THE ROLE OF HAZOPS IN GETTING IT RIGHT FIRST TIME

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Hazard and Operability studies are now being used by a variety of industries to reveal potential weaknesses in new and existing plants. The method pioneered by ICI has been adapted by various Hazop study leaders to suit the needs of other companies, using strategies differing somewhat from the CIA Guide. These changes are illustrated by the results of Hazop studies led by the author for clients in the chemical, offshore and water industries. The paper presents techniques for maximizing the effectiveness of Hazop studies.

Keywords: Hazop. Hazard severity. Protocols. Computer aid.
Sequential operations.

INTRODUCTION

The current usage of the Hazop technique in various industries can be very different from that presented in the early papers by Lawley (1) and the CIA Guide (2) which was based on a report by Knowlton and Shipley of ICI Pharmaceuticals Division. In reality the Hazop concept as currently applied, reflects its true "method study" origin presented by Elliott and Owen (3) using the keywords : What ? How ? When ? Where ? They recommended also the use of the heuristic Why ? as a means of stimulating further thought. In the penultimate section of their paper which was presented to the Midlands Branch of the IChemE, these authors from ICI Mond Division suggested the use of their "structured questioning approach in hazard surveys".

Computer Aid

Companies often debate when to schedule the Hazop study in a new project and what parts of existing plant would benefit from application of the Hazop method. Consideration needs to be given also to the management of the studies in order to maximize their effectiveness. Until recently, a major drawback was the tedium of handwritten records and the delay in getting these transcribed accurately into a typewritten report. The Hazop C program (4) can produce Hazop Tables and Action Sheets after every meeting, without losing the facility provided by handwritten records of being able to search back through the records at any point in the meeting.

Using this computer aid the author can now produce a complete Hazop report, including the types of analyses presented below, within two working days of the end of the study. As a result of computer aids, companies can economically justify more Hazop studies per year. The program has been written to accommodate the differing styles and strategies adopted by Hazop study leaders and extends the Hazop method to include the application of the hazard severity criteria presented in Tables 1 to 3 for various industries.

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Three Stage Approach

Many of the early papers by members of ICI, for example Gibson (5), explained the six-stage hazard survey strategy adopted within a large organization such as ICI, to co-ordinate the activities of the numerous engineering disciplines from the contractors, equipment vendors and the client, who are involved in large new projects.

For smaller projects, smaller client organizations and shorter time-scales, a three-stage approach is very effective using the following types of Hazop:-

1. Conceptual Hazop
2. P&ID Hazop
3. Task Hazop

CONCEPTUAL HAZOP

A useful technique to be applied at the conceptual design stage of new projects might be called a Process Deviation Analysis in which each major item of equipment on the Process Flow Diagram is examined for potential causes of deviations from its design specification. These causes are often obvious but may get overlooked when specifying control strategies, including operator actions, for slightly unusual "unit operations". Conversely, there may be a tendency to routinely include a proliferation of protective systems without considering the severity of the failure modes of control actions. Application of the principles of Failure Mode Effect and Criticality Analysis can be used even at this stage to achieve a uniform level of risk, based on criteria for deciding the severity of the consequences of failure (6).

The aim of Process Deviation Analysis is similar in concept to the "Critical examination in process design" presented by Elliott and Owen (3). The following questions must be addressed:-

* What are we trying to achieve with this item of equipment ?
* How might it fail to achieve this specification ?
* What are the possible causes of each type of failure ?
* How can we prevent these causes (by controls or alternative methods of operation) ?
* Why is this the best way to achieve our aim ?

Not infrequently these types of questions are raised during the P&ID Hazops when a debate develops about whether or not a design feature is practicable or what strategy should be adopted to prevent a deviation which might have serious consequences. More often these conceptual questions are not addressed in Hazop studies which follow slavishly the classical sequence set out in the CIA Guide (2). If faults are revealed in the conceptual design during P&ID Hazops, economic factors often constrain the available actions.

