AN APPROACH TO THE PROBLEMS OF PROCESS HAZARDS IN PLANT DESIGN

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SUMMARY

This paper deals with the work of a process safety department as a distinct unit in the engineering headquarters of a company involved in chemical engineering.

Introduction

'Process safety' is defined as the safeguarding of people in the first place and of productive capacity in the second place against breakdown of equipment caused by over-pressure, fire, or explosion, and also against the escape of dangerous materials or radiation.

Although such safeguards are part and parcel of all good engineering design, the authors' company has more than 30 factories throughout the world and may have more than a dozen major engineering construction projects simultaneously on hand: the directors have found the need for a special department to apply the required standards of safety and to see that these standards are maintained. Comparable departments were already established for boilers and power plant, metallurgy, buildings, and other branches of engineering.

The company manufacturers soaps, synthetic detergents, edible fats, cellulose, and other products.

Organisation

The company has a headquarters engineering division in the United States of America. This division undertakes the main development and construction work and also checks the work of the engineering departments in the factories, advising them as needed. The process safety department is one of the departments making up the division.

The British subsidiary company also has a headquarters engineering division doing the same thing for the factories in this country. It is in very close contact, technically, with the main division in the United States.

The Task Facing a Process Safety Department

The duties of a process safety department may be classified under three main headings:

1. For new construction: directing the engineering work in this respect.
2. For equipment in operation: checking the quality of inspection and maintenance.
3. For people: giving technical information, training, and propaganda.

Information

The department builds up its own library of technical and legal information. This gives the references for assessing the risks of fire and explosion in given conditions, and also the physical quantities on which to base calculations. In particular, it has assembled a *Process Safety Manual.* This book lays down all the procedures, as described later, and condenses and standardises the calculations which are usually needed. All factories receive this book.

Flow charts

When an installation is being designed, the process safety department keeps in continual touch with the development of the flow charts by the design engineers principally concerned. When the flow charts are complete, they carry the data about protective devices and the pressure ratings for all vessels and other equipment which result from the studies of the process safety department.

Summary

The work of the process safety department on any installation is assembled into a special manual which is handed to the factory operating and engineering staff on commissioning.

Inspection

As an over-riding check on the work of others, the process safety department undertakes its own inspection of the protective devices of an installation before it begins to operate.

Auditing of current operations

The process safety engineer of a factory has to see that safety devices are inspected and maintained. He also scrutinises changes to equipment for new hazards. The headquarters department sees that he uses the standard procedures for this and checks and reports on the work done by the factory staff.

Training

Besides training staff for the factories and for headquarters for this specialised work, there is need occasionally to bring it to the notice of other members of the engineering and operating staffs. This parallels the extensive propaganda on personal safety which has proved of very great value.

Detailed Procedure

The work regularly done by the process safety department is described in more detail under these headings:

General safety study.
Detailed safety study.
Rating the hazards.

*Thomas Hedley & Co. Limited, Newcastle upon Tyne.

Specifying protective measures.
Process safety summary.
Pre-start up inspection.
Checks on the work of the factories.
Training.

General safety study

During the design of an installation, the process materials, the chemical reactions, and the general concept of the proposed plant are studied. The research and development departments are asked to elicit dangerous characteristics of the materials in the process. The intention at this stage is to bring out the major potential sources of hazard. Typical points to be considered are:

Ignition of flammable gases and dusts due to sparks with the system.

Mixing of two materials giving rise to a high rate of liberation of heat *(e.g.* sodium and water).

Escape of hot flashing, toxic, corrosive, or flammable materials or radiation.

The possible occurrence of pressures greater than those produced by normal working.

integrated with that of the process plant. The need for earthing pipe lines may affect choice of pipe materials and cost. Electrical installations may need to be flameproof.

The general safety study is a joint task for process safety and process equipment design.

