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Fire Safety Management in Chemical Industries

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Abstract: The chemical industry uses most of the hazardous chemicals having a significant bearing on safety, health and environment problems encountered in running any industry. Although there is no universal consensus as to the scale of production and use of chemicals, it is estimated that the average annual world production of chemicals is more than 400 million tons. As per an ILO document of 1987, as back as in 1978, the American Chemical Society's Chemical Abstract Services identified 4 million distinct chemical compounds and it has been calculated that this number is increasing at the rate of over a quarter of a million every year. It is accepted that few of these substances and compounds are used commercially. However the United States Environmental Protection Agency (EPA) suggests that about 70,000 chemical compounds can be considered as being in everyday use. World Health Organization (WHO), the Organization for Economic Co-operation and Development (OECD) and the EPA estimated that new chemicals in excess of one ton placed on the market each year range from 200 to over 1000, most of which, until recently, have not been tested for deleterious effects. ILO's book entitled "Occupational Exposure Limits for Airborne Toxic Substances", lists occupational exposure limits for 1,178 chemical substances which, have been adopted by various countries. This number constitutes but a small fraction of chemicals in use. This article will focus on the characteristics and elements of fire, potential fire hazards, and measures to be followed for fire preparedness, fire protection and evacuation procedures in chemical industries and the accident investigation procedures.

I. INTRODUCTION

A. General

The chemical industry uses most of the hazardous chemicals having a significant bearing on safety, health and environment problems encountered in running any industry. Although there is no universal consensus as to the scale of production and use of chemicals, it is estimated that the average annual world production of chemicals is more than 400 million tons. As per an ILO document of 1987, as back as in 1978, the American Chemical Society's Chemical Abstract Services identified 4 million distinct chemical compounds and it has been calculated that this number is increasing at the rate of over a quarter of a million every year. It is accepted that few of these substances and compounds are used commercially. However the United States Environmental Protection Agency (EPA) suggests that about 70,000 chemical compounds can be considered as being in everyday use. World Health Organization (WHO), the Organization for Economic Co-operation and Development (OECD) and the EPA estimated that new chemicals in excess of one ton placed on the market each year range from 200 to over 1000, most of which, until recently, have not been tested for deleterious effects. ILO's book entitled "Occupational Exposure Limits for Airborne Toxic Substances", lists occupational exposure limits for 1,178 chemical substances which, have been adopted by various countries. This number constitutes but a small fraction of chemicals in use.

With increasing sophistication of processes and severity of process parameters, the possibilities of something going wrong have assumed a far greater magnitude. The magnitude of exposure of working population to chemicals is not known with any certainty. A variety of chemicals are used in the field of agriculture, which is accounting for fifty percent of the total world workforce. Most of these workers among the least protected. In the same way that the scale of use of chemicals in the developing countries is increasing, day by day, so is the apparent trend in occupational diseases and illness. Adequate statistics on occupational diseases and injuries, due to exposure to chemicals at work are not easy to find even in developed countries. This is due to different criteria of recognition, classification and reporting of diseases and injuries among other factors. However, as per an article published in "Safety Science" 44 (2006), the average figure of global occupational accidents, was estimated to be 264 million accidents yearly, so more than 7,00,000 workers in a day suffer an accident which causes absence of 3 days or more.

In India approximately 10 million persons are employed in various factories. As per the Directorate General Factory Advice Service and Labour Institutes (DGFASLI), more than 36,500 hazardous factories out of the 3,00,000 registered factories, employs 20,46,092. No precious data is available for the occupational ill-health or injuries caused in the chemical industry in India. However, the current burden of accumulated occupational diseases in India is estimated to be about 18 million cases.

B. Classification Of Chemicals

Harmful chemical pollutants in the workplaces may be generally categorized into three different groups, viz. (i) Toxic Chemicals, (ii) Flammable Chemicals, and (iii) Explosive Chemicals.

1) *Toxic Chemicals:* Toxic chemicals or materials include simple and chemical asphyxiates, irritants, narcotics, systemic poisons, carcinogens, teratogens, mutagens and those with dermatological effects. The hazards arising from exposure to toxic materials depend on the circumstances of the exposure and the nature of chemicals involved. Such exposure range from sudden brief exposure, perhaps at high concentrations, to prolonged exposure at low, often changing concentrations over a period of years which may be as long as a working lifetime. In most cases, exposure will be to a range of chemicals of varying degrees of harmful potential, with perhaps synergistic effects between some of the substances involved. The routes of entry of toxic chemicals are: (i) Inhalation – probably the most common industrial case, (ii) Ingestion – frequent as a route for industrial poisoning except through eating and smoking without adequate attention to hygiene and (iii) Skin absorption via external contact. Generally, dusts, fumes, gases and vapours are inhaled and liquids and solids are ingested or penetrate the damaged or undamaged skin. Once on or in the body, the toxic material may have varying effects. There are local effects when the material is an irritant to the skin, eye or respiratory tract; or there is a systemic effect because of the substances toxicity. Delayed effects may be carcinogenic while other substances may involve fatal or chromosome damage.
2) *Fire and Explosive Chemicals:* The fire and explosion risks associated with many chemicals present an acute hazard both to property and to life. While fire is normally regarded as having a disaster potential less than that of explosion, fires tend to occur more frequently and are extensively documented. There have been substantial losses due to fire and explosion. Even where there has not been hazard to life, major product losses have been reported world-wide. The numerous standards and code of practices applicable to storage are, for this reason, concerned primarily with risk of explosion and fire. Storage, handling and internal transport of flammable materials pose many problems, especially on account of spillage and similar risks.