Actions falling into the category "to be decided during commissioning" arise when insufficient attention is devoted to the Conceptual Hazop of PFDs which are intended to achieve on a larger scale what was achieved, not what was done, in the laboratory or pilot plant.

Some examples of Process Deviation Analysis are set out below for four items of equipment in very different industries. It is important in PDA to state the functional specification clearly and succinctly so that one or two deviations cover all possible failures to achieve the design intent. Do not get into the level of detail covered by the keywords used in P&ID Hazops; the intention at this stage is to ensure that the conceptual design is sound, robust and the best way of achieving the design intentions.

Chlorination of Potable Water

Functional Specification: To kill bacteria in the treated water and leave a specified residual concentration of chlorine to counteract subsequent contamination in the service reservoir.

Deviation 1: Bacteria in reservoir water
Causes: Insufficient chlorine supplied. Unexpected high contamination of reservoir water. Chlorine reacts with inerts in the feed water.

Deviation 2: Excess chlorine in water supplied to the customer
Cause: Excess chlorine supplied.

Note that although the method of dosing chlorine into treated water, flowing at hundreds of mega litres per hour, is known to involve the use of a slip-stream of water flowing through an eductor, consideration of the failure modes of the eductor, the chlorine supply and the final SO_2 treatment controlling residual chlorine must be left to the P&ID Hazop when details of these items of equipment are known. The most that the Conceptual Hazop can achieve is to decide the severity of the deviations and specify acceptable hazard rates (6).

Leaching Lipids from Grass

Functional Specification: To extract the valuable products from a particular pelleted grass into acetone in a counter-current extractor from which the raffinate grass containing residual acetone passes to a dryer.

Deviation 1: Raffinate grass contains residual product
Causes: Acetone/grass ratio too low. Residence time of grass is too low.

Deviation 2: Too much acetone in the raffinate grass
Causes: Pellet disintegration causing compaction. Acetone fed too fast.

Note that the above deviations and causes would be relevant for any counter-current leaching operation. Therefore, Process Deviation Analysis can be carried out by all process designers using a sets of typical deviations and causes for typical "unit operations"; these may need to be altered slightly to highlight features of particular applications. The duty of the designer would be to state the methods to be used to control the causes and how these controls might fail

Separation of Gas Water and Sand from Well-head Crude

Functional Specification: To separate water and sand from oil and to separate 40% of the dissolved gas (C_1 and C_2) by dropping the pressure from 100 bar to 50 bar at 50^{0}C.

Deviation 1: Entrainment of oil into the HP gas header
Causes: High oil level in the separator. Lift gas breakthrough. Foaming.

Deviation 2: Oil escape with the water or during sand purging
Causes: Low oil water interface. Insufficient residence time. Low interfacial tension.

Deviation 3: Large amount of water in the oil off-take
Causes: Stable emulsions. High interface level on the inlet side of the weir.

Degassing Liquefied Ammonia

Functional Specification: To flash off dissolved methane and inerts from liquid ammonia at 14 barg and -5^{0}C before storage (7).

Deviation 1: Liquid entrainment into the off-gas
Causes: High level. Gas breakthrough from upstream HP separator.

Deviation 2: Methane contamination of the liquefied storage vessel
Causes: Pressure too high. Temperature lower than expected. Very low level.

Note the similarity between the deviations and causes in these two examples from very different industries. Note also that in both cases gas breakthrough could cause loss of containment from flanges around the separator, which would be much more severe than entrainment and must either be catered for by a high integrity protective system (HIPS) or by raising the pressure rating of the separator and its vent system.

P&ID HAZOP

Numerous papers have described and illustrated the classical approach to Hazop studies of P&IDs. Few people working in the process industries can be unaware of the method and most have some experience of participating in Hazop studies. The following sections present techniques for maximizing the effectiveness of Hazop studies, which are based on the personal experiences of the author.

