

The EHSC Notes on "Safety Issues in the Scale Up of Chemical Reactions" and "Inherently Safer Chemical Processes" published by the Royal Society of Chemistry refer to Hazard and Operability Studies. The Society believes that Hazard and Operability Studies is an issue which is important to all chemists.

This Note is designed to provide guidance to RSC members, particularly those involved in the design and development of chemical processes. It assumes familiarity with basic terms such as 'hazard' and 'risk'. The Note is intended to be an introduction rather than a full or definitive guide. Readers are urged to obtain more detailed information and/or expert advice if this is required.

1. INTRODUCTION

Traditionally, safety in the design of chemical plants relied upon the application of codes of practice, design codes and checklists based on the wide experience and knowledge of professional experts and specialists in the industry. However, such approaches can only cope with problems that have arisen before.

With the increasing complexity of modern plant, these traditional approaches are likely to miss other issues which need to be considered at the design stage of a project. Hazard and Operability Studies (HAZOPs) were developed by ICI during the 1960s as a technique to overcome this problem and to systematically identify potential hazards and operability problems with new designs for chemical and petrochemical plant, in both batch and continuous processes. HAZOPs can also be used for modifications and for the review of existing processes.

2. WHAT ARE HAZOPs?

HAZOPs are structured critical examinations of plant or processes, either batch or continuous, and are undertaken by an experienced team of company staff in order to identify all possible deviations from an intended design, along with the consequent undesirable effects concerning safety, operability and the environment. The possible deviations are generated by rigorous questioning, prompted by a series of standard 'guidewords' applied to the intended design.

Standard guidewords and their generic meanings

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<u>Guideword</u>	<u>Meaning</u>
No (not, none)	None of the design intent is achieved
More (more of, higher)	Quantitative increase in a parameter
Less (less of, lower)	Quantitative decrease in a parameter
As well as (more than)	An additional activity occurs

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The EHSC welcomes comments on this Note. Please send your comments to: The Secretary Environment, Health and Safety Committee Royal Society of Chemistry Burlington House Piccadilly London W1J 0BA

Tel: +44 (0) 207 440 3337
Fax: +44 (0)207 734 1227
Email: ehsc@rsc.org

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Part of	Only some of the design intention is achieved
Reverse	Logical opposite of the design intention occurs
Other than (other)	Complete substitution. Another activity takes place.

Other useful guidewords include

Where else	Applicable for flows, transfers, sources and destinations
Before/after	The step (or some part of it) is effected out of sequence
Early/late	The timing is different from the intention
Faster/slower	The step is done/not done with the right timing

The deviations from the intended design are generated by coupling the guideword with a variable parameter or characteristic of the plant or process, such as the quantity of reactants, the reaction sequence, stirring, temperature, pressure, flow, phase, etc.. In other words:

GUIDEWORD + PARAMETER = DEVIATION

For example, when considering a reaction vessel in which an exothermic reaction is to be undertaken and one of the reactants is to be added stepwise, the guideword "more" would be coupled with the parameter "reactant" and the deviation generated "more reactant", the cause of which may have been double charging, leading to the consequence of "thermal runaway".

Systematic examinations are made of each part of a plant or process using these guidewords. Batch operations need to be broken into a sequence of time-based stages. Continuous operations can usually be broken down into a series of hardware sections, working downstream through the plant.

For each section or stage of a plant or process, a design intention must be derived. This states what is involved, what is intended to be done and how and, if possible, the acceptable range of operational conditions. The examination involves searching for possible deviations from this design intention. For each meaningful deviation the team seeks causes that could move the plant or the process outside its acceptable range, potentially causing hazards or operability problems.

Having examined the design of first section or stage and recorded any potential hazards and operability problems associated with it, the study progresses to focus on the next part of the design or the next step in the operation. The examination is repeated until the whole plant has been studied for all major modes of operation, including start-ups, shutdowns and catalyst regenerations. Recommendations for changes in design, operating procedure, materials or for referral outside for further consideration can then be made to overcome the problems which have been identified.

The approach described above will generate hypothetical deviations from the design intention. The success or failure of study depends on four aspects:

- the accuracy of the design drawings and other data used as the basis for the study;
- the technical skills and expertise of the team;
- the ability of the team to use the approach as an aid to their imagination in visualising possible deviations, causes and consequences; and
- the ability of the team to maintain a sense of proportion, particularly when assessing the seriousness of the hazards which are identified.