The process safety department brings to this study a fund of company experience. It studies statutory regulations and the recommendations of outside bodies. It seeks advice from other companies about handling unfamiliar materials. Such help has been freely given and is highly appreciated. The literature is studied. Experimental work may be initiated for example to establish realistic flammability tests, or to test the effectiveness of explosion vents.

Detailed safety study

INITIAL PREPARATION OF HAZARD SHEETS

When the general safety study is complete the process equipment design department finalises the flow chart and layout *(e.g.* Fig. 1). The process safety department reviews the flow charts in complete detail, looking for potential sources of hazard.

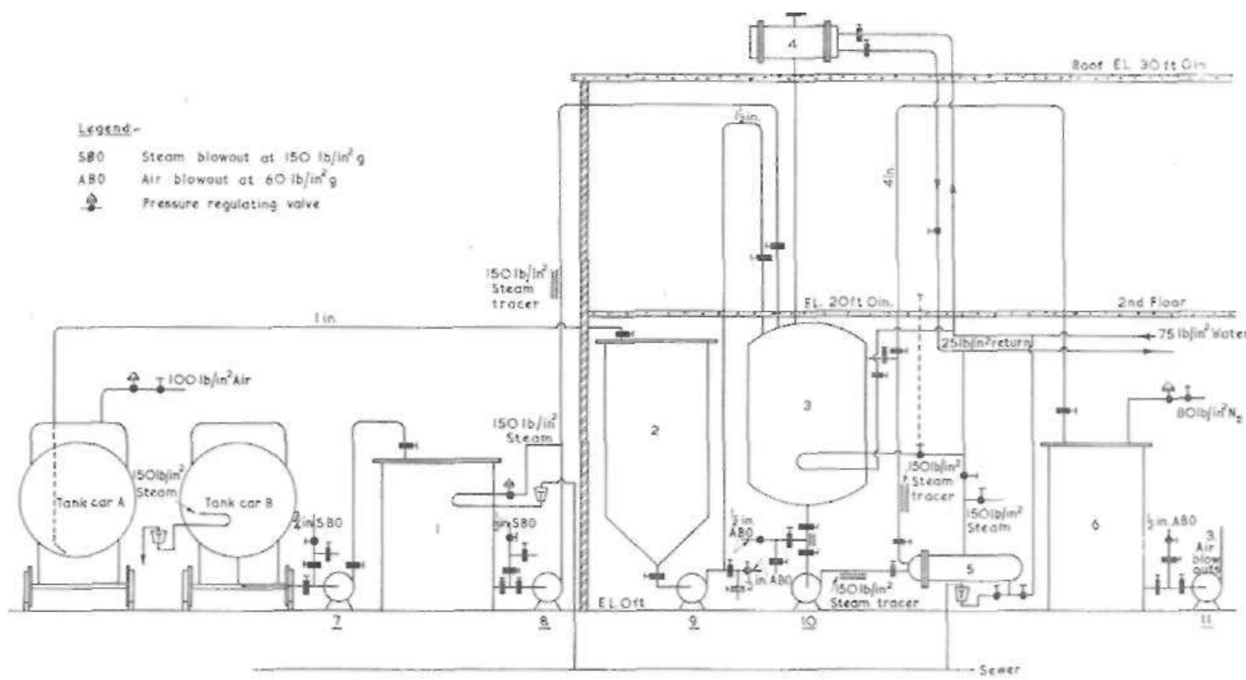


Fig. 1.—*Engineering flow chart prior to detailed safety study.*

It is essential that this general study should be done early. It will often result in recommendations which affect the concept of the plant, its location, layout, and cost. Explosion-prone sections of plant may need to be built in the open, or in areas with blast walls, vents, and sufficient ventilation. Special fire equipment may be required of which the design should be

A hazard sheet is prepared for each item or groups of items where a hazard exists which must carry certain key information:

Clear and positive identification of the item or items to which it refers.

Statement of maximum allowable pressure or vacuum.

The process safety engineer must satisfy himself that he has the right figures. If no proper calculations have been made, he must do them.

A list of the hazards to which the item may be exposed.

