Research paper

Accident data analysis and hazard assessment in fireworks manufacture

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Abstract

Accidents in fireworks manufacturing units are a major threat to the society due to their devastating effects. Several accidents during processing, storage and transportation have been reported in Indian fireworks manufacturing units. In this paper, the analysis of 70 case histories of fatal accidents reported during 1994 - 2006 in Tamil Nadu, India is presented. The analysis showed that most of the fatal accidents in fireworks industry occurred in filling and mixing sections. Mechanical effects and chemical reactivity are found to be major contributors to accidents. Hot weather is one another major contributing factors. This showed that fireworks chemicals are susceptible to thermal stimuli. The analysis also brought to notice that processing of flash compositions and rocket mixtures are more hazardous than other pyrotechnic mixtures.

For the first time, an intensive Job Safety Analysis (JSA) was carried out for various unit operations such as weighing, sieving, mixing, filling, fuse cutting, drying and finishing activity of fireworks manufacturing. The study explored the various possible hazards during manual processing and handling of fireworks mixtures. It was evaluated that during normal processing of fireworks the chemical mixture can be subjected to a frictional load and impact energy of 17.2 N and 19.6 J respectively. On comparing this value with the reported friction and impact sensitivity data, it could be found that the fireworks mixtures carry with them the risk of fire and explosion as a consequence of abnormal operations like excess force exertion, mishandling, dropping of utensils / tools, slip and fall.

Keywords: Accident analysis, Fireworks, Pyrotechnics, Job safety analysis, Impact stimulus, Frictional stimulus.

1.0 Introduction

With the rapid development in Science and Technology, several new innovations emerge and process industries have to deal with a variety of chemicals and processes. Unsafe handling and unsafe conditions during the process lead to accidents of major or minor in nature. Firework industries, in particular have proved to be more vulnerable than other industries due to handling of large quantity of explosive mixtures [1), 2)]. A scientific and systematic analysis of the accidents with their causes and consequences above law provide better solutions in handling and processing of these chemicals thus minimizing the accidents.

Studies on thermal stability [2)], impact sensitivity and friction sensitivity [3), 4)] of firework compositions have been reported. The results of the experimental investigations can be used to determine the hazard potential and safety limits during processing of flash compositions [5)]. Nevertheless, it is necessary to determine hazards and hazardous situations that could sensitize the flash compositions during processing. These hazards can be identified using anyone of the appropriate hazard assessment techniques such as Safety Audit, Checklist analysis, Job safety Analysis (JSA), "What - If Analysis", HAZOP, Fire and Explosion Index (F&EI), Failure mode effect analysis (FMEA), Fault tree analysis (FTA) and Event tree analysis (ETA). Since the fireworks manufacture employs mostly manual and labour intensive operations, "Job Safety Analysis" is found to be most suitable and relevant technique. An intensive Job Safety Analysis (JSA) was carried out for various unit operations such as weighing, sieving, mixing, filling, fuse cutting, drying and finishing activity of fireworks manufacturing and this paper discusses in detail the findings of the analysis.

2.0 Accident data analysis of fireworks industry

Several accidents during processing, storage and transportation have been reported in Indian fireworks manufacturing units [6), 7)]. Seventy (70) case histories of fatal