Careful thought must, therefore, be given to preparative work, team composition, keeping of records and so on.

3. PREPARATION FOR CARRYING OUT HAZOP

The amount of preparation required for a HAZOP depends upon the size and complexity of the plant. Typically, the data required consist of various drawings in the form of line diagrams, flowsheets, plant layouts, isometrics and fabrication drawings, operating instructions, instrument sequence control charts, logic diagrams and computer programmes. It is important to have available data on the kinetics and thermochemistry of the process, on possible side reactions and the formal statement of the "basis for safe operation" that spells out the key controls that avoid the development of unsafe conditions, such as the rate of addition of reactants, limiting the maximum temperature or maintaining stirring. Information on the thermal stability of the reactants, intermediates and products is also helpful.

Occasionally there are plant manuals and equipment manufacturers' manuals. The data must be accurate and sufficiently comprehensive. In particular, for existing plant, line diagrams must be checked to ensure they are up to date and that modifications have not been made since the plant was constructed.

4. COMPOSITION OF THE TEAM TO CARRY OUT A HAZOP

HAZOPs are normally carried out by a multi-disciplinary team, including chemical engineers and chemists, with members being chosen for their individual knowledge and experience in design, operation, maintenance or health and safety. A typical team would have between 4 and 7 members, each with a detailed knowledge of the way in which the plant is intended to operate. The technique allows experts in the process to bring their knowledge and expertise to bear systematically so that problems are less likely to be missed. HAZOP is not a technique for bringing fresh minds to work on a problem.

HAZOP studies generate recommendations for design changes. The team should have the authority to agree changes there and then, as progress can be slow if every change has to be referred elsewhere for a decision. However, in practice there may be items that have to be referred elsewhere for more information, more investigation and/or approval.

It is also essential that the team leader is an expert in the HAZOP technique. The team leader's role is to ensure the team follows the procedure. He or she needs to be skilled in leading a team of people who may not normally be responsible to him or her and the sort of person who pays meticulous attention to detail. The team should have a secretary who usually writes up the study as the meeting goes along, rather than afterwards. It is commonplace now to use a laptop and projector so that all the team can see, correct and agree the record during the meeting.

It is recommended that the team leader should be an independent person, i.e., this should not be somebody who is closely associated with the plant under study. The team leader must have sufficient technical knowledge to guide the study properly. Whilst his/her primary role is to lead the study, it is rare for team leader not to make his/her own technical contribution during the meeting. It is beneficial if team members have had some training in the HAZOP technique.

HAZOP team meetings should be planned well in advance so that members of the team can keep the dates free. Attendance should be subject to a "three-line whip" and deputies should only be sent as a last resort. They do not know what has gone before and are likely to find it difficult to make a full contribution.

5. RECORD KEEPING

It is usual to record each step of a HAZOP for all the physically meaningful deviations or, if a subset is used, to include those requiring an action plus those which considered significant but required no action because the existing protection was deemed adequate.

A particularly useful type of record is the 'Hazard file'. This would normally include:

- a copy of the data (flowsheets, original and final process and instrument diagrams, running instructions, bar sheets, models etc) used by the team during the examinations sessions and marked by the study leader to show that they have been examined;
- a copy of all the working papers, questions, recommendations, re-designs etc, produced by the team and others as a result of the study; and
- confirmation that all the agreed actions have been carried out.

Increasingly with computer aided recording, full records are generated during meetings. The computer can also provide prompts to the team to ensure that all questions are asked and are recorded. Therefore, every deviation that the team considered possible and discussed will appear in the records, even if they found no likely cause or no significant consequence. The minimum line of records would be Identifier No/deviation/cause/consequence/safeguards/action. The file should be retained on the plant to provide a source of information for future use and in the event that changes are subsequently contemplated by the operating personnel.

6. ASSUMPTIONS

In a HAZOP study 'operability' is as important as 'hazard' and in most cases more operating problems are identified than hazards. The HAZOP technique can therefore enable companies to use resources more effectively and become more efficient as well as safer. It must be remembered, however, that the use of the HAZOP technique comes too late for fundamental change in design. All that can usually be done is to add on equipment or procedures to control the hazards that have been identified.