Severity Criteria and Event Types

In order to allocate resources to controlling risks, it is essential to devise a consistent set of criteria for deciding the severity of the likely outcome. This approach forms the basis for "Rapid ranking of hazards" (8). The semi-log relationship between severity rating and acceptable hazard rate which has been explained elsewhere (6) is incorporated in the first and last lines of Tables 1 to 3.

In effect the criteria is that if the severity rating is S the target value for the hazard rate is less than 1 in 10^S years. The criteria set out in the body of the tables are stated to reflect the acceptable risks for each event type. These criteria have evolved through leading Hazop studies for different clients in various industries; similar tables exist for the food and paper pulp industries. These criteria are applied by the Hazop teams to provide a consistent rating of the potential severity of consequences recorded in the Hazop Tables.

The principal benefit derived from the allocation of severity ratings by Hazop teams is that it emphasizes the need to consider the efficacy and reliability of the actions taken. For example, it is usual to expect numerical calculations to be submitted where the severity rating exceeds 2. These calculations include "consequence analysis" and reliability evaluations; what might be loosely called "Hazan".

The allocation of a severity of 0, indicating minor consequences, does not devalue the importance of the actions recommended; all Action Sheets should be completed and returned by their respective due dates. The severity criteria are useful when preparing the introductory sections of a Hazop report, to show the profile of hazards identified by the team when studying various sections of the plant. Typical profiles are reported in Table 4, grouped into sets of similar units on different plants. The numbers in brackets are [Event Type] and {Severity Rating}.

TABLE 1 - Consequence Severity Criteria for Chemical Plants

SEVERITY	0	1	2	3	4
EVENT TYPE	MINOR	APPRECIABLE	MAJOR	SEVERE	CATASTROPHIC
1. Equipment Damage (Cost)	£ 10^3	£ 10^4	£ 10^5	£ 10^6	£ 10^7
2. Employee Injury	Minor Injury	Loss Time Accident	Multiple Injuries with Return to Work	Permanent Disability Unable to Work	One Fatality
3. Production Loss Production Cost	1 Shift £ 10^3	1 Day £ 10^4	1 - 3 Weeks £ 10^5	3 - 12 Weeks	Over 3 Months
4. Damage Off-Site	None	None	Superficial Damage eg.from Fire-water and to Paintwork	Fabric Damage Windows, Roof tiles Steel cladding	Structural Damage
5. Public Injury	None	Discomfort	Some Hospitalisation for Screening	Minor Injury to One or More People	Major Injury to One or More People
6. Public Reaction	None	Minor Local Complaint	Local Media Coverage	National Media Coverage	Severe Pressure to Cease Production
7. Environmental Impact	None	Satisfy Regulatory Release Criteria	Controlled Release to Avoid More Severe Consequences	Uncontrolled or Unknown Release	Short term Damage to local Flora and Fauna
Max. Hazard Rate	1 per Year	1 in 10 years	1 in 100 years	1 in 1000 years	1 in 10,000 years

TABLE 2 - Consequence Severity Criteria for Offshore Operations

SEVERITY	0	1	2	3	4
EVENT TYPE	MINOR	APPRECIABLE	MAJOR	SEVERE	CATASTROPHIC
1. Equipment Damage (Cost)	£ 10^4	£ 10^5	£ 10^6	£ 10^7	£ 10^8
2. Employee Injury	Loss Time Accident	Major Injury with Return to Work	Permanent Disability Unable to Work	One Fatality	Multiple Fatalities
3. Production Loss	8 Hours	1 Day	1 Week	1 Month	3 Months
4. Oil Release to the Sea	< 10 bbls	10 bbls	100 bbls	1000 bbls	10,000 bbls
5. Effects on Marine Life	None	Minor Discomfort to Sea Birds	Sea Birds require Cleaning	Major Clean-up Local Fish Affected	Major Loss of Life cf. Exxon Valdez
6. Public Reaction	None	Visible Oil Slick Reported	Considerable Local & National Press Reporting	Severe Local Pressure to Stop Production	Severe National Pressure on UKOOA
Max. Hazard Rate	1 per Year	1 in 10 years	1 in 100 years	1 in 1000 years	1 in 10,000 years

