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TITLE: Hazop Analysis Database Programming For Petrochemical Utility Systems

NAME: Mr. Pisak Wichakool

THIS THESIS HAS BEEN ACCEPTED BY

.... **THESIS ADVISOR**

(Associate Professor Penjit Srinophakun, Ph.D.)

.... **THESIS CO-ADVISOR**

(Associate Professor Thongchai Srinophakun, Ph.D.)

.... **GRADUATE COMMITTEE CHAIRMAN**

(Associate Professor Peerayuth Charnsethikul, Ph.D.)

APPROVED BY THE GRADUATE SCHOOL ON ....

.... **DEAN**

(Associate Professor Gunjana Theeragool, D.Agr.)

THESIS

HAZOP ANALYSIS DATABASE PROGRAMMING FOR PETROCHEMICAL UTILITY SYSTEMS

PISAK WICHAKOOL

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Engineering (Safety Engineering)
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Pisak Wichakool 2009: Hazop Analysis Database Programming For Petrochemical Utility Systems. Master of Engineering (Safety Engineering), Major Field: Safety Engineering, Interdisciplinary Graduate Program. Thesis Advisor: Associate Professor Penjit Srinophakun, Ph.D. 78 pages.

Hazard and Operability (HAZOP) analysis is a popular method for performing hazard analysis in chemical plant. HAZOP analysis is based on assumption that hazards occurs because of deviations from the normal behavior. However, conventional HAZOP have both favorable and unfavorable characteristic as take a lot of time consuming, demand considerable cognitive load from the analyst, and required multidisciplinary knowledge during the analysis period. Therefore, HAZOP database is developed based on Microsoft Access in order to minimise time and cost for HAZOP analysis.

This HAZOP database system consists of equipment definition, guideword, safeguard, cause and consequence library, and method for finding result. The HAZOP database system uses its relationship between cause and consequence to analyze the study node. Then the HAZOP results will be shown in report. In verifying, the process variable deviations of equipments are compared with the data of conventional HAZOP. These results from HAZOP analysis database programming can detect the potential accident more exhaustively than other hazard analysis system with narrow viewpoint. However, further improvement of the database of the system is required for use in other specific chemical plants

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Student’s signature Thesis Advisor’s signature

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INTRODUCTION

The growth of an industry depended on technological advances. This is especially true in the chemical industry which is entered an era of more complex processes: higher pressure, more reactive chemicals, and exotic chemistry. More complex processes require more complex safety technology. Many industrialists are even believed that the development and application of safety technology are actually the constraints on the growth of the chemical industry.

Therefore, the safety technologies are required in order to reduce the hazard from chemical industry. Process Hazard Analysis (PHA) is the systematic identification, evaluation and mitigation of potential process hazards that could endanger the health and safety of humans and cause serious economic losses.

The Occupational Safety and Health Administration of the United States government (OSHA) determines standard for Safety Management that explains about high hazard chemical management and analyst the hazardous of process. A wide range of PHA methods such as checklists, what-if analysis, preliminary hazard analysis (PHA), hazard and operability study (HAZOP), failure modes, effects and criticality analysis (FMECA) and fault tree analysis (FTA) are taken into account. However, whatever method is used, there is no guarantee that all the causes and consequences of real accidents in process plants have been found and considered (CCPS, 1992).

1. Background

The utilities as steam supply system, cooling water system, utility water supply or demin water system are important part in any kind of plants. Also there are many hazardous substances such as chemical dosing packages (acid, caustic), high pressure steam, or flammable gas. Due to these features, utility plants always have high possibility of accidents as a result of equipment failure or operator error, and it is common that the accidents in utility plants are injury or fatal, not only to the individuals at the plant, but to the offsite area, residents and environment. Therefore, ensuring plant safety is a basic important task in many chemical process plants. The Process Hazards Analysis (PHA) is used in order to prevent accident and find the way to solve this problem immediately.