Space for hazard rating, which is described later.

Space for the specification of protective devices, described later.

Space for relevant calculations.

Fig. 2 (a & b) gives examples of hazard sheets. At this stage the centre and right hand columns would be empty.

This is the initial preparation of hazard sheets. Their completion is described later. The important first step is to recognise all the hazards; protecting against them is a separate matter. If they are not found they will not be guarded against.

CHECK LISTS

In probing for possible hazards, the process safety engineer uses a check list of possible sources.

Over-pressure is checked against several headings: for example ruptured tank coils, blow outs, thermal expansion of trapped liquids, condensation, chemical reaction, pumping pressures. All possible operating mistakes are considered. Fire and explosion hazards are similarly checked. Process materials may include flammable liquids, gases, or dusts. Compounds may be unstable. Ignition may come from open flame, electrical devices, lightning, static, addition of hot materials, or sparks from process furnaces.

ESCAPE OF HARMFUL MATERIALS OR RADIATION

Radiation is not a major factor in the authors' company, but radioactive sources are in use, and are included in the process safety department.

The possible escape of materials harmful to people is also noted. The design engineer and the people concerned directly with the safety of operation have the prime responsibility though the process safety engineer is closely concerned. The process safety engineer does make recommendations on vent capacity. If a flammable material may escape, he is directly concerned because there may be a fire or explosion hazard in the area.

HAZARD SHEET No.4.

EQUIPMENT TANK N° 2
ENG. FLOW CHART ______

DATE: 8/8/60
MAP 1·33 psig
MAV ______

HAZARD.

No.	DESCRIPTION	RATING	PROTECTION	
1.	27·5 lb/in² LIQUID PRESSURE FROM TANK CAR 'A'	A.1.	4in OVERFLOW	SI.106
2	OVERPRESSURE FROM A.B.O AT PUMP N° 9	A.1.	6in VENT	SI 107
3	OVERPRESSURE DUE TO REVERSED FLOW FROM TANK 3	A.2.	6in VENT AND 4" OVERFLOW	SI 106&7
4	VACUUM PULLED BY PUMP N° 9	A.1.	6in. VENT.	SI 107
5	27·5 lb/in² AIR PRESSURE FROM TANK CAR 'A'	A.1.	6in VENT	SI. 107

NOTE:-
THE SIZES OF VENTS AND OVERFLOWS ARE CALCULATED FROM METHODS AND DATA WHICH ARE STANDARDIZED IN THE "PROCESS SAFETY MANUAL."

Fig. 2a.—*Completed hazard sheet*

HAZARD SHEET No. 7.

EQUIPMENT HEAT EXCHANGER Nº 5

ENG. FLOW CHART

DATE: 3/6/60

MAP SHELL 150 lb/in² TUBES 150 lb/in²

MAV FULL VACUUM.

HAZARD			
No.	DESCRIPTION	RATING	PROTECTION
1.	OVERPRESSURE FROM 150 lb/in² STEAM IN SHELL	A.1.	ADEQUATE M. A. P.
2.	DITTO. IN TUBES.	A.1.	DITTO
3.	THERMAL EXP. OF VALVED OFF CONTENTS IN TUBES.	A.2.	½ in R/V SET AT 150 lb/in² (STAINLESS STEEL) SI 110
4.	OVERPRESSURE FROM PUMP 10	A.2.	ADEQUATE M. A. P.
5.	" " ½" A.B.C. AT PUMP 10.	A.3.	DITTO
6.	VACUUM CAUSED BY CONDENSATION OF VAPOURS.	A.2.	ADEQUATE M. A. V.
7.	80 lb/in² N_2 FROM TANK Nº 6.	A.3.	ADEQUATE M. A. P.
8.	THERMAL EXP. OF SHELL.	A.2.	½ in. R/V SET AT 150 lb/in² SI 111
9.	VACUUM CAUSED BY PUMP 11.	A.2.	ADEQUATE M.A.V.
10.	OVERPRESSURE FROM REACTOR 3.	A.3.	ADEQUATE M.A.P.
11.	FLASHED STEAM FROM STOCK BLOWING INTO WATER SYSTEM DUE TO TUBE RUPTURE	A.1.	VALVE-FREE 25 lb/in² WATER RETURN LINE.
12.	100 lb/in² AIR BLOWING INTO WATER SYSTEM DUE TO TUBE RUPTURE.	A.1.	DITTO
13.	STEAM INTO WATER SYSTEM DUE TO COMMON CONNECTIONS AT HEAT EXCHANGER.	A.1.	2/2 WAY 3-PORT COCKS INTERLOCKED SI 113

