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ORIGINAL ARTICLE

The Dust Explosion Threat within Biomass Thermal Operation in Industries: A review in Malaysia Cases

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ABSTRACT - Process Safety Management (PSM) is one of the most important aspects of a company's safety management system. In Malaysia, there have been a lot of accidents related to dust explosions that have occurred involving different biomass thermal operations recorded since 2008, but started since 1785 worldwide, it comes to the new cases leading to significant problems of injuries, fatalities, destruction of equipment, and property loss. The authors present in this paper an overview of lesson learning in Malaysia and identify the areas in need of further research and improvement. The article reviews the regulations applicable to this type of facility and recommends emergency response procedures to identify gaps between what happened in the West and the current regulations and discusses how the current regulation could be modified to prevent or minimize future losses. The following recommendations are given to SMEs and government agencies that intend to help SMEs in accident prevention. The Malaysian approaches introduced in this article can provide easily applicable methodologies for SMEs with limited resources to coordinate their PSM activities.

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INTRODUCTION

The incident normally happened in unit operations such as grinders, silos, mills, dust collectors, bucket elevators, conveyors, and other modes of transportation. Tauseef and Abbasi [1] do find that the record of dust explosion incidents shows that on average, one dust explosion could happen in each industrialized country every day.

Unfortunately, there is still a lack of publications whether in printed or soft copies present in developing countries that provide details information available on dust explosions [2]. An increasing number of accidents related to dust explosions have recorded and been discussed since 1785 worldwide, it comes to the new cases leading to significant problems of injuries, fatalities, destruction of equipment, and property loss.

This event may still occur in various industries handling particulate organic and inorganic powders and dust. Those industries include grain and food, metal and metal finish products, power generation, textile manufacturing, coal mining, and chemical manufacturing.

Even though not much significant coal mining industry is being commercialized in Malaysia, there is a risk of having coal dust explosion due to transportation, storage, and uses of coal in the power generation industry, cement industry, and other manufacturing industries that use coal as fuel or raw material of their products. Coal dust is commonly difficult to ignite and has low explosibility, however it can pose a dangerous hazard when exploded [3].

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LITERATURE REVIEW

Mechanism of Dust Explosion

A dust fire occurs when fuel (the combustible dust) is exposed to heat (an ignition source) in the presence of oxygen (air). Removing any one of these elements of the typical fire triangle (Figure 1) eliminates the possibility of fire [4].

Figure 1. Fire Triangle

Dust explosion may occur with the existence of five (5) elements which are oxygen, heat, confinement, fuel, and dispersion.

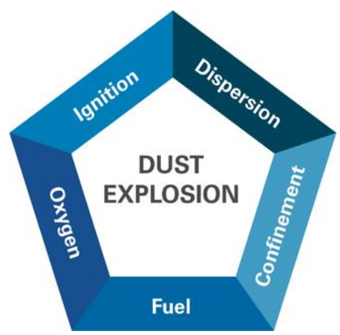

Figure 2. Dust Explosion Pentagon

A dust explosion requires the simultaneous presence of two additional elements which are dust suspension and confinement (Figure 2). Suspended dust burns more rapidly, and confinement allows for pressure build-up. Removal of either the suspension or the confinement components prevent an explosion, although a fire may still occur [4].

Furthermore, the concentration of suspended dust must be within an explosible range for an explosion to occur. This is analogous to the flammability range frequently used for vapors (such as natural gas and propane).

Dust explosions can be very dynamic, creating powerful waves of pressure that can destroy buildings and hurt people across an area. People caught in dust explosions are often either burned by the intense heat within the burning dust cloud or injured by flying objects or falling structures.

