Chapter 1

Introduction

1.1 Process Safety—A Persistent Challenge to Educators

Right from the start of the development of the oil and natural gas industry on the Norwegian continental shelf, very high safety standards were established. These standards were a matter of both industry attitude and official national policy. Until the "Piper Alpha" catastrophe, it was felt by some that Norway was overdoing safety issues in its offshore industry. However, after this accident, the imposition of strict safety requirements in this industry has gained wide international acceptance. Moreover, it has also been pointed out that substantial benefits would result if the high standards of safety in the offshore industries could be adapted to industry onshore and to society at large.

However, high safety levels cannot be established once and for all by a single all-out effort. Deterioration results if the high level—once attained—is not actively secured by continuous maintenance and renewal. This applies both to safety technology and to human factors.

Education has a key role in the continuous maintenance and renewal process. This ranges from short practical training courses to in-depth long-term education. Universities and colleges have responded to the challenge by establishing courses of study on a wide range of safety aspects. In the case of process safety, relevant topics include reliability and risk analysis, the physics, chemistry and technology of processes and hazards, and means of accident prevention and mitigation. Much emphasis has been put on methods of reliability and risk analysis, which are indeed very important. However, it is sometimes felt by the process industry itself that education in the "hard" aspects, i.e. the physics, chemistry, and technology of processes and process hazards has been somewhat left behind. This situation presents a special challenge to universities and colleges. Nine years ago my own university established a course of studies in process safety technology, with particular emphasis on the scientific and technological aspects.

In process safety, the prevention of fires and explosions, and the mitigation of their effects, is a central concern. Most often loss of confinement of flammable/explosive substances is the first link in the accidental chain of events. The next step is generation and ignition of flammable clouds, resulting in explosions and fires, which may in turn cause loss of life and limb and damage to the process plant, adjacent process areas, and even more remote building structures. Understanding the processes of accident escalation is an important aspect of process safety technology. Quantitative risk analysis plays an increasing role in the effort to improve offshore process safety. In the offshore oil and gas industries, a highly packed, congested process plant, with compact living quarters as a close neighbor, demands very systematic and thorough analysis of all possible risk factors, including the human elements. A concise and constructive official authority policy constitutes an important basis for ensuring the necessary high level of safety.

The purpose of this book is to provide a source of basic information on the origin, course, prevention, and mitigation of accidental explosions in the process industries. Potential readers/users of the book should include people both from a wide range of process industries, official authorities, engineering companies, and, not least, students in technical colleges and universities.

1.2 What Is an Explosion?

The concept of explosion is not unambiguous. Various encyclopedias give varying definitions that mainly fall in two categories. The first focuses on the noise or "bang" due to the sudden release of a strong pressure wave or blast wave. The origin of this pressure wave, whether a chemical or mechanical energy release, is of secondary concern. This definition of an explosion is in accordance with the basic meaning of the word ("sudden outburst").The second category of definitions relevant in the present context is explosions caused by a sudden release of chemical energy. This includes explosions of gases and dusts and solid explosives. The emphasis is then often put on the chemical energy release itself, and explosion is defined accordingly. A possible definition could then be "An explosion is an exothermal chemical process that, when occurring at constant volume, gives rise to a sudden and significant pressure rise."

In the present book the definition of an explosion will shift pragmatically between the two alternatives, by focusing on either cause or effect, depending upon the context.

1.3 Accidental Explosions—A Real Hazard in the Process Industries

The industries or facilities in which gas, spray/mist, or dust explosions may exist include:

Oil and natural gas industries/activities

- oil and natural gas production installations on and offshore
- oil and gas refineries
- systems for transportation of oil and gas (pipelines, ships, trains, cars etc.)

Petrochemical, chemical, and metallurgical process industries

- petrochemical industries producing chemicals and polymers
- plants producing pharmaceuticals, pesticides, organic pigments etc.
- paint production plants
- pulverized metal production (aluminum, magnesium, silicon, and silicon alloys etc.)
- chemical food and feed production
- production of cellulose, paper etc. from wood

Mechanical processing

- grain and feed storage
- flour mills
- sugar refineries
- mechanical wood refining (hardboard etc.)

