstrates stockpile self-heating. Oxygen and air moving across the pile surface warm the coal. This heat is transported inwards and outwardly, but the inward heat can build up and form a hotspot. This hotspot will spread to the surface and react with oxygen in the air, causing blazing embers and coal pile ignition. Sasaki et al. (Sasaki, Wang, Sugai, & Zhang, 2014) offered a more extensive explanation of oxidation along with equations to evaluate oxygen consumption and heat output. This isn't limited to stockpiled coal. Newly exposed mine surfaces can also entrain air, leading to spontaneous combustion. According to (Sloss, 2013), thousands of underground mines, surface mines, and coal heaps have spontaneously combusted, contributing to local and regional air pollution.

Spontaneous combustion is a common fire disaster in coal mines and is more dangerous in underground mines due to poor evacuation processes

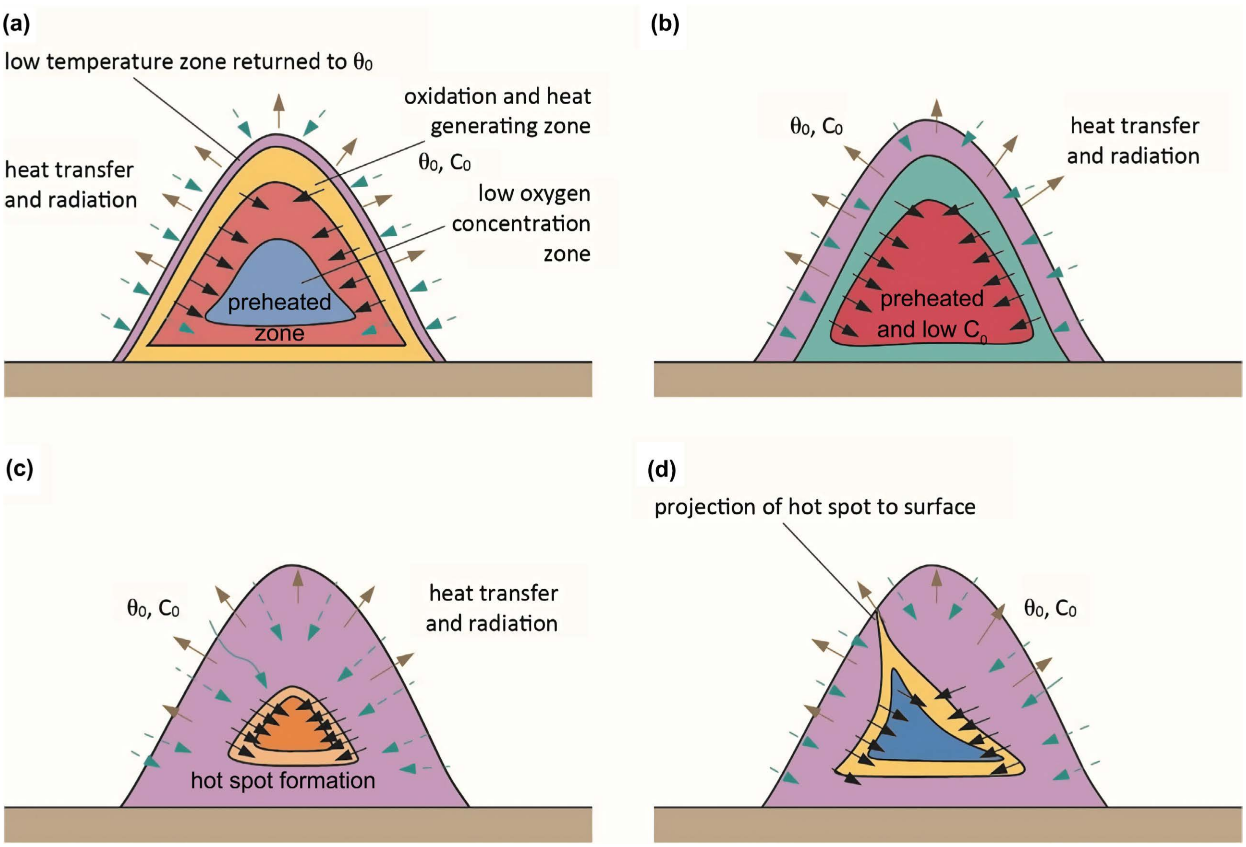

Figure 1. Schematic of the self-ignition process of a coal accumulation (Source: Sasaki et al., 2014).

