A Course on Health, Safety & Accident Management

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I. Introduction

The rapid growth and expansion of the chemical industry has been accompanied by a spontaneous rise in human, material, and property losses because of fires, explosions, hazardous and toxic spills, equipment failures, other accidents, and business interruptions. Concern over the potential consequences of catastrophic accidents, particularly at chemical and petrochemical plants, has sparked interest at both the industrial and regulatory levels in obtaining a better understanding of the subject of Health, Safety, and Accident Management (HS&AM). The development of this course was undertaken, in part, as a result of this growing concern.

The Accreditation Board for Engineering and Technology (ABET) requires that engineering graduates understand the engineer's responsibility to protect both occupational and public health safety. Traditionally, engineering schools have done a superb job of educating their students on the fundamental laws of nature governing their fields and on the application of these laws to engineering problems. Unfortunately, they have been less successful in conveying to the students the importance of occupational and environmental safety in the design of chemical processes. This concern also served as a driving force for the development of this course.

This course is divided into five parts: the problem(s), accidents, health risk, hazard risk, and hazard risk analysis. Part I, an introduction to HS&AM, presents legal considerations, emergency planning, and emergency response. This Part basically serves as an overview to the more technical topics covered in the remainder of the course. Part II treats the broad subject of accidents—discussing fires, explosions and other accidents. Parts III and IV provide introductory material to health and hazard risk assessment, respectively. Part V examines hazard risk analysis in significant detail. This final Part includes material on fundamentals of applicable statistics theory, and the calculations and applications of hazard risk analysis in real systems. In addition to a detailed course outline, the paper is complimented with three illustrative examples and a homework problem set.

II. Course Content

Details on course content are provided below. A short introduction to each of the five Parts of the course is followed by the subject matter for each topic. This material is essentially the proposed Table of Contents for the 2001 Marcel Dekker book titled "Health, Safety and Accidental Management in the Chemical Process Industry", authored by Flynn and Theodore.

Part I

Part I of this course serves as an introduction to Health, Safety and Accident Management. The more technical aspects of this subject –accident and emergency details, health and hazard risk assessment, etc. – are covered in the remaining Parts of the course. There are three topics in Part I. In Topic 1, the history of accidents is examined from early incidents to recent catastrophes. The evolution of safety precautions, particularly as they apply to chemical plants, is also reviewed. Topic 2 is concerned with legislation. The fear of accidents is probably the major reason for the promulgation of emergency planning and response legislation. The major applicable legislation—the *Clean Air Act,* the *Clean Water Act,* the *Resource Conservation and Recovery Act* (RCRA), the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA), and the *Superfund Amendments and Reauthorization Act* (SARA) are discussed. Increased public awareness is the major goal of the new legislation. Title III, which is the heart of SARA, establishes requirements for emergency planning and "community right to know" for federal, state, and local governments as well as for industry. Title III is a major stepping-stone in the protection of the environment, but its major principal thrust is to facilitate planning for possible catastrophes. A more comprehensive examination of Title III is provided in Topic 3—Emergency Planning and Response.

Topic 1: Past History
Topic 2: Legislation
Topic 3: Emergency Planning and Response

Part II

Many of the accidents described in Topic 1 are plant and/or process related. For this reason, Topic 4 and 5 are devoted entirely to process fundaments and plant equipment, respectively. The material is presented in the traditional engineering format, but without specific references to accidents and emergencies. Topic 6 provides a basic overview of fires, explosions, and other potential accidents. Topic 7 focuses on the means to reduce the frequency of accidents, particularly in industry. Part II concludes with Topic 8, which addresses the process application of several chemicals that are considered to be highly toxic; these include chlorine, ammonia, hydrogen cyanide, hydrogen fluoride, and sulfuric acid. Physical and chemical properties, health effects, and methods of manufacture of these chemicals are discussed in conjunction with potential causes of release.

