

Occupational Heat Stress and Workplace Accident Risk Assessment in the Indian Fireworks Manufacturing Industry

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ABSTRACT

The Indian fireworks manufacturing industry, concentrated primarily in Sivakasi, Tamil Nadu, is one of the country's most hazardous industrial sectors due to the combined risks of high ambient temperatures, hazardous chemical handling, and inadequate occupational safety practices. This study presents an integrated assessment of occupational heat stress and workplace accident risk among workers employed in the Indian fireworks industry. A systematic review of published literature, accident reports, and occupational safety studies was conducted to identify the major causes, trends, and contributing factors associated with workplace accidents. The findings indicate that excessive heat exposure adversely affects workers' physiological and cognitive performance, increasing fatigue, dehydration, reduced concentration, and the likelihood of human error. Accident analysis further reveals that friction, chemical decomposition, static electricity, unsafe work practices, and elevated environmental temperatures are the principal contributors to fire and explosion incidents. The study also highlights significant gaps in heat stress monitoring, worker training, risk assessment, and implementation of preventive safety measures. Based on the findings, an integrated occupational safety framework is proposed that emphasizes heat stress monitoring, engineering controls, administrative interventions, worker awareness, and compliance with safety regulations. The study contributes to occupational health and industrial safety literature by demonstrating the critical relationship between heat stress and accident occurrence, thereby providing practical recommendations for improving worker safety, reducing accident frequency, and promoting sustainable manufacturing practices in the Indian fireworks industry.

Keywords: Fireworks Industry, Heat Stress, Fireworks Accidents, FTA, Sivakasi, Cracker

INTRODUCTION

Fireworks have long been associated with cultural celebrations, religious festivals, and social events across the world. Historical records trace their origin to ancient China during the Han Dynasty (206–220 BC), when bamboo stalks were burned to produce loud sounds believed to ward off evil spirits. During the Northern and Southern Dynasties (420–589 AD), these practices evolved into ceremonial traditions symbolising prosperity and good fortune. The subsequent discovery of gunpowder led to the development of paper-based fireworks, which gradually became an integral part of cultural celebrations worldwide. India is the world's second-largest producer of fireworks after China, with the majority of manufacturing concentrated in Sivakasi, Tamil Nadu, often referred to as the "Fireworks Capital of India." The industry provides employment to thousands of workers and plays a significant role in meeting the country's seasonal demand for pyrotechnic products. Despite its economic importance, fireworks manufacturing remains one of the most hazardous industrial sectors because workers are routinely exposed to explosive chemicals, combustible materials, and elevated environmental temperatures. These hazardous conditions substantially increase the risk of fires, explosions, occupational injuries, and fatalities [1].

Evolution of Fireworks

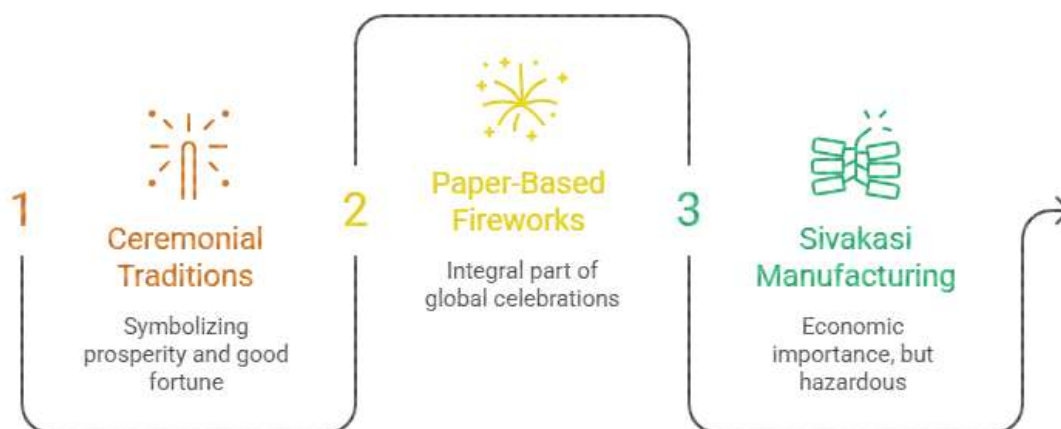


Figure 1: Evolution of Fireworks

Several catastrophic accidents have highlighted the vulnerability of the Indian fireworks industry. Major incidents, including the 2012 Sivakasi factory explosion, which resulted in numerous fatalities and injuries, and subsequent accidents in Virudhunagar district, have demonstrated the severe consequences of inadequate safety practices, poor infrastructure, improper handling of pyrotechnic chemicals, and unfavourable climatic conditions. Previous investigations have suggested that elevated ambient temperatures, combined with highly reactive chemical mixtures, significantly increase the probability of accidental ignition during manufacturing operations. Occupational heat stress has emerged as an important but often overlooked factor affecting worker safety in the fireworks industry. Continuous exposure to high temperatures can lead to dehydration, heat exhaustion, fatigue, impaired cognitive performance, and reduced decision-making ability, thereby increasing the likelihood of operational errors and workplace accidents. When combined with hazardous manufacturing processes involving friction-sensitive and thermally unstable chemicals, heat stress becomes a critical contributor to fire and explosion risks [1].