According to the principle and the following reason, affect Plant A need make up the Process Hazards Analysis (PHA). HAZOP is the most widely used PHA methodology and hence it is the approach that we have chosen to discuss in this paper. This analysis is typically performed by a team of experts who has specialized knowledge and expertise in the design, operation, and maintenance of the plant. The team members examine the process P&ID systematically and identify every conceivable deviation from design intent in the plant; determine all the possible abnormal causes and the adverse hazardous consequences of that deviation (CCPS, 1985). Thus, HAZOP analysis is a laborious, time-consuming and expensive activity that can benefit from automation.

In order to reduce the time, cost and increase its reliability, computerized support systems have been considered. The HAZOP database is chosen to make up HAZOP in Plant A. The HAZOP database programming is selected because this database collects knowledge and experience of expertise that it uses knowledge facts and reasoning techniques to solve problems and make easy decisions.

2. Problem Definition

1. To analyze hazardous for utility system of petrochemical plant using HAZOP.

2. To create HAZOP database programming based on Automatic HAZOP analyzer and expert system.

OBJECTIVE

To create HAZOP database programming for Utility system of Petrochemical Plant based on automatic HAZOP structure.

Scope of work

1. Study the detail of Utility system (Steam/ Condensate distribution system, Cooling water system and raw water system) of Petrochemical Plant

2. Analyze hazard of Utility system (Steam/ Condensate distribution system, Cooling water system and raw water system) by using HAZOP

3. Study algorithm of automatic HAZOP

4. Create HAZOP database programming by using Microsoft access 2000.

Benefit

To reduce the HAZOP review time, cost, increase its reliability.

LITERATURE REVIEW

1. Automatic Hazard Analyzer

In 2001, Phatthara Prudthisoontorn developed HAZOP Expert System based on G2 shell (Gensym, USA.) in order to save time and cost for conventional HAZOP analysis. This Expert System consists of several modules including process general knowledge, process specific knowledge, inference engine and user interface. The graphical user interface enable user to easily draw process P&ID and input information about equipment via dialogue window. The Expert System uses its knowledge base to analyze the study node and reported in HTML format. Testing with Textile Auxiliary Process Plants showed that the expert system can produce satisfied results compared with those from human expert. However, further improvement of the knowledge base of the system is required for use in other specific chemical plants.

In 2000, Venkatasubramanian *et al*., discussed the progress that has been made in their laboratory on the industrial application of intelligent systems for operating procedure synthesis and HAZOP analysis because process safety, occupational health and environmental issues are ever increasing in importance in response to heightening public concerns and the resultant tightening of regulations. Recent advances in this area have promising implications for process hazards analysis, inherently safer design, operator training, and real-time fault diagnosis

In 1998, Srinivasan and Venkatasubramanian presented a knowledge-based system, called Batch HAZOP Expert, which is an implementation of the framework propose in the HAZOP knowledge for batch chemical plants. The important features of Batch HAZOP Expert and its performance on an industrial case study are described.

In 1990, Nilsen presented about using the expert system shell G2 for one particular application, namely a safety assessment and post- trip guidance system intended for the control room of the Forsmark unit 2 nuclear power plant in Sweden. The experiences made are believed to be general enough to be relevant in a general discussion about expert system technology. In particular their paper focuses on real-time aspects and matters concerning data types.

2. Hazard and Operability (HAZOP) study

HAZOP stand for Hazard and Operability. It is a structured and systematic examination of a planned or existing process or operation in order to identify and evaluate problems that may represent risks to personnel or equipment, or prevent efficient operation. The HAZOP technique was initially developed to analyze chemical process systems, but has later been extended to other types of systems and also to complex operations and to software systems. A HAZOP is a qualitative technique based on guide-words and is carried out by a multi-disciplinary team (HAZOP team) during a set of meetings.

The HAZOP team focuses on specific portions of the process called "nodes". Generally these are identified from the P&ID of the process before the study begins. A process parameter is identified, say flow, and an intention is created for the node under consideration. Then a series of guidewords is combined with the parameter "flow" to create a deviation. For example, the guideword "no" is combined with the parameter flow to give the deviation "no flow". The team then focuses on listing all the credible causes of a "no flow" deviation beginning with the cause that can result in the worst possible consequence the team can think of at the time. Once the causes are recorded the team lists the consequences, safeguards and any recommendations deemed appropriate. The process is repeated for the next deviation and so on until completion of the node. The team moves on to the next node and repeats the process.