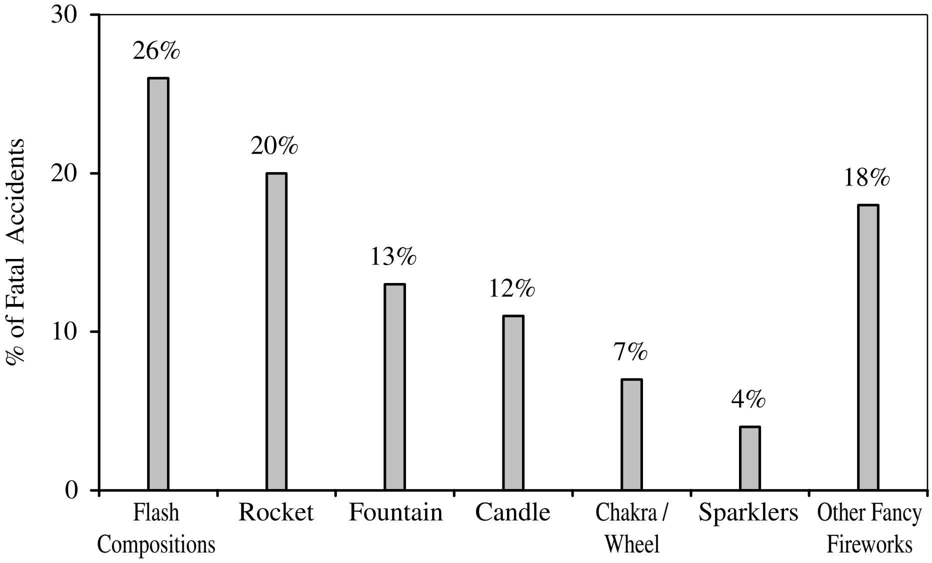

Fig. 1 Accidents due to fireworks compositions during 1994-2006.

accidents were reported during 1994 - 2006 in Tamil Nadu, India. An analysis was done specifically on this data. The objective of this analysis was to identify the contributing factors to accidents, to identify the areas of concern and to initiate research to prevent these accidents.

The accident data analysis was carried out in the following aspects of firework chemicals:

a. Fireworks compositions
b. Related unit operations
c. Causes for accidents
d. Characteristic influence of climate and weather conditions in accidents.

2.1 Fireworks compositions

Figure 1 shows the percentage of fatal accidents due to fireworks compositions used during manufacturing. About 26 % of accidents occurred during the preparation of the flash compositions (consisting of potassium nitrate, sulphur and aluminum) and 20 % while processing the 'rocket' compositions (consisting of potassium nitrate, sulphur and charcoal). The remaining 54 % occurred during processing of various fancy fireworks. The distribution of accidents showed that the hazardous nature of fireworks directly related to the state, condition or quality / type of composition employed.

2.2 Related unit operations

The distribution of fatality rate due to various unit operations of fireworks manufacturing is illustrated in the form of a chart in Fig. 2. The chart shows that out of 70 accidents, nearly 57 % occurred in the filling and mixing sections and other accidents occurred in the storage facility, fuse cutting operations, drying process, burning of fire works wastes and packing processes. Therefore it was identified that filling activity is prone to accidents followed by mixing and storage.

2.3 Causes for accidents

Figure 3 illustrates the factors responsible for accidents.

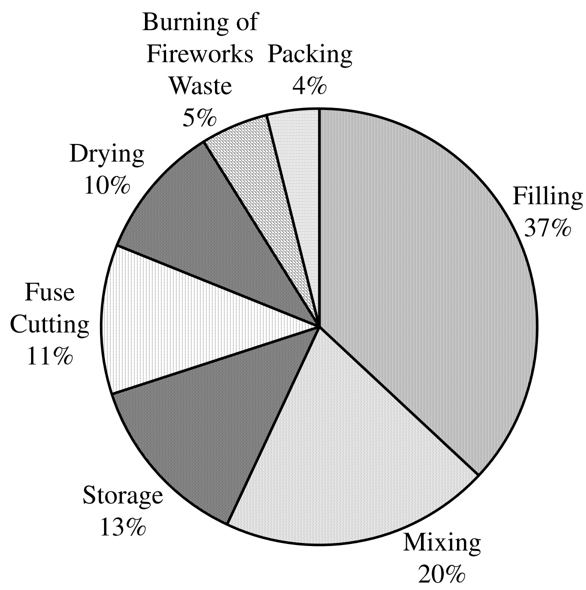

Fig. 2 Accidents in fireworks manufacturing, during 1994-2006.

The Figure. 3 shows that 36 % of the accidents were due to ignition stimulus caused due to friction sensitiveness and 25 % were due to impact sensitiveness. The third contributing factor was the decomposition of chemicals, which occurred due to the presence of moisture or impurities during storing, and processing. Other accidents occurred due to lightning, and static electricity.