Fig. 2b.—Completed hazard sheet

CORROSION

The process safety department, while keeping corrosion in mind, does not carry the direct responsibility for ensuring that items of plant are constructed of the right materials. This responsibility is assigned to the process equipment designers.

PRESSURE VESSELS

A separate technical check is made on all pressure vessels for correct design and choice of material. A separate programme of inspection and auditing ensures proper maintenance of pressure vessels and controls changes of design.

The operating managers are responsible for seeing that corrosive process materials are not, through mistakes in operation, fed into vessels unsuited to them. The process safety department does not protect against mal-operation of this kind, unless there is a risk of over-pressure, fire, or explosion.

Rating the hazards

APPROACH

Once a hazard is recognised there are often many courses of action which will remove it or minimise its effects. A uniform level of protection must be applied to many diverse plants over a period of years. If there is under-protection there is danger. If there is over-protection, money is wasted, and moreover all protective measures may be brought into disrepute because some will be seen to be unnecessary. To help decide the course of action the facts are assembled logically:

How precisely might an incident develop from each particular hazard?

How likely is the incident to happen?

How serious would the incident be if it happened?

The likelihood and seriousness of result are considered separately.

This is one of the key points.

Likelihood is expressed as:

1—Likely
2—Possible
3—Remote

Seriousness is expressed as:

A—Very serious
B—Serious
C—Less serious

To help to rate the hazard in a reasonably uniform and simple manner, examples of each rating are built up, though it is realised there is a need for informed judgment supported by the company experience.

RATING LIKELIHOOD

The cause of an incident may be broadly classified as mechanical or operational failure. Typical ratings are given in Table I.

against completely, so that their study in particular requires the exercise of informed judgment. Nevertheless, the general approach of judging likelihood and consequence in turn is valuable here too.

Technical solutions to protection problems are not included in this paper but general practice can be illustrated by the points given below.

Example of practice

Overpressure or vacuum

a. Assume that all pressure sources rated **Al**, **A2**, **A3**, **Bl**, **B2**, can come into effect together.
b. If natural vents are inadequate, first seek to restrict the sources of pressure.
c. If relieving devices are needed establish the quantity which each must handle.
d. If the rate of build up of pressure or vacuum from a known source is uncertain, establish it, by calculation, reference to published data, or test.
e. When **B3**, **C2**, or **C3** hazards are noted, the plant operator is relied upon but will specify restrictions clearly in the process safety summary.
f. Certain vessels are exempted from the need for special relief devices.

TABLE I—*Rating of Hazards.*

Likelihood of hazard	*Mechanical hazard*	*Operational hazard*
1. Likely	Failure of a tube of a heat exchanger which is handling corrosive material. Passing valve.	Opening one valve to source of pressure.
2. Possible	Disintegration of two non-return valves in series. Failure of a tube of a heat exchanger which is handling non-corrosive material.	Opening two or more valves in series to a source of pressure. Valve off a vessel completely (two or more valves).
3. Remote	Tank coil rupture. Isolating valve breakage.	Closing a number of valves on down-stream side of vessel.

Rating seriousness	
A. Very serious	Failure of any pressure vessel containing air or gas. Failure of a pressure vessel containing strongly corrosive liquid. Explosion or fire.
B. Serious	Momentary overpressure of pressure vessel containing air or gas by more than 100 per cent. Failure of a vessel or pump resulting in fairly large losses of not particularly hazardous materials.
C. Less serious	Tanks with weak flat tops which will fail under overpressure before the shell. Failure of vessel or pump containing non-hazardous material, small losses.