Although numerous studies have examined fireworks-related accidents and industrial hazards, relatively limited research has systematically investigated the relationship between occupational heat stress and workplace accident occurrence in the Indian fireworks industry. Furthermore, comprehensive quantitative analyses integrating accident patterns, environmental conditions, and occupational health risks remain scarce. Therefore, this study aims to assess occupational heat stress and analyse workplace accident patterns in the Indian fireworks manufacturing industry. The study investigates the major causes of accidents, evaluates the influence of heat stress on worker safety, and identifies critical occupational hazards associated with fireworks production. The findings are expected to support the development of effective heat stress management strategies, improved workplace safety practices, and evidence-based policy recommendations for reducing occupational risks and enhancing the overall safety and sustainability of the Indian fireworks industry.

MAJOR REASONS BEHIND FIREWORKS ACCIDENTS

FRICION/IMPACT:

During manufacturing of the fireworks, the pyrotechnic mixtures undergo various mechanical forces under various processes due to which sometimes it leads to a catastrophic event just because of too much of force and friction can generates the spark which is sufficient to ignite these explosive and flammable chemicals[2].While studying the reasons behind fireworks accidents in detail, we found that almost 72% of the total reported accidents in the past ten years accounts to friction/Impact. This data itself signifies the humongous role of friction/impact in terms of fireworks

accidents. Further, the composition of the mixture plays a major role in terms of impact and frictional sensitivity because if the composition is not prepared well then with a small impact it can lead to a fire and explosion. Still the accidents due to mechanical impact and friction continue to occur if the proper knowledge of the pyrotechnic mixtures are not being analysed with experimental test and calculations. In addition to it the flash compositions and the mixtures used in aerial fireworks are very sensitive to the mechanical impact and friction. Although the mixtures composed of the sulphur and chlorates are banned according to the Indian Explosives Act 1884 just because they are very sensitive to fire and explosion even with a small amount of force or friction and can easily lead to a thermal decomposition reaction in presence of moisture. The process that leads to the mechanical impact parameters are weighing, sieving, mixing and filling and thus it is extremely important to understand the safety concerns related with this process in order to avoid fireworks accidents due to friction/impact.

CHEMICAL DECOMPOSITION:

The chemicals used in the process of manufacturing fireworks are highly reactive and sensitive in nature and thus special precautions are required to be taken while handling them. But, Fireworks industries specially in India can be categorised as unorganised sector due to so many limitations available such as inadequate infrastructure, poor work culture, inadequate research and development facilities and also the workforce is generally not trained or competent enough to handle the sensitive chemicals efficiently which ultimately results in several havoc scenarios. Through our analysis of past accident data of fireworks industry, chemical decomposition was the major reason behind 18% of the total reported accidents. In fancy fireworks manufacturing, the chemicals are prepared into the slurry and made into the ball shaped chemicals to perform the aerial display. So, the chemicals are mixed with appropriate quantity of water, which leads to decomposition. Correct drying time and well ventilation shall be maintained to avoid the heat accumulation. Here, even small ignorance leads to fire accidents.

STATIC ELECTRICITY: When we talk about the reasons behind the accidents during manufacturing of fireworks, it is very important to acknowledge the risks involved in the operations being performed and the tools being used for the same. One of such major risks is the generation of static spark that ultimately leads to fire/explosion in the fireworks industry. As per our study, the major contributions in this cause accounts to usage of synthetic clothes, plastic tubs and buckets along with continuous running of Vibro screening and other machineries etc.

unorganized sectors in India. There are several operations which are performed directly under the sky. Since the nature of the materials used are highly flammable, so they are capable of doing extensive damage to life, property and environment. As per our study, nearly 3% of the accidents in fireworks industry happens due to the lightning strike at the manufacturing facility and thus it is an important concern that needs to be addressed in order to reduce the number of accidents and safeguard the facilities.