Special processes

- production, storage, and handling of explosives, pyrotechnics, and propellants

1.4 Basic Differences in How and Where Explosive Gas, Spray/Mist, and Dust Clouds Are Likely to Be Generated

1.4.1 Similar Ignition and Combustion Properties of the Various Clouds

Explosive gas mixtures and explosive clouds of sprays/mists and dusts, once existing, exhibit very similar ignition and combustion properties, such as

- flammability/explosibility limits
- laminar burning velocities and quenching distances
- the response of the burning velocity to cloud turbulence
- detonation phenomena
- adiabatic constant-volume explosion pressures of similar magnitudes
- well-defined minimum ignition energies, and
- minimum ignition temperatures for given experimental conditions

Recognition of these similarities may have contributed to the development of the idea that the hazards of accidental gas, spray/mist, and dust explosions can be regarded as more or less identical. As discussed in Section 1.4.2, this is a misconception. Also, there is a basic difference in the ranges of hazardous fuel concentrations between dusts, sprays/mists, and gases. For combustible gases and sprays/mists, flame propagation is only possible when the fuel to air mixing ratios lie between the lower and the upper flammability limits. Dust flame propagation, however, is not limited only to the flammable dust concentration range of clouds. The state of settled layers and deposits constitutes an additional singular regime of flame propagation. This is because, contrary to combustible gases and liquids, settled powders/dusts will always have some air trapped in the voids between the particles, which makes it possible for sustained, although often very slow, combustion to propagate throughout the deposit.

1.4.2 Influence of Inertial Forces on the Movement of Dust Particles and Liquid Droplets

Once a combustible gas has been homogeneously mixed with air, the mixture will for most practical purposes stay homogeneous, due to random molecular motion. In clouds of dust particles and liquid droplets, however, the fuel particles are generally so much larger than the molecules of the air (often in the range 1–100 μm), that their movement within the air is controlled by inertial forces, including gravity, rather than by random molecular motion. The role of inertial forces increases systematically with increasing particle or droplet size and increasing density of the particle or droplet material. Turbulence and other convective movement of the air can prolong the time over which the particles will stay in suspension. When liquid droplets in a cloud collide, the droplets may coalesce and form one larger drop, which may require special considerations.

1.4.3 Fundamental Differences between the Ways Explosive Clouds Are Generated

There are fundamental differences in the ways and circumstances in which clouds of the three different fuel categories are generated and sustained, which have a major impact on the choice of means by which accidental explosions should be prevented and mitigated. The paramount question is whether there will be an explosive cloud in the first place. The physics of generation and sustainment of clouds of dusts, sprays/mists, and premixed gas clouds are substantially different.

In the case of *gases* and *vapors*, the fuel mixes with the air on the molecular level. Explosive clouds are generated readily when combustible gases and vapors are accidentally released into the atmosphere. Gas and vapor cloud explosions can be initiated inside process equipment, but most often the initiation is in accidental clouds generated outside process equipment, following loss of confinement due to leaks or equipment failure.

Explosive *spray* clouds will also, in most cases, be generated outside process equipment, in situations where pressurized combustible liquids are accidentally released from process equipment through narrow holes, slits, or cracks, and the liquid is broken up into fine droplets mechanically. Explosive *mists* are formed when hot mixtures of combustible vapor and air become cooled, and some of the vapor condenses out as very fine droplets. This may occur both inside and outside process equipment.

In the case of *dusts*, however, primary explosive clouds are practically exclusively found inside process equipment. Inside mills, mixers and blenders, bucket elevators, pneumatic conveying systems, silos and hoppers, cyclones, and filters the dust/powder can be kept in suspension more or less continually by rotation of the whole unit, movement of inserts, or an air flow. Therefore, explosive dust clouds may exist more or less continually in normal operation due to the basic nature of the operation.

Primary dust clouds generated outside process equipment by leaks from pressurized equipment are rare and do not play any significant role as far as primary dust explosions are concerned. The duration of the process of cloud generation is then normally very short (e.g., pouring or discharging operations, accidental bursting of sacks and bags). The dust particles will start to settle out of suspension as soon as the cloud generation process terminates, and typical total lifetimes of explosive primary dust clouds outside process equipment will be of the order of fractions of a minute. One exception would be long-duration minor dust leaks from, for example, flanges in pneumatic transport lines, but the dust cloud volumes produced in such cases would normally be quite small.

However, dust layers accumulated outside process equipment present a hazard of secondary dust clouds and secondary dust explosions if such layers can be thrown into suspension by blasts from primary explosions initiated inside process equipment.