Almost the HAZOP study should preferably be carried out as early in the design phase as possible - to have influence on the design. On the other hand; to carry out a HAZOP we need a rather complete design. As a compromise, the HAZOP is usually carried out as a final check when the detailed design has been completed.

3. The HAZOP Process

3.1 Introduction

The Hazard and Operability Study technique described in this Work Practice is based on a publication entitled "HAZOP: Guide to Best Practice" published by CIA, EPSC and IChemE. The HAZOP Study involves a formal team review of P&IDs. HAZOP Studies start by reviewing normal operation to ensure that it is safe and operable. Then the technique is used to assess what deviations from the design intention can occur and, in each case, to review whether such deviations are likely to be hazardous, or would make the plant difficult to control, or inoperable.

The HAZOP procedure may be illustrated as Figure 1. It starts from studying P&ID and dividing it into study nodes. Next, HAZOP team will select study nodes that are interesting. Later, the team describes the design intent, select a process parameter, apply a guide-word, determine cause(s), and evaluate consequence /problems including recommend action after that these information are recorded . Finally all steps are repeated for other nodes. If the HAZOP team is not sure for that information, they need search more information.

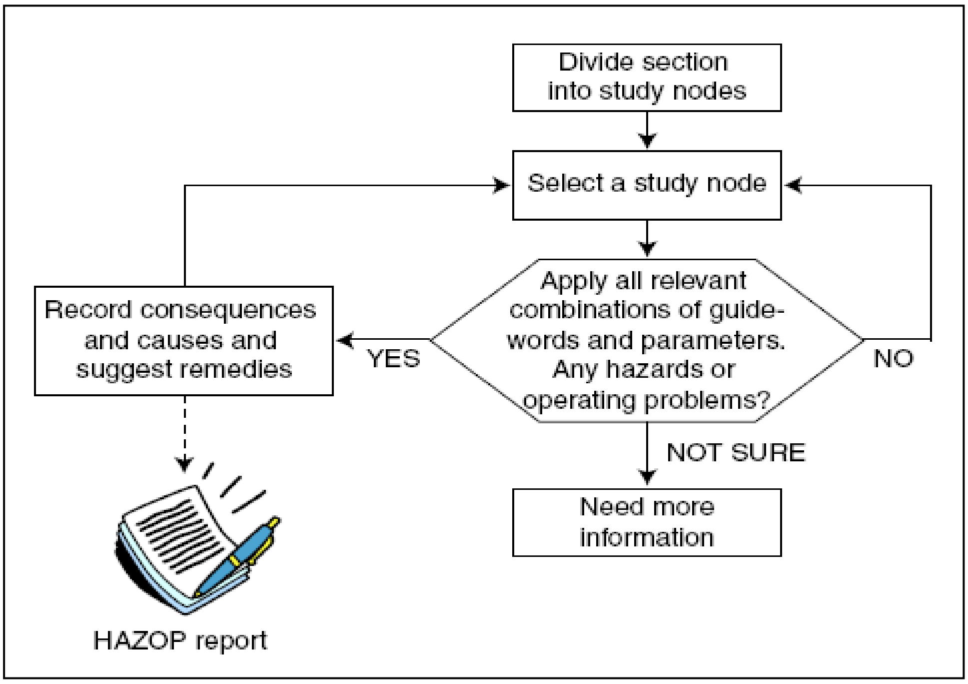


Figure 1 The HAZOP procedure

The technique relies on the systematic application of guidewords, to the various systems comprising the P&ID. The list of HAZOP guidewords is contained in Table 1.

The guideword list is in two parts. The first set of guidewords is applied to the P&ID line systems requiring evaluation. The second set based on 'Other Than' is applied at the end of the unit or facility review to assess the overall unit or specific vessels as appropriate. The selection of vessel or unit approach shall be at the discretion of the Chairman.

