HAZOP, Yesterday, Today, Tomorrow.

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2018 celebrates the 50th anniversary of Hazard and Operability Studies (HAZOP).

This paper describes the evolution of HAZOP and shows that it has now developed into many forms which were not in the original intent. The present state of evolution is defined and as processes are becoming smaller, more varied and less steady state a new approach is recommended for the process industry. This has been outlined and the users are encouraged to develop their own variations as befits their processes. HAZOP is is only limited by the imagination and creativity of the users.

The paper illustrates and encourages new ways that HAZOP can be used in a more creative manner to the benefit of safety and operability none less than accident investigation and the critical analysis of a written procedure.

At the end of the paper there are a number of recommendations for enhancing the quality of a HAZOP, all based on experience.

Key words: HAZOP, matrix, parameters and guidewords.

Yesterday

There is no doubt that the seeds of Hazard and Operability Studies, now known simply as HAZOP, were sown in 1964 within the then Heavy Organic Chemicals Division (HOC) of ICI (ref 1) using the Method Study approach on the design of a new a Phenol Plant. It should be noted that the original intent of the study was to examine the steady state of a large continuous process plant as that was what HOC Division specialised in but is now not necessarily the case.

In the early 1960s there was a rapid scale up in Process Plants with the attendant problems. The first was Para xylene IV which took about 3 years to reach full capacity. Then followed Vinyl Acetate which was decommissioned and abandoned in 1967/8 within 6 months of the initial start-up. Something had to be done about this. The fully developed methodology, which was an evolution of Method Study, was test run on the Boiler Plant associated with Olefines V in 1968 under the "chairmanship" of Ron Fawcett and Frank Mitchell (ex-Works Study) (ref 1). HAZOP is therefore 50 this year. However HAZOP is reviewed it is really a variation of Method Study which examines the "word picture" of what is to be achieved, the *parameter,* and challenges each step or parameter with a *guideword*.

As with any new technique it takes time and experience in its use to learn how it works and to develop it to the full. Most of the evolution fell to ICI and more particular Lawley, Shipley and Knowlton who will be known to many. However who knows of Fawcett and Mitchell who were the real instigators of Hazard and Operability Studies? This evolution resulted in the first formulation by CIA in 1977 (ref 2). Following this it became a recognised and useful tool in Process Engineering. Over the years the tool was used but possibly not as detailed as was intended and possibly not often enough.

In the 1980s the HAZOP technique had become a useful tool used in Chemical Process industry for the identification of problem areas in a design. There was a developing perspective that HAZOP was a necessary tool but having carried out the study it was no longer necessary to finish it and write it up with the actions initiated and how they were completed as either a verification of an action or a material change in the design. There was also a tendency to treat a *batch* HAZOP in the same way as a *continuous* HAZOP. In reality a different approach was required but not necessarily recognised. Each step in a batch process has to be analysed as a discreet action with a different set of *guidewords* and *parameters* and not as a continuum of actions as in a continuous process. As a result many of the possible outcomes were not necessarily identified.

Many of the "chairpersons", not yet recognised as "facilitators", were untrained and used the tool after only a few days of exposure. The role of the chairperson was often to repeat the combination of *parameters* and *guideword* in a staccato manner without adding colour to the discussion so as to stimulate discussion. The "secretary" was sometimes a non-technical person who just recorded the words without any understanding of the technology. The layout of the work sheets was often individual to the chairperson and as a result could be difficult to follow. A standard layout is easier to follow and is totally recognisable. There was also a tendency to apply EVERY *guideword* (the deviation from the design intent) to a *parameter* (flow, pressure, temperature etcetera) even if the deviation was totally meaningless. Team members became so used to this that an omission of a set *of parameters* and *guidewords*, left out for good reasons, was often challenged. Equally some of the parameters were used time and again without any reference to their involvement in the actual process (chemical) this wasted valuable time. The role of the facilitator, as opposed to chairperson, was developing.