There are a number of risks of explosions including chemicals, to which workers may be exposed. These can be caused by: the detonation of explosive materials, the detonation of deflagration of gas or vapour cloud which are within flammable limits, or the detonation of dust cloud in confinement. These may result in overpressure or the individual being hit by debris or suffering directly or indirectly from the effect of the blast which damages the building. Organic peroxides and some azo and nitro-compounds, have unstable properties and may be formed as intermediates in chemical reactions, or by the inadvertent, or accidental mixing of incompatible substances. Boiling liquid expanding vapour (BLEVES) are not confined to large scale installations although it is these which have received the greatest attention. A BLEVE need not involve flammable materials. In all cases, the initial effect may be the generation of a blast wave and missiles and the expanding vapour cloud, if ignited, will produce thermal radiations. Explosions in a chemical process plant may include mist and spray explosions, superheated liquid explosions, compressed air or other gas system explosions. Explosion – preventions measure may involve complex engineering procedures. These may include control of the atmosphere by the use of inert gas, and explosive protection and relief by containment, separation, flame arrestors, automatic isolation, suppression and wetting. A particular hazard in the process industries is that of dust explosions. Many industrial materials are at some stage handled as dusts or powders and many final products are in finely divided dust or powder from which will form explosive mixtures in the air. The risk is not only of primary explosions within the plant but of secondary must larger, explosions in buildings in which dust has been allowed to collect on beams, ledges and fittings as a result of poor housekeeping. Incidents involving dust explosions have been recorded for many years; these particularly affected have been flour milling, grain storage, and metal powder manufacturers.

C. Classification Of Chemical Hazards

The exposure of these chemicals can lead to many hazards, which can be broadly be grouped into two viz.: (i) Toxic Hazards and (ii) Fire and Explosion Hazards.

D. Hazard Control Methods

As far as India is concerned many provisions relating to chemical safety has been incorporated in the existing legislations after the Bhopal Tragedy. The Factories Act, 1948, which is mainly concerned with factories, has been amended to incorporate many provisions relating to chemical safety. The Government of India has even formulated a new act i.e. Environment (Protection) Act in 1986 and a series of legislations have been brought under this Act. In view of the appearance of health hazards associated with particular chemical substances, specific laws have been passed by different countries or rules formulated under existing general legislation.

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1) *Identification And Labelling:* Requirements for identification and labelling of chemical substances exist in several countries including India. Requirements differ from one country to another as to the details of the components of identification and labelling.
2) *Transport:* National regulations or guidelines regarding transport of chemicals within the enterprise only exist in few countries. However more attention is given to external transport. In India, transport of chemicals is dealt with the Motor Vehicles Act, 1988 and the Central Motor Vehicles Rules, 1989.
3) *Storage:* Most chemicals in the work place are held in storage, prior to distribution and use. This storage may be in one or each of several locations at the manufacturers, suppliers, in transit or at the work place, before, or during after use. Considerable quantities of harmful materials may be stored in ways which may have the potential in the event of an incident, to cause several hazards not only to workers but also to the population in the vicinity of the place of storage and general environment. There have been many such incidents involving flammable, explosive and toxic materials. The incidents involving explosive materials at Oppau, Germany, in 1921, flammable material at San Juan Ixhuatepec, Mexico, in 1984 and toxic material at Bhopal, India, in 1984 and Switzerland in 1986 are few examples. General or specific legislation on storage of chemicals exists in various countries including India. Because of the associations with major accident hazards and incidents, such as those in Flixborough (1974) and Seveso (1976), storage of chemicals became a major accident component of the EC Directive on major accident hazards. Standards for the storage of toxic materials tend to be contained in guidance notes, MSDS, codes of practices and manufacturer's code. In India, storage of chemicals is mainly dealt with the Factories Act, 1948 and the Environment (Protection) Act, 1986.
4) *Handling and Use:* Legislation on handling and use of chemicals at work is available in several countries. In EC, extensive provisions exist on the safe handling and use of chemicals aimed at both the "no risk" and "acceptable risk" philosophies. System similar to that of the EC exist elsewhere in the world including USA and India. In India, safe handling and use of chemicals is mainly dealt with the Manufacture, Storage and Import of Hazardous Chemicals (MSIHC) Rules, 1989. The amended Factories Act 1948 also dealt with chemical safety in a separate chapter.
5) *Waste Disposal:* The Law and practice regarding waste disposal within the enterprise differs markedly from one country to another. In the United Kingdom, disposal of waste within the enterprise is provided for in several acts of legislation notably the Health and Safety at Work Act 1974 and the Public Health Acts. The control of waste in general is mainly dealt with under the Control of Pollution Act 1974. The EC has Directives on waste disposal. In India the control of waste in general is mainly dealt with the Hazardous Wastes (Management and Handling) Rules 1989.

E. Role Of The ILO

ILO activities, designed to stimulate or to reinforce national action in occupational safety and health are promoted through, the International Programme for Improvement of Working Conditions and Environment (PIACT).