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TABLE 3 - Consequence Severity Criteria for the Water Industry

SEVERITY	0	1	2	3	4
EVENT TYPE	MINOR	APPRECIABLE	MAJOR	SEVERE	CATASTROPHIC
1. Equipment Damage (Cost)	< £10^3	£10^3	£10^4	£10^5	£10^6
2. Employee Injury	Minor Injury	Loss Time Accident	Major Injury with Return to Work	Permanent Disability Unable to Work	Death
3. Production Loss	Reduced Output for up to 1 day	Reduced Output for up to 2 days	Total Shutdown for up to 1 week	Total Shutdown for up to 2 weeks	Total Shutdown for > 1 month
4. Bacterial Contamination	Fails Standards	Minor Stomach Upsets	Reservoir Contaminated	Widespread Acute Illness	Death
5. Chemical Contamination	Fails Standards	Bad Taste	Reservoir Contaminated	Permanent Health Impairment	Epidemic
6. On-Site Emergency	Operator Requires Assistance	Partial Shutdown	Total Shutdown	Emergency Services Called Out	Major Emergency Plan Activated
7. Public Emergency	Notify Emergency Services	Houses Evacuated Minor Physical Discomfort	Road/Rail Disruption Some Hospitalisation for Screening	Road/Rail Accidents Permanent Injury	Fatality
Max. Hazard Rate	1 per Year	1 in 10 years	1 in 100 years	1 in 1000 years	1 in 10,000 years

In Tables 1 to 3 there are 6 or 7 event types representing areas at risk; these have evolved from the early days of "rapid ranking" (8). Using numbers to identify the event types facilitates recording on the Hazop Tables. Note that although there is approximate parity vertically between the severity of the events, it is not a requirement that all criteria be satisfied before allocating a severity rating. One selects from the event types the one which could suffer the worst consequences. This event type is recorded first; others which may be less severe can be recorded second and third as an aide memoire.

For example, the Hazop of the oil export section on an offshore platform revealed that in the line used for filling the pig launcher there were two valves: One referred to as "D" in the operating instructions was a 1/4 turn ball valve, the other shown on the P&ID was not lettered and not mentioned in the instructions. The record in the consequence column of the Hazop Table is: " The unmentioned valve is probably left open so that if valve D is accidentally opened hot oil could escape injuring someone and releasing oil to the sea" Severity {1} Event Type [2] [4]. Table 2 list the criteria on which these numbers are based.

The data in Table 4 are taken from 8 Hazop studies:- 4 on chemical plants, 3 on offshore platforms and 1 on a water treatment plant. The Hazop on Unit G which is used to modify the aggressiveness of potable water, revealed also 8 causes of chemical contamination (event type [5]):- 1 of potential severity {2} and 7 of potential severity {1}

TABLE 4 - Severity Ratings {1} {2} {3} vs the Event Types [1] [2] [3]
from Hazop studies of the units listed below

Event Type	[1] Plant Damage			[2] Employee Injury			[3] Production Loss/Cost		
Severity Rating	{3}	{2}	{1}	{3}	{2}	{1}	{3}	{2}	{1}
Unit A	4		1	4	4	9		2	10
Unit B		1	3		2	8	2	6	10
Unit C					3	7	1	9	5
Unit D			1	3	1	1			6
Unit E			1	3	10	8	1	3	11
Unit F	6		4		1	2	2	2	7
Unit G		1	5		3	8			8
Unit H	5	1		4	1	1	5	1	1
Unit I		3	13	3	12	13	4	9	19
Unit J		1	4		4	4	1	5	5
Unit K			1		2	3	1	7	12
Unit L			1			1	1	2	1
Unit M	2	2	3	1	1	3		6	10
Unit N		2	4		1	6		5	6
Unit O		2	2	2	4	1	2	7	3
Plant P	8	13	21	1	18	8		9	26