(Guo, Wen, Zheng, Liu, & Cheng, 2019; Liang, Zhang, Wang, Luo, & Ren, 2019). The most recent occurrences of mine fires in various coal mines worldwide are mainly a result of the spontaneous combustion of coal (Zhou et al., 2021). The primary cause of this occurrence is the auto-oxidation of coal. In this process, coal and other carbonaceous materials self-heat thereby resulting in ignition known as spontaneous heating. When coal is given enough oxygen, it can spontaneously heat up, and the coal can store the heat that is released (Więckowski, Howaniec, Postnikov, Chorążewski, & Smoliński, 2018).

Coal oxidation is an irreversible exothermic reaction that increases as the temperature rises (Onifade & Genc, 2020; Yuan & Smith, 2008; Yuan & Smith, 2009, 2011, 2012, 2013). Temperature boosts oxidation. Coal's exposed surface absorbs oxygen from the air. Some exposed coal receives more oxygen than others, increasing oxidation and gas production. CO, CO_2, water vapour, and heat release during the chemical reaction. When heat is accumulated, the interaction rate increases, leading to spontaneous emission that generates fire at an ignition temperature of about 175˚C. This phenomenon causes sterilization of coal reserves as well as loss of equipment. Paramountly, it is imperative to know that coal is the fuel in spontaneous combustion, and oxidation occurs when oxygen interacts with the coal's surface, resulting in heat. Also, if the surfaces are abandoned without treatment, it will result in fire.

2.2. Flammable Gas Explosions

From a literature survey of flammable gas explosions in South African hard rock mines, the number of such incidents reported from 1988 to 2005 is 78, with a total of 89 fatalities and 144 injuries. According to the research conducted by Krog and Schatzel (2009) documented that, between 2000 and 2005, the number of frictional ignitions reported in underground coal mines in the United States was estimated between 34 and 60 per year (Courtney, 1990; Krog & Schatzel, 2009). However, these ignitions are considerable, but there is a tendency for more giant explosions. From 2004 to 2018, China's total number of coal mine accidents exhibited a downward trend. The cause of fatality rate decreased drastically due to improvements in the mechanization and intelligence of coal mining operations (Tong et al., 2019).

Figure 2 shows that gas explosion accidents have been declining. This is because China has invested more in mining safety and innovative equipment and technology. Many countries have used sophisticated coal mine production equipment and technologies to ensure miner safety. Gas explosion accidents are a major source of serious and special mining accidents in China (Burgherr & Hirschberg, 2007; Jin & Courtney, 2009). To prevent gas explosion mishaps, it's important to understand their causes (Liu, Cheng, Yu, & Xu, 2018). The three primary causes of gas explosion mishaps are the presence of gas, an ignite source, and adequate oxygen.

Flammable gas explosion in coal mines is caused by Explosive gases, Coal dust,

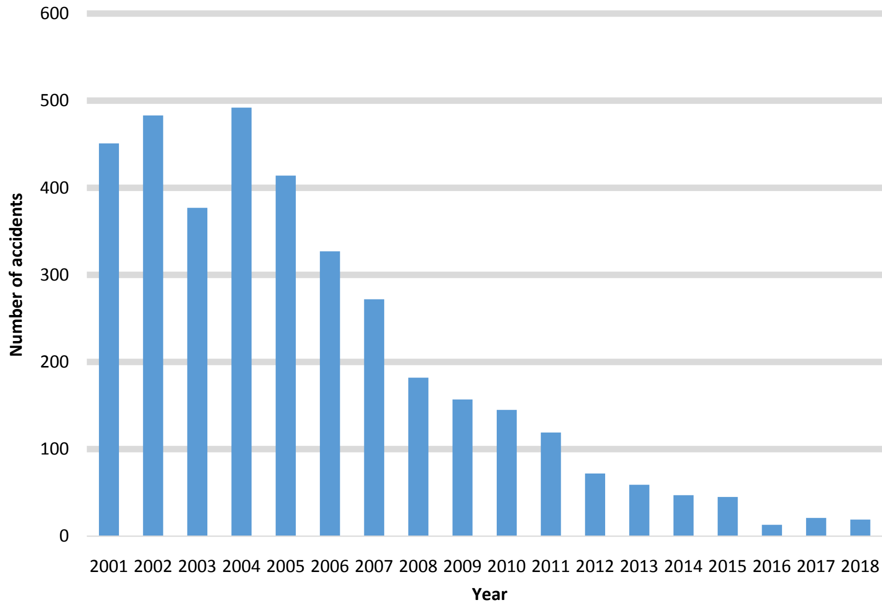

Figure 2. Statistics of gas explosion accidents from 2001 to 2018 in China (Tong et al., 2019).