Despite the considerable activities of the ILO in the field of occupational safety and health, there is no comprehensive instrument which deals with the control of all chemical substances at workplace, though there are few Conventions and Recommendations, which are mostly in general terms. The following ILO Conventions (C) and Recommendations (R) have direct or indirect relevance to the control of chemicals at work

1) White Lead (Painting) – C 013;
2) Protection Of Workers' Health – R 097
3) Radiation Protection – C 115 and R 114
4) Hygiene (Commerce & Office) – C 120 and R 120
5) Benzene – C 136 and R 144
6) Occupational Cancer – C 139 and R 147
7) Working Environment (Air pollution, Noise and Vibration) – C 148 and R 156
8) Occupational Safety And Health (Dock Work) – C 152 and R 160
9) Occupational Safety And Health – C 155 and R 164
10) Occupational Health Service – C 161 and R 171
11) Asbestos – C 162 and R 172
12) Chemicals – C 170 and R 177
13) Prevention of Major Industrial Accidents – C 174 and R 181
14) List of Occupational Diseases – R 194

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II. LITERATURE REVIEW

A. General

The definition of risk is one that varies from area to area and even between members in the same area. Watts and Hall use the following definition of risk, which is based on the definition of the Society for Risk analysis, risk is the potential for realization of unwanted, adverse consequences to human life, health, property, or the environment. Estimation of risk (for an event) is usually based on the expected value conditional probability of the event occurring times the consequence of the event, given that it has occurred. It follows that risk for a building, a process, or some other entity would be the probability distribution of events and associated consequences relevant to that building, process, or entity.

In Meacham, a comprehensive definition of fire risk is given as follows: fire risk can be viewed as the possibility of an unwanted fire hazard in a uncertain situation, where loss or harm may be induced to the valued, typically life, property, business continuity, heritage, and/or environment. The key factors include unwanted outcomes or consequences, uncertainty, valuation, and likelihood of occurrence. Building fire risk analysis can be considered as the process of understanding and characterizing fire hazard in building, unwanted outcomes that may result from a fire and the likelihood of fire and unwanted outcomes occurring.

B. Measures Of Fire Risk

Before quantitatively assessing fire risk, it is essential to determine its measure. As Bukowskimentioned, it is difficult to express risk to life in a way that can be understood by the public. This leads to the consideration of other metrics for risk. Financial loss is the perfect metric for the property related risk, however, the primary focus of fire codes is life safety, which then requires that risk to life must include a measure of the value of human life. This regards the economic value of an individual as the present value of the stream of income that he or she expects to earn during the rest of his or her working life. The concept that some people have less value to society than others has encountered great objection, especially by those, whose value is deemed lower. Thus risk to life is usually separately assessed to avoid the difficulty of assigning a monetary value to human life.

C. International Journal On Engineering Performance-Based Fire Codes

In Beck's work as well as in the relevant fire risk assessment models such as CESARE-Risk andFiRECAM, fire risk is measured separately using two comprehensive parameters: the expected risk to-life (ERL) and the fire cost expectation (FCE).ERL is defined as the expected number of deaths over the design life of a building, divided by the population of the building and the design life of the building. FCE is defined as the expected total fire cost, divided by the cost of the building and its contents. The ERL value and FCE value can be used for making decisions.

D. Acceptable Fire Risk Levels

As Dungan mentioned, absolute risk is more difficult to declare as acceptable because it requires the acceptance of a known risk. Applying risk measures as a relative ranking to establish priorities or to compare cost-benefit of different approaches makes effective use of the methods without becoming mired down in the acceptability of anyone risk. In a relative risk assessment method, the risk of the subject building is usually assessed and compared with the risk of a similar building designed in accordance with the prescriptive code. The justification of the relative risk approach usually states that the public appears to be satisfied with the safety levels of buildings designed to the current regulations, although some argue that this statement is debatable.

The draft code of practice from the British Standards Institution (BSI) is the only method which has attempted to set acceptable levels of risk. They suggest a value for the risk of death per individual per year at home or elsewhere, and for the risk of multiple deaths per building per year. The problem is that risk to life is too abstract to be understood by the public. To make decisions about the appropriate level of fire safety or risk, it is necessary to balance the benefits of safety and costs of achieving it. From this view, risks should be reduced until the marginal cost equals the marginal benefits. The cost of fire protection measures is fairly straightforward and can be calculated in the same way as any other building cost. However, it is more difficult to quantify the benefits. A number of studies have been made to estimate acceptable or tolerable risk level in terms of costs and benefits as well as human capital.

E. Types Of Fire Risk Assessment Methods

As pointed out by Watts methods of fire risk analysis may be classified into four categories, narratives, checklists, indexing, and probabilistic methods. Narratives do not attempt to evaluate the fire risk quantitatively; instead, a risk is judged acceptable if it complies with published recommendations. An obvious limitation to the narratives approach is that it cannot cover the myriad conditions of human activity.

A common accessory of fire protection is a listing of hazards and recommended practices. These checklists comprise valuable tools for identifying fire risk factors but they do not distinguish among the importance of these factors. Fire risk indexing methods assign values to selected variables based on professional judgment and past experience. The selected variables represent both positive and negative fire protection features and the assigned values are then operated on by some combination of arithmetic functions to arrive at a single value. This single value can be compared to other similar assessments or to a standard.

This method is a useful and powerful cost-effective tool that can provide valuable fire risk assessment, especially when an in-depth analysis is not appropriate. Probabilistic methods are the most informative approaches to fire risk assessment in that they produce quantitative values, typically produced by methods that can be traced back through explicit assumptions, data, and mathematical relationships to the underlying risk distribution that all methods are presumably seeking to address.