Unit	Function of Unit
Unit A :	Bulk storage and tanker delivery of acrylonitrile
Unit B :	Bulk storage and despatch of an isocyanate dissolved in a flammable solvent
Unit C :	Mixing toxic liquids delivered in drums
Unit D :	Charging a flammable dust into a vessel containing a flammable solvent
Unit E :	Bulk storage of chlorine with vaporization
Unit F :	Bulk storage of LPG with vaporization
Unit G :	Bulk CO_2 storage and dosing of water supply
Unit H :	Hydrogen production from natural gas by steam reforming
Unit I :	Phosgene generation
Unit J :	Batch phosgenation (rapid endothermic reaction)
Unit K :	Batch chlorination (rapid exothermic reaction)
Unit L :	Scrubber system for chlorination
Unit M :	Recovery system for phosgenation
Unit N :	Gas import to offshore platform
Unit O :	Crude export from offshore platform
Plant P :	Offshore platform gas and oil production trains

TABLE 5 - Numbers of potentially catastrophic consequences (severity rating = 4)
revealed in Hazops on the above Units

Event Type	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Unit B	2						
Unit E		2					
Unit F	1						
Unit H	1	4					
Unit I		1					
Unit J	1	1	1				
Unit K	2						
Plant P	3	1					

Causes of Potentially Catastrophic Consequences

The consequences reported in Table 5 all emanate from loss of containment. For the offshore production trains, reported as Plant P, the 3 events in Table 5 and 6 of the 8 events in Table 4 which were recorded under [1] Plant Damage, all relate to overpressure of vessels; any of these events could produce one or more fatalities but the team preferred to enter Employee Injury [2] in the second box because the likelihood of someone being nearby when a flange springs is difficult to verify during a Hazop study but can be addressed during the "Hazan".

The likelihood of a fatality was the principal criterion for allocating severity 4 to potential consequences in the Hazop studies of chemical plants. In all the studies the likely causes of death were:-

- Flash Fires
- Scalding Liquids
- Toxic Gas

A common cause of loss of containment revealed in Hazops is the inadvertent contact between incompatible materials such as:-

* Evaporating LPG causing water trapped in a heat exchanger to freeze and fracture tubes.
* High pressure gas or vapour and a hazardous liquid such as hot oil or superheated boiler feed water on the low pressure side of an exchanger.
* Gas break-through from a high pressure gas/liquid separator due to sticking of the level control valve. If these systems cannot be avoided, either the downstream vessel and pipework must be rated for the upstream pressure or a HIPS must be provided.

Another cause of loss of containment is manually operated valves such as:-

* Inadequate facilities for isolation prior to maintenance. Although the potential injury to maintenance tradesmen should be rated as severity {3} or {4}, Hazop teams often give a 2 rating for Production Loss [3], on the basis that without adequate isolation the plant would need to be shut down to allow the maintenance to be undertaken safely.
* Manual operation of high level vent valves when filling an extensive system.

Feyzin and other near misses have driven home the lesson that one must not expect a man to shut a valve quickly to stop the escape of flashing liquid when draining liquefied storage vessels. It is equally unrealistic to expect someone to stand-by one or more vent valves and shut them when a hazardous liquid starts to spray out.

The potential fatality identified on the Offshore Plant P, shown as event type [2] in Table 5, related to the manual venting of a hot oil system fed from a ring main at 180°C and 18 barg. Hazop teams often need reminding that venting operations are not confined to commissioning; they may need to be repeated every time that a section of the system is drained for maintenance.