The facilitator must be willing to challenge a comment but must not deliver an answer. The role of the facilitator is to stimulate both discussion and creative thinking but not to identify any problem even though the facilitator may have seen the same scenario in the past. This could lead to team demotivation. Further and probably more important is that the facilitator must be alert to *body* and *voice language* or clues that there could be a challenge to a statement made by another team member. A whole list of clues could be written; this is a study in itself and can only be recognised through experience. Little has been written on body language during a HAZOP session and maybe some guidance should be written. The facilitator must be alert to such as the subtle shake of the head or the raised eyebrow and then draw that team member into the discussion. This is most likely when that member disagrees with a statement by another team member or does not follow the logic of the statement, the simple word "e*rrr*!" is a form of voice language – it should be pursued. Maybe the team member does not have the confidence to make a verbal challenge. Equally some team members may be over awed by other team members so the facilitator must draw that person into the discussion. The one feature that the facilitator has to be recognised is that mental fatigue can hit the team suddenly – possibly over less than 5 minutes. Mental fatigue is usually demonstrated by the sudden lack of constructive discussion or a slow response to a prompt. It is then necessary to stop the study even if it is mid-way through a node. Any attempt to stimulate discussion will probably be futile.

While not body language the facilitator has to be alert to discussion which has no outcome (unproductive and time wasting) and equally discussion which has become a repeat of itself. The first can be terminated with a request "*Is it the opinion of the team that this point has been given sufficient attention and should a note be put into the records*?" The second can be terminated by the request "*Mike, can you summarise the issue in two sentences for the scribe*?"

The HAZOP had matured over 15 years and was being used widely in the process industry but not necessarily in the best manner or as initially intended. It was in need of a major revision. This leads to the development phase.

HAZOP was introduced to the Offshore Oil and Gas Industry in the late 1970s. It could be readily transferred from the traditional study process but once again it was the steady state that was most often studied. This was easily rectified by talking through the start-up sequence which was effectively *flow – low* and threw up the temperature and two phase flow transients during the pressurising and depressurising cycles. In addition "prompts" were added so as act as an aide memoire for the facilitator to stimulate discussion. An example of this is shown in Appendix 1 for drilling.

The development of the Drilling variation of HAZOP in the early 1980s took some time as Drilling is not a single steady state operation but a mixture of batch and steady state with many actual operations. The following is a listing of some of the potential drilling operations:

Possible Operations to be considered (Scope) during Drilling

Setting/Driving Conductor

Drilling with BOP in place

Casing off (porous formations, aquifers or salt domes)

Leak off tests

Setting a "pill",

Setting a plug

Logging

Circulating out a "kick"

Top Hole Drilling – Diverter in place

Running Casing

Cementing

Cement Squeeze

Running Production Tubing

Perforation

Circulation

Possible Batch operations to be included:

Mixing Muds

Mixing Cement

De-weighting Muds

Transport of Oils/Barites

Weighting up Muds

Jarring (a stuck bit)

One item identified during a Drilling HAZOP in 1984 on the Clyde Platform was the potential blow-out of a seal in the Mud Gas Degasser should there be a high ingress of gases in the mud returns (see fig 1). The degasser is a simple two phase separator designed to release gases from the mud which may have resulted from contact with an/or ingress of oil or gas in the rock formation during the drilling phase. This is often referred to as a "kick". The degasser is simple and often treated as a standard "off the shelf" piece of equipment. The liquid seal on Clyde was increased in depth against a full set of design parameters which included the likely porosity of the formation. The degasser on Deepwater Horizon on the Macondo Field is shown below in fig1. This was "off the shelf" and had no design parameters. The influx of hydrocarbons into the degasser on Deepwater Horizon blew the seal in the "liquid leg" so releasing hydrocarbon gasses into the drilling area (ref 3).