2.4 Characteristic influence of climate and weather conditions

Most of the accidents in fireworks industry was in the month of August. This is due to the increase in production during the month of August for the following Diwali festival (one of the biggest festival in India during which fireworks cracking is the major attraction). Figure 4 shows the fatality rate during different months in a year from 1994 to 2004.

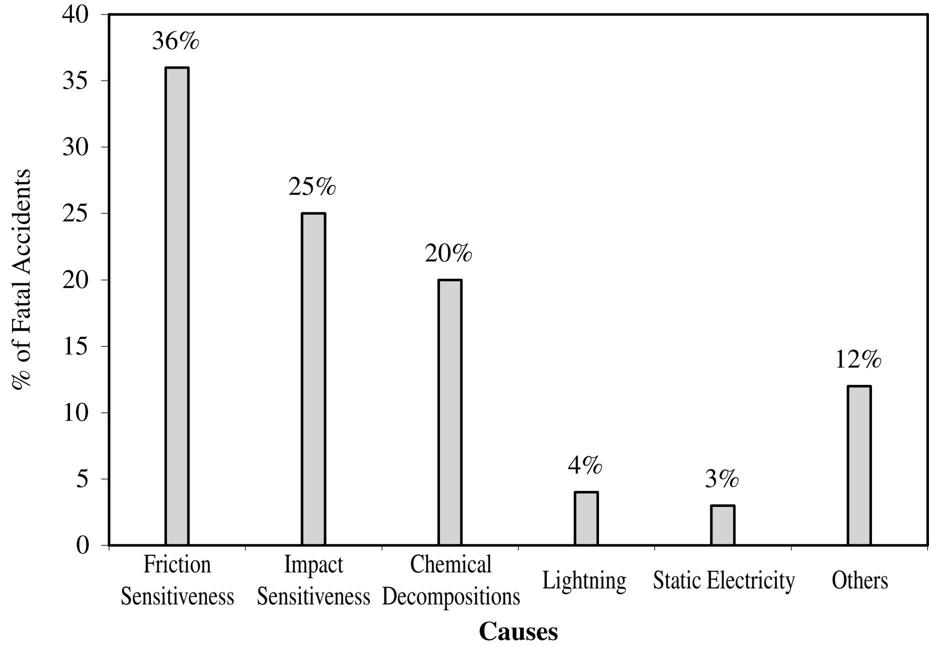

Fig. 3 Accidents due to causes in the manufacturing of fireworks during 1994-2006.

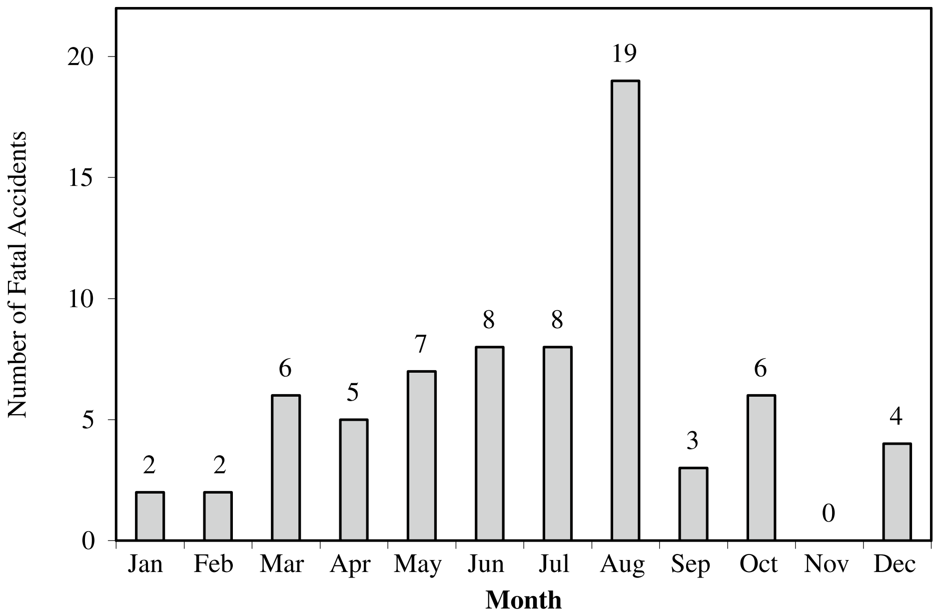

Fig. 4 Characteristic Influence of climate on fireworks accidents during 1994-2006.