Fraser-Mitchell discussed three methods of fire risk assessment: point schemes, state transition models, and simulation models. Point scheme methods are equivalent to indexing methods mentioned above, which correlate fire statistics with parameters such as size of building and fire load. It is difficult to assign numerical values to some of the parameters, so the correlations are probably rather weak. The method is also not applicable to novel buildings or techniques. A more sophisticated approach is based on state transition models, with probabilities assigned to each event. The determination of the probabilities may also be rather subjective process, or may use deterministic models to examine the consequences of various starting conditions. Fire realm models are more complex than but similar to state transition models, and both are difficult to deal with the interactions between components. It is necessary to develop a simulation model with all component sub-models running simultaneously, and their results communicating to each other. The model is mainly deterministic, but with starting conditions and certain values drawn from suitable probability distributions. The overall risk is simply given by the average value of some output parameters over a suitable number of runs of the simulation. The advantage of this technique is that the structure of the model can in principle be directly based on physical theory and experimental measurements.

III. METHODOLOGY

A. Fire Safety Methodology

In India, every year about 25000 persons die in fires and related causes. The leading causes for these accidents are bursting of gas cylinders or stoves and electrical short circuits. Many of these deaths could have been prevented. A fire can occur at any time at any place. It can cause major disasters and loss of lives in buildings such as offices, hotels, shopping centres, hospitals, schools and homes. Such disasters can be avoided if proper fire safety practices are observed. It is the interests of the community at large that proper attention be paid to fire loss since it is the community in the end which has to pay for all the losses. Insurance company's may be paying for a part of the damage, but can only do so out of the premium collected out of the insured.

A major fire can bring a business to a halt. Fires are caused almost entirely by people, either through their actions, which may be accidental or deliberate and malicious or through their failure to take appropriate precautions such as, for example, the regular inspection, maintenance and repair of defective equipment. To mitigate the fire, the first step, the management should take is to identify the fire risks. The successful prevention of fire loss depends almost entirely on the management of the business. Fire creates total waste. Such waste would not be tolerated by efficient management, if it resulted from inefficient operation. This article will focus on the characteristics and elements of fire, potential fire hazards, and measures to be followed for fire preparedness, fire protection and evacuation procedures.

B. Characteristics Of Fire

In order to protect yourself from fire, it is important to understand the basic characteristics of fires. A fire has many characteristics and some of them are listed below:

a) A fire can occur at any time.
b) Short circuit is one of the leading causes of fire.
c) In just two minutes, a residence can be engulfed in flames.
d) The water is the best medium to fight fires except electrical and oil fires.
e) Most deaths due to fire occur at night when people are sleeping.
f) Fire produces gases that make you drowsy.

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g) Smoke and poisonous gases are the primary killer in fires.
h) Instead of being awakened by fire, you may fall into a deeper sleep.
i) Asphyxiation is the leading cause of fire deaths exceeding burns.
j) Heat and smoke from fire can be more dangerous than the flames.
k) Inhaling the super hot air can sear your lungs.
l) Pouring water on electrical or oil fires will be dangerous.

1) *Elements of Fire:* A majority of fires can be prevented. Any **fire prevention** programme is built around the knowledge of basic elements of fire. Fuel, Air (oxygen) and Heat (ignition source) must exist together for a fire to exist which is popularly known as the science of the fire triangle. Without any one of these elements, a fire is not

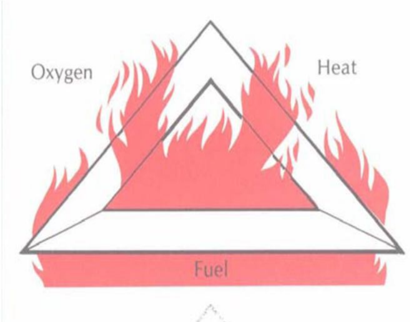

Fig 3.1 FIRE TRIANGLE

Possible. “Un-inhibited Combustion Chain Reaction”, is also considered as fourth element for certain types of fires especially chemical fires.

The source of these elements can be:

a) A source of fuel is anything that can burn a potential fuel for a fire. The examples are coal dust, wood, paper, plastics, waste materials, mineral oils, diesel, some explosives, etc.
b) A source of ignition is anything that has potential to get hot enough to ignite a material, substances in the home or workplace. The examples are electrical sparks, hot surface from electrical equipment, short circuits, spontaneous heating of coal, hot work, smokers material (cigarettes, lighters, matches), candles, explosives, detonators, etc.
c) The main source of oxygen for a fire is in the general body of air.

C. Fire Prevention

A fire can occur at any time. Therefore various measures are to be adopted in advance to prevent a fire in your building. Some of the measures need to be adopted are given below:

a) Prohibit smoking in storage areas of flammable materials.
b) If electrical equipment is not working properly or if it gives off an unusual odour disconnect the equipment and call an approved electrician.
c) Properly replace any electrical cord that is cracked or has broken connection.
d) When using extension cords, protect them from damage. Do not put them across doorways or any place where they will be stepped on or chafed. Check the amperage load specified by the manufacturer.
e) Do not plug an extension cord into another, and do not plug more than one extension cord into one outlet.
f) Keeps all heat producing appliances away from the wall and away from anything that might burn. Leave plenty of space for air to circulate around equipment that normally gives off heat.
g) Make sure all appliances in your area such as hot plates, ovens, toasters, mixers, grinders, geezers, clothing irons are turned off when not in use.
h) Use ash trays and empty them only when you are sure the ashes, matches and butts are cold.
i) Make sure that no one including visitors, has left cigarettes smolderings in waste – baskets or on furniture’s, sofas, beds, etc.
j) Keep storage areas, stairway landings and other out of way locations free of waste paper, empty cartons, dirty rags and other material that could fuel a fire.
k) Report all fire hazards to the officer or any person authorized.

l) Create awareness to use fire retardant furniture's, carpets, curtains, etc.
m) Follow good housekeeping practices – because a clean house is a safe house.