The combined rating, **Al**, **B3**, **C2**, etc., is noted on the hazard sheet and this helps in deciding the extent of the protection which will be specified.

Specifying protective measures

APPROACH

The process safety engineer now has a qualitative picture of the hazards, how likely incidents are to develop, and how serious the consequences might be. Major recommendations will have been made during the general study. Therefore by this time it is normally possible to protect the plant by specifying protective devices and/or by imposing restrictions. The ratings offer a guide in deciding what protective devices or other measures are justified.

Where practicable, all A hazards (very serious) and **Bl** and **B2** (serious and possible) and **C1** (less serious but likely) are positively guarded against: others are not, *i.e.* in the case of ratings **B3**, **C2**, and **C3** good operation is relied upon.

This approach is relatively easy to apply to over-pressure hazards and it is used extensively for this purpose. Fire and explosion are usually A, and are normally difficult to guard

Fire

1. The normal codes and regulations arc complied with except where company requirements are more stringent.

2. The aim is to prevent fires. A closed system, or separate location may be provided. Sources of ignition can often be removed, *e.g.*

Pressurised or Buxton certified electrical fixtures.
No open flame.
Spark-proof tools and chains.

Good ventilation can prevent dangerous concentrations of vapours.

3. The spread of fire is limited by dykes, fire walls, or space.
4. The best means of fighting a fire are provided.

5. The total quantity of flammable materials present may be restricted.

Explosion

The practices illustrated under Fire generally apply. Tn addition:

1. 'Allowable pressure' is determined by yield stress rather than design stress.

2. If the equipment cannot stand the pressure generated by an explosion the maximum possible rate of pressure rise is determined and vents provided. If venting is impracticable the likelihood of the maximum rate of rise being attained, as compared with a lower figure is considered. Structural strengthening may be needed. Normally, major items of equipment are so studied at the general safety study.

COMPLETION OF HAZARD SHEETS

The specification of safety devices and other measures is noted on each hazard sheet. Calculations and reasons are included.

Examples of completed hazard sheets are given in Fig. 2 (a & b).

SAFETY FLOW CHART

The safety flow chart is the equipment flow chart which has been prepared by the process design department, but with the work of the process safety department added to it. Compare Fig. 3 with Fig. 1.

The completed flow chart is the key document for the listing design and procurement of all equipment and material and subsequent testing. The safety equipment is included with the rest.

Process safety summary

The process safety department prepares a 'Process Safety Summary' for each project. Its purpose is to present important information to the engineering and operating people concerned, and to record information for future reference. The summary comprises:

1. General considerations

This section contains a general discussion of the main hazards, together with the means of protection. It also contains a reference to any unusual circumstances or hazards encountered in the study, together with a short summary of hazards to personnel, including precautions which should be taken in the event of injury from unfamiliar chemicals.

2. Equipment limitations

This section includes a note of any safety compromises, any hazards which are not automatically protected against, and any limitations of the equipment. It may contain instructions on mode of operation. This is an important section, particularly where subsequent changes of process are likely.

3. Safety notes and inspection procedures

This comprises the complete list and description of all the safety items specified and itemised in the study, together with guidance on the frequency of inspection and the testing procedures to be adopted for all the safety devices.

4. Hazard sheets and calculations

The process safety engineer puts on record the basis of his decisions on type of protection, sizing of protective devices, and methods of calculation.

5. Specifications

Specifications for buying protective devices, drawings, manufacturer's instructions, and similar information.

6. Safety flow chart

This is the engineering flow chart marked up with safety devices and symbols which was mentioned earlier. An example is given in Fig. 3.