The technique assumes a good level of general management competence, in particular that the plant will be operated and maintained in the manner assumed by the design team and in accordance with good management and engineering practices.

If these assumptions are not valid, then HAZOPs are of little value. It is no use identifying hazards if nothing is to be done to manage and control the consequent risk; it is of little use installing trips and alarms if they are going to be badly maintained. The time spent on a HAZOP would be better spent improving management awareness and commitment to the provision of maintenance schedules, systems for controlling plant modifications, and so on.

7. RESOURCE IMPLICATIONS

HAZOPs are time-consuming and on a continuous plant can take, perhaps, up to half a day per main item of plant (e.g., still, furnace, reactor, pipeline or transfer line, etc) depending on whether the plant is similar to an existing one or completely new. For batch plants both the preparation of data and the study itself will take longer, especially where the same equipment is used to manufacture a range of different products.

Meetings are usually restricted to 3 hours, 2 or 3 days per week, to give the team time to attend to their other duties and because people's concentration wanes after 3 hours at a stretch. Many HAZOP studies can be completed in 5 to 10 meetings, although for a small modification only one or two meetings may be necessary. However, for a large project it may take several months even with 2 or 3 teams working in parallel on different sections of the plant.

HAZOPs have major resource implications which should not be under-estimated. If HAZOPs are to be introduced to any organisation for the first time, it may be appropriate to apply the technique to one or two problems to find out whether it is useful and can be applied successfully. If so the technique can grow naturally and be applied to larger projects.

For major projects, there may be six (or eight) different hazard studies. A HAZOP study is often the third of these studies. Inherent safer design is usually covered in the second study.

8. RESULTS OF HAZOP

On completion of a HAZOP study the likely outcomes are:

- some improvements in operating/maintenance procedures, control programmes and instructions which may already have been implemented together with minor (low cost) hardware alterations. These will have been put in hand as parts of the study are completed;
- some proposed changes may await the result of a more detailed quantitative assessment;
- major recommendations will have yet to be implemented, possibly awaiting capital sanction; and
- the team members will already have both a better understanding of the plan/process and a better appreciation of potential hazards and risks than if the study had not been carried out.

9. BENEFITS OF HAZOPs

The circumstances when HAZOPs are likely to produce benefits are:

- during the design or installation of any new plant or process, or major modification to an existing one;
- when there are novel hazards such as environmental hazards and quality or cost issues associated with the operation;
- following a major incident involving fire, explosion, toxic release etc; and
- to justify why a particular code of practice, guidance note or industry code is not to be followed.

10. CAUTIONS

Even the most rigorous HAZOP cannot be relied upon to foresee every hazard and some accidents may well occur in the future.

When an accident occurs on a plant which has undergone a HAZOP study, several questions of particular significance should be asked:

- had the set of conditions (deviations) which led to the incident been considered by the HAZOP study team? If not, could the team reasonably have been expected to have done so? and
- if such deviations and their causes had been considered, had the team made a reasonable judgement of the likely frequency of the events and had concluded that they were unlikely to occur and thus posed 'acceptable risks'?

In such circumstances it is clearly important to document all the outcomes of study in order to answer these questions.

Modern designs are so complex that even most expert engineers cannot spot all the weaknesses just by looking at the drawings. HAZOPs allow us to make the best use of their knowledge and experience by applying it in a systematic way. If the team lack knowledge and experience then the HAZOP becomes an empty shell that will achieve nothing.

11. CONCLUSION

HAZOPs are an essential tool for hazard identification and have been used successfully to improve the safety and operability of both new and existing chemical plant. The technique is not confined to the chemical and pharmaceutical industries and has also been used successfully in a number of other industries, including the off-shore oil and food industries.

FURTHER READING

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This Note was prepared by a Working Party of the RSC Environment, Health and Safety Committee

The members of the Working Party were : Dr I Wrightson [Chairman], Sara J Cooper, Dr M Crookes, Dr C L Grundy, Dr N King, Dr P Lewis, Dr D H Lohmann, Dr C Maxwell, Dr G V McHattie, Mr D M Sanderson and Dr S Lipworth [Secretary].

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