1) *Fire Evacuation:* Fires are often inspected but that are usually predictable in their behavior. People, however, are unpredictable in their behavior with fire. People often panic when faced with a fire situation. During the fire, you should follow the following procedures to evacuate.

a) During fire do not use the elevator.
b) Use a building telephone only if you are safe from the fire.
c) While exiting, walk and do not run.
d) If possible shut all doors behind you and alert those who have difficulty hearing that an emergency evacuation of the building is under-way.
e) Proceed along the corridors and through exits in a quite and orderly manner.
f) As the high heeled shoes are hazardous while proceeding down stairs, it is advisable to remove them before entering the stairwell.
g) Do not push or jostle.
h) Assist persons requiring assistance to reach the nearest safe exit. It may be necessary to hold persons requiring assistance in or near the exit.
i) In case you use an escape route, where there is smoke, stay as low as possible. Crawling lets you breathe the cleaner air near the floor as you move toward the exit.
j) When you are opening a closed door, feel it with the back of year hand. If it is hot, leave it closed and use your alternative escape route. If it feels normal, brace your body against the door and open it a crack.
k) If all exits are blocked by fire or smoke, enter a room preferably with an exterior window, and seal the cracks in the door with available materials to prevent smoke entering the room.
l) If possible phone or report your situation and attract the attention of someone outside the building by any possible means
m) When you have reached the outside of the building, move away from the exit allowing others behind you to emerge.
n) Do not attempt to drive your vehicle from the parking area.
o) Do not enter the building again until permitted by a fire department officer of fire officer.
p) Choose a safe meeting place outside the house.
q) If a refuge area is provided, move to these areas.

IV. ACCIDENT INVESTIGATION

A. Introduction

The prime objective of accident investigation is prevention. Finding the causes of an accident and taking steps to control or eliminate it can help prevent similar accidents from happening in the future. Accidents can rarely be attributed to a single cause. Work environment, job constraints, and supervisory or worker experience can all play a part. These factors must be examined to determine what role each had in causing the accident.

Once the causes are established, precautions must be identified and implemented to prevent a recurrence. Investigators must always keep in mind that effective accident investigation means fact-finding, not fault-finding.

To explain why and how an accident happened, investigators must collect information on the events that took place before and during the event.

Investigators can then determine accident conditions by examining physical evidence and interviewing witnesses. Both of these steps are of equal importance and should be done as soon as possible to ensure complete accident investigation. Equally important is the need to document the steps that were taken immediately after the accident to deal with the emergency and to begin the investigation. It also identifies the forms to be used and the procedures to be followed within specified time frames.

In order for an investigation to be a valuable tool in accident prevention, three things must take place:

1) the information gathered must be analyzed;
2) corrective action must be taken; and
3) the action must be monitored for effectiveness.

B. Steps Involved In Accident Investigation

1) First
   a) Report the incident occurrence to a designated person within the organization.
   b) Provide first aid and medical care to injured person(s) and prevent further injuries or damage.
2) The incident investigation team would perform the following general steps
   a) Scene management and scene assessment (secure the scene, make sure it is safe for investigators to do their job).
   b) Witness management (provide support, limit interaction with other witnesses, interview).
   c) Investigate the incident, collect data.
   d) Analyze the data, identify the root causes.
   e) Report the findings and recommendations.
3) The organization would then
   a) Develop a plan for corrective action.
   b) Implement the plan.
   c) Evaluate the effectiveness of the corrective action.
   d) Make changes for continual improvement.

As little time as possible should be lost between the moment of an incident and the beginning of the investigation. In this way, one is most likely to be able to observe the conditions as they were at the time, prevent disturbance of evidence, and identify witnesses. The tools that members of the investigating team may need (pencil, paper, camera or recording device, tape measure, etc.) should be immediately available so that no time is wasted.

C. Purpose Of Accident Investigation

There are several definition for accidents. In the context of accident investigation, here we will use the definition that an accident is an unplanned, unwanted, but controllable event which disrupts the work process and inflicts injuries.

An accident investigation may have different purposes.

1) Identify and describe the true course of events (what, where, when)
2) Identify the direct and root causes / contributing factors of the accident (why)
3) Identify risk reducing measures to prevent future, comparable accidents (learning)
4) Investigate and evaluate the basis for potential criminal prosecution (blame)
5) Evaluate the question of guilt in order to assess the liability for compensation (pay)

In an accident investigation, one tires to obtain answers to the following questions: what happened, why it happened, and how could this have been prevented?

An accident investigation should adopt a systematic approach to identify the factors leading to the accident, and in addition, it should examine what improvements are needed in the work environment and in organisational procedures as well as clarifying the responsibilities of each participant. The use of a systematic approach confers reliability on the investigation and making it possible to describe in a comprehensive manner the course of accident and all factors influencing the accident. In brief, one needs to have rules of conduct for an investigation: who should participate and how to implement the investigation in practise.