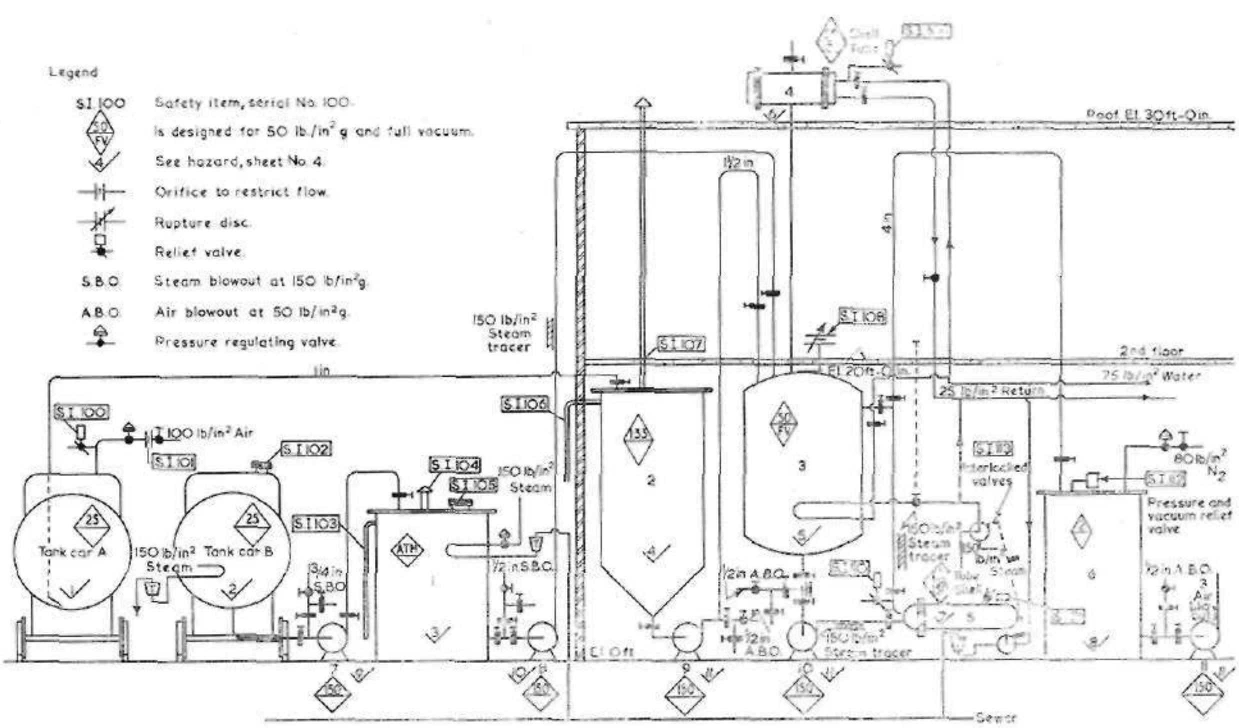


Fig. 3. *Safety flow chart*

7. Design changes

In this section are noted all alterations to the equipment after it has been commissioned. Such alterations must be reviewed by the factory's own process safety engineer before they are undertaken, and recorded by him here for the benefit of future audits.

Pre-start up inspections

The process safety department makes a physical inspection of the plant before and during commissioning. They check that every safety device shown on the safety flow chart is present, properly installed, and tested. They hand over a copy of process safety summary to the factory, and in doing so, they discuss personally with the operating people all special features, particularly equipment limitations.