Biomass Combustible Dust Materials

The manufacturing processes for products involving biomass combustible dust materials. Combustible dusts are fine particles that may present an explosion hazard when suspended in the air under certain conditions [5]. Example of combustible dust are presented in table below are referred:

Table 1. Powder or Particles according to category

Category	Powder or Particles
Organic Matter	Sugars, Corn Starch, Flour, Charcoal, Coal, Peat, Soot, Cellulose Pulp
Chemicals	Adipic Acid, Ascorbic Acid, Sodium Ascorbate, Calcium Acetate, Calcium Stearate, Sodium Stearate, Lead Stearate, Dextrin Lactose, Methylcellulose, Paraformaldehyde, Sulphur.
Metals	Aluminium, Bronze, Magnesium, Zinc, Iron Carbonyl.
Plastics	Polymers e.g. Polymethylmethacrylate, Polyacrylamide, Polyacrylonitrile, Polyethylene, Polyvinylchloride, Resins, Melamine.

The diagram below illustrates the biomass combustible dust explosion pathway that is possible to happen in manufacturing processes.

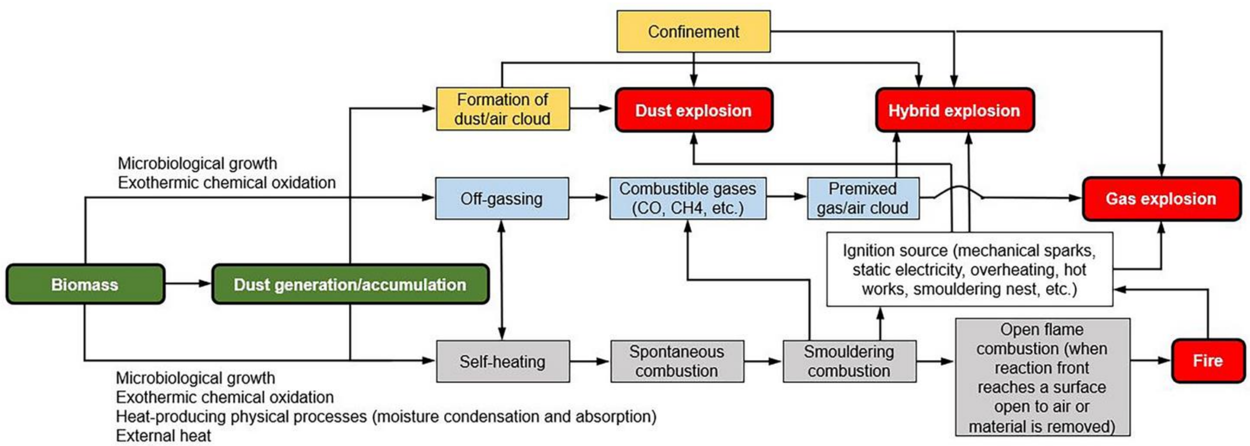

Figure 3. Illustration of incidents involving processes in manufacturing related to biomass [6].

Incidents Involving Combustible Dust Materials

Several types of potential ignition sources can trigger a dust explosion in plants that handle, store or process bulk solids. Ignition of dust layers and deposits accumulated on hot surfaces and overheated equipment is a frequent cause of fires and explosions [7].

Dispersion of either smoldering or flame nests generated by the self-heating of the material is another possibility. Other likely ignition sources are electrical and mechanical sparks, welding and cutting operations, static electricity, and flames from earlier fires or explosions [8]. When the risk of explosion is not adequately addressed, the consequences can be catastrophic.

Several large incidents have occurred in Europe, UK and Asian region involving different types of materials. The Imperial Sugar manufacturing facility housed a refinery that converts raw cane sugar into granulated sugar. A system of screw and belt conveyors and bucket elevators transported granulated sugar from the refinery to three 105-foot-tall sugar storage silos. Granulated sugar was then transported through conveyors and bucket elevators to specialty sugar processing areas and granulated sugar packing machines. Sugar products were packaged in a four-story building surrounding the silos that contained packaging machines for the sugar products. Granulated sugar was also bulk shipped in railcars and tanker trucks in the bulk sugar loading area. In 2008, a series of sugar dust explosions at the Imperial Sugar manufacturing facility in Port Wentworth, Georgia, resulted in 14 worker fatalities. Thirty-six (36) workers were treated for serious burns and injuries where some affected permanent, life-altering conditions. The explosions and subsequent fires destroyed the sugar packing buildings, palletizer room, and silos, and severely damaged the bulk train car loading area and parts of the sugar refining process areas [9].