2.5 Summary of accident data analysis

Most of the fatal accidents in fireworks industry occurred in filling and mixing sections. Mechanical effects and chemical reactivity are major contributors to accidents. Hot weather is one of the major contributing factors. This shows fireworks chemicals are susceptible to thermal reactivity. Further, the analysis showed that processing of flash compositions is more hazardous than other pyrotechnic mixtures. Therefore, fireworks industry with its full dependence on human interface for various operations requires a in depth, scientific and systematic analysis of the chemicals employed and the operations. Job Safety Analysis is one such approach among the host of the analytical techniques employed for hazard identification was found to be more suitable for this purpose.

3.0 Job Safety Analysis (JSA) for a fireworks industry

Job Safety Analysis was carried out for a typical Indian fireworks manufacturing industry, located in Tamilnadu, India.

In firework industry the chances for accidents are very high due to the sensitiveness of the pyrotechnic chemicals so there is always some hazard involved in each step. To identify these and evaluate these hazards in each firework manufacturing operation job safety analysis has been employed.

Table 1 Job Safety Analysis worksheet for weighing process.

Sl. no	Operation	Hazard	Suggested safeguards
1	Holding the balance	Balance slips down from worker's hand resulting in an impact load of 4 J	Use digital balance
2	Placing the chemicals on balance	Dragging of chemical vessel results in friction of 17.2 N	Arrange all the items for easy working
		Scooping / Transfer of chemicals with improper vessel	Use brass material
		Chemicals spill on ground due to hasty action of workers	Extra sheet can be used in floor so that any spill could be disposed properly
3	Weighing	Mixing of chemicals due to non cleanliness of balance	Clean the balance before and after weighing
		Improper balance material	Brass material must be used
4	Weighing	Weighing more than the capacity of balance	Instruct the worker about the limits of the balance before work
		Dragging of the balance results in friction 13.73 N	Arrange all the items for easy working
		Improper weight due to fault in balance	Balance should be properly standardized before weighing

Table 2 Job Safety Analysis worksheet for mixing process.

Sl. no	Operation	Hazard	Suggested safeguards
1	Placing the rubber sheet	Slip from worker's hand and spillage of chemicals.	Proper handles should be provided in the vessel
		Poor cleanliness	Proper cleaning is advised after each mixing
2	Placing the chemicals on the sheet	Dragging of chemical vessel results in friction 17.2 N	Arrange all the items for easy working
		Scooping / Transfer of chemicals with improper vessel	Use brass material
		Chemicals spill on ground due to hasty action of workers	Extra sheet can be used in floor so that any spill could be disposed properly
		Chemical vessel trips down from workers hand results in friction load of 19.6 J	Proper handles should be provided in the vessel and careful handling suggested
3	Mixing	Applying too much pressure	Instruct the worker with experimental results / hazards of application of extra pressure
		Improper mixing place	Rubber sheet must be used
		Moisture mixed with chemicals due to factors such as sweating of waters	Provide cool and dry environment to the workers

Table 3 Job Safety Analysis worksheet for sieving process.

Sl. no	Operation	Hazard	Suggested safeguards
1	Placing the chemicals on the sieve	Scooping / Transfer of chemicals with improper vessel	Use brass material
		Chemicals spill on ground due to hasty action of workers	Extra sheet can be used in floor so that any spill could be disposed properly
2	Sieving	Applying too much pressure on chemicals by workers hand	Instruct the worker with our experimental results
		Dragging of sieve results in friction of 3.4 N	Arrange all the items for easy working
		Fast working of sieve by worker	Instruct the worker with experimental results / hazards of application of extra pressure
		Improper sieve material	Brass material must be used
		Improper sieving results in friction	Homogeneous mixture must be obtained
		Sieve falls down from workers hand results in impact load of 1.3 J	Proper handles should be provided in the sieve

Table 4 Job Safety Analysis for filling process.

