SAFETY AND LOSS PREVENTION IN THE UNDERGRADUATE CURRICULUM

A Dual Perspective

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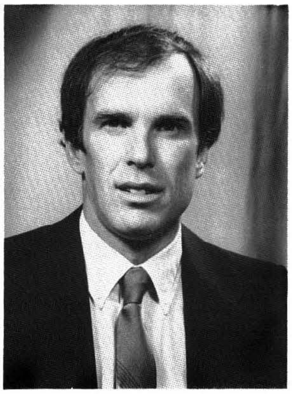
RECENT CHEMICAL PLANT accidents in India and in Switzerland have increased public and industry-wide concern and awareness of safety and loss prevention. This is in spite of the fact that the chemical process industries are safer than most other industries [1]. However, due to the potential for a serious plant accident, both the public and industry recognize that safety must be increased.

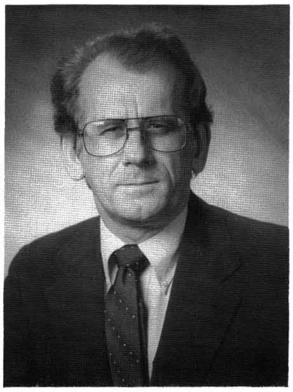
The AICHE is taking considerable steps to improve safety. First, it has formed a Center for Chemical Process Safety with the charge to "address the concerns about the handling of toxic or reactive materials and the safety of plant operating procedures" [2]. Second, it has formed the Design Institute for Emergency Relief Systems (DIERS) User Group to continue the cooperative industrial activities to extend the DIERS technology [3]. And third, a Task Force on Safety and Health in the Undergraduate Curriculum has been formed under the Safety and Health Division of the AICHE with the major objective to "identify the key concepts of loss prevention, safety, and health which should be considered essential for accreditation of the curriculum by 1990" [4]. As a result of this new awareness and concern for safety, it is apparent that safety and loss prevention will become a part of the future undergraduate chemical engineering curriculum.

Most undergraduate chemical engineering curricula in the United States contain little in the way of safety and loss prevention. In fact, university laboratories are, typically, serious safety offenders.

Great Britain has had an ambitious safety and loss prevention program in their undergraduate curriculum for some years now. This is a result of a substantial chemical process accident that occurred at Flixborough, England, in 1974 [1]. All British chemical, engineering curricula are presently required to contain a significant amount of safety related content for accreditation. This is achieved through a combination of dedicated courses or by demonstrating a certain fraction of safety related content in the existing courses.

This article will provide a dual perspective on the need for more emphasis on safety in our chemical engineering undergraduate curricula. Both the academic





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> **This article provides[s] a dual perspective on the need for more emphasis on safety in our . . . undergraduate curricula. Both the academic and industrial viewpoints [are] presented. We . . . also discuss a unique safety related course development effort being undertaken at Wayne State and Michigan Tech Universities . . .**

and industrial viewpoints will be presented. We will also discuss a unique safety related course development effort being undertaken at Wayne State University and Michigan Technological University, with substantial technical assistance from BASF Corporation. This program is being supported by the National Science Foundation under its University/Industry/Government (UIG) program.

THE UNIVERSITY PERSPECTIVE

Dan Crowl

In the summer of 1986 I had an opportunity to spend a few months at BASF Corporation working on a computer simulation project. One day I was visited by Joe Louvar, Director of Chemical Engineering, who asked me if I was interested in working on a few safety related projects. In total ignorance I replied, "You mean hard hats and safety shoes?" Joe went on to explain some of the more fundamental aspects of safety, including reactor dynamics, two-phase flow during reactor venting, gas dispersion models, and so forth. It had never occurred to me that safety had a fundamental aspect! I had always assumed safety was simply a set of rules developed as a result of practical experience.

During the remainder of my stay at BASF, I observed how safety was practiced in an industrial environment. It became apparent to me that practicing chemical engineers spend a considerable amount of time on safety related activities. In spite of all my years of academic training, I felt woefully inadequate with respect to safety. I could indeed understand pieces of the fundamental components, but using those pieces in the practical application and management of safety seemed a mystery to me.

Despite a continuing feeling of inadequacy, I was now aware of safety. I began to look at my past academic experiences and at the experiences we are providing for our present students. I found little in the way of safety instruction. Many of you will argue that the academic experience is designed to provide only a fundamental knowledge, with practical application being the responsibility of industry. But safety is a systems science, involving the application of a broad range of fundamental skills strongly coupled with practical application. Why not adjust the fundamental skills taught to our undergraduates to strengthen the safety aspect? Can the academic community continue to neglect an area that is already very important to the industrial community?

As an undergraduate I learned that process design is motivated by savings in material usage and capital investment. In the 1970's energy also became an important driving force in design. Now, safety considerations are becoming just as important.

The academic community is in a difficult position with respect to safety. First, most faculty have little safety experience. This is either a result of little industrial experience or of participation in industry during a time when safety was a lower priority and was practiced in a different fashion than it is today. Second, we have inadequate equipment and facilities for demonstrating safety. Finally, our curricula are already at their practical maximums. Where can we find room to add a safety component?

One possibility is to add safety instruction throughout all of the chemical engineering courses. Safety is practiced in every aspect of the industrial experience, so why not practice it throughout the entire undergraduate course sequence? I agree with this approach. However, a final capstone course is necessary to culminate the course sequence. One can teach reactor safety (runaway reactors) in the kinetics and reactor design course, but a capstone course is essential for the teaching of safety reviews, hazard identification, risk assessment, and other topics that are special to safety.

I recently attended the International Symposium on Preventing Major Chemical Accidents, organized by the Center for Chemical Process Safety of the AICHE. This symposium was held in Washington, DC, during the week of February 3, 1987. Of the over four hundred participants, less than five were from academia. This was surprising since the papers presented were as fundamental and research-oriented as those presented at academic conferences. I believe that safety can become an important academic area if faculty become aware of 1) the potentially fundamental nature of safety, and 2) the opportunities for research and funding. Safety is an excellent area for industry/academic research collaboration since most of the industrial proprietary barriers dissolve.

Safety is an essential part of the industrial experience, more now than some of the traditional fundamental chemical engineering areas. I believe it is time to include safety as an important part of the undergraduate chemical engineering experience as well.

THE INDUSTRIAL PERSPECTIVE

Joe Louvar

All of my safety knowledge has been acquired in an industrial setting. It came in bits and pieces, and it took several years to really appreciate the significance, the subtlety, and the technical complexity of chemical process safety. In hindsight, I recognize that during those formative years I made many serious safety errors. It was only the result of pure chance that I escaped having serious accidents and/or injuries.

Using today's standards, most of my past errors would have been identified and corrected by supervision or by the safety review process which is used very effectively within industry. Unfortunately, I am convinced that the self-motivation necessary to take on the responsibility for safety (responsibility of every engineer), and to learn the technology of safety, still requires years within an industrial setting.

From a management standpoint I have also recognized that supervision has a serious handicap when working with fresh graduates. Although they have an

TABLE 1

Course Outline

1. ***Introduction***
   - **A. Course syllabus**
   - **B. Introduction**
   - **C. Accident and loss statistics**
   - **D. The accident process**
   - **E. Three significant disasters**
   - **F. Personal and management responsibilities**
   - **G. Legislative responsibilities**
   - **H. Employee and community "right to know"**
2. ***Fundamentals of Safety***
   - **A. Toxicology, industrial hygiene and exposure control**
     - **1. Toxicology**
       - **History**
       - **Dose *vs* response**
       - **How the body responds to exposure**
       - **Determining safe working levels**
     - **2. Industrial hygiene and exposure control**
       - **Types of exposure**
       - **Methods for exposure control**
       - **Administrative and engineering methods**
       - **Personal protection**
   - **B. Fires**
     - **1. Flammability of vapors and liquids**
     - **2. Minimum oxygen concentration**
     - **3. Inerting**
     - **4. Autoignition temperature**
     - **5. Auto-oxidation**
     - **6. Adiabatic compression**
     - **7. Effects of sprays and mists**
   - **C. Explosions**
     - **1. Definitions: Explosion, detonation, deflagration, confined and unconfined vapor explosion, BLEVE**
     - **2. The nature of the explosion process**
     - **3. Effects of explosions**
     - **4. Calculations relating to explosions**
   - **D. Liquid and Vapor releases**
     - **1. Gaussian distribution**
     - **2. Gaussian plume model**
     - **3. Gaussian puff model**
     - **4. Spill models**
     - **5. Inhalation exposure: spills or from vessels**
     - **6. Inhalation exposure: filling containers**
3. ***Applications for safety***
   - **A. Introduction**
   - **B. Designing for safety**
     - **1. Intrinsic design**
     - **2. Extrinsic design**
     - **3. Maintenance**
   - **C. Engineering to Prevent Fires and Explosions**
     - **1. The Fire Triangle**
     - **2. Passive Protection Methods**
       - **Types of environments**
       - **Eliminating sources of ignition**
       - **Atmospheric control, including inerting and purging**
       - **Plant siting**
     - **3. Active Protection Methods**
       - **Shutoff and check valves**
       - **Combustible gas monitors**
       - **Emergency material transfer**
       - **Sprinkler systems**
       - **Water *vs.* foams for fire control**
   - **D. Engineering to Prevent Toxic Release**
     - **1. Relief systems**
     - **2. Design and selection of relief valves**
     - **3. Flares, vents and scrubbers**
   - **E. Process hazards identification and risk assessment**
     - **1. Hazards identification**
       - **Hazards surveys, including the Dow Index**
       - **HAZOP**
       - **FMECA**
     - **2. Risk Assessment**
       - **Event trees**
       - **Fault trees**
       - **Consequences analysis**
       - **Limitations to risk assessment**
     - **3. Safety reviews**
4. ***Accident Investigations***
5. ***Case histories***

excellent foundation in the traditional chemical engineering fundamentals, the concepts of safety are foreign to them. In fact, they perceive safety to be unimportant because the subject is hardly mentioned during their schooling. In some universities, safety practices are totally neglected. Consequently, industry starts with graduates who need a basic improvement in attitude prior to addressing the more complex features of safety.

TABLE 2
Video Session 1

INTRODUCTION

1. **Introduction**
2. **Brief description of five video sessions**
3. **BASF Corporation's safety program**
    a. **Policy**
    b. **Committments**
    c. **Training**
    d. **Activities**
    e. **Audits**
4. **Introduction to safety terminology and principles**
    a. **XP *vs.* non-XP**
    b. **Relief *vs.* rupture disc**
    c. **Runaway reaction**
    d. **Two phase flow**
    e. **Design Institute for Emergency Relief Systems (DIERS)**

TABLE 3
Video Session 2

BASIC SAFETY EQUIPMENT AND PROCEDURES

1. **Introduction**
2. **Personal protection equipment**
    a. **Motivation**
    b. **Face and eye protection: glasses, goggles, face shield**
    c. **Clothing: aprons, gloves, suits**
    d. **Respirators: dust, cartridge, canister, air-line**
    e. **Miscellaneous: hats and shoes**
3. **Sources of toxicity and safety information**
    a. **Material Safety Data Sheets (MSDS)**
    b. **Vendor information**
4. **Safety procedures**
    a. **Hot work permits**
    b. **Lock - Tag - Try**
    c. **Vessel entry**
    d. **Grounding and bonding**
    e. **Fail safe**
    f. **Safety reviews**
5. **Safety features**
    a. **Sprinklers**
    b. **Alarms**
    c. **Showers**
    d. **Color indicator tubes**
    e. **Extinguishers**

The chemical industry is entering an era where processes will be even more complex. To prepare our future engineers for this era, I believe we must begin to educate them on the principles of safety. This education must begin at the university, with an emphasis equal to heat transfer, mass transfer, thermodynamics, *etc.*, and should be given during the same period as the core courses. This would be an effective way of emphasizing the importance of safety.

I believe that there should be a three-hour course during the third year which is dedicated to safety. Some educators believe that safety should be a part of every course, and I agree. But the more technically complex areas of safety need more time and attention than could possibly be allotted in core courses. The following subjects could only be adequately covered in a separate safety course:

- **Dispersion studies**
- **Relief valve sizing (including 2-phase flow)**
- **Safety reviews and hazard identification**
- **Flammability of chemicals**
- **Toxicity of chemicals**

The benefits of teaching safety in the university exceed those mentioned above. An important spin-off of safety courses could be the development of more interest in initiating safety-oriented research. In a review of university research (PhD dissertations), it is apparent that there is very little research devoted to safety. Topics which could be fruitfully addressed by universities include:

- **Advanced adaptive reactor control methods for hazardous reactions**
- **Expert systems for monitoring reactor and/or plant safety**
- **Expert systems to improve the reliability of fault analysis**
- **Advanced relief methods for runaway two-phase flow systems**

From my perspective, the chemical industry will continue to stress faster reactions, more complex reaction systems, and a more complex utilization of investments via multiple product reactor systems. The success of these complex processes will depend upon our ability to design modern systems with the safety features demanded by both industry and the public. To meet these challenges of the future, we must give more attention, concern, and respect to safety.

NEW COURSE DEVELOPMENT

We have developed a senior level course entitled "Safety in the Chemical Process Industries." This development effort was supported by the National Science Foundation under their UIG program. The unique feature of the course was that it included five two-hour lectures, broadcast live from the chemical pilot plant facilities at BASF Corporation in Wyandotte, MI. The format supported interactive questioning between the students in the classroom and the practicing chemical engineering professionals in the pilot plant. The broadcasts were uplinked to a satellite for downlinking at both Wayne State University in Detroit and Michigan Technological University in the upper peninsula. The course was taught simultaneously at both locations during the fall of 1987.

The course provided a rare opportunity for students to see safety being practiced by professional chemical engineers in an actual chemical plant environment. Demonstrations were provided using actual equipment and safety situations that could never be shown in the classroom or laboratory. The video lectures were in addition to a series of 25 one and one-half hour classroom lectures. These lectures presented the fundamental and theoretical features of safety, subjects requiring problem solving and discussion within the classroom environment.

A total of four industrial and seven academic contributors were involve with the effort. The BASF Corporation industrial participants were: G. W. Boicourt, M. Capraro, J. F. Louvar, and J. Strickland. Their effort was directed mostly towards the video lecture material and scripts. J. F. Louvar also contributed towards the development of lecture material. The academic participants were D. A. Crowl and R. W. Powitz from Wayne State University and M. Banks, B. A. Barna, E. R. Fisher, N. K. Kim, and D. G. Leddy from Michigan Technological University. The major focus of the academic group was toward

TABLE 4
Video Session 3

INSPECTION OF LABORATORY AND PROCESS AREA

1. **Introduction**
2. **Inspection concepts**
3. **Review film on Stop - Observe - Act - Report (SOAR)**
4. **Inspection of laboratory (several examples of poor safety practices will be staged)**
    a. **Storage of solvents**
    b. **Storage of glass equipment**
    c. **Safety equipment and operation**
    d. **Principles of using hoods**
5. **Inspection of Process Development (PD) area (several examples of poor safety practices will be staged)**
    a. **Reliefs and rupture discs**
    b. **Nitrogen vented in room**
    c. **Non-XP in XP room**
    d. **Poor grounds**
    e. **Belts not guarded**
    f. **Bad drum vent**
    g. **Incorrect tools**
    h. **Poor ventilation**
    i. **No double block and bleed (show correct configuration via glass system)**
    j. **No hot-work permit**

TABLE 5
Video Session 4

EXPERIMENTS FOR SAFETY

1. **Introduction**
2. **Vent Sizing Package (VSP) for sizing reliefs**
    a. **Show features of equipment**
    b. **Show types of data collected**
    c. **Illustrate specific tests for various objectives**
    d. **Introduce relief valve sizing concepts**
3. **Characterizing dusts**
    a. **Deflagration index**
    b. **Illustrate features of equipment**
    c. **Describe test procedures**
    d. **Describe data from tests**
    e. **Introduce relief sizing concepts**
4. **Flammability limits**
    a. **Illustrate features of equipment**
    b. **Describe test procedures**
    c. **Describe data from tests**
    d. **Introduce relief sizing concepts**

TABLE 6
Video Session 5

SAFETY REVIEWS

1. **Introduction**
2. **Informal safety review in laboratory**
    a. **Describe phosgenation system**
    b. **Analyze procedures relevant to safety**
    c. **Progressively make improvements via team dialogue concept**
3. **Formal safety review**
    a. **Introduction**
    b. **Safety Review Meeting**
    c. **Equipment inspection**
    d. **Wrap-up meeting and development of Action Plan**
4. **Wrap-up of video sessions**
    a. **Summary remarks**
    b. **Open questions and answers**

development of the lecture materials. The overall project was managed by D. A. Crowl.

The course outline is shown in Table 1. It is divided into two major parts. The first part presents the fundamentals of safety and includes discussions of toxicology, fire, explosion, and toxic release. The second part deals with using those fundamentals in practice and includes a discussion of "designing for safety" and using various safety review procedures (such as hazards and operability studies). The course also includes a discussion on case histories and accident investigations.

The outlines for the five video lectures are shown in Tables 2 through 6. Except for video session 4, the videos are not dependent on the lecture material. The emphasis of the videos was to show the students how safety is practiced on real process equipment. The fourth video lecture on "Experiments for Safety" required some fundamental lecture material prior to broadcast.

SUMMARY

This paper has presented both the industrial and university perspectives regarding the need for teaching safety in the chemical engineering undergraduate curriculum. We have also presented one approach to teaching safety and loss prevention. As a result of NSF support we had a unique opportunity to bring the students into an operating chemical pilot plant, through the use of live TV.

We hope that this approach, and others, will improve the engineers of the future and result in safer chemical process plants.

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ChE book reviews

INTRODUCTION TO POLYMER VISCOELASTICITY, Second Edition

by John J. Aklonis, William J. MacKnight
John Wiley & Sons, Somerset, NJ 08873; $39.95 (1983)

Reviewed by Albert Co
University of Maine

This book introduces various fundamental concepts in studying the viscoelastic behavior of polymers, with an emphasis on the molecular approach. The book consists of nine chapters.

Chapter 1 introduces the reader to several experiments that display the viscoelastic nature of polymers. In Chapter 2, viscoelastic material properties in transient and oscillatory experiments are defined and are illustrated clearly with simple experiments. The Boltzmann superposition principle is stated; its applications in relating the creep compliance and the stress relaxation modulus and in relating transient and oscillatory properties are demonstrated.

In Chapter 3 the regions of viscoelastic behavior are described and the effects of molecular weight, crystallinity, and plasticizing agents are explained. The concept of time-temperature superposition, the master curves, and the WLF equation are then presented. In Chapter 4, the phenomenon of glass transition is examined, and explanations based on free volume, thermodynamics, and kinetic theories are presented. The effects of structural parameters on glass transition temperature and the relaxation occurring in the glassy state are rationalized in terms of molecular motion and chain mobility. In preparing the reader for subsequent chapters, the statistics of a polymer chain are reviewed in Chapter 5.

In Chapter 6, various treatments of rubber elasticity and the structural factors that affect rubber elasticity are discussed. In Chapter 7, the behavior of typical mechanical models is analyzed and the Rouse-Zimm molecular theories for polymer solutions are discussed. Extensions of these molecular theories to bulk polymers are then considered and the reptation theories are briefly described. In Chapters 8 and 9, the phenomena of dielectric relaxation and chemical stress relaxation are examined, respectively.

Throughout the book, the mathematical treatments are maintained at a level comfortable for undergraduates. Advanced mathematics required for the discussion of a subject matter are elaborated in the corresponding appendices. The problems at the end of each chapter range from simple calculations to advanced problems requiring a certain degree of mathematical sophistication. Readers will find the solutions located at the end of the book to be helpful.

Overall, this book is an excellent introduction to polymer viscoelasticity. However, the treatise is restricted to amorphous polymers. The treatment on crystalline polymers is very limited, and topics such as solution behavior, melt rheology, and birefringence are not covered. Nevertheless, it is a good choice as a textbook for one of a series of courses on polymer viscoelasticity. ☐