and Water gas explosion. Flammable gases encountered in coal mines are methane, ethane, propane, butane, and hydrogen. The most common of these gas explosions are explosive gases which include Firedamp (methane), Whitedamp (carbon monoxide), Stinkdamp (hydrogen sulfide), and Black damp (Carbon Dioxide). In surface and underground coal mines, these explosive gases cause explosions when they are in contact with sufficient heat and fire (Lin, Liu, Qian, Li, & Zhang, 2021).

Amongst these explosive gases, Firedamp is the primary cause of the explosion due to unsafe acts and conditions such as negligence of miners, use of damaged safety lamps and improper handling, blasting in the grassy area, frictional heating, and sparks. The most reliable and efficient method of keeping mines free from hazardous gases is achieved through quality mining ventilation systems. Since 1980, effective ventilation measures have significantly reduced the number of fatalities and injuries caused by explosions in coal mines in the United States.

2.3. Cab Vehicle Fire

See **Figure 3** describes the order of vehicle fires:

1) Cab/passenger compartment (44 cases);

2) Cable feeder (36 cases);

3) Exhaust pipe (21 cases);

4) Engine compartment (119 cases).

In six incidents, the driver, operator, or repairman saw the fire; in the other six, a passerby did.

When specified, the following fire suppression operations were noted:

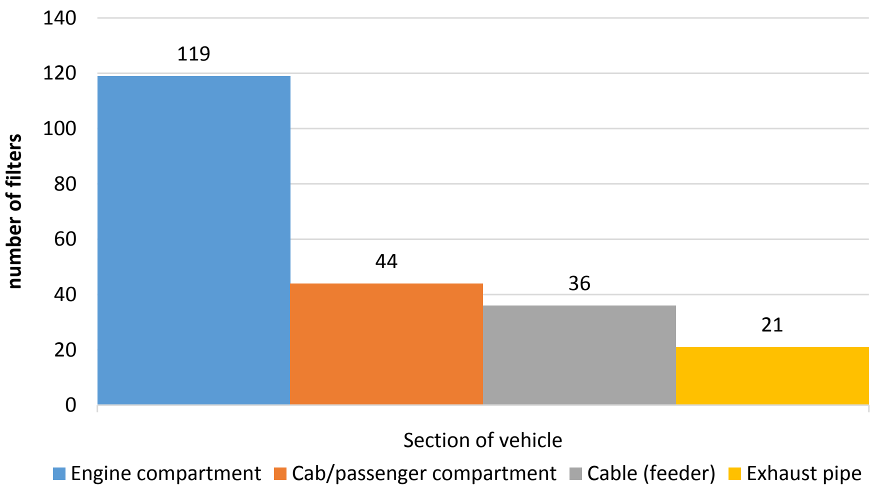

Figure 3. Common section of mine cab vehicle where fire occurs (Hansen, 2013).

1) The use of fire extinguisher (107 cases);

2) Turn off the engine, the main switch, or the battery (36 cases);

3) Using a water hose (19 cases);

4) The vehicle's sprinkler system was activated, putting out the fire (12 cases);

5) The fire was put out manually or self-extinguished;

6) The supply of oil was cut off;

7) A rag was used to put out the fire. (1 case); and

8) Extinguishing was done with wet mud (1 case).

Many times, using a fire extinguisher and shutting off the power supply, the fire was put out. Nine times the vehicle's sprinkler system was turned on, but it either didn't work at all or worked properly but failed to put out the fire. Before using a water hose, a fire extinguisher effort had been made without result. In five instances, the fire crew was said to have put it out (Hansen, 2013).

3. Dual Cab Suppression System

A dual cab fire incident that resulted in a fatality was reported in 2018. After starting a fire on the Caterpillar 793BC haul truck he was driving, a miner sustained serious injuries. Later, he passed away as a result of the burns he sustained while attempting to exit the cab of the cargo truck. Under the operator's cab, a steering hose that had ruptured was the most likely culprit of the fire. There were numerous broken steel wire braids in a 37.5 mm by 37.5 mm region of the hose that transported the steering metering pump's primary hydraulic pressure from the steering valve (Litton, 1979). A hole measuring around 3.125 mm by 25 mm was also present in the internal hose lining. The cause of the hose rupture was not discovered by investigators.