Sl. no	Operation	Hazard	Suggested safeguards
1	Placing the ring on rubber sheet	Slip and fall on rubber sheet results in impact load of 8.6 J	Proper handle can be provided
2	Applying chemicals on shells	Dragging of aluminium rings result in friction of 17.8 N	Arrange all the items which is easy to work
		Applying excess tapping	Instruct the worker with our experimental results
		Applying excess quantity	Should be properly weighed
		Moisture on chemicals	Worker and environment must be kept free from moisture
3	Mud filling	Applying excess mud	Apply optimum quantity
		Improper mixing of mud	Mud should not be too wet. Allow only minimum wetness.
4	Punching	Excess pressure results in explosion	Instruct the worker with our experimental results
		Improper punching material	Brass or Bamboo stick can be used
		Sand filling not effectively done	Proper method of sand filling should be done

The steps involved in JSA are:

- Jobs with the highest risk for a workplace injury or illness were selected.
- An experienced employee who is willing to be observed was selected. Then the employee was made to involve in the process with his/her supervisor.
- Each and every step necessary to accomplish the task was identified and recorded. Action verbs like pick up, turn on were used to describe each step.
- All the actual or potential safety and health hazards associated with each task were identified.
- The recommended action (s) or procedure (s) for performing each step that will eliminate or reduce the hazard (i.e. engineering changes, job rotation, PPE, etc.) was determined and recorded.
- The magnitude of the hazards was quantified by using suitable mathematical models.

3.1 Job Safety Analysis (JSA) work sheet

Each process was split into different operations and hazard involved in each operation were identified and precautionary measures evaluated, which formed the outcome

Table 5 Job Safety Analysis for the process fuse fitting.

Sl. no	Operation	Hazard	Precaution
1	Applying gunpowder & gum solution	Excess quantity results in failure of cracker	Optimum quantity should be used
		Spillage of solutions on the crackers	Separate sheet can be used
2	Inserting fuse	Improper fitting results in failure of cracker	Fuse should be properly fitted

Table 6 Job Safety Analysis for the process drying and breaking of shells.

Sl. no	Operation	Hazard	Precaution
1	Drying	Improper platform results in explosion	Proper platform should be developed
		Excess drying results in overheating	Dry up to the required time
		Moisture on the cracker results in failure	Should be free from moisture
2	Breaking of shells	High hammering force can cause explosion	Instruct the worker with our experimental results
		Breaking with improper material	Wood stick only should be used

Table 7 Calculation of hazard stimuli due to impact and friction during firework manufcturing process.

Process	Total Weight, m, (Kg)	Max. Height Lifted, h, (cm)	Impact Load (m*g*h), J	Normal force on the balance (Rn) (m*g), N	Frictional Load (μ*Rn), N
Weighing (weight of balance (2 kg) + Max weight measured (2 kg))	4	10	3.924	39.24	13.73
Sieving Process (weight of sieve (1 kg))	1	13	1.3	9.81	3.4
Filling (weight of Al ring (1.1 kg))	1.1	80	8.6	10.79	17.8
Mixing (weight of storage vessel (5 kg))	5	40	19.6	49.05	17.2

Acceleration due to gravity (g) = 9.81 ms^{-2}, Coefficient of friction between the materials (μ) = 0.35

of Job Safety Analysis. Tables 1, 2, 3, 4, 5 and 6 show the JSA worksheet for the weighing, mixing, sieving, filling, fuse fitting, drying and shell cutting of pyrotechnic flash compositions processing respectively.

3.2 Quantification of the process safety in the preaparation of flash composition

Job safety analysis was carried out for the various processes in the manufacturing of flash crackers. The results of job safety analysis were tabulated in Tables 1 to 6. Calculation of hazard stimuli due to impact and friction during firework manufacturing process is shown in Table 7. The impact load is calculated using the equation 1. The frictional load is calculated using the equation 2.