Cause and Effect Tables

Hazop teams need to consider what action is effected by various HH and LL switches. This data may be summarised in cause and effect tables; but unless the person who prepared these tables is a member of the team, considerable time can be spent deciphering what action is effected. It can save time to list beforehand the actions in words, for groups of switches associated with each vessel.

In the study of the gas separation train of Plant P, the cause and effect tables had not been prepared and the process designer was unavailable; so the team listed their assumptions and verified these with the process designer before each meeting. This exercise helped to focus attention on the protective systems before studying each section of plant; in much the same way that the Hazop leader should point out changes in piping specs. For the oil production train, cause and effect tables were available; but it took so long to follow the "effects" that it became distracting to consult these tables in the Hazop meetings and we reverted to listing beforehand the response to the switches associated with each vessel.

Protocol

Actions raised in the Hazop meeting should be placed on one or more members of the team because although they may seek the assistance of colleagues, they represent the team in ensuring that the background to the action is understood. The Lihou Hazop program (4) produces an Action Sheets for each action item showing:-

* Description of the item being studied
* Cause
* Consequence
* Severity
* Event types
* One or more actions
* Initials of the team member responsible for the action(s)
* Response date
* Name of person responsible for collating the actions and calling a review meetings
* Space for recording what was done.

This computer-aided facility effectively allows the Action Sheets, rather than the classical Hazop Tables, to be the principal product of Hazop studies.

Actions fall into four categories:-

* Changes to process design and P&IDs
* Changes to instrumentation and/or control logic
* Points to highlight in procedures
* Verification or elucidation of technical data.

Action Reviews

Action response dates should be set with due regard to the critical path programme of the project. Usually this results in 3 or 4 dates. Bearing in mind that Action Sheets are being issued throughout the study, the dates for action review meetings should be agreed at the end of the study, to follow closely after the response dates.

The person responsible for collating the returned Action Sheets should study the responses as they come in and set aside those which require more detailed attention by the review team. These should not be ranked in order of severity. Those actions which are specific and have been done as suggested by the Hazop team need no further review. Actions which say "provide a facility" or "find a solution to this problem" need to be examined for:-

* The efficacy of the proposed action
* Possible adverse effects on other parts of the plant.

TASK HAZOP

Many process plants are operated sequentially, such as batch reactions, batch distillations, pig launching operations, tanker loading and off-loading, etc. These operations may not be carried out according to the sequence laid out in the operating instructions due to :-

* Human error
* Equipment failure
* Problems elsewhere.

In preparation for these Hazops the operating instructions must be presented as a flow chart of operations each consisting of more than one step, inter-spaced with cues such as "when the temperature gets above 60°C " do the next step. Fig.1 shows a typical flowchart; it refers to the recovery of solvents by batch distillation of purge streams on a polystyrene plant. The Hazop study of sequential operations should apply the following guide words to the flowcharts, using the P&ID as background information. The "property" words are simply the numbered operations. These guide words can be used when examining selected aspects of operating and maintenance procedures which could be hazardous.

Guide Word	Meaning
NO	Operation missed or inhibited by abnormal conditions
LESS	Fail to achieve the end-point of a quantitative step
MORE	Exceed the end-point of a quantitative step
ALSO	Something else going on which could interact with the operation Inappropriate step added
PART	One or more steps missed
REVERSE	Operation must be reversed to regain a safe state Opposite of a step; eg move, fill/empty, heat/cool etc
OTHER	Inappropriate operation carried out Step goes wrong; eg material goes where it should not
EARLY	Operation or step started ahead of cue Step done ahead of required sequence
LATE	Cue missed or circumstances delay the start of operation or step Step done later in the sequence
REPEAT	Successive failures to do a step; eg light a burner Duplicating a quantitative step; eg adding twice the amount

DISCUSSION

This paper recommends that there should be three levels of Hazops for every new project, in order to create a safe and operable plant. Not infrequently the P&ID Hazop raises fundamental questions about the control philosophy for a unit and sometimes the team questions the relevance and efficacy of interlocks and trips. These are aspects which would normally be resolved in a Conceptual Hazop.