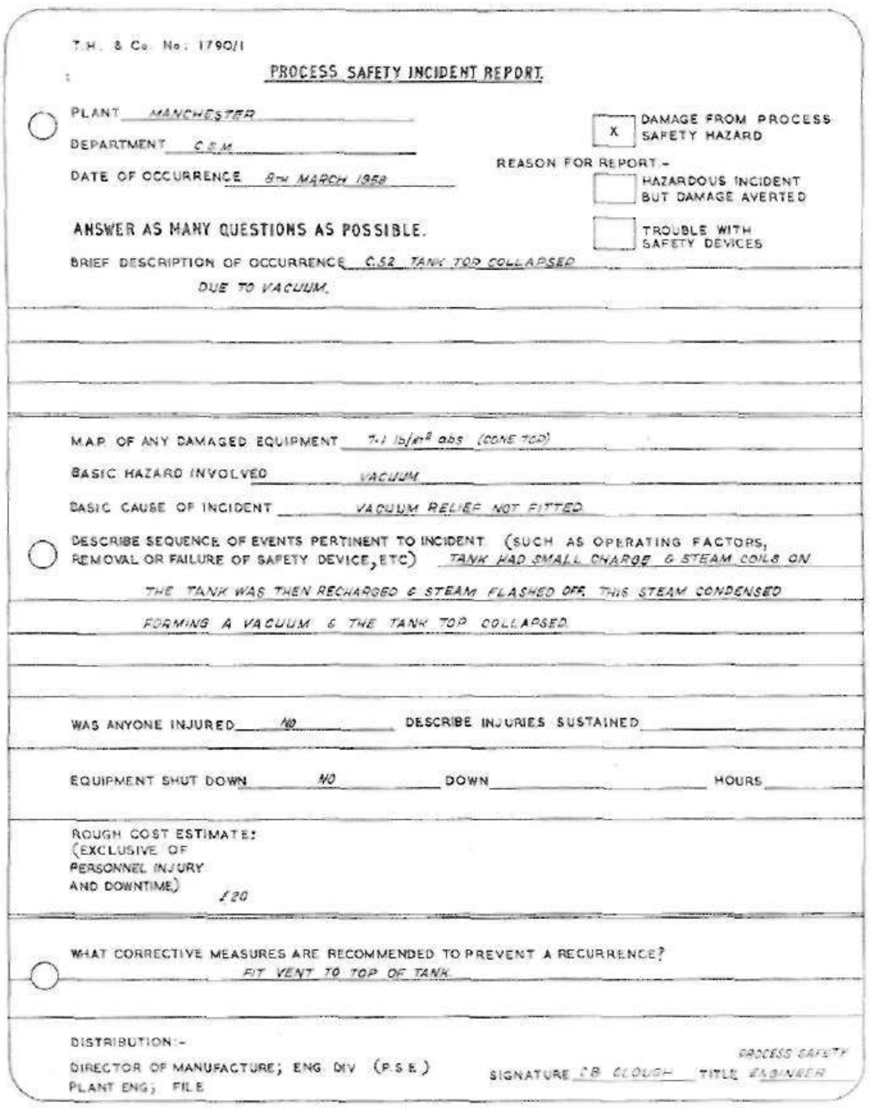
Checks on the work of the factories

The process safety engineer at each factory is given a series of explicit instructions to do the following:

1. See that all safety devices are tested regularly.
2. Keep records in standard form of tests and maintenance work.
3. Check and approve changes to equipment from the point of view of process safety.
4. Examine and report on any accident, or incident which might have led to an accident, on process equipment. Fig. 4 gives an example of a report on such an incident.
5. Study afresh each department of the factory in full detail using basically the methods that have been described above in connection with new installations. This uncovers any feature which has fallen short of the required standards of safety. Each department gets re-studied every four years. The process safety department of engineering division carries out an audit every two years on the work at each factory and reports the findings. The department receives copies of all incident reports. It discusses with the factory staff all proposals arising out of the four-yearly review. Less formal contacts are frequent.

Training

Training is provided at headquarters for engineers who will



T.H. & Co. No: 1790/1

PROCESS SAFETY INCIDENT REPORT.

PLANT MANCHESTER

DEPARTMENT C.S.M.

DATE OF OCCURRENCE 8TH MARCH 1958

REASON FOR REPORT –
[X] DAMAGE FROM PROCESS SAFETY HAZARD
[ ] HAZARDOUS INCIDENT BUT DAMAGE AVERTED
[ ] TROUBLE WITH SAFETY DEVICES

ANSWER AS MANY QUESTIONS AS POSSIBLE.