In United states, a dust explosion occurred in 2003 at West Pharmaceutical Services, CTA Acoustics and Hayes Lemmerz Automotive Parts followed in 14 fatalities. History is long for dust explosion incidents, but the main point of sharing was not captured in scientifically [2].

A very wide range of materials can cause dust explosions, including agricultural and food industry products and various biomass material [10]. In some cases, the main product itself is sufficiently fine to generate explosive dust clouds if dispersed in the air, such as with wheat flour or maize starch. In other cases, the main product is quite coarse, such as grain and wood pellets, and the fine dust constitutes only a small, but undesired mass fraction of the total bulk material, generated by the abrasion and crushing of the larger material particles during the product handling processes [6].

On August 2, 2014, a disastrous dust explosion occurred in a large industrial plant for polishing various aluminium-alloy parts in Kunshan, China. The explosion occurred during manual polishing of the surfaces of aluminium-alloy wheel hubs for the car industry. 75 people lost their lives immediately and another 185 were injured. Afterward, 71 of the seriously injured also died, which increased the total loss of lives to 146. The direct financial loss of was 351 million yuan. This is most likely one of the most serious dust explosion disasters known apart from some very major coal dust explosion disasters in coal mines [11].

In addition, case studies showed the severity of dust explosions occurring in South Korea. This study analyzed the characteristics of 53 dust explosions that occurred in South Korea over the last 30 years and investigated the differences of dust explosions that happened in various countries, such as Japan, the United States, the United Kingdom, and France. Through the special focus on the three most recent years of dust explosions, the causes and processes of the accidents were identified. Analyses of dust explosions in South Korea show that they were mainly caused by organic matter and metal, and, unfortunately, dust explosions occurred repeatedly during grinding, mixing, and injection of powder materials into facilities. No reported accidents occurred during the production processes of wood or paper during the last three years. Taking these characteristics into account, effective ways are proposed to prevent or mitigate dust explosions at workplaces [12].

MATERIALS AND METHODOLOGY

In this research, data collection methods are used for mixed methods comprising of qualitative (case study). For case studies, the researcher is discussing during awareness on dust explosion at industries, observation at site and document review. The flow of the process shown in below diagram:

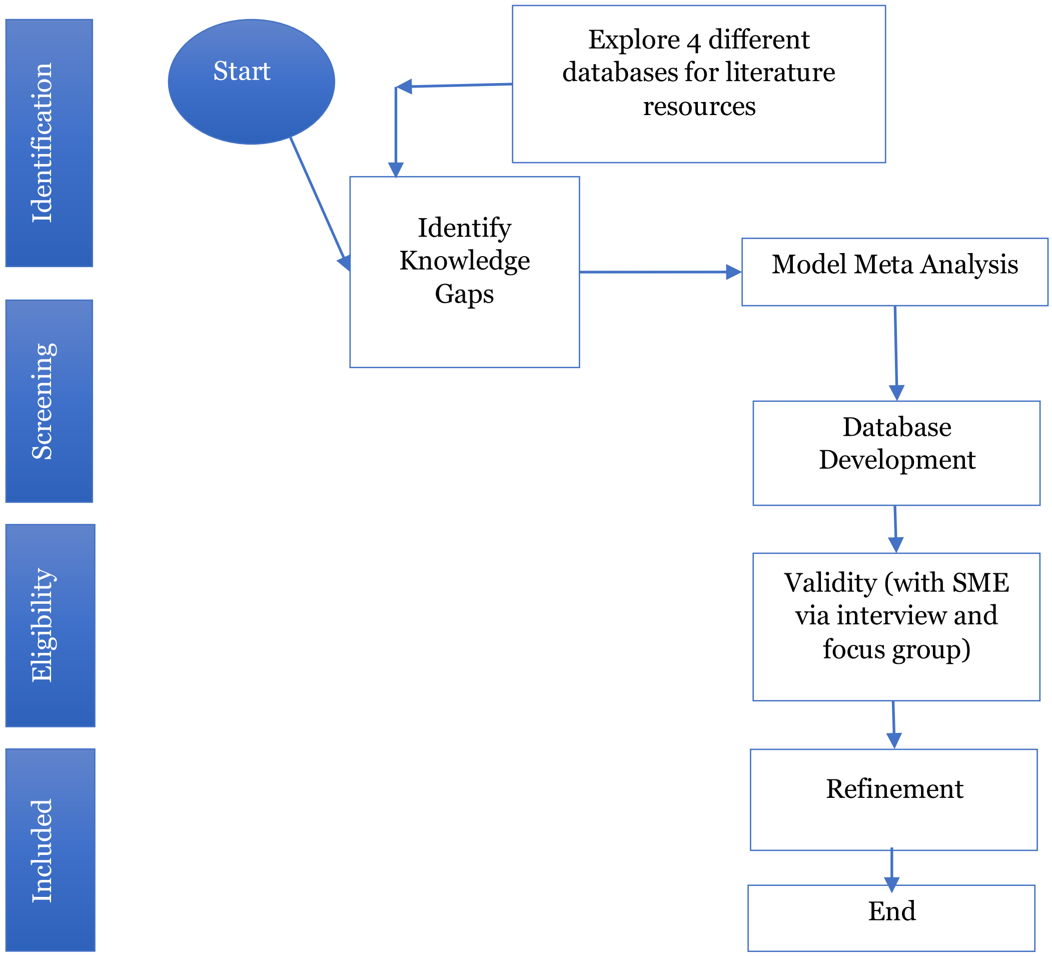

Figure 4. Methodology Flow Chart.

RESULTS

Dust Explosion Cases in Malaysia

During the research works, researcher found that there are historical cases reported and recorded on the website of the Department of Safety and Health Malaysia. Later the current incidents record was then undergoing verification with local DOSH state office. The site incidents record was then tabulated as shown in summary Table 2.

All the cases were distributed according to state the incidents took place, unit operating involves and later the consequences which are injured and recorded death cases. The summary of the incidents later will be deliberated, and the site's pictures are shown in this paper.

The first recorded cases which happened in Mac 2008 in Lumut, Perak. The incident takes place at a flour factory. The incident was triggered by the hot work activity (welding) in the confined space area filled in with corn starch dust. The explosion covered vastly in the tunnel. The impact of this incident also involves a jetty, a conveyor system, and a destroyed installation in the tunnel with four (4) fatal deaths was concluded.

Meanwhile, in Nov 2010 at Pulau Pinang, the rim manufacturer factory was burned down due to combustible dust explosion from the polishing activity in making the rim. The origin of the cases was found to start from the fire and resulted in an explosion in the ducting system which transported the aluminum dust to the tower duct collector. The impact during this incident caused injury to eight (8) workers and three (3) factory areas were destroyed.

Figure 5. Lumut Port incident, March 2008

The next case was reported to take place at the factory in Seberang Jaya, Penang in March 2013 involving Magnesium Stearate & Zinc Stearate, later the dust explosion incident at the herb factory in August 2013 at Pulau Pinang. The officer reported the incident started from the herb manufacturing process in dust form. The local exhaust ventilation, ducting system, and tower dust collector were involved in this explosion. The explosion started from the oven that was used for heating the herb dust. There are no injuries reported.

Figure 6. Factory in Seberang Jaya, March 2013

There is a case that took place in wood chip manufacturing in Gebeng, Pahang in August 2014. The dust collector was found to be on fire and exploded. There are no fatalities reported. There is a possibility spark in the conveyor system, but the official report is yet to be confirmed by the authority. The report was not listed, as not being reported as incident occurrences to the authorities.

The increasing cases are written above as mentioned by Ahmad et al. [13]. It can be seen from the tabulated table below on the summary of the fire and explosion cases in Malaysia involving combustible dust still being reported in the mass media and DOSH Malaysia social media platform, yet no official reports were made available after that. All the incidents recorded in the above tables have been vetted by DOSH office in Pahang and Perak state office.

The incidents are a threat to the combustible material processing factory, thus the are needed for proactive intervention by all stakeholders in managing the risk involves and planning for the risk control so that their health and safety will be in good conditions. The recommendations for this research work later will be included for the practitioners in the same working environment can benefit.