Impact load = m*g*h 1

Where m is the total weight (kg), g is the acceleration due to gravity ie. 9.81 ms^{-2}, h is the height

Frictional Load = μ*Rn 2

Where μ is the coefficient of friction between the materials (0.35) and Rn is the normal force acting on the balance which is calculated as

Rn = m*g 3

Table 8 Job Safety Analysis results for flash compositions.

Types of flash	Flash Composition Wt %	Weignhig process	Mixing process	Sieving process	Filling process	Fuse fitting process	Drying and breaking
Potassium Nitrate	Al: 20 KNO_3: 50 S: 30	Safe	Hazardous	Safe	Hazardous	Safe	Safe
	Al: 50 KNO_3: 50	Safe	Hazardous	Safe	Safe	Safe	Safe
	Mg: 50 KNO_3: 50	Safe	Hazardous	Safe	Safe	Safe	Safe
	Charcoal: 25 KNO_3: 50 S: 25	Safe	Hazardous	Safe	Safe	Safe	Safe
Barium Nitrate	$Ba(NO_3)_2$: 57 Al: 28 S: 15	Hazardous	Hazardous	Safe	Hazardous	Safe	Safe
	$Ba(NO_3)_2$.: 68 Al: 23 S: 9	Hazardous	Hazardous	Safe	Hazardous	Safe	Safe
	$Ba(NO_3)_2$.: 66 Al: 25 S: 9	Hazardous	Hazardous	Safe	Hazardous	Safe	Safe
	$Ba(NO_3)_2$: 70 Al: 10 S: 20	Hazardous	Hazardous	Safe	Hazardous	Safe	Safe
	$Ba(NO_3)_2$: 64 Al: 20 S: 16	Hazardous	Hazardous	Safe	Hazardous	Safe	Safe
Potassium Per chlorate	$KClO_4$: 50 Al: 25 S: 25	Hazardous	Hazardous	Safe	Hazardous	Safe	Safe
	$KCLO_4$: 53 Al: 31 S: 16	Safe	Hazardous	Safe	Hazardous	Safe	Safe

Where m is the weight, and g is the acceleration due to gravity. It could be seen that the possibilities of hazards are mainly due to improper handling of tools / equipments during processing. Specifically it can be seen that the frictional load of 17.2 N approximately is applied during normal processing of flash compositions. On comparing the job safety analysis and experimental results, it could be seen that a maximum frictional load of 17.2 N does not lead to fire and explosion as the friction sensitivity of flash compositions studied fell above 32 N. However, during abnormal conditions ie. When chemicals are loaded more than the allowed limits, the frictional load will increase above 32 N, which would lead to explosion.

Similarly, the calculation of impact stimuli during processing of flash crackers was carried out for the job safety analysis (Table 7). During normal operating conditions the mixtures are subjected to the maximum of 19.6 J of impact energy. Comparing this value with the experimental results showed that all the flash compositions are highly dangerous, as the impact sensitivity of flash compositions fell below the range of 19.6 J. But certain flash compositions are safe to be processed in specific operations. The following table shows (Table 8) the various firework processes where the flash compositions could be safely processed.

4.0 Conclusions

The accident data and the analytical results of the flash composition are indicative of the criticality of the properties of the chemicals used and the operations employed with human interface in the fireworks industry. In certain cases, the inherent sensitivity of the chemicals can be a major cause for an accident. In most cases it is the improper handling, friction, thermal effects, moisture and human error turn out to be the major contributing factors for the accident.

This fairly exhaustive exercise compiles the information on the worker's alertness, safety concern and providing safe work place in an integrated manner. It is therefore imperative that based on the chemical composition used, working environment and the psyche of the worker, properly designed working place, accessories, equipment and above all educational training have to be provided to the work force. In the fireworks industry this type of analysis needs to be conducted for all individual units to identify where the emphasis on safety have to be introduced.

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