Topic 4: Process Fundamentals
Topic 5: Process Equipment
Topic 6: Classification of Accidents
Topic 7: Fires, Explosions, Toxic Emissions and Hazardous Spills
Topic 8: Process Applications

Part III

Most human or environmental chronic health hazards can be evaluated by dissecting the analysis into four parts: hazard identification; dose-response assessment or hazard assessment; exposure assessment; and, risk characterization. For some perceived hazards, the risk assessment might stop with the first step (hazard identification) if no adverse effect is identified or if an agency elects to take regulatory action without further analysis. Regarding hazard identification, a hazard is defined as a toxic agent or a set of conditions that has the potential to cause adverse effects to human health or the environment. Hazard identification involves an evaluation of various forms of information in order to identify the different hazards. Dose-response or toxicity assessment is also required in an overall assessment; responses/effects can vary widely since all chemicals and contaminants vary in their capacity to cause adverse effects. This step frequently requires that assumptions be made to relate experimental data for animals and humans. Exposure assessment is the determination of the magnitude, frequency, duration, and routes of exposure of human populations and ecosystems. Finally, in risk characterization, toxicology and exposure data/information are combined to obtain a qualitative or quantitative expression of risk. Following an introduction to this area (Topic 9), these four subjects are treated in detail in Topics 10-13.

Topic 9: Introduction to Health Risk Assessment
Topic 10: Health Hazard Identification
Topic 11: Dose-Response
Topic 12: Exposure Assessment
Topic 13: Health Risk Analysis and Characterization

Part IV

There are four basic steps in evaluating the risk of an “acute” accident. These include: event identification; accident probability; evaluation of accident consequences; and, risk determination. An introduction to the subject is presented in Topic 14. The four basic topics described above are reviewed in Topics 15-18.

Topic 14: Introduction to Hazard Risk Assessment
Topic 15: Event/Hazard Identification

Topic 16: Accident Causes and Probability
Topic 17: Accident Consequences and Evaluation
Topic 18: Hazard Risk Analysis

Part V

Part V of the book reviews and develops quantitative methods for the analysis of hazardous conditions in terms of the frequency of occurrence of unfavorable consequences. Uncertainty characterizes not only the transformation of a hazard into an accident, disaster, or catastrophe, but also the effects of such a transformation. Measurement of uncertainty falls within the purview of mathematical probability. Accordingly, Topic 19 presents fundamental concepts and theorems of probability used in risk assessment. Topic 20 discusses special probability distributions and techniques pertinent to risk assessment, and Topic 21 presents actual case studies illustrating techniques in hazard and risk assessment that use probability concepts, theorems, and special distributions.

Topic 19: Hazard Risk Assessment Fundamentals
Topic 20: Hazard Risk Assessment Calculations
Topic 21: Hazard Risk Analysis Applications

III. Illustrative Examples

Nearly 75 illustrative examples are reviewed in this course. Three samples are presented below to illustrate the varied nature of the types of problems that are introduced to the students.

Example 1 (from the Topic, *Dose-Response*)

The air in a factory contains 500 ppm of butane (TLV = 800 ppm), 100 ppm of cyclohexane (TLV = 300 ppm), 100 ppm of ethyl ether (TLV = 400 ppm) and 500 ppm of liquid petroleum gas (TLV = 1000 ppm). Is this a safe work place?

Solution 1

When two or more hazardous substances which act upon the same organ system are present, their combined effect, rather than the isolated individual effects, must be calculated. If the sum of the following fractions exceeds unity, the threshold limit of the mixture has been exceeded. Thus,

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \frac{C_4}{T_4} + \ldots \frac{C_n}{T_n} > 1; \quad \text{Not a safe working place}$$

$$= 1; \quad \text{Caution}$$

$$< 1; \quad \text{A safe working place}$$

where C = concentration measured in work area, ppm;

T = corresponding threshold limit values, TLVs, ppm.

Based on the equation presented above, the mixture of butane, cyclohexane, ethyl ether and liquid petroleum gas is evaluated in terms of the combined TLVs as follows:

butane + cyclohexane + ethyl ether + liquid petroleum gas = ?

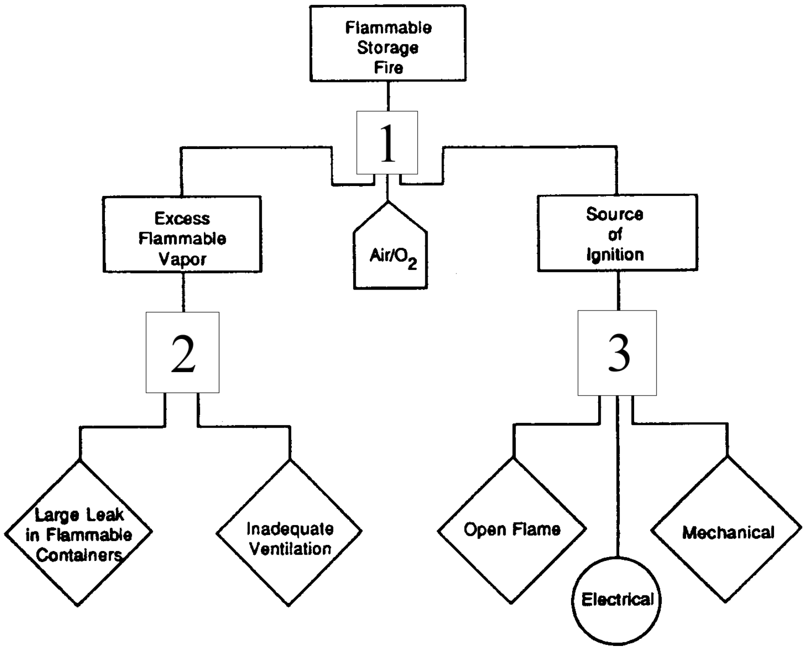
$$\frac{500\text{ppm}}{800\text{ppm}} + \frac{100\text{ppm}}{300\text{ppm}} + \frac{100\text{ppm}}{400\text{ppm}} + \frac{500\text{ppm}}{1000\text{ppm}} = 1.708 > 1$$

Therefore, this room is not a safe working place and should be controlled to prevent life and health-threatening situations at this facility.

For Threshold Limit Values (TLVs) of other chemicals, refer to the American Conference of Industrial Hygienist Handbook.

Example 2 (from the Topic, *Accident Causes and Probability*)

Consider the following fault tree for a flammable storage tank fire. Identify whether the numbered boxes are (and) or (or) gates.



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Solution 2

The numbered boxes above are as follows:

1. For a Flammable Storage Fire to occur, Excess Flammable Vapor and Air/O_2, and Source of Ignition must be present. Therefore, Box 1 is an *and* gate since all situations must occur.
2. For Excess Flammable Vapor to occur, a Large Leak in Flammable Containers or Inadequate Ventilation must be present. Therefore, Box 2 is an *or* gate since only one situation need occur.
3. For a Source of Ignition to occur, there must be an Open Flame or an Electrical Ignition or a Mechanical Ignition must be present. Therefore, Box 3 is an *or* gate since only one situation need occur.

Example 3 (from the Topic, *Process Equipment*)

List and briefly discuss the various types of fire system equipment.

Solution 3

Chemical plants require a well-engineered system for fire protection. Many of the basic fire protection facilities must be incorporated into the original plant design in order to achieve maximum effectiveness. Fire extinguishing facilities and equipment should include:

1. Water supply – It is the most important of all extinguishing agents for most chemical plant fires. The water supply should be sufficient to fulfill the demand for automatic protection and hose streams for at least a four-hour period. Allowance should be made for explosion damage to the system and protection against freezing.
2. Distribution system–This system should cover all facets of outside fire protection water demands in order to provide adequate water distribution for existing conditions and the possibility of plant expansion.
3. Monitors and deluge sets–Many chemical plants use monitors for general use and for high hazard locations in order to provide maximum water supply with a minimum of manpower exposure. Deluge sets supported by ample hose streams are preferred for some protection uses.
4. Sprinkler and water spray installations–Many process and storage area buildings should be protected by automatic sprinkler systems. The size and arrangement for water supply are dependent upon the nature of the hazard and the degree of protection desired. Water spray installations are particularly adapted for cooling uninsulated steel structures, elevated pipe lines, vessels, spheres, and similar plant installations.
5. Foam extinguishing system–Available in automatic and manual systems, foam has the ability to adhere to surfaces, and thus provide a blanketing as well as cooling effect.

6. Carbon dioxide systems–This system can be used where there is a handling and storage of gaseous and flammable materials, electrical equipment, and hazardous solids by introducing an inert gas (such as carbon dioxide) into the area in order to reduce the concentration of oxygen to the point where the fire will be extinguished.
7. Dry chemical extinguishing systems–This is used primarily for flammable liquid fires since they provide rapid flame extinguishment.
8. High expansion foam systems–This is a concentration of air-filled bubbles resulting from the mechanical expansion of a foam solution to smother surface fires involving flammable liquids.
9. Halogenated extinguishing systems–This system can be used to protect flammable liquid storage and processing units. It is used with caution since, in the appropriate concentration, the products of decomposition are toxic and can result in injury or death of exposed personnel. These systems have become less popular in recent years because of environmental concerns.
10. Combination extinguishing systems–Combining dry chemicals and foam agents unites the fast flame control of the dry chemical with the cooling and sealing ability of foam to provide an efficient portable extinguishing system.
11. Portable extinguishers–These are used in small fires since they can easily be transported and operated. Ideal placement would be in laboratories and pilot plant installations where fires of limited size can be anticipated.

IV. Problems

The problem section from the Topic, *Fires, Explosions, Toxic Emissions, and Hazardous Spills* is presented below. These essentially serve as the homework problems for the topic in question.

1. Calculate the upper and lower flammability limits of a gas mixture that consists of 50% methane, 10% ethane, and 40% pentane by volume.
2. Calculate the burning velocity of a paraffin hydrocarbon gas-air mixture at 150°C if the burning velocity of the mixture is 45 cm/s at 25°C and 80 cm/s at 38°C.
3. Calculate the peak overpressure of a 50-pound TNT explosion at a distance 200 feet from the ignition point, if the peak overpressure at 1000 feet is 0.10 psi when 150 pounds of TNT is detonated.
4. Calculate the fluid expansion energy for an isothermal expansion for a cylindrical vessel at 550°C with initial and final pressures of 147 and 450 psi, respectively.
5. Calculate the discharge rate of butane through a 50-mm diameter hole at 10 bar, 25°C with 10 m liquid head.
6. With reference to Problem 6, recalculate the butane emission rate in kg/s if the discharge occurs through a 20-mm by 100-mm rectangular opening.

Note: A solution manual to all the problems presented in the Marcel Dekker book referred to earlier is available.

V. Conclusions

The course has been successfully offered at Manhattan College six times as either a graduate course (700-level) or a combined senior undergraduate—graduate course (500-level). The course has been traditionally populated by chemical engineering students but graduate mechanical and environmental engineering students have also registered for the course. In addition, the course was presented to engineering faculty through a National Science Foundation (NSF) grant in 1992; that effort resulted in the publication of a text titled “Accident and Emergency Management: Problems and Solutions”. The course was also offered twice to USEPA regulatory personnel through the Air Pollution Training Institute (APTI).

ANN MARIE FLYNN became the newest member in the Chemical Engineering Department at Manhattan College, when she joined the faculty in the Fall of 1996. She is also a graduate of Manhattan College, receiving her Bachelors degree in 1981 and her Masters in 1991. Both degrees were in Chemical Engineering. She received Ph.D. in Chemical Engineering from the New Jersey Institute of Technology in January, 2000.

JOSEPH REYNOLDS is a Professor of Chemical Engineering at Manhattan College and was Chairman of the Chemical Engineering Department from 1976 to 1983. He is listed in *American Men and Women in Science, Who’s Who in Technology Today, Who’s Who Among America’s Teachers, International Who’s Who in Engineering, Who’s Who in the East,* and *Who’s Who in Engineering.*

LOUIS THEODORE is Professor of Chemical Engineering at Manhattan College. Dr. Theodore is the recent recipient of the International Air and Waste Management Association’s prestigious Ripperton award and the recipient of the American Society for Engineering Education (ASEE) AT&T Foundation award for "excellence in the instruction of engineering students".