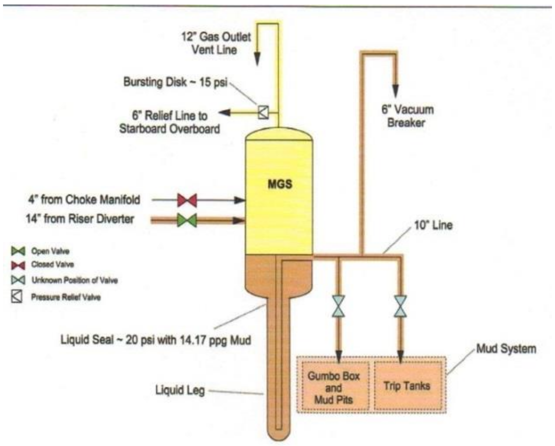
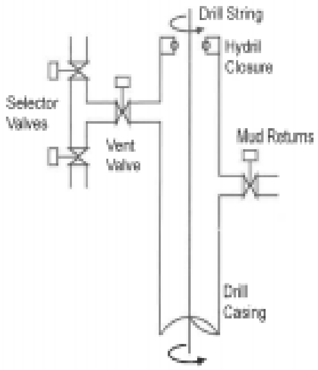
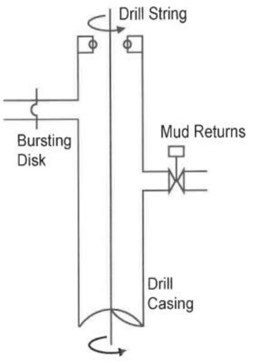


Figure 1 Mud Gas Degasser (MGD)

In addition on the Clyde Platform the design proposed a bidirectional "diverter", similar to that on the Macondo well. (The diverter is a simple device which is used to vent shallow high pressure gas lens contained in an enclose [encapsulated] zone which has been drilled prior to the rock formation is sufficiently strong to achieve full containment using a Blow-out Preventer [BOP]. If not vented there is the significant risk of a blow-out through the formation and under the drill rig.) The HAZOP on Clyde identified that this design was both unreliable and subject to erosion at bends (guide word – *as well as*). This resulted in the FIRST ever single Diverter drilling operation (in the world) on the Clyde Field (ref 4 & 5). (Sketchs 1a & 1b). The analysis of the two phase reduction in sonic velocity, the pressure balance at different points in the well bore and the influence of a second phase in the momentum flux required detailed analysis. Both of these findings on Clyde were significant as had they been implemented on Deepwater Horizon they could have attenuated the damage and possibly the total loss.



Sketch 1a Diverter Original Design (note vulnerable Tee Piece)



Sketch 1b Diverter as installed

Further the 3 dimensional layouts of Oil and Gas platforms was such as to create layout issues such as damage to means of escape and secondary damage (potentially an escalation) due to a single event such as a fire. This was an evolution of HAZOP and called a 3 D HAZOP which later became known as HAZID. See later.

Today

HAZOP is a key element of Hazard Study 3 (Ref 6) within the ICI "six stage hazard study" approach. In a meeting with the IChemE Loss Prevention Subject Group in 1998 at Loughborough University it was proposed that the HAZOP procedure be reviewed and that "HAZOP – Guide to Best Practice" should be developed. This required the convening of a small team to carry out the work under a Steering Committee. This was helped by the results of a wide ranging questionnaire completed by many company members. This lead to:

HAZOP Guide to Best Practice Edition 1 - Published 2000 (ref 6) (Awarded the IChemE Brennan Medal)

The HAZOP Guide to Best Practice Ed 1, developed over two years, attempted to lay down the rules for consistency and uniformity. It also tried to show how HAZOP linked into the wider Hazard Study Process as the two are of equal importance in Loss Prevention (Process Safety as it is now called.) The time frame might appear to be long but it was essential that ***best practice*** was defined and agreed by all.

The first edition included the features of a HAZOP Study and the detail required in the procedure (the HAZOP PROCESS). It then expanded on the derivation of guidewords and also, equally important, the possible parameters. The combination of realistic combinations of *parameters* and *guidewords* becomes the "Matrix" and is a demonstration of the understanding of the CHEMICAL/OPERATIONAL PROCESS. The parameters and guidewords were more expansive than previously anticipated. It was recognised that a variety of terminology and approaches were possible which could achieve good results provided the essential principles were respected. The use of a predetermined Matrix resulted in the elimination of trivial or impossible combinations so allowing the team to focus on the bigger picture.

This edition emphasised the need for a consistent (uniform and recognisable) recording structure which would detail the *hazard* and the *effect* with the *protective systems* in place. These are is important in the assessment of the level of the risk and in layer of protection analysis (LOPA). The record would also have a unique reference number, action and action on such that each action could be tracked to completion.