LITERATURE REVIEW: These types of industries are considered as most hazardous industries just because of the poor safety measures. The potential hazards associated in these types of industries basically are burn and explosion hazard, manufacturing hazard and respiratory hazard[3]. Burn and explosion hazard leads to burn injury caused by the highly explosive chemicals and powders which possesses deep injury wound, also leads to third degree burn just because of very high temperature and impact force at the time of fire and explosion. Manufacturing hazards can be caused by numerous factors such as generation of spark by friction and sudden impact forces during filling operation, carelessness in handling of materials, mixing wrong proportion of chemicals that can lead to thermal decomposition[4]. Respiratory hazard can be because of inhalation of harmful chemicals and explosive powders such as aluminium, barium and potassium nitrate, chromium, lead, magnesium including the metallic oxides[5]. In this the Analysis has been done on the basis of data from 1994 to 2008 in Sivakasi, Virudhunagar District which has been provided by the Government of Tamil Nadu. As per the data given there are total 216 fatalities, out of which the average age of the persons died are from 35-40 years and the total numbers of accidents reported are 193 in fireworks manufacturing factories. Most of the accidents happened because of the unsafe acts and the unsafe conditions during the manufacturing of fireworks, where majority of the accidents are due to the wrong procedure in filling operation[6]. In this the analysis has been done on the percentage of accidents in fireworks industries in different manufacturing processes. Here the data is analysed from the year 1994 – 2006 where it has been found that the percentage of accidents in different fireworks manufacturing processes and the chemical filling process has highest number of accidents that is 37%, which is considered to be the most critical process. The potential causes for majority of

accidents are due to generation of spark, static electricity, impact force and friction and thermal decomposition reactions[2]. The climatic condition of the region has a big impact on these accidents as from the study it shows that the temperature in the month from May to August is very high as most of the accidents are occurred in these months because of some faults such as generation of spark or presence of any ignition source accidentally then there may be a fire and explosion accident. It has been found that there are no standard procedures or methods for manufacturing and for mixing the proportion of the chemicals, in addition to it the workers have no idea about the hazardous nature of the chemicals they are handling as they do not have any training for these types of jobs[7]. Impact of explosion in fireworks industry is catastrophic in nature which leads to loss of life as well as property and severe damage to the infrastructure. The generation of the high kinetic energy from the chemical reactions of the explosive materials can produce enormous explosion hazards from flying objects, debris, collapsing of structure, fire and projectiles of the fireworks.

In it the number of fatal accidents has been analysed from the year 2003 – 2009 in fireworks industry due to fire and explosion just because of no proper safety measure are taken. Also, one factor that is important for preventing the accidents is to design a proper planning of the entire estate right from the construction of the buildings, sheds and manufacturing production units[8]. In the manufacturing of the fireworks usually pyrotechnic chemicals are used including oxidizers, colouring agents, reducing agents, fuel, certain chemical chlorates and per chlorates for getting perfect light and sound on burning of fireworks. Apart from getting the light and sound, the chemicals used for manufacturing of fireworks have severe effects on the health of the workers engaged in the processes. It can cause severe lungs problems, respiratory disorder, cancer and sometimes can cause death in case of high exposure[3]. As fireworks industries are associated with dealing harmful and explosive chemicals so it is considered as one of the most hazardous industries since no safety protocols are there. According to this study a fire safety risk assessment is being done in it to determine the fire and explosion index, fire densities and fire load to evaluate the infrastructure of the manufacturing units for sustaining the impact of the fire and explosion accident as per the National Building Code and also to analyse the criteria to be maintained for the construction of the units[9]. Most of the accidents in the fireworks industry are occurred due to explosion caused by friction and impact force in different processes. Since the pyrotechnic chemicals are used in manufacturing of fireworks especially aluminium flash powder which is highly sensitive to friction. In this paper instead of using aluminium flash powder there should be use of boron mixed flash powder which has several properties and the best thing is that it leads to explosion and fire in case of extreme pressure only in any processes whereas aluminium powder catches fire with a small frictional force. The study is totally based on what should be the required effective chemical composition of the fireworks and the results are being experimentally calculated with accelerating rate calorimeter[10]. In order to find the critical processes in a chemical industry the application of failure mode effect and criticality analysis FMECA is very useful. For determining the critical process three factors are needed to be considered that is severity, occurrence and detection with the help of which the risk priority number is calculated which ultimately defines which process is critical. The process which is having highest RPN considered as critical and the one having less then it is less critical but sometimes two or more processes have same RPN so in this case fuzzy logic is being applied to get unique RPN otherwise getting same RPN is a questionable topic[11]. To find the critical processes for the fireworks manufacturing the fatality data from 1989 – 2013 is being analysed and it has been found that 38% of the total fatality in fireworks industry is occurred in filling of powder and chemical process, 21 % in mixing of powder and chemicals, 17 % in packaging and storage and 12% in drying of fireworks. Also it discuss about the factors that are contributing to this accident such as friction, impact, static electricity, chemical reactions, lightening and also the climatic condition of the place plays a major role[12].