The manufacturer claims that during steering, the hose's pressure can reach 3100 psi. The operator was probably doing a sweeping manoeuvre to match the truck with the dump point position when the fire broke out. This twist will apply full pressure to the broken hose, possibly causing it to explode and release high-pressure hydraulic fluid onto the hot engine surface, starting a fire that will spread quickly.

3.1. Analysis of the Dual Cab Fire Suppression System of Caterpillar 793BC Truck

The fire suppression system had four tanks holding 30 pounds of dry chemical agent. The four tanks were installed on the truck deck near the engine and piped to discharge concurrently. Fire minimally damaged four storage tanks and cartridges. The engine compartment has 16 fixed discharge nozzles.

The vehicle had two manual actuator stations: one in the cab to the right of the driver's seat and one on the front bumper. The truck driver would pull a pin and depress the plunger to activate the mechanism, breaking a foil seal and bursting the actuator hoses. The pressure would cause nitrogen bottles on chemical storage tanks to burst, unleashing fire suppression chemicals into 16 nozzles.

The cab actuator was used. The cab's actuator bottle was discharged once the safety pin was withdrawn. The nitrogen bottles on the chemical storage tanks weren't released, and the four tanks contained enough fire suppression powder. The storage tanks' safety relief valve and pneumatic actuators worked as predicted when tested. Fire suppression hoses were routed into the truck's engine compartment. They weren't protected with a heat-resistant fire jacket, contrary to ANSUL's instructions. The manual cites the engine compartment as a fire hazard and says the actuation hose shouldn't be sent there. If not, the hose must be fire-jacketed.

Destruction of the actuation hoses in a fire would render the fire suppression system unworkable because the hoses couldn't transfer pressure from manual actuators to dry chemical storage tank actuators. MSHA's examination concluded that the fire consumed the engine compartment's rubber components (hose coverings).

During the investigation, the actuator in the cab was near a display panel that conveyed directions from the control room. Plastic components burned, however the LCD screen's metal mounting post survived. Depending on how the mounting arm was positioned before the fire, the screen may have blocked manual actuator strikes. The front bumper's manual actuator wasn't on. Safety pin and foil seal were intact.

When actuated, the fire suppression system's engine shutdown pressure switch shuts down the engine. The pressure switch looked to be off, indicating that pressure from the actuation circuit reached it during the fire. It's possible that the heat from the fire caused the nitrogen actuator cartridge to burst through the foil seal and release some of the built-up pressure. Because the Production Manager removed the actuator cartridge from the cab before the accident was reported, It's unknown if the victim or heat pressure shifted the shutdown switch.

3.2. Fire Detection in Dual Cab Suppression System

Fire detection systems in mining dual-cabs are designed based on the fire elements and emissions (Litton, 1979). Fire detectors are designed for optimal performance as smoke detectors and flame detectors. For any mine fire to be detected during an incident, three significant factors are considered;

1) The fire must be large enough to generate alarm levels of the desired fire characteristic. The fire must be significant enough to produce 5 ppm of CO in the ventilation airflow, for instance, if CO is the fire characteristic to be detected and the alert level is 5 ppm of CO. It means that before this event may happen, a certain length of time must pass. For this incident, lower alert levels will take less time, while higher ones will take more time.

2) The ventilation airflow must carry this level of CO or smoke from the fire to the sensor position once a distinctive alarm level has been attained at the fire source.

3) The sensor requires a limited amount of time to respond once the above level of CO or smoke hits it.

Time affects how much smoke and carbon monoxide (CO) are created. However, air velocity has a significant impact on the CO generation rates prior to burning. The determinant equation for the levels of CO produced inside an opening with a specified air flow rate is represented by the following equation (Hapuarachchi, 2010):

$$\text{ppm CO} = \frac{\dot{G}_{\text{CO}}}{v_o A_o} \quad (1)$$

where, $\dot{G}_{\text{CO}}$ is the generation rate of CO, ppm·m³·s⁻¹; v_o is the air velocity, m/s; and A is the entry cross-sectional area, m²

The majority of dual-cab fire detection designs in the past merely included an alarm system for signaling purposes. In more recent systems, the detector alarm improves the discharge of an interior fire suppression system, which puts out cab material fires. Building an alarm model as a signal and trigger that offers a timely alert with maximum sensitivity to smoke, flame, and sparks will enable the creation of a complex fire detection system.