It was then necessary to define the roles and skills of the leader (facilitator), scribe (recorder) and team members. These were not necessarily recognised before and now there are training courses for both team members and facilitators run by IChemE. One important recommendation was the encouragement to carry out a review of the potential hazards and consequences using pre-read Accident Data Bases by the facilitator so as to draw up a detailed HAZOP matrix and by the team to alert them to possible issues. The details on the planning of the meeting, the completion of the reports, the follow-up and the management of change (MoC) was given. This edition ventured into the review of modifications, repeat designs, periodic reviews of the whole plant treatment of vents and drains (a thorn in the side of any designer) as well as operating procedures. At the time, 2000, the operating procedures were not perceived as important as they are now. This edition had a wealth of guidance on most topics and became the bedrock for future editions.

HAZOP Guide to Best Practice Edition 2 – Published 2008 (ref 7)

This revision was done to fill in some parts which perceived not to be fully covered by the first edition. Minor editorial changes were made and there was the important addition of a “dialogue” within a study showing the team and facilitator interaction this showed how the facilitator could enhance the value of the HAZOP. This was thought important as it emphasised the role of the facilitator as opposed to chairperson. The full 8 (as opposed to 6) step Hazard Study sequence was included. Of more importance was a discussion of the HAZOP of a computer controlled process (new chapter 10). This was a significant addition. The time frame for rewriting was 4 months.

HAZOP Guide to Best Practice Edition 3 – 2015 (ref 8)

This edition was initiated by the need to review “human factors” following a fatal accident on a batch process. This used a written procedure to control the rate and order of the batch chemical additions.

A Peer Review was undertaken for this edition which resulted in the addition of several further sections. Of note was the need for more attention to the process dynamics and also “safe holding positions” following a process upset. (In military terms to where should the troops make the tactical retreat). This could require only a partial shutdown of the plant with the rest of the plant the running in a safe and stable condition. The time frame for rewriting was nearly 2 years. This edition demonstrated the use of HAZOP in the analysis of a procedure. The study produced some unexpected conclusions none less than that the original procedure was dangerous! In some respects this particular HAZOP analysis had returned to its roots in Method Study

Two examples of the flexibility of HAZOP are illustrated:

1. Analysis of a mechanical system

A simple example of this was the analysis of the potential issues associated with a Pilot Operated Relief Valve activated by an interposing relay using an inert gas which was triggered by a potentially fouling fluid. Sadly this was an issue thrown up at the end of a defined HAZOP – “*the project would like you to consider this Pilot Operated Relief Valve within the study*!!”A methodology which was NOT a Failure Modes and Effects analysis had to be developed during the HAZOP meeting, this was embarrassing as the facilitator had to develop the methodology while running the HAZOP and at the same time not displaying ignorance. This methodology was a form of leak path analysis, has been tested, and it is available to all.

2. Accident investigation

The simple line diagram of two saline water tanks on an offshore platform is shown below in figure 2 (this is a re-draw of the figure in ref 9 so as to make the layout easier to understand). The elevation difference of tanks A and B was about 20 m. A being above B and about 40 m horizontally displaced. The vent was a vertical pipe to atmosphere.

The overflows on both tanks went below sea level which made some of the diagnostics difficult; the vacuum break is via the vent line. The text in ref 9 was changed to make the story simpler and easier to understand. The reality is that the feed into tank A had increased some two fold over 5 years and in addition the control of the level in tank A was by a controller on the feed to tank A which would “dump” excess water. This control was unreliable so it was decided to use the overflow of tank A to control the level in tank A. This was a flawed approach as it uses a protective system as a controller and is one that a management of change procedure should have prevented. During one upset the flow out of tank A was interrupted and the tank A overflow became overloaded such that water tracked up into the vent line and down to tank B. The pressure regimes were finely balanced. It is not difficult to see that there was a lute with the potential to collapse tank A if the feed into tank A was interrupted. It was, with the inevitable collapse of tank A.