Similarly, the actions arising out of P&ID Hazops often include the need to devise a safe method for "responding to an alarm" or sampling or performing critical phases of "start up" and "shut down". When details of the plant layout are known, these procedures should be cast into flowcharts and Task Hazops done on these, with the layout drawings as background information. The Task Hazop technique may be imbedded also in a P&ID Hazop to study particular sequential operations on a plant which is otherwise run continuously. Such as pigging operations in offshore oil pipelines.

REFERENCES

1. Lawley H G, 1974. "Operability studies and hazard analysis", Chem Eng Progress, Vol 70, No 4, p 45.

2. Chemical Industry Safety & Health Council, 1977. "A guide to hazard and operability studies", Chemical Industries Association, London.

3. Elliott D M and Owen J M, 1968. "Critical examination in process design", The Chemical Engineer, CE 377.

4. Lihou M T, 1989. "HAZOP - An aid to more efficient hazard and operability studies", North Western Branch Papers No.6, IChemE.

5. Gibson S B, 1976. "The design of new chemical plants using hazard analysis", IChemE Symposium Series No 47, p 135.

6. Lihou D A, 1988. "A safe and operable plant at minimum cost", IChemE Symposium Series No 110, p 27.

7. Lihou D A, 1983. "Computer-aided operability study", Loss Prevention Bulletin No 051, p 19.

8. Mumford C J and Lihou DA, 1984. "Rapid ranking of hazards", Loss Prevention Bulletin No 059, p 6.

Fig.1 Flowchart of Distilling Crude Volatiles

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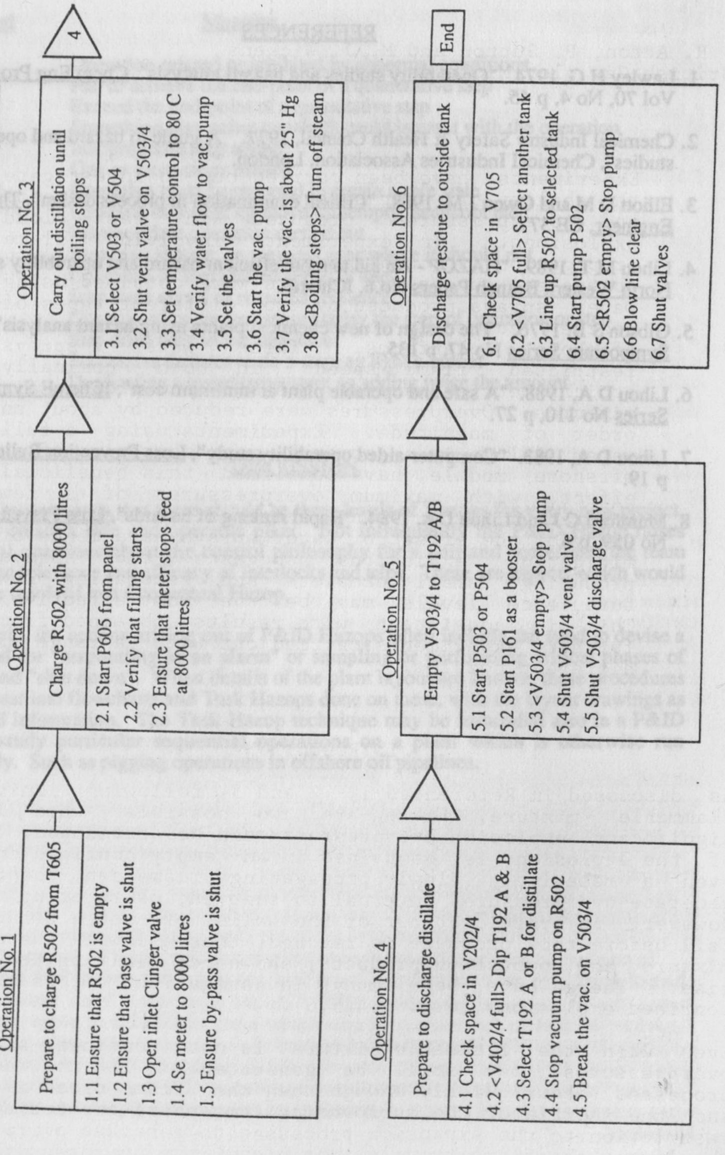

