Unconfined Vapour Cloud Explosions, by Keith Gugan, George Goodwin, London, 1979, 168 pp., £ 16.00.

The Flixborough incident of June 1, 1974, one of the most serious and devestating explosions in the history of the chemical industry, was a turning point in the concern of engineers and others for the safe operation of chemical plants. In the chemical industry, the protection of workers is of paramount concern, but so is the protection of a large financial investment. Loss of property, lawsuits and interruption of production are also important reasons why accidents must be minimized.

Commissioned by the Institution of Chemical Engineers, Gugan made a thorough study of known incidents involving unconfined vapour cloud explosions (UCVE's). One hundred cases were examined, the first having occurred in 1921 and the last in 1977. Data reported in the book (if known) are date, location, chemical source, quantity, blast, TNT equivalent, yield, fatalities and reference source; incidentally, the author has listed 210 references.

The table of the 100 incidents is followed by discussion of the best-documented of the cases, including excellent plot plans, equipment diagrams and photographs. The 31 photographs, several in color, are especially revealing.

The author notes that of the 100 major flammable gas or vapour releases which have ignited in the past 55 years, 56 have produced blast effects of varying magnitudes and more than half of the incidents have occurred during the last twelve years. Fatalities totalled 725 for all cases, ranging from 0 in many cases to 213 for a methane explosion at a LNG storage site in Cleveland in 1944. One encouraging point however, is the reduced number of deaths recently — only 226 in the last 12 years, in spite of that period having the majority of explosions.

That the state-of-the-art in this area is in its infancy, is revealed by this statement in the book's introduction: "rigorous theory may, one day, enable a complete appraisal of the hazard — but that has not happened yet. The essence of this study is to quantify and correlate damage, potential and actual damage — as revealed by incidents — and further to compare this with mortality and damage statistics from incidents involving more conventional explosives".

To this end, the author first describes combustion and physical fundamentals as gaseous mixtures, including deflagration and detonation — but realizing that a large number who might use the book are not theorists, leaves the theory mainly to the appendices. Here the theoretician can revel in the theoretical equations that describe vapour cloud formation, blast waves, mode of energy release and the effects of blast.

The heart of the book is the review of the known incidents in the 50 pages of chapters IV and V. Chapter IV contains the table discussed above, plus a review of 8 of the major incidents. Five other well-documented incidents, including Flixborough, are discussed in Chapter V.

Gugan's 12 page discussion (with its attendant analysis) of Flixborough, reveals what can be learned from thorough post-accident evaluation. What possibly happened was a rupture of an 8-inch (200-mm) pipe allowing cyclohexane to escape; this was followed by a short period of intense localized fire — the cyclohexane which escaped ignited as a cloud with sufficient force to bring down a temporary pipe running between two 710-mm openings; the gap so produced allowed cyclohexane to escape and ignite in a blast equivalent to 16 ± 2 tons of TNT or 35 kg of cyclohexane on an energy—equivalent basis.

Calculations made in the analysis include flame speed, pressure gradient, ignition point (45 m above ground), amount of cyclohexane (30 tonnes), and created pressure (637 psig or 4.4×10^6 Pa).

A final table in this chapter is one relating damage to pressure, to allow comparison with TNT explosions. For example, 0.2 kPa will cause occasional breaking of large glass windows already under strain; 1.0 kPa is typical for glass failure; 17.3 kPa will destroy 50% of brick houses; 48.3 kPa will overturn railroad cars; and 69.0 kPa will destroy almost all buildings.

The relatively short sixth chapter reviews the literature on experiments conducted on unconfined flammable vapours. The results leave no doubt there is much room for work: "The results of the experimental work are equivocal. There would seem to be no doubt, based strictly on experimental evidence, that plant designers andoperators could, for the most part, claim that there was very little, if any, evidence that severely damaging UCVE's could or would happen."

Gugan notes that the most obvious limitation on the experimental work has been in the scale of testing (small, so far), with mass, frame speed, burning velocity, "edge", ignition effects, molecular weight of the flammable gas, its temperatures and physical state all fruitful variables to be studied. He also advocates detailed attention to the wave form generated by experimental UCVE's and the effects of point of ignition, terrain, wind, etc., or for example, any polarisation or pressure effects there might be.

Under a chapter title of Miscellaneous Issues, Gugan treats the important issue of death. People do not die from pressure *per se* but rather from its associated effects: missiles, temperature, etc. However one dies is academic, but what is not is the better design of chemical plants for the future. However, improved design is complicated by the wide range of types of chemical plants currently operating and the extremes of environments in which they are located. Moreover, as the chemical plants get larger (and even though smaller plants are more susceptible to failure), size alone increases the potential number of deaths. The relation between potential death rates and size of plant is illustrated by this equation:

$$\text{Mortality Index} = 4 \times (\text{tonnes of explosives})^{-1/2}$$

Although the equation was developed for explosives, one can draw the analogy easily (as the book's tables do) between chemical explosions and TNT, and as chemical plants become larger, the potential for devastation outside the plant (in the community) increases.

Perhaps the most important chapter in the book is the last one on "Predictions, prevention and protection". The author tries to give guidance based on what he has learned — that unsaturated compounds lead more readily to UCVE's, that one can predict blast potentials, and that one can attempt to prevent (not very successfully) UCVE's by preventing ignition. Finally, given that the certainty of UCVE's can be predicted, but not prevented, protection for process workers and the community must be provided.

Several minor, but important features make this book very useful — a concluding list of the 16 important points and conclusions made in this book; all the theory presented in the appendix, which also contains a list of all symbols used and their meaning; a table of conversion factors; a glossary; and finally a list of 210 references. An index is not provided, but is not badly missed.

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