Table 2. Summary of Dust Explosion Incident in Malaysia

No	Year	State	Industry	Unit Operation	Casualties
1	March 2008	Perak	Wheat Manufacturer	Silo	4 killed, 2 injured
2	March 2010	Penang	Aluminium Rim Manufacturer	Dust Collector	2 injured
3	January 2013	Nilai, Negeri Sembilan	Aluminium Dust	LEV	-
4	March 2013	Penang	Magnesium Stearate & Zinc Stearate	Dust Collector	3 killed, 2 injured
5	August 2013	Penang	Herb Manufacturer	LEV	1 injury
6	March 2014	Sarawak	Fertilizer Dust	-	-
7	November 2014	Sarawak	Coal Mine	-	3 killed, 26 injured
8	June 2015	Terengganu	Ethylene Dust	Silo	-
9	Oct 2016	Terengganu	Kenaf Coal Manufacturer	-	1 injured
10	Nov 2017	Perak	Wood Manufacturer	Silo	2 injured
11	Oct 2021	Perak (Chemor)	Cement Manufacturer	Coal Pulverized Bin	2 injured
12	Dec 2021	Perak (Gopeng)	Cement Manufacturer	Coal Bin Calciner	3 injured
13	Feb 2023	Perak (Sungai Siput)	Cement Manufacturer	Conveyor belt	-

RECOMMENDATIONS

In Malaysia, compliance with legal frameworks such as the Process Safety Management standards requires substantial resources and may become complex to be implemented but still will bring a lot of improvement in SME operations in Malaysia.

According to the statistics noted above the real cases may be more than reported but still, there are three main causes to investigate details which are inadequate process hazard analysis, training, and emergency response planning. These are the major contributors that contribute significantly to the incident cases to take place in Malaysia. These contributions were later published in another paper publications. As this study focusing on the incident's cases in Malaysia, the alternative solutions for the incident prevention strategies are explored as presented below. Thus, the following recommendations are given to SMEs and government agencies that intend to help SMEs in accident prevention.

Built the Relationship between Local Authorities with Relevant SMES

Coordinating PSM-related activity between SMEs, industry park administration, local authorities, research centers, universities, and communities should work along with the assessment and improvement of their operating procedure to reduce the risk. It depends on a strategic approach to prepare for and respond to the emergency event with community involvement. This collaboration will have further guidance for learning lessons and developing operation sustainability [14].

Drawing on historical data we show that the international community of process engineers, authorities and safety practitioners has not been good at learning lessons from their past accidents. There are needs for a paradigm change in the way we approach this and the creation of a single new, multi-national, multilingual accident database that is free at the point of use and that includes immediate and underlying causes as well as "lessons learned". It must be user-friendly and provide links to key source documents. The purpose of this paper is to challenge those in authority, and with the power to do so, to make this happen [2].

The relationship between authorities and stakeholders in SMEs is a must to improve their understanding on risk mitigation and control. There is a need to establish a simple step-by-step methodology addressing PSM elements targeting SMEs. The local authorities should review the current legislative in managing major hazard incidents, SME's operating procedure and discuss the process of hazard analysis, training, and emergency response planning [15].

Investigation of the Root Cause of PSM System Level

The root cause analysis usually is a weak point in accident investigation, so the effectiveness of lesson learning is often questioned [16]. Accident investigations often stop at events close to the accident, which usually concern only the behaviors of the hardware and the operators directly concerned with carrying out the activity.

Changing hardware or disciplining operators will not systematically eradicate the root causes that exist in the safety management system [17]. With the deterioration of the performance of the hardware or the operators, similar accidents will inevitably occur again. Therefore, the causal analysis should be sufficiently robust such that it does not stop at the technical causes (as example equipment failure, human error), but instead it should eventually determine what failures occurred in the process safety management (PSM)'s system that created the conditions for the technical failures to occur [18]. The root causes of PSM elements should be examined and reported thoroughly and systematically [19].

Disclosure of Information to the Public

More information about chemical accident risks and accidents needs to be shared with the public, particularly in areas where a significant lack of information has made citizens distrust local agencies. Information also needs to be shared on the causes and lessons learned of accidents so that government and industry experts can improve their accident prevention, preparedness, and response programs and procedures. In this regard, the government should establish information systems and requirements that can achieve these goals [20].