Operation No. 1

Prepare to charge R502 from T605

1.1 Ensure that R502 is empty
1.2 Ensure that base valve is shut
1.3 Open inlet Clinger valve
1.4 Se meter to 8000 litres
1.5 Ensure by-pass valve is shut

Operation No. 2

Charge R502 with 8000 litres

2.1 Start P605 from panel
2.2 Verify that filling starts
2.3 Ensure that meter stops feed at 8000 litres

Operation No. 3

Carry out distillation until boiling stops

3.1 Select V503 or V504
3.2 Shut vent valve on V503/4
3.3 Set temperature control to 80 C
3.4 Verify water flow to vac.pump
3.5 Set the valves
3.6 Start the vac. pump
3.7 Verify the vac. is about 25" Hg
3.8 <Boiling stops> Turn off steam

Operation No. 4

Prepare to discharge distillate

4.1 Check space in V202/4
4.2 <V402/4 full> Dip T192 A & B
4.3 Select T192 A or B for distillate
4.4 Stop vacuum pump on R502
4.5 Break the vac. on V503/4

Operation No. 5

Empty V503/4 to T192 A/B

5.1 Start P503 or P504
5.2 Start P161 as a booster
5.3 <V503/4 empty> Stop pump
5.4 Shut V503/4 vent valve
5.5 Shut V503/4 discharge valve

Operation No. 6

Discharge residue to outside tank

6.1 Check space in V705
6.2 <V705 full> Select another tank
6.3 Line up R502 to selected tank
6.4 Start pump P502
6.5 <R502 empty> Stop pump
6.6 Blow line clear
6.7 Shut valves

AN INVESTIGATION OF THE MITIGATION OF GAS CLOUD EXPLOSIONS BY WATER SPRAYS

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Experiments have been carried out to investigate the ability of water sprays to limit flame speeds and overpressures produced in gas cloud explosions. In experiments involving flame propagation through repeated arrays of pipework obstacles, successful results were obtained using water sprays produced by two different types of nozzle currently used in deluge systems on offshore platforms. These water sprays restricted flame speeds in both nominally stoichiometric natural gas-air and propane-air mixtures. Overpressures were reduced by about an order of magnitude. Experiments using a full water deluge in a geometry representative of an offshore module, have confirmed this beneficial effect, with maximum overpressures of a few hundred millibar being generated. A theoretical study of the effect of water sprays as a means of mitigating explosions suggests that sprays producing small droplets and generating low turbulence levels may be the most effective. This is consistent with results obtained from further experiments carried out with a range of different nozzles.

INTRODUCTION

As discussed in References 1, 2 and 3, following ignition of a flammable mixture, there are two possible ways in which significant explosion overpressures can be developed. Firstly, if the explosion is contained in an empty confined enclosure, even a relatively slowly propagating flame can theoretically generate overpressures internal to that enclosure of up to 8 bar. However, in practice, part of the walls of such a structure may fail before this pressure is reached, thus allowing the escape of mixture and combustion products, and hence limiting the pressure rise. There have been many investigations of such vented, confined explosions (e.g. 1,4,5,6).

Even when the flammable mixture is not confined, significant overpressures may still be generated. If the combustion processes occur quickly enough then the flame speed is enhanced and the inertia of the surrounding atmosphere creates sufficient restriction to the expansion processes to generate overpressures. The faster the flame travels, the higher the overpressure that is