1.4.4 Migration of Dust Particles and Liquid Droplets through Narrow Holes and Gaps in Enclosure Walls

Because dust particles and liquid droplets are so much bigger than gas molecules, they will not travel through narrow holes and slots of the order of 1 mm diameter and smaller in the same way as gas molecules will do. In principle, dust particles and liquid droplets may be carried through narrow passages by the air flow generated by a moderate pressure difference across the passage. However, both dust particles and liquid droplets will easily adhere to the area around the passage entrance and to the passage walls and eventually block the passage. In the case of liquid droplets, they will most often coalesce and form a liquid film.

Dust particles or liquid droplets that have been able to pass through narrow holes or gaps in this way will not remain suspended in the air inside the enclosure and form an explosive cloud. Instead, they will settle out of suspension and form a dust layer or a liquid film. In the case of dusts, it is also difficult to envision any mechanical process inside typical electrical apparatus enclosures that could possibly redisperse such dust layers into explosive dust clouds within the enclosure. In the case of liquid droplets, liquid films will be formed.

1.5 European Union Definition of Explosive Atmospheres

The two European Union directives “Atex 100a” (1994) and “Atex 118a” (1999) define explosive atmospheres as follows: Mixtures with air, under atmospheric conditions, of flammable substances in the form of gases, vapors, mists or dusts in which, after ignition has occurred, combustion spreads to the entire unburnt mixture.

Unfortunately the two directives are vague regarding clarification of the basic differences in the ways in which explosive clouds of gases/vapors, spray/mists, and dusts are, and can be, generated in industrial practice. Such a clarification is an essential basis for giving adequate differentiated guidance on selection of suitable means for preventing gas/vapor, spray/mist, and dust explosions. This not least applies to design of electrical apparatus (see Chapter 7).

1.6 The "Human Factor"

Proper build-up and maintenance of an integrated system for preventing and mitigating explosions in the process industries very much depends on human relations and human behavior.

A number of different personnel categories may be involved, including

- workers in the plant
- foremen in the plant
- workers from the maintenance department
- plant engineers
- safety engineers
- purchasing department officers
- safety manager
- middle management
- top management
- suppliers of equipment
- explosion experts/consultants

Adequate prevention and mitigation of accidental explosions cannot be realized unless there is meaningful communication between the various categories of personnel involved. If such communication is lacking, the result can easily become both unsatisfactory and confusing.

In general terms, meaningful communication may be defined as conveyance and proper receipt and appreciation of adequate information whenever required. However, in order to receive, appreciate, and use the information in a proper way, one must have

- adequate knowledge,
- adequate motivation, and
- adequate resources and deciding power.

Knowledge about accidental explosions can be acquired by reading, listening to lectures, talking to experts etc., although experience from actual explosion prevention and mitigation work is perhaps the best form of knowledge.

Genuine motivation is perhaps more difficult to achieve indirectly. It seems to be a law of life that people who have themselves experienced serious explosion accidents possess the highest level of motivation, in particular if the accident caused injuries and perhaps even loss of life. This applies to workers as well as top management. However, high levels of motivation can also result from good demonstrations of real explosions, including their initiation by various ignition sources, as well as their propagation and damaging effects. Video and film can also be a good help, if used properly.

The final element, adequate resources and the authority to put the good plans into practice, is in reality controlled by the top management. Verhaegen (1989) concluded from this that the real responsibility for establishing and running a proper safety assurance system must always lie on the top management. Summarizing the experience of a large, multinational chemical company, Verhaegen suggested that the following ten essential elements be involved to ensure proper safety management:

- top management responsibility
- safety statement (explicit commitment from top management)
- objectives and goals (specification of long and short term expectations)
- stated standards (written guidelines and rules)
- safety committees (a dedicated organization for handling safety issues at all levels)
- safety audits (regular reexamination of work practices)
- accident records (written analyses of accidents. Why did they happen? How can similar future accidents be prevented?)
- safety personnel (qualified specialists essential as advisers, but responsibility remains with top management)
- motivation (by information and involvement, etc.)
- training (a continual process; courses essential; the message must get through!)

Verhaegen emphasized the problem that a good safety organization is in reality often kept active by one or two dedicated individuals. If they change position within the company, or even leave, the safety organization may suffer. Management should foresee this problem and provide a workable solution.