BRIEF DESCRIPTION OF OCCURRENCE C.52 TANK TOP COLLAPSED DUE TO VACUUM.

M.A.P. OF ANY DAMAGED EQUIPMENT 7·1 lb/in² abs (CONE TOP)

BASIC HAZARD INVOLVED VACUUM

BASIC CAUSE OF INCIDENT VACUUM RELIEF NOT FITTED

DESCRIBE SEQUENCE OF EVENTS PERTINENT TO INCIDENT (SUCH AS OPERATING FACTORS, REMOVAL OR FAILURE OF SAFETY DEVICE, ETC) TANK HAD SMALL CHARGE & STEAM COILS ON THE TANK WAS THEN RECHARGED & STEAM FLASHED OFF. THIS STEAM CONDENSED FORMING A VACUUM & THE TANK TOP COLLAPSED.

WAS ANYONE INJURED NO DESCRIBE INJURIES SUSTAINED

EQUIPMENT SHUT DOWN NO DOWN HOURS

ROUGH COST ESTIMATE: (EXCLUSIVE OF PERSONNEL INJURY AND DOWNTIME) £20

WHAT CORRECTIVE MEASURES ARE RECOMMENDED TO PREVENT A RECURRENCE? FIT VENT TO TOP OF TANK

DISTRIBUTION:–
DIRECTOR OF MANUFACTURE; ENG DIV (P.S.E.)
PLANT ENG; FILE

SIGNATURE C.B. CLOUGH TITLE PROCESS SAFETY ENGINEER

Fig. 4.—Typical report of minor factory incident

undertake process safety work. An intensive course, lasting a week, is repeated when needed. This is largely based on the process safety manual and explains in detail the methods of working contained therein. Practical demonstrations of studies and calculations are undertaken. Infrequently, as needed by extensions and promotions and the resulting arrival of new men on the operating and engineering staff of the factories, formal lectures are held explaining the work of the process safety department, the reasons why it was founded, and the parts which the company expects other members of its staff to play in helping it to further its ends.

Characteristics and Value of the Process Safety Programme

The paper has concentrated on an approach to the problem of process hazards in the design of new plant. This approach is part of a rather wider programme of work.

Characteristics of programme

Important characteristics of this programme are that:

It **is** applicable to a wide variety of processes and equipment.

It helps to secure a known standard of safety throughout a number of plants and for the full life of the plant.

It is thorough, reveals the less apparent hazards, and attends to important detail.

It makes specialised experience and knowledge widely available:

Cost and value of programme

The cost of the programme is appreciable. A number of engineers is needed to operate it. Safety measures generally cost money.

However, tangible advantages accrue:

The programme helps the company to provide safe working conditions.

It enables the company to move with assurance into new fields. Freedom from major failures during the early stages of operation can be crucial to the successful exploitation of a market. Experience has been that hazards, particularly on unfamiliar plants, are not revealed by normal engineering checks.

It provides basic reliability during the life of the plant. The need for standby plant is reduced. Production can be scheduled with confidence so that excessive stocks of finished product can be avoided.

Proper understanding of the risks may permit reduction of the factor of safety provided against the unknown, and hence reduce capital cost.

The programme is justified not only on ethical grounds but also in terms of money.

Conclusion

The approach outlined is but one part of the effort required to attain the objectives of safety and reliability in a factory as a whole. Similar effort must be applied in other fields including safety of personnel, steam and power, buildings and structures, key vessels, and mechanical plant. Conversely, the procedures outlined will be valueless unless the will to use them exists. Fostering and preserving the will to use them is a task for management.

Acknowledgments

The authors, on behalf of Thomas Hedley & **Co.** Limited, Newcastle-on-Tyne, wish to acknowledge the help of the parent company, Procter & Gamble of Cincinnati, Ohio, who developed the programme, helped to apply it in England, and who have given them permission to publish this paper.

The manuscript of this paper was received on 3 *March,* 1960.