After every incident and accident, we should decide what kind of safety measures, guiding, training and information will be needed in the workplace to prevent the same kind of incidents and who should deal with this information in the first place.

V. THEORIES OF ACCIDENT INVESTIGATION

A. Introduction

Accidents are unplanned occurrences involving movement of persons, objects or materials which may result in injuries, damages and losses to properties or people. The majority of accidents happen as result of unsafe acts and unsafe conditions. Since all hazards in construction workplaces are not always possible to be identified and eliminated therefore effective accident investigation programs are essential for collecting critical data. Accidents can be prevented just by identifying the root causes of accidents, which is possible by accident investigation techniques such as theories of accident causation theories and human errors; these theories provide explanations of why accidents happen. This paper is aimed at reviewing the most common accident causation theories which mainly focus on people variable, management aspects and physical characteristics of hazards.

The intention of this paper is to enhance the overall understanding of the accident causation theories which signifies the identification of how hazards in the workplaces cause losses. On the contrary the weakness of these theories is that they do not offer extensive strategic guidelines for managers and supervisors for reducing risks at construction workplaces. Moreover, these theories imply the inappropriate perception that accidents in workplaces can be prevented if human errors are eliminated. Strategies need to be revised to manage the risk and workers need to be watchful of it. A great number of accidents can be prevented if the safety management system reflects both natural degradation and these intrinsic threats. The initial step in developing such system is preparing a model which shows the interaction between the accident likelihood and organizational tasks and activities in the presence of these hazards.

1) *Heinrich Domino Theory Of Accident Causation:* Heinrich was the pioneer in the Accident causation theories. He described the accidents causation theory, man and machine relationship, frequency and severity relation, unsafe acts reasons, management role in accident prevention, costs of accidents and the impact of safety on efficiency .According to statistics on accident's reports Heinrich deduced that 88 percent of accidents are due to unsafe act of workers, 10 percent due to unsafe conditions and 2 percent of all accidents are associated with act of God such as natural disasters. According to his analysis Heinrich defined accident as 'an unplanned and uncontrolled event in which the action or reaction of an object, substance, person, or radiation results in personal injury or the probability thereof. Heinrich(1959) described the accidents causation theory, man and machine relationship, frequency and severity relation, unsafe acts reasons, management role in accident prevention, costs of accidents and the impact of safety on efficiency

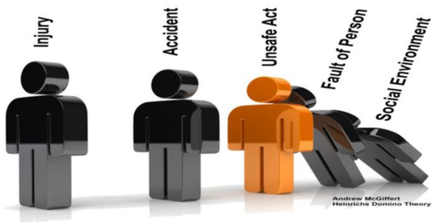

Fig-5.1Heinrich Domino Theory

2) *Multiple Causation Model (Petersen, 1971; Non-Domino-Based Model):* The Heinrich domino theory is structured on theory that an accident is caused by a single cause.Petersen (1971) developed a model based on management system rather than individual. Petersen believed that there are two major features of the events which leading to an accident, namely an unsafe act and an unsafe condition. However, there are more than single cause which contribute or lead to both unsafe act and unsafe condition and finally occurrence of an accident. Unlike simplified theory of domino, there are causes and sub-causes when an accident happens. Through identification of these multiple contributing causes of accident, the unsafe acts and unsafe conditions should be prevented from arising.

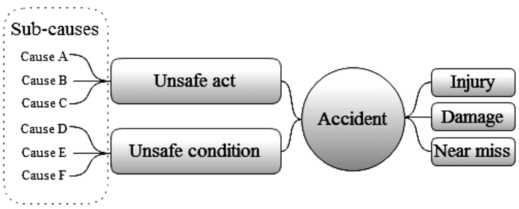

FIG 5.2 Multiple Causation Theory

3) *Updated Domino Sequence (Bird, 1974; Domino-Based Model):* Bird and Loftus (1974) updated the "Domino theory" in order to reflect the role of management system in the sequence of accident causes defined by Heinrich (Domino-based model)

The updated and modified sequence of events is

a) Lack of control/management (inadequate program, inadequate program standard, inadequate compliance to standard)
b) Basic causes/origins (basic causes: 1-personal factors, 2-job factors)
c) Immediate causes/Symptoms (sub-standard act and condition)
d) Incident (contact with energy and substance)
e) Loss (property, people, process)

The update domino sequence can be used and applied to all types of accidents and is fundamental inloss control management

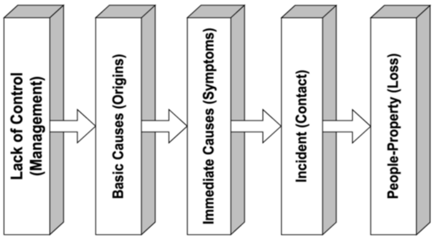

FIG 5.3 Updated Domino sequence of accident causation theory (Bird 1974)

4) *The 'Swiss Cheese' Model:* The 'Swiss Cheese' accident causation model was first developed by James Reason (1970-1977) as a linear accident causation model. The theory is currently widely used since it simply suggests that the organizations try to prevent accidents by defences in order not to allow the risks and hazards become loss (See Figure 5). These organizational defences are divided into two groups

a) Hard defences which are automatic alarming systems, physical obstacles, engineered safety appliances and weak points included into the main system for protection such as fuses.

b) Soft defences which are dependent upon the personnel and procedures; regulations of required performance, investigation, checking, regular procedures of performance, education and training, supervision and working permission. Soft defences also involve supervisors and operators as the pioneers. Losses to people, equipment, assets are the potential consequences of hazards in an organization.