Table 1 List of Approved Guidewords

GUIDEWORD	EXAMPLES OF CAUSE	AREA OF APPLICATION
FLOW		
No Flow	Wrong routing, complete blockage, slip plate, incorrectly fitted non return valves, burst pipe, large leak, equipment failure (control valve or isolation etc)	SYSTEM
Reverse Flow	Wrong routing	SYSTEM
More Flow	More than one pump, reduced delivery head, increased suction pressure, static generation under high velocity, pump gland leaks	SYSTEM
Less Flow	Line blockage, filter blockage, fouling in vessels, valves, etc and restrictor or orifice plates	SYSTEM

Table 1 (Continued)

GUIDEWORD	EXAMPLES OF CAUSE	AREA OF APPLICATION
TEMPERATURE		
More Temperature	Higher than normal temperature, fouled cooler tubes, cooling water temp wrong, cooling water failure	SYSTEM
Less Temperature	Line contents freezing	SYSTEM
PRESSURE		
More Pressure	Surge problems (line and flange sizes) leakage from any connected higher pressure system, thermal relief	SYSTEM
Less Pressure	Generation of vacuum conditions, operation with reduced pressure	SYSTEM
Composition Change	Passing isolation valves, double isolations	SYSTEM
Contamination	Wrong material, wrong operation, ingress of air, shutdown and start up conditions	SYSTEM
OTHER		
Relief	Pressure or thermal relief	

Table 1 (Continued)

GUIDEWORD	EXAMPLES OF CAUSE	AREA OF APPLICATION
Instrumentation	Control, flow measurement, pump overheating due to closed control valves, location of alarms etc, temp indicators, etc	VESSEL* OR UNIT
Sampling		
Corrosion		
Service Failure	Power, cooling water, instrument air, steam, nitrogen etc	VESSEL* OR UNIT
Maintenance	System drainage, isolation of equipment and preparation for maintenance,	VESSEL* OR UNIT
Commissioning	Start-up and shutdown	
Leakage	Tube rupture in exchanger or tank	VESSEL* OR UNIT
Static		
Spare Equipment		
Safety	Lagging, fire fighting, toxic gas, safety showers, security, etc.	VESSEL* OR UNIT

Remark * Where there are significant variations to the nature of the process hazard within a unit the "OTHER THAN" guidewords should be applied for individual vessels.

3.2 Team Composition

The core of the review team shall normally consist of the Authorised Engineers responsible for the input by the respective specialist groups into the particular P&IDs for review. The Authorised Engineer(s) may not be involved in the detailed engineering of P&IDs. In such situations the Authorised Engineer(s) should monitor the performance of the Participating Engineer(s) within the review session but should not normally attend on a regular basis. Routine "doubling up" of personnel is to be avoided

Other personnel may be required to attend. For example where complex mechanical equipment is included in a particular P&ID the Mechanical Equipment Engineer shall be required to attend.

The Operators and maintenances, who have relevant plant experience, are normally invited to participate in the HAZOP Studies and should be advised of review schedule in advance of the meetings.

To be effective the HAZOP Study shall involve the members of the project team responsible for P&ID input and development. The team needs to be multi-disciplined with authority to make appropriate decisions.

The Instrument Engineer shall agree with the HAZOP Chairman those P&IDs where his participation is not required.

As studies will be scheduled on a unit by unit basis, team composition may be varied appropriately.

3.3 Meetings Schedule and Duration

A HAZOP Study schedule, arranged on a unit by unit basis and complying with the overall project schedule, shall be compiled by the Project Engineer or the Design Safety Engineer. The schedule shall show the number of meetings, their location, timing and the attendees.

The Project Engineer shall convene the meetings and make sure that all attendees including the Operators and maintenances have been invited with proper notice.

Where P&IDs are dependent on Supplier's information the review shall be deferred until Supplier's P&IDs are available for review.

Due to the intensive nature of the technique, the duration of each daily session should not exceed two meetings of three hours each.

3.4 Reviewing a System (or Node)

The Chairman will divide the P&ID into a number of discrete systems or nodes for review. This may be undertaken in advance of the meeting.