A team of researchers from the Pittsburgh Research Laboratory of the National Institute for Occupational Safety and Health analyzed the results of an experiment that included a smoke detector that was installed in the dual cab of a piece of mining equipment (Litton, 1979; Litton, Mura, Thomas, & Verakis, 1900). They conducted an experiment to examine the efficiency of four commercially available fire detectors in spotting flame and smoke fires in dual cab mine equipment. Two of these trials, nevertheless, will be covered in this study. Photoelectric Smoke Detector (PSD) and Optical Flame Detector (OFD) are. Without a doubt, this study is exploratory and descriptive, serving as a manual for the mining safety industry in deploying cab fire detectors rather than doing direct testing of fire detectors that are now on the market. **Table 1** shows the experimental data.

Table 1. Experimental data.

Fire source kW	Additional fire source (candle source)	Cab fire source	Fuel	Surface area m^2	Diameter of Surf. Area m
32, 0.5, 0.05	0.005	See Figure 4 and Figure 5	Diesel and gasoline	0.041, 0.002, 0.00049	0.23, 0.05, 0.025

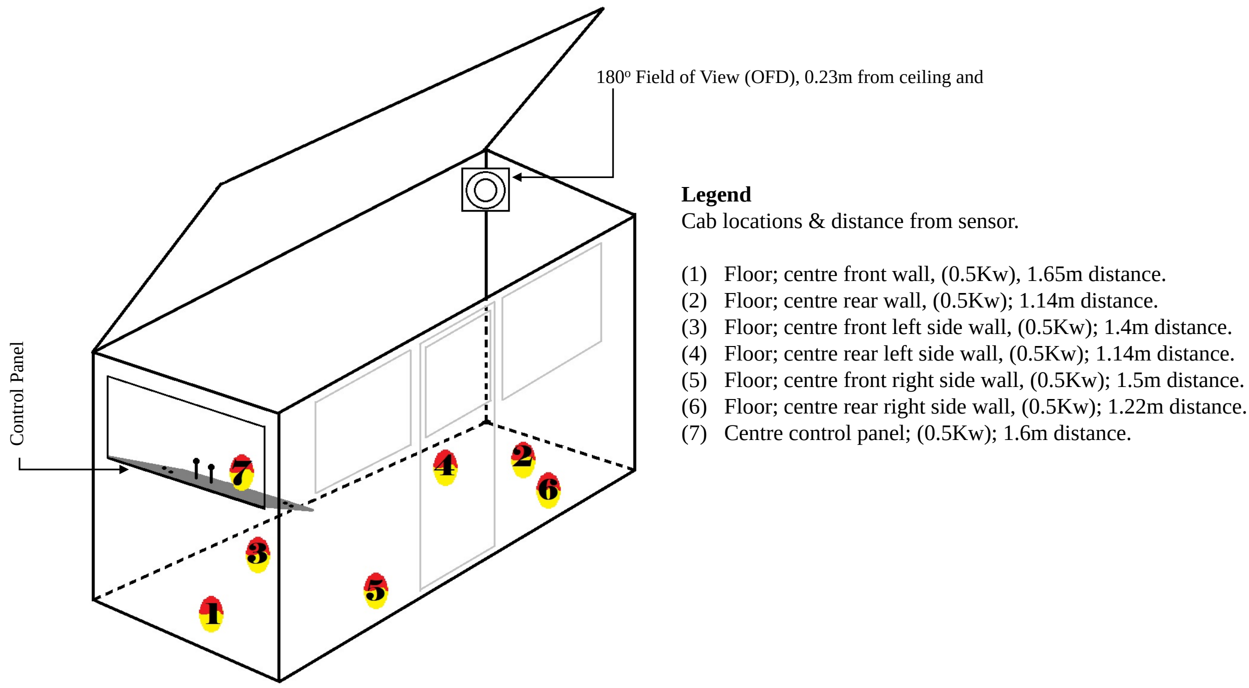

Figure 4. Schematic of the cab with an Optical Flame Detector (OFD) exposed to fire sources.