Reason claims that a trade-off exists between the level of protection provided for the product and the production; the risks included in any product should be defended by the organization for the wellbeing of customers but the level of safety and protection should be equivalent to the risks associated with the work. If the level of protection is higher than required then the company will not be commercially profitable and if the protection level is less than the associated risks the occurrence of accident is susceptible and the organization will lose the business opportunities. The equilibrium between the protection and the production is essential for the durable commercial survival of the business; since the production process is visible the product can be managed and inspected for the desired output but the level of protection can be measured only after the inadequacy is determined.

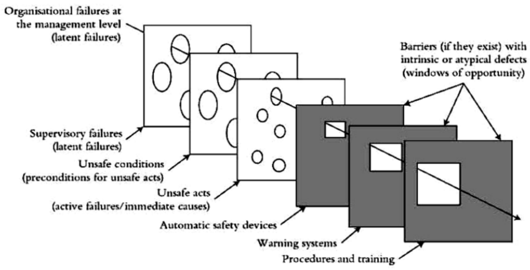

FIG 5.4 Swiss Cheese Accident Causation

VI. ACCIDENTS IN CHEMICAL PLANT AND RECOMMENDATIONS

A. *Introduction*

Workplace safety and health (WSH) plays a key role in a chemical plant in achieving better productivity and good reputation. Hence, every chemical plant should be designed to be safe and easy to manage and operate. However, accidents can still occur due to other factors such as technical and engineering failures, human errors or management/procedural faults.

B. *Chemical Splash at Process Plant*

Description of Incident A worker was sent to collect samples from a process plant at midnight as there was a recent process upset. For a representative sample, flushing of the sampling line was carried out before taking the actual sample. The worker drained the flushing liquid into an open bucket which would then be disposed into a waste pit. When the worker failed to locate the hatch on the pit cover for proper disposal of the liquid, he decided to open the pit cover. While moving the pit cover, the worker knocked over the bucket. Contents from the bucket splashed onto his arms, neck and lower half of his face. The worker suffered from chemical burns as result of the incident.

1) *Possible Causes And Contributing Factors*
a) *Medium*
i) The work area was insufficiently lit for the task and made it difficult for the worker to locate the hatch on the pit cover to carry out the disposal.
b) *Man*
i) The worker decided to open the pit cover to dispose the flushing liquid when he failed to locate the disposal hatch.
ii) While moving the heavy pit cover, the worker lost his balance and knocked over the bucket containing flushing liquid from the sampling line.
c) *Management*
i) Risk assessment was not performed; hence the job hazards were not identified.
ii) There was no safe work procedures for proper disposal of flushing liquid.
iii) The worker was not provided with suitable PPE for protection against chemical splash during the sampling and disposal process.
2) *Recommendations And Learning Points:* Carry out risk assessment prior to any work involving hazardous chemicals and develop safe work procedures to include all control measures used to address the identified risks. Control measures to be put in place to ensure that risks are kept to a level as-low-as reasonably-practicable (ALARP).
a) Ensure any deviation from the standard operating procedures, such as opening of the pit cover, as mentioned in this case, is subjected to management of change and risk assessment before implementation.
b) Ensure all workplaces, including outdoor work areas are adequately lighted, especially at night.
c) Paint the disposal hatch in a different colour to make sure it is clearly visible.
d) Equip workers with suitable PPE like safety goggles, face shield, long sleeved chemical-resistant aprons, rubber gloves and safety shoes. Ensure that they are worn correctly for protection against chemical splash during sampling and disposal.
e) Use sealed containers instead of open buckets to transfer hazardous chemicals if manual transfer is absolutely required. Where possible, eliminate the need for manual transfer by redesigning the sampling line to include in-line or closed loop flushing system direct to disposal pit.

C. *Chemical Burns During Blending Operation*

After carrying out a chemical blending operation, a worker felt severe pain in the fingers of his left hand. As the pain did not subside, he was sent to the hospital for treatment and was warded for one day. He was also given a total of 16 days of medical leave.
a) Possible causes and contributing factors
b) Mission
i) The blending operation involved a highly corrosive substance, hydrofluoric (HF) acid. **MAN**
ii) The worker removed his impervious gloves and replaced them with cotton gloves during the blending operation as he thought that the cotton gloves would provide sufficient protection.
1) *Recommendations And Learning Points*
a) Use the correct equipment for storage and handling of corrosive substances. Equipment used for storing or handling corrosive substances must go through a preventive maintenance programme to ensure that the equipment remains fit for use.
b) Ensure all chemical containers are labelled clearly. The relevant SDS for each chemical should be made easily available to the workers so that they can quickly identify the hazardous properties of the chemical being handled.
c) Provide workers with proper documentation of the safe work procedures specifying the correct PPE (e.g., face shield, chemical protective suits, chemical resistant gloves) to be used during the chemical blending operation. Specifically to this incident, impervious gloves must be provided for basic hand protection and properly fitted for firm grip.
d) Organise sufficient training in hazard communication and conduct safety briefings so that workers are fully aware of the hazards and risks associated with the chemical(s) in use.
e) Provide local exhaust ventilation and/or respiratory protection for the chemical blending operation to prevent or minimise inhalation of toxic and/or corrosive vapours.