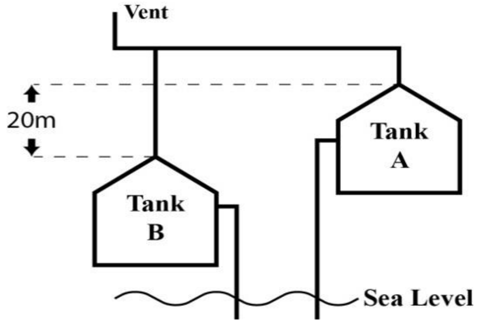


Figure 2 Simple layout of tanks and vent (re-drawn from ref 9)

The investigating team visited the platform and talked to the operations personnel. A verbal report by the operator on shift at the time of the incident indicated that tank A was over pressured as some water came out of a dip-hatch – luckily the roof weld did not fail. Excess flow from tank A overflowed into tank B but was not sufficient to over-pressure tank B as the overflow of tank B handled the extra flow satisfactorily, The evidence was far from conclusive and however much the sequence of overfilling and siphoning was tested it was rejected for one reason or another. As a result a HAZOP was carried out on the various interlinked P & IDs including tanks A and B and the vent system. As the study proceeded the conclusions were still unclear until one guideword was applied and one of the team members said very slowly "*If the line slope creates a hold up at the vent end….."* (Pause) "*Then there is the possibility of a vacuum*……" (Pause) "*And tank A will collapse*!!" The event was now fully explained and the cause was now verified. In effect the vent for the two tanks had a slope such that traces of rain water or condensation would self-drain into a small pot at the foot of the vent which emptied into a drain via a small lute seal. This was not obvious on inspection but was shown on the P&IDs and over the length of the vent line it probably represented a 0.75 m seal. This meant that there was a short term seal in the vent which resulted in the collapse of tank B. Would this be identified in a HAZOP – probably not. Would it be identified in a Management of Change? Possibly.

Tomorrow

In all some 2,000 man hours (and it was man hours) have been invested in the three versions of the HAZOP Guide to Best Practice. For a number of reasons the authors of the Guide feel that they can no longer keep the Guide "current". In addition the large bulk processes for which HAZOP was originally formulated have now been replaced in the UK by new and different processes such as water treatment and food processing. The bulk processes for which HAZOP was originally devised will still be needed but they will not necessarily be in the in UK. It is reasonable to propose that that new variants of HAZOP are developed within, and are appropriate to, each industry.

Further there are still some fundamentals which require attention. It is recognised that HAZOP is potentially expensive and time consuming BUT so also will be the problems that will have to be handled if it is not carried out!! There is some evidence that HAZOP is perceived to be a necessary evil that has to be done but then the actions can be overlooked. The actions could be a *discoverable document* following an incident so they must be handled properly. Further there is too little time allocated to the review of history of the process and incidents that have occurred (the process research).

While there are some excellent training courses for facilitators and team members it is the facilitator who is more important to the success of the study than the lack of adequate training for team members. Further the Project Management still appear to think that the HAZOP is a problem solving exercise, it is an audit exercise and the major problems should have being flushed out by the Project Team during the Hazard Studies, a point made in a recent "Letters to the tce Editor". This is not necessarily the case. Too often the Project will say at the beginning of the study "the HAZOP should also examine "xyz".

There MUST be a detailed discussion of the scope and terms of reference with the facilitator. The terms of reference should include such as recording style, in addition the availability of team members must be clarified. The scope should include the start and end points for the study, which may or may not be in another process and a detailed analysis of the physical process so as to define the Matrix. This should be constructed by dialogue with the Project as the Project is responsible for taking any actions. Further the discussion may throw up a number of potential issues which had not been thought significant previously and should help to develop prompts or leading questions for the facilitator. As previously noted the Matrix represents the understanding of the physical (plant) process. Taking this to a logical conclusion the Matrix will probably be a *process specific* item and cannot be used as a generic item (see appendix 1). For example water treatment will want to examine the means by which organisms may track past filters and how pathogens should be handled. The foods industry may also have their own specific matrix which might include guidewords such as "*too long/too high residence*" (duration in an oven) or "*incomplete – mixing*". Each industry must now take on itself the development of its own methodology. Another example in the pharmaceutical industry (as well as chemical) might be the size and distribution of crystals particularly with classifying crystallisers. Industries should make the effort to not only develop their specific matrices but also to investigate variations of the tool so as to satisfy their own requirements. Two examples have been given under **Today**.