Role of Heat Stress in Firework Accidents

In India, most of the fireworks is manufactured in southern part of the country. As a matter of fact, the average temperature of the southern region of India remains on the higher side.

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	25.1°C (77.3)°F	27°C (80.6)°F	29.2°C (84.5)°F	30.4°C (86.7)°F	30.7°C (87.2)°F	29.6°C (85.3)°F	29.3°C (84.8)°F	29.1°C (84.4)°F	29.1°C (84.4)°F	27.3°C (81.1)°F	25.3°C (77.6)°F	24.7°C (76.4)°F
Min. Temperature °C (°F)	19.7°C (67.5)°F	21.1°C (69.9)°F	23.3°C (73.9)°F	25.3°C (77.5)°F	25.7°C (78.2)°F	25.1°C (77.2)°F	24.8°C (76.6)°F	24.4°C (76)°F	24.3°C (75.7)°F	23.4°C (74.2)°F	22°C (71.5)°F	20.4°C (68.8)°F
Max. Temperature °C (°F)	30.6°C (87.1)°F	33.5°C (92.4)°F	36.1°C (97)°F	35.9°C (96.4)°F	37.2°C (98.9)°F	35.5°C (95.9)°F	35.2°C (95.3)°F	35.1°C (95.2)°F	35.2°C (95.4)°F	32.1°C (89.8)°F	29.3°C (84.7)°F	28.9°C (84)°F
Precipitation / Rainfall mm (in)	27 (1.1)	24 (0.9)	36 (1.4)	58 (2.3)	63 (2.5)	39 (1.5)	39 (1.5)	49 (1.9)	70 (2.8)	196 (7.8)	197 (7.8)	102 (4)
Humidity(%)	64%	57%	53%	59%	57%	59%	58%	58%	58%	71%	79%	73%
Rainy days (d)	4	3	4	8	9	5	6	7	8	14	14	9
avg. Sun hours (hours)	8.0	9.0	9.7	10.3	10.8	10.8	10.8	10.6	10.2	9.0	7.4	7.0

Figure 2: Climate Data

Source: climate-data.org[14]

Thus, we believe that there is certainly an important role of Heat stress in numerous fireworks accidents occurring specially in India. To get a better picture, it is probably a good research idea to calculate the heat index of all the days on which accident occurred in fireworks industries in India for the past few years.

GAPS IN AVAILABLE RESEARCH

There have been several studies carried out in the past on hazards associated with fireworks industries globally. But there has been **no prior work done** in order to quantify the accident data to understand the loopholes of the system. All we have is qualitative analysis of the accidents discussing the hazardous processes. This research will be an extensive work focused on the quantification of accident data in fireworks industries in India which is **first of its kind**. The research will also highlight the role of heat stress among workers in fireworks industries which is again one of the neglected aspects of fireworks accidents and has never been discussed across the globe.

CONCLUSION

Being one of the major contributors in fireworks industry, India also possesses some serious threats when it comes to occupational hazards in the industry. In India, the highest percentage of crackers are manufactured in a city called Sivakasi. As a part of this paper, several published works in authentic journals have been reviewed to collect the data regarding the accidents in fireworks industries in India. It has been analysed through the review that The potential hazards associated in these types of industries basically are burn and explosion hazard, manufacturing hazard and respiratory hazard[3]. Manufacturing hazards can be cause by numerous factors such as generation of spark by friction and sudden impact forces during filling operation, carelessness in handling of materials, mixing wrong proportion of chemicals that can lead to thermal decomposition[4]. It has been found that there are no standard procedures or methods for manufacturing and for mixing the proportion of the chemicals, in addition to it the workers have no idea about the hazardous nature of the chemicals they are handling as they do not have any training for these types of jobs [7]. As fireworks industries are associated with dealing harmful and explosive chemicals so it is considered as one of the most hazardous industries since no or barely few safety protocols are there. As a part of study, we found out that most of the fireworks is manufactured in southern part of the country. As a matter of fact, the average temperature of the southern region of India remains on the higher side thus it is probably a good research idea to calculate the heat index of all the days on which accident occurred in fireworks industries in India for the past few years. As a conclusion of several studies, we found out that several works have been carried out in the past on hazards associated with fireworks industries globally. But there has been **no prior work done** in order to quantify the accident data to understand the loopholes of the system. All we have is qualitative analysis of the accidents discussing the hazardous processes. So, even after so many studies, accidents do occur in fireworks industries hampering numerous lives every year. Thus, it is the need of the hour to perform quantitative analysis of the accidents in order to investigate the neglected aspects of accidents in fireworks industries in India.

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