There should be information for the public on accidents that have occurred in a region, on sites where potential accidents could occur, and on what to do in case of a major accident on one of these sites. When people are treated with fairness and honesty, and their right to take their own decisions is respected, they are less likely to overestimate small hazards and will support the local authorities and companies actively [21].

Build a Dedicated Website for Lessons Learned

Government and industry also need additional knowledge about causes and lessons learned from accidents that can be used to update their standards, systems, and procedures supporting accident prevention, preparedness, and response. The government should therefore also create a common register specifically for reporting causes and lessons learned from investigations of major chemical accidents directly by industry or by the government based on its own or industry investigations [17].

Full accident reports should be published on a dedicated website that is publicly accessible so that other operators and industries can learn from these accidents. Examples of such websites can be found in Europe (e- Mars) and the US (CSB) [1].

As written by Laboureur et al. [22] in West, Texas on April 17, 2013, chemical storage, and distribution facility caught fire followed by the explosion of around 30 tons of ammonium nitrate while the emergency responders were trying to extinguish the fire, leading to 15 fatalities and numerous buildings, businesses, and homes destroyed or damaged. This incident resulted in devastating consequences for the community around the facility and shed light on the need to improve the safety management of local small businesses like the West facility. As no official report on the findings of the incident has been released yet, this article first investigates the root causes of the incident and presents a simplified consequence analysis. The article reviews the regulations applicable to this type of facility and recommended emergency response procedures to identify gaps between what happened in the West and the current regulations and discusses how the current regulations could be modified to prevent or minimize future losses. Finally, the federal response that followed the incident until the publication of this paper is summarized.

Cristina Galassi et al. [23] highlighted that the Hydrogen Incident and Accident Database (HIAD) is being developed as a repository of systematic data describing in detail hydrogen-related undesired events (incidents or accidents). It is an open web-based information system serving various purposes such as a data source for lessons learnt, risk communication and partly risk assessment. The paper describes the features of the three HIAD modules e the Data Entry Module (DEM), the Data Retrieval Module (DRM) and the Data Analysis Module (DAM) and the potential impact the database may have on hydrogen safety. The importance of data quality assurance process is also addressed.

Establish Lesson Sharing Mechanism for the Industry

While this paper is mostly directed at the role of government and industrial owners, safety is in the end in the hands of industry. The chemical process industries must take a leading role in preventing accidents with big companies investing resources to build industry-wide awareness and capacity. The industry should establish mechanisms to voluntarily share lessons learned with each other, by expanding existing industry and professional associations to support forums, publications, workshops, and training events on risk management and lessons learned [24].

The establishment of the Malaysia equivalents to the Center for Chemical Process Safety (CCPS) and Chemical Safety Board (CSB) of the United States should also be considered. Universiti Sains Malaysia stands as a pioneer in developing such an environment for the related industries in Malaysia with partnership in-line. Building up expertise and a total understanding of PSM criteria will help fasten the preparation of Malaysia towards process safety incidents yet to have occurred [25].

CONCLUSION

Lesson learning is not only difficult for small medium enterprise companies that have limited human resources and expertise but also for large multinational corporations. Incident investigation is regulated under Malaysian law. However, how to effectively and systematically learn lessons from incident investigation reports has not been specified by the standard. Lesson learning does not only require high quality investigation reports but also a high self-learning capability. A continuously learning organization has been recognized as one of the ten attributes that are important to create a best-in-class safety culture.

Learning is not completed until a relatively permanent change of behaviors including process design or procedure is verified. Lesson learning should not be constrained within one organization. It should be encouraged and facilitated across industries and countries as a long-term process. Priorities for Malaysia SMEs should be put on improving their capabilities in process hazard analysis and emergency preparedness and providing all necessary training to their employees. To get effective uptake of these practices, the Malaysian approaches introduced in this paper can provide easily applicable methodologies for SMEs with limited resources to coordinate their PSM activities. Improving chemical process safety management and emergency preparedness supports sustainable industrial development.

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