The dynamics of the process - particularly during start up and process shutdown - requires more attention, particularly the safe holding position. There are other issues such as where should the off-spec materials be stored and, if contaminated, does this impose specific issues this may create metallurgical issues, chemical stability issues and storage capacity issues? This list is not exhaustive but indicative of the details that must be considered.

Facilitators are encouraged to develop a more challenging approach to the Matrix as shown in Appendix 1. The incantation of *guideword – parameter* such as *no – flow* is not creative but the question as follows is constructive. "*What would happen if pump "X" were to trip and what would happen if this control valve "Y" were to close*? They all mean *no – flow* but the facilitator is now pointing the team at issues and allowing them to think laterally. The next question is "What other situations could create loss of flow?" This is what facilitation means.

Finally HAZID, which evolved from HAZOP (ref 10), has become a tried and tested identification tool in the Oil and Gas Industry (ref 10, 11 & 12). The use of HAZID was initially designed to identify lay out issues or incompatible operations in a 3 dimensional space. It has evolved into a very flexible tool. It has been used in many scenarios from the examination of the location of new equipment to the examination of the construction of a new facility and the acid treatment of wells, just to give three examples. In the original format it was the **effect** (define) **on** (define) **by** (define). For some reason it has not found use on-shore, this is thought to be a weakness. Spouge (ref 12) has redefined it as:

HAZID – A systematic review of the possible causes and consequences of hazardous events.

Strengths

- It is flexible and applicable to any type of installation, operation or process
- It uses the experience of operating personnel as part of the team
- It is quick as it avoids repetitive consideration of deviations
- It is able to cover low frequency events and hence relates better to QRA than most hazard assessment techniques

Weaknesses

- Guidewords require development for each installation and may omit some hazards
- Its benefits depend on the experience of the leader and the knowledge of the team. (This is not necessarily the experience of the originator of the technique; however the originator had the experience.)

In summary HAZOP is infinitely flexible and requires a little imagination to be used to its best as opposed to using it by rote. Users are encouraged to be more adventurous in its use.

Postscript

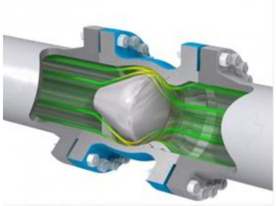
There is always a lot of discussion on the accuracy of a HAZOP, more particularly any issues not identified. Some issues are identified at least twice under *different* combinations of *parameter* and *guideword*, sometimes it is only once. This might suggest that there is a form of binomial equation of success (S) and failure (F). $S^2 + 2FS + F^2$. F^2 is unlikely but is real.

One particular "failure" was the identification of the style of a non-return valve (NRV) in the drain on a suction catch pot of a hydrocarbon refrigeration cycle operating at a pressure of 15 kPa above atmospheric pressure. The drain was there to discharge any oils that had accumulated (and they did). The drain was also fitted with a spring loaded plug in a NRV so as to prevent air ingress. – see Zebedee – Photo 1. The design is such that there was a tapered/chamfered metal to metal seat giving a negligible leak when closed. The theory was right but the specification was flawed. The spring force (closing) was significantly higher than the process force (opening) so no oil could be drained (but equally no air could enter if the valve was opened). The symbol in the P & ID did not give any indication of style.

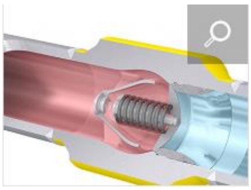
Photo 1 "Zebedee" (as in "The Magic Roundabout")

7 cm high and 4 cm across the sealing face – note the taper

A second "failure" involved a Mokveld non return valve (NRV) in a 48 inch (1.2m) suction to a propylene refrigeration compressor. (The valve was fitted as a means to preventing contra-rotation at a surge or shut down). The Mokveld NRV is concentric piston as shown in sketch 2; there is a soft spring to park the piston in the seat and also a dash pot to reduce slamming, this is shown in sketch 3. When on recycle the temperature of the refrigerant was -35°C with negligible pressure drop across the NRV. As the process load increased the temperature fell to – 40°C and the pressure drop across the NRV rose to about 5 kPa. The impact of this pressure loss was to increase the power draw of the compressor. Careful NDT examination of the position of the piston relative to the seat in the NRV using gamma rays showed that the piston had moved slightly towards the closed position. The obvious cause was a change in the spring stiffness as the temperature fell past a threshold. This was obviously a feature that had been missed in the specification. Once again the theory was right but the specification was flawed.