VII. FUTURE WORK AND CONCLUSION

Accidents and incidents in workplaces are unplanned and unwanted occurrences involving movement of persons, objects or materials which may result in injury, damage or loss to property or people. The majority of accidents happen when employees disregard safety rules (Unsafe acts) and management ignore the presence of unsafe conditions. Therefore unsafe acts and unsafe conditions are the immediate (direct) causes of accidents.

On the other hand, physical and mental condition of the person as well as environmental forces and supervisory safety performance are the contributory (indirect) causes of accidents. Accidents are determined to follow a pattern; accidents causation theories and models provide explanations of why accidents and incidents happen.

All the accident causation theories and models developed have considerably increased the understanding of accidents and how they happen. They have stimulated a strong and powerful emphasis on the role of human error which has resulted into a reasonable place for training and education of workers in order to develop competencies and safety awareness.

However there is a fundamental dilemma which is the different interpretations of risk, safety and the extent of risk which needs to be reduced to be acceptable. People are likely to believe that once an action is executed in response to a hazard, the situation is safe or safe enough. The weakness of the accident causation theories is that they do not offer extensive strategic guidelines for managers and supervisors for reducing risks at construction workplaces. Moreover, these theories have implied the inappropriate perception that accidents in workplaces can be prevented in case human errors are eliminated. Since risk is beyond the human intervention, not all accidents are preventable. Strategies require to be revised in a manner to manage the risk and workers need to be watchful of it.

A great number of accidents can be prevented if the safety management system reflects both natural degradation and these intrinsic threats. The initial step in developing such system is preparing a model which shows the interaction between the accident likelihood and organizational tasks and activities in the presence of these hazards

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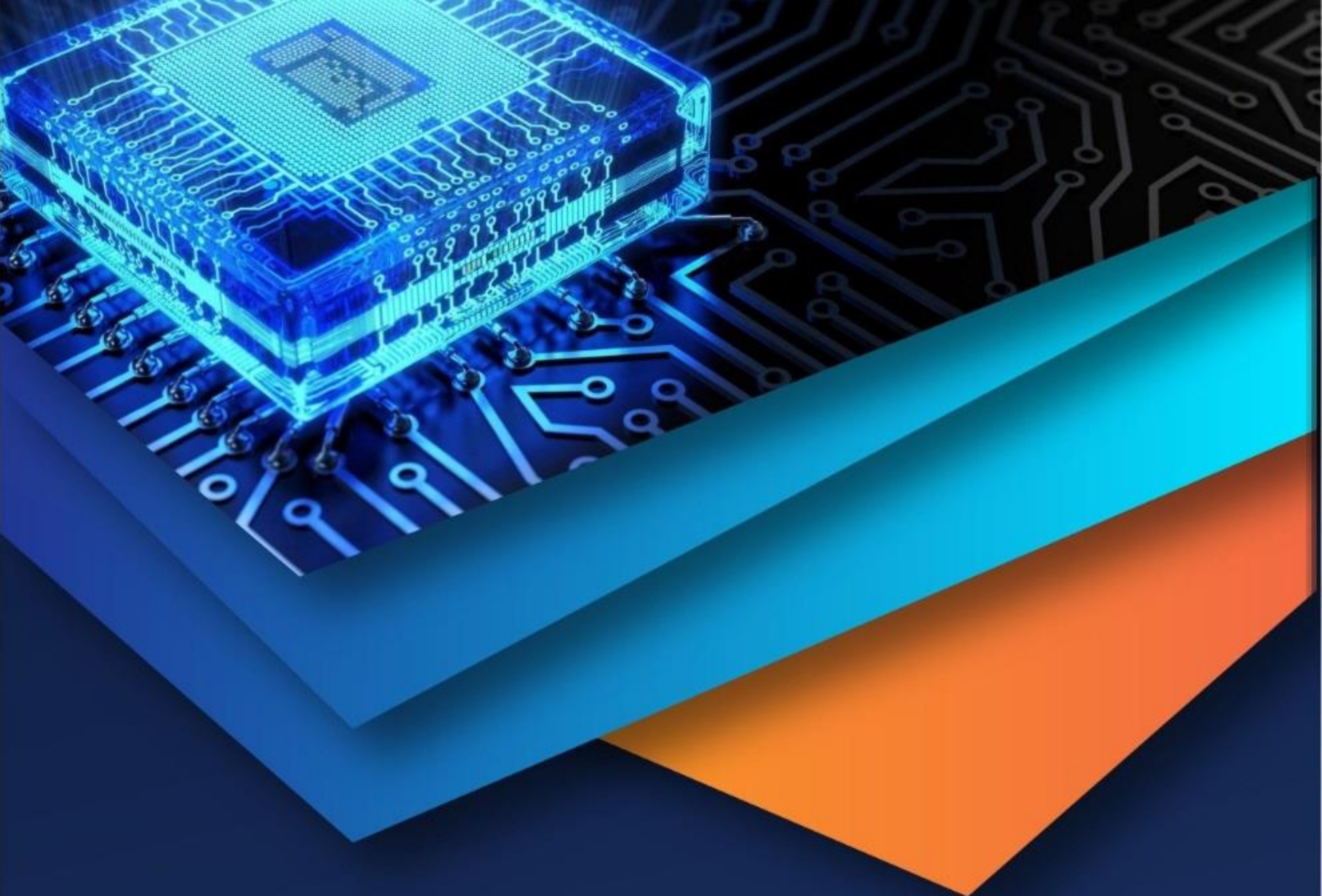

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