3.5 The HAZOP Recording

The Chairman shall specify the extent of the first system to be reviewed and these details are recorded on the HAZOP Report, as a heading written right across the page. Systems of this kind generally consist of a pipeline, starting at one vessel and ending at another vessel.

The HAZOP worksheet had been illustrated as Figure 2.

<table>
<tr><td colspan="7">Study title:</td><td colspan="3">Page: of</td></tr>
<tr><td colspan="3">Drawing no.:</td><td colspan="4">Rev no.:</td><td colspan="3">Date:</td></tr>
<tr><td colspan="7">HAZOP team:</td><td colspan="3">Meeting date:</td></tr>
<tr><td colspan="10">Part considered:</td></tr>
<tr><td colspan="3">Design intent:</td><td colspan="7">Material: Activity:
Source: Destination:</td></tr>
<tr><td>No.</td><td>Guide-word</td><td>Element</td><td>Deviation</td><td>Possible causes</td><td>Conse-quences</td><td>Safeguards</td><td>Comments</td><td>Actions required</td><td>Action allocated to</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Figure 2 The HAZOP worksheet

3.5.1. HAZOP Worksheet

The Figure 2 shows HAZOP worksheet. It consists of:

Node: A node is a specific location in the process in which (the deviations of) the design/process intent are evaluated. Examples might be: separators, heat exchangers, pumps, compressors, and interconnecting pipes with equipment.

Design intent: The design intent is a description of how the process is expected to behave at the node; this is qualitatively described as an activity (e.g., feed, reaction, sedimentation) and/or quantitatively in the process parameters, like temperature, flow rate, pressure, composition, etc.

Deviation: A deviation is a way in which the process conditions may depart from their design/process intent.

Parameter: The relevant parameter for the condition(s) of the process (e.g. pressure, temperature, composition)

Guide-word: A short word creates the imagination of a deviation of the design/process intent. The most commonly used set of guide-words is: no, more, less, as well as, part of, other than, and reverse. In addition, guidewords like too early, too late, instead of, are used; the latter mainly for batch-like processes. The guidewords are applied, in turn, to all the parameters, in order to identify unexpected and yet credible deviations from the design/process intent.

Guide-word + Parameter = Deviation

Possible Causes: The reason(s), why the deviation could occur. Several causes may be identified for one deviation. It is often recommended to start with the causes that may result in the worst possible consequence.

Consequence: The results of the deviation, in case it occurs. Consequences may both comprise process hazards and operability problems, like plant shut-down or reduced quality of the product. Several consequences may follow from one cause and, in turn, one consequence can have several causes

Safeguard: Facilities, it helps to reduce the occurrence frequency of the deviation or to mitigate its consequence.

Currently used conventional HAZOP have both favourable and unfavourable as take a long time consuming, demand considerable cognitive load from the analysts, and required multidisciplinary knowledge during the analysis period. Additionally, since these methods are traditionally performed by human experts, it was very difficult to expect the perfect analysis of the accidents.

At the start of the review sessions scheduled for a complete unit, the Process Engineer shall describe the process function briefly to the Review Team and indicate the nature of the process material hazards. Thereafter, at the start of each new session the Process Engineer shall describe the specific system being reviewed.

To assist in the review, reference documentation shall be available. Typically this will include:

1. Cause and Effect Diagrams (if they are to be produced)
2. Safety Philosophy Document
3. Process Specifications/Equipment Process Data Sheets
4. Process Flow Diagram(s)
5. Design Pressure and Temperature Diagram
6. Details of Hazardous Materials (MSDS's)
7. Plot Plan(s)
8. Line Classification Lists
9. PSV Schedule
10. Material Balance, (if not included above)
11. Materials of Construction Diagram(s)
12. A Complete set of P&ID prints.

The Chairman shall lead the review of the system by selecting the first guideword from the system set of guidewords. The team shall endeavour to establish whether deviations to the behaviour of the intended system could occur and if so, whether these have a significant effect on safety and / or operability. Where no deviation is predicted, or where the consequences of a deviation are not significant, the analysis is stopped. No written entry is made on the HAZOP worksheet. All causes of the deