HOW MUCH SAFETY DO WE NEED IN ChE EDUCATION?

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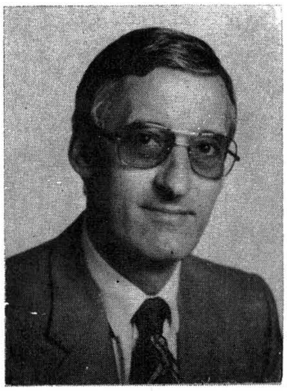

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TECHNOLOGICAL CHANGES ARE not only dictated by progress in science and engineering, but also by shifts in external conditions. This can be illustrated by the impact of oil prices on process design and by the limitations imposed on technology by society. Engineering education is supposed to keep track of technological innovations and even to anticipate them. However, changes in external conditions affect research more than education. It could be argued that the use of new engineering principles was not required and consequently that new courses were unnecessary. Can conventional chemical engineering handle the requirements imposed by society through the various authorities?

The two major areas which are of great concern to society are ecology and safety. Ecology entered engineering education both as a new curriculum and as a separate course in existing programs where there was a need for solving some environmental problems. Also, the scope of the problem made specialization possible and useful.

The second area, safety, hardly affected the academic world, with the possible exception of nuclear engineering. Nevertheless, safety considerations play an important role in making a number of vital decisions in the chemical industry. Examples are plant location and layout, feasibility studies, process selection, and design. In all of these areas the safety aspect does more nowadays than just change the boundary conditions or the optimum process parameters. The question arises whether chemical engineering students should be confronted with safety problems.

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Until recently there seemed to be no need to introduce formal safety courses. It was felt that the topic did not essentially alter usual chemical engineering practices. Admittedly the practicing chemical engineer should know about safety, but it was felt that the essential elements could hardly be developed into a course of academic level. Therefore it was concluded that on-the-job training was indicated. Recently the situation has evolved somewhat, especially in Europe, and safety engineering programs were introduced in countries such as the U.K., GFR, Holland and Belgium. In Leuven we have had, for several years now, a safety engineering program and a safety course for chemical engineering students. The latter will be discussed here.

MOTIVATION

Various topics can be covered by the term "safety." Therefore our subject should first be specified more accurately. In its most restricted meaning, it refers to the prevention of accidents to employees and to the protection of their health. More specific terms for this are occupational safety, accident prevention, or internal safety. The latter is used in opposition to "external safety," which refers to public hazards caused by industrial activity. The difference between internal and external safety is important for regulatory purposes. The same methods are often used to solve problems in both fields. Finally, one could also concentrate on the prevention of losses to the plant (loss prevention). For the present purpose, the term "safety" will be used in its broadest sense, covering all the previous domains.

The motivation of the course is based on some changes which have taken place in the approach to industrial hazards. Traditionally, experience provided the main basis for assessing and dealing with risks. One more or less waited until an accident occurred before measures were taken; the "dog was allowed its first bite." Safety measures often consisted of adding safety devices to the plant or providing suitable protective equipment for its people. The resulting level of safety was reasonable, but the whole approach lacked a rationale. In addition, it could not guarantee the safety of new processes.

The growing public concern for the risks of industrial activities triggered research in this area and the appearance of new, potentially dangerous technologies (nuclear energy, space programs) accelerated the trend. Research, which is still going on, encompasses divergent disciplines; its results have already drastically changed the approach to safety. The empirical assessment of hazards has been replaced by a number of prognostic methods for risk analysis. A final solution has not been found yet, but the available techniques are steadily improving and are increasingly applied in industry. The occurrence and evolution of accidents are now better understood, and this leads to the introduction of more general prevention strategies.

The rational approach to safety also confirmed that safety is not a separate part of a design which can be added on afterwards. It is intertwined with the whole design operation and should be taken into consideration when various decisions are made along the way. It should not be concluded that accident prevention is a purely technical matter. A systems approach clearly shows the need for organizational measures to guarantee the proper functioning of man in the global system. This result has important repercussions. Among other things it places more responsibility on people who design and run plants. In a growing number of countries the responsibility of engineers and managers for industrial accidents is now explicitly specified by law.

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Reviewing the present situation, one can detect a clear trend towards a situation where

- **Young chemical engineers have to take safety considerations into account in their daily work, whether it is in production, development or design**
- **Safety engineering is developing into a separate discipline, with its own specific concepts and its own methodology**
- **Chemical engineers carry a larger responsibility in safety matters.**

These conclusions point to a necessity for some kind of safety training. The genesis of a separate discipline makes its incorporation into the engineering curriculum appropriate; the fundamentals of any science are more efficiently taught in college than on the job. Furthermore, safety engineering has definitely reached a level that is suitable for an academic course.

The introduction of such a course offers additional educational opportunities which go beyond the course subject. They are associated with the interdisciplinary nature of safety. A safety course exposes engineering students to concepts, methods, and arguments from outside the realm of natural sciences. At the same time students are made aware of the nontechnical consequences of industrial activities. These experiences can compensate the linear and sometimes naive way of thinking about nontechnical matters which engineering students often develop. Finally, on a purely technical level, such a course requires the application of chemical engineering principles in a synthetic and integrated fashion which is often lacking in other courses.

AIM AND GENERAL OBJECTIVES

In principle, a safety course is aimed at providing the future chemical engineer with the necessary tools to cope with safety problems in his industrial environment. He therefore should be able to detect, assess, and counteract hazards in the design and operation of chemical plants. The risks refer to the safety and health of people inside and outside the plant and to the integrity and functioning of the plant itself.

The subject covers a vast area that includes elements from various disciplines. The usual pitfalls of such a situation should be avoided. In particular, the course should not be reduced to a mere compilation of concepts where the higher levels of learning are completely overlooked. This procedure would strip the course of most of its educational value. The aim of the general course objectives should reflect the necessary balance between covering a lot of ground and an in-depth analysis. This still leaves room for various alternatives. Only a basic set of general objectives is discussed here. Specific didactical objectives would depend too much on the other elements of the curriculum.

First, a proper attitude towards risk and safety is of paramount importance and should be stated as a specific goal

1) **A chemical engineer should be aware of the existence of hazards and of his responsibility in this respect.**

This is not a professional ethics course but students should realize their involvement with hazards. Rather than ignoring this factor, they should realize that some kind of rational approach is necessary. Awareness should entail motivation as a natural consequence.

The objectives in the cognitive domain take into account the points raised earlier. The lowest meaningful level of knowledge about general principles is incorporated in the second objective

2) **A chemical engineer should know the basic concepts and principles of safety engineering in order to apply them in chemical engineering practice and to use the available literature efficiently.**

This statement is less trivial than it may look. It presupposes the existence of a useful general approach, a fact which is often ignored by engineers even when they do safety work. Further, it assumes that sufficient concepts and methods can be taught and learned in a single course. This question will be reconsidered later.

The general concepts and methods of safety engineering can be applied to the process industry, even though it is characterized by problems for which specific techniques are being developed. These problems should be incorporated because they have a direct bearing on chemical engineering work and also because they cannot be handled by safety experts with a different background. As a result a third general objective is formulated

3) **A chemical engineer should be able to recognize, assess, and remedy specific risks occurring in chemical plants.**

Since the general aim has now been divided in three main themes, the course answers the expectations and possibilities discussed under "Motivation."

GENERAL COURSE OUTLINE

As mentioned earlier, no detailed set of didactical objectives will be discussed. Instead attention will be concentrated on the feasibility of adequately covering the three given themes during a single course. Obviously some difficulties are encountered, and compromises must be made. Nevertheless, experience indicates that the goal can be achieved.

In a chronological order the development of a suitable attitude towards safety and towards the course comes first. Group discussions provide the necessary tools for this. Using statistical evidence a number of questions can be considered: How hazardous are industrial activities in general and the process industry in particular? How do these risks compare with other risks we take? What is the level of acceptable risk? Why should we bother about safety? The resulting discussions not only contribute to attitude development, but they also lead to definitions of concepts such as hazard, risk, objective against subjective risk, risk perception, and acceptable risk.

The next step is motivated by the need to tackle safety problems in a systematic and scientific manner. Considering the available amount of time, only a limited number of safety engineering topics [2] can be covered. The system dynamics approach can be considered to be the most important feature. It is used as a starting point in every further analysis. It guarantees that all elements are systematically covered (man, machine, material, and environmental conditions). Perhaps for the first time the students are confronted with a science where not the machine, but man and his environment, are central. Later on it will put the organizational prevention measures into perspective.

Another essential topic of safety engineering is found in the analysis of accidents and in the general strategy for protective measures. An accident should be approached as a dynamic process which evolves through a series of simul-

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taneous and consecutive events. The analysis provides a means for searching systematically for sources of risks. Similarly, a taxonomy of techniques for risk reduction can be developed. The general strategies will be further applied in the last part of the course, which deals with the specific aspects of the process industry.

The discussion of general safety engineering principles is also used to stress the interdisciplinary nature of safety. By means of the system dynamics approach, the relevance of various disciplines, including the human sciences, can be made clear. It is easy to demonstrate that ignoring this complexity will definitely lead to inadequate safety policies. The need for different engineering disciplines can be demonstrated again in the last part of the course (the Flixborough disaster [3] provides a dramatic illustration for this problem). The middle section of the course is also the natural choice for mentioning legal aspects.

When the general strategy is applied to the process industries some specific problems arise. They are mainly related to the presence of hazardous materials and to the complexity of such plants. The specific problems can easily fill a 2-semester course [3]. Therefore the selection of relevant topics should be very discriminating. Starting from the general objectives, three major areas have been included in the program at Leuven. Except for illustrating the specific safety aspects of chemical plants, the chosen topics offer the opportunity to apply the general principles and strategies. These topics are

- **Risk analysis**
- **Dealing with hazardous materials**
- **Technical methods in loss prevention**

A good understanding of how to assess the safety of a design or of an existing process is obviously an essential requirement in a safety program. Although a complete methodology is still lacking, the process industry has at its disposal an extensive set of methods and techniques. The students should be taught the different elements of risk analysis. This includes a qualitative step (inventory of possible accidents) and a quantitative step (frequency and size of possible accidents). The students should be able to select suitable methods in each stage of a project and realize the limitations of the methods used. In our course we particularly stress Hazard and Operability Studies [4], Fault Free Analysis [5], and Effect Calculations (calculation of the possible effects of fires, explosions and releases of toxic products) [6].

The presence of hazardous materials can be dealt with according to the general principles and strategies of safety engineering. However, additional knowledge is required to systematically investigate the intrinsic material hazards (toxicity, flammability, and reactivity). Special emphasis is put on the use of material properties and hazard indices where the use of non-technical data, i.e. toxicity parameters, must be introduced. This kind of information surfaces in risk analysis and in the prevention methods.

The final section covers the technical aspects of loss prevention in the process industries. The skills in applying the general strategy can be further developed here. The typical hazards (overpressurizing, overheating, material escape) will arise automatically. This offers an opportunity to discuss their prevention, including the corresponding control and safety devices. Two points should be made very clear: First, safety considerations can affect the basic aspects of a project (selection of the site, lay-out, process, raw materials and intermediates, reactor type, etc.), and second, the optimal design and selection of safety devices is based on the same chemical engineering principles as the process development itself. It requires at least the same degree of sophistication in modelling (e.g. temperature or pressure changes under deviations from normal process conditions). This point is important because students often think that safety is a second rate activity for engineers.

COURSE IMPLEMENTATION

A large variety of didactical methods can be used. Group discussions (attitude development and motivation), formal teaching (e.g. for concept learning in the general part), individual and group work (e.g. skill development in applying the methodology), all have their place.

Experience shows that a one-semester course provides sufficient time to cover the topics discussed above. The basic elements of safety and loss prevention can then be treated in such a way that the various levels of learning are included. The section on risk analysis involves complex inductive and deductive thinking processes.

At Leuven the course is offered as optional and is taken by more than 80% of the chemical engineering students. The group discussions on risk start from the students' own perception of risk and hazard. This is compared with objective, statistical evidence. In the next step, industry-related risks are compared with other risks. The problems of acceptable risk and risk assessment are introduced here.

The first part poses no problems in practice except for controlling and ending the discussions! The next part, on general safety engineering, concentrates on concepts and general methodology. The danger of becoming too abstract can be overcome by the use of specific accidents as examples and exercises (e.g. transport accident, overheating of a stirred tank reactor). An introductory example for the assessment of safety devices is given in an addendum.

About two thirds of the course is devoted to the specific aspects of chemical plants. More than in most courses, a critical attitude towards the methods used is important in safety. Limitations and drawbacks are discussed with each method. Most applications are open-ended problems and creativity is often required. Hence, high level learning is possible. Class problems have to be selected carefully since the students do not have knowledge of a plant's technical features. It is interesting to challenge the students to find the weak spots in accidents that really occurred. When presented with cases such as Flixborough or Seveso, they succeed in pinpointing the problems.

Safety might still be an unusual component of the chemical engineering curriculum but there is a growing need to cover the topic, and experience indicates that a valuable and attractive course can be set up. It features many nontechnical elements which increasingly affect engineering practice. The knowledge and skills which are taught here are also required in normal engineering and management functions. This contributes further to the usefulness of the course.

ADDENDUM: EXAMPLE

This simple example illustrates

- **The general procedure for assessing the use of protective systems**
- **How to take into account human reliability**

Kletz [7] discusses a situation in which a tank had to be filled daily. The hazard of overfill was avoided by the operator who watched the level of fluid and stopped the pump at the right moment. After a few years an accidental overfill occurred because of human error. It was decided to install a high level trip, which essentially replaced the operator as a protective device. It was tested monthly to improve its reliability, but within the year another overfill occurred.

The theory for simple protective devices provides an expression for the hazard rate (H) of the process

$$H = f(1-e^{-DT/2})$$

where
- f = failure rate of the protective system
- D = rate at which the protective device is commanded to operate
- T = time length between controls of the protective device.

An operator of a task as described above is generally attributed a failure rate of 10^{-3} per occasion. Assuming 250 fillings a year the tank will be overfilled on the average every 4 years

$$H = 0.25 \text{ year}^{-1}$$

A trip has a failure rate of $f = 0.5 \text{ year}^{-1}$.

With a monthly testing ($T = 0.1$ year) and a demand of rate of 250 year^{-1} the given formula predicts

$$H \cong f = 0.5 \text{ year}^{-1}$$

As empirically verified, the trip could be expected to be less reliable than the operator, at least in cases as discussed here. The monthly control could not reduce the hazard rate because of the high demand rate. The probability of detecting a failure of the trip before it is required to function is negligible. Much more reliable devices are required if an occasional overflow is to be avoided. The theory can be extended to include multiple safety devices. Theory and examples can be found in Ref. [3]. □

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