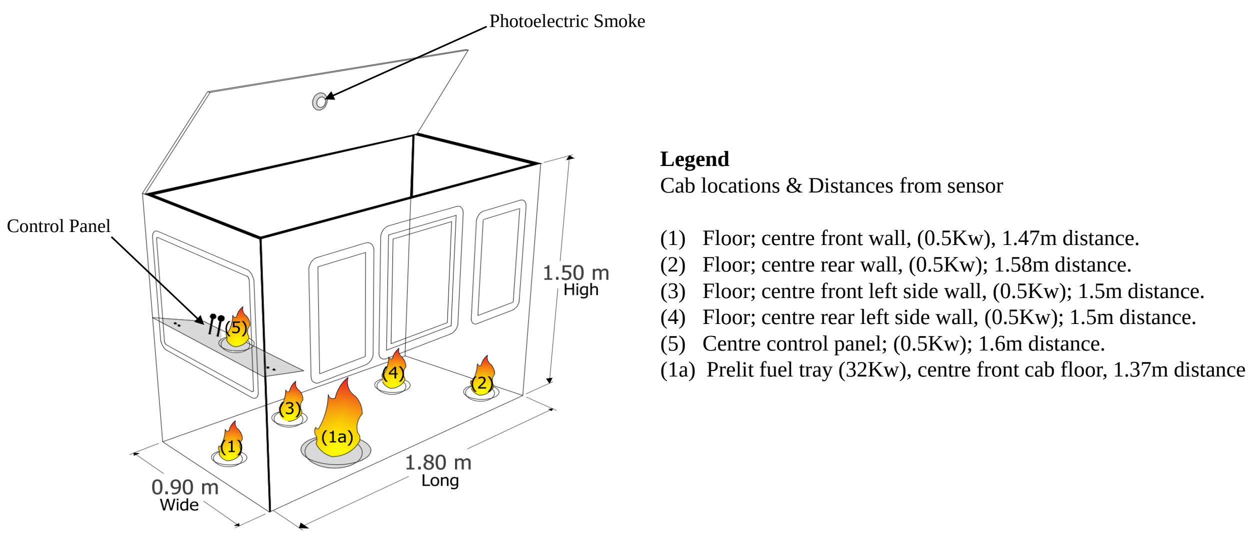

Figure 5. Schematic of the cab with a Photoelectric Smoke Detector (PSD) exposed to fire sources.

Using the common formula, the fire heat release rate (kW), Q_f, was determined.

$$Q_f = (A_s)(H_c)(m_f^n) \tag{2}$$

where, A_s is the fuel surface (m^2); H_c is the average combustion heat (approximately 40 kJ/g); and m_f^n is the fuel mass flux from the surface as determined by the expression $m_f^n = 55(1-e^{2.1d})$ with d being the fuel surface diameter in *m*.

Combining these formulae gives heat release rates of 32, 0.5, and 0.05 kW for fuel surfaces of 0.041, 0.002, and 0.00049 m^2. The calculated heat release rate for the 32 kW fire-sized source is given below:

$$\left(0.041 \text{ fueltray surface area}\right) \text{m}^2 \left(\frac{40 \text{ kJ}}{\text{g}}\right)\left(19 : \frac{5 \text{ g}}{\text{m}^2 \times \text{s}}\right) = 32 \text{ kW} \quad (3)$$

3.3. Optical Flame Detector (OFD)

The optical flame sensor in the OFD experiment with 180˚ field of view finds electromagnetic radiation given off by a flame. The sensors detect radiation from both the ultraviolet and infrared (UV and IR) portions of the electromagnetic spectrum. UV sensors detect energy between 0.18 and 0.4 μm, while IR sensors detect energy between 0.75 and 20 μm (Armenise, 2001; Charumporn, Yoshioka, Fujinaka, & Omatu, 2003; Lo, Yuen, Lu, & Chen, 2002). These sensors have a quick millisecond reaction time and were created for wide-area coverage.

4. Discussion and Analysis of the Experiment

Twenty-one experiments were conducted with the Optical Flame Detector (OFD) positioned at the upper left corner of the rear cab wall (**Figure 4**).

Distance from ceiling = 0.23 m;

Distance from wall = 0.26 m.

4.1. Detector Dimensions

Diameter (ϕ) = 25 cm;

Height (H) = 12 cm.

There were three different fire sources used: one with 32 kW (containing 5 ml of diesel and 5 ml of gasoline in a tray with a diameter of 5 cm), one with 0.5 kW (containing 2.5 ml of diesel and 2.5 ml of gasoline in a tray with a diameter of 2.5 cm), and one with 0.05 kW (containing a candle). These fire sources were placed in the cab at various locations and distances from the detector (**Figure 4**).