Sketch 2 Concentric NRV (flow R to L)



Sketch 3 Spring loading and dashpot in NRV

A third "possible failure" involved a condensing turbine driver of about 25MW located in an open sided (Dutch barn type) compressor house. The condenser was kept under "vacuum" by a steam ejector, (this was NOT part of a HAZOP). The steam from the ejector was pre-condensed against water such only the water wet air passed to a 1 m long un-lagged tail pipe, pointing *downwards*, which was probably significant. The wall temperature was normally about 25ºC. One VERY cold night with a high wind chill factor the exit point, bottom, of the tail pipe froze over time and vacuum was lost. The solution was to play a steam lance on the tail pipe and to lag it in the morning. Of note is the fact that a similar ejector set in the same compressor house did NOT ice up. What is the chance of this being identified in a HAZOP? About 50%?

There is a warning in these stories; HAZOP will not necessarily identify poorly specified hardware. Is this part of the F^2? In the case of critical equipment it might be necessary for the HAZOP to recommend that the equipment is examined by a FMEA if not already carried out as part of Hazard Study 2, particularly examining the extremes of the operational boundaries or envelope.

It would be wrong if some strong recommendations are not made to strengthen the HAZOP technique and to ensure the success of the study.

1. The facilitator must liaise with the client (Project) to develop the scope and terms of reference for the study
2. This will be used to develop the HAZOP Matrix and suitable prompts for the facilitator.
3. The facilitator should try to be more imaginative in the leadership of the HAZOP using prompts and not *parameter and guideword* alone.
4. The facilitator must be alert to body language, including fatigue, and help the team to identify scenarios which the facilitator may have already recognised from his/her experience. Obviously the facilitator cannot do the identification for the team as they would become demotivated.
5. Newer processing industries must adapt the technique to their specific industries.
6. Prior to the study the team should have reviewed the accidents data bases plus an analysis of the failure modes of equipment and humans to refresh themselves of problems that have arisen or may arise.
7. It is a strong recommendation that Project Teams make more use of Hazard Studies to flush out issues which should not be left to the HAZOP Team.
8. It is a strong recommendation that other users of HAZOP should incorporate HAZID into the Hazards 2 study.
9. It is a strong recommendation that the team identify "the safe operating - tactical - retreat position" following an upset.

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* Please note the name reversal for ref 5. This was appropriate as the first alphabetical name was on the point of leaving BP.

Acknowledgement

Once again the author would like to thank Brian Tyler for his, usual, detailed comments during the draft of this paper.

Appendix 1

Parameter/Guideword V/H	No/None	More/Higher	Less/Lower	Reverse	Other than	As well as	Change
Flow	1.1	1.2	1.3	1.4	1.5	1.6	?
Pressure	2.1	2.2	2.3	2.4			
Temperature		3.2	3.3				
Level	4.1	4.2	4.3				
Settling	5.1	5.2	5.3	5.4	5.5		
Reaction forces		6.2	6.3				
Viscosity		7.2	7.3				7.7
Density		8.2	8.3				8.7
Barriers (in place)			9.3.				
Composition		10.2	10.3			10.6	10.7
Erosion		11.2					
Corrosion		12.2					
Communication	13.1		13.3				
Monitoring	14.1						
Mechanical State	15.1						

Possible Combinations of Parameters and Guidewords (HAZOP Matrix) for Piping and Oil Circulation while Drilling - following discussion with client

Number	Consider	Possible other implications
Flow		
1.1	Valve closure, mud pump failure Also cement pumps	Loss of lubrication and cooling of the drill bit. Potential to induce a “kick”.
1.2	Pumps run dead head, valves open fully. Trivial case is line rupture.	Impact on erosion and on the mud gutters/shale shakers

Number	Consider	Possible other implications
1.3	See 1.2 a lesser case	
1.4	Pump failure, abnormal pressure distributions – a “kick”	Non return valve failure or a “kick”

Prompts for the Facilitator as to possible causes of actions arising from the Matrix – above - from discussion with client