Figure 4 shows the cab floor locations: 1) Centre of the front wall (under the control panel, 20 cm from the front wall; distance from the detector, 1.65 m); 2) Centre of the rear wall (distance, 1.14 m); 3) Centre of the front and rear left side walls (1.5 m and 1.22 m, respectively); and 4) Centre of the front and rear right side walls (1.5 m and 1.22 m, respectively) (1.5 m and 1.22 m, respectively). The control panel also had a flame source (distance, 1.6 m).

4.2. Photoelectric Smoke Detector

A light source in a light-sensitive sensor is used in a photoelectric smoke detector. Smoke disturbs and scatters the light in the photoelectric alarm chamber, which is always at an angle, and the detector starts an alert sequence as a result.

Two tests were carried out utilizing smouldering fire sources situated in the middle of the front and back cab floors and the Photoelectric Smoke Detector, which has the following dimensions: 7.5 cm in diameter by 5 cm in height (distances from the detector, 1.37 and 1.4 m, respectively).

4.3. Detector Response Times for Optical Flame Detector

The two trials' results are in Table 2, Table 3, and Figure 6 shows the response times (2 s) of an OFD with a 180˚ field of view exposed to a 0.5 kW fire source on the cab floor near the front wall (distance from the detector, 1.65 m). The detector responded similarly to 0.05 kW and 0.005 kW fire sources at all cab locations and distances (maximum distance, 1.65 m).

4.4. Detector Response Time for Photoelectric Smoke Detector

In relation to Table 3, 32 kW fire source 1.37 m from detector responded in 5 s. The fast ascent of smoke particles in the flame employing buoyancy offers this detector speedy response times (De Rosa & Litton, 2010; Liu & Wen, 2002). PSD response times were 10 s at all cab locations and distances for lesser fire sources (0.5 and 0.05 kW) (maximum distance, 1.58 m). Lack of smoke particle evolution prevented the PSD from detecting the candle fire (0.005 kW). The PSD detected smouldering fire sources within 60 s in the front and rear cab floors (distances, 1.37 and 1.4 m, respectively) (Table 3).

Table 2. Optical flame detector response times for various sized fire sources, cab locations, and distances from the detector (De Rosa & Litton, 2010).

Fire Size	Response Time	Distance from sensor	Cab location
OFD: Positioned in the cab, at the upper left corner of the rear wall			
			Cab
0.5 kW	2 s	1.65 and 1.14 m	Centre front and rear wall
	2 s	1.4 and 1.14 m	Centre front and rear left sidewalls
	2 s	1.5 and 1.22 m	Centre front and rear right sidewalls
	2 s	1.6 m	Centre control panel
0.05 kW	2 s	1.65 and 1.14 m	Centre front and rear walls
	2 s	1.4 and 1.14 m	Centre front and rear left sidewalls
	2 s	1.5 and 1.22 m	Centre front and rear right sidewalls
	2 s	1.6 m	Centre control panel
0.005 kW (candle)	2 s	1.65 and 1.14 m	Centre front and rear walls
	2 s	1.4 and 1.14 m	Centre front and rear left sidewalls
	2 s	1.5 and 1.22 m	Centre front and rear right sidewalls
	2 s	1.6 m	Centre control panel

Table 3. Smoke detector response times for various sized fire sources, cab locations, and distances from the detector (De Rosa & Litton, 2010).

Fire Size	Response Time	Distance from sensor	Cab location
OFD: Positioned in the cab, at the centre of the cab ceiling			
			Cab
32 kW	5 s	1.37 m	Centre front floor
0.5 kW	10 s	1.47 and 1.58 m	Centre front and rear walls
	10 s		Centre front and rear left sidewalls
	10 s	0.84 m	Centre control panel
	10 s	1.47 and 1.58 m	Centre front and rear walls
	10 s	1.5 and 1.5 m	Centre front and rear left sidewalls
	10 s	0.84 m	Centre front control panel
0.005 kW (candle)	No response	1.47 and 1.58 m	Centre control panel
	No response	1.5 and 1.5 m	Centre front and rear walls
	No response	0.84 m	Centre front and rear left sidewalls
Smouldering fire source	60 s	1.37 and 1.4 m	Centre front and rear floor
PSD; positioned in the cab, at the centre of the cab ceiling			
Smouldering fire source	60 s	1.37 and 1.4 m	Cab floor Centre front and rear floor

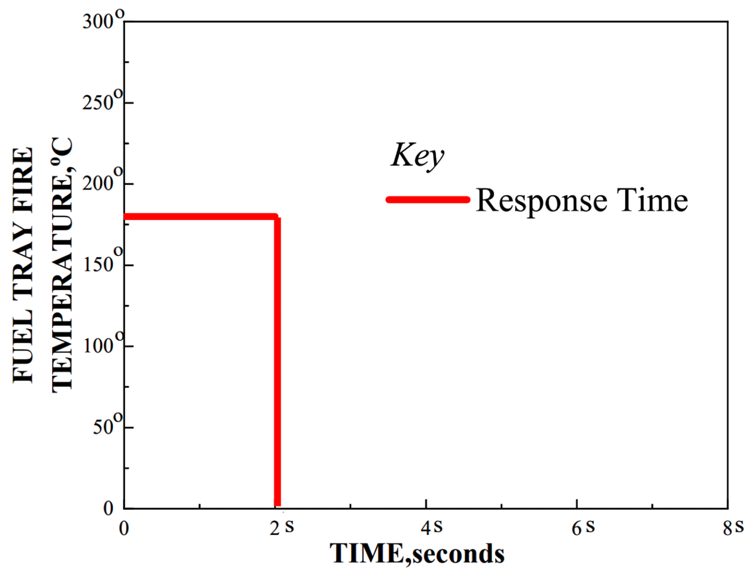

Figure 6. OFD response time, while being exposed to a fire source with a power output of 0.5 kW in an equipment cab, at each possible placement of the cab and distance from the detector.

5. Suggestions and Recommendations

Optical Flame Detector (OFD) and Photoelectric Smoke Detector (PSD) should be tailored into one design to enhance safety. OFD should have a minimum perspective coverage range of 180˚ ≤ 360˚. The self-actuated heat-sensitive line detector should detect milliseconds of smoke, flame, and other warning signals. The alarm should trigger upon activation. These alarms should be internal and external. The external alarms should be a strobe light and loud alarm, which alert all on duty drawing their attention to the situation, and an internal control panel that begins flashing to alert the driver of the danger. A few seconds after the alarm alert, the self-actuated suppression system should automatically release the application of an external substance to extinguish the fire after the detection. Then the driver can exit for safety.

This should take less than five seconds, from melting the heat-sensitive line detector to fighting the fire. When combined with infrared and ultraviolet detective sensors to detect smoke, flame, and other warning signals, it is certain to have the best chance of saving the operator's life, dual-cab, and stopping the fire from spreading.

Recommendations

1) Mine operators should use fire suppression systems effectively.

2) Mine operators and miners must minimize or mitigate fire threats.

3) There should be adequate training for dual cab operators and a detailed review of the fire suppression system owner's manual.

4) Workplace complaints should be discouraged, and there should be full compliance with safety standards and policies.

5) All dual-cab should have a temperature monitor and thermal protective device. Also, these devices should function to stop the vehicle automatically before its temperature exceeds a level that might give rise to a fire. The surface temperature at which equipment is automatically tripped in coal mines should not exceed 150˚C as this is below the ignition point of greases, hydraulic oils, and lubricating oils.

6. Conclusion

Mine fires, especially mobile equipment fires, are highly hazardous to the safety of miners, and it is more disastrous when they occur in the confined space of underground mines. Mine fire possibilities result from mine operators' inherent negligence and carelessness. For fire detection, the review of the NIOSH experiment verifies that an optical flame detector with a 180˚ field of view (OFD) proves effective in detecting within 2 s fires ranging from 0.5 to 0.005 kW, located at various cab locations and distances from the detector. Similarly, a photoelectric smoke detector (PSD) was effective in detecting small smoldering fires within the 60 s. Technological advancement in the design of fire detection and suppression system for a dual cab and a careful application of the above suggestions and recommendations will enhance the safety of miners.

Acknowledgements

The authors gratefully acknowledge the financial support of the National Natural Science Foundation of China (51274146), the Research Project Supported by Shanxi Scholarship Council of China (2020-043), and the Basic Research Project of Shanxi Province (202103021224089).

Conflicts of Interest

The authors declare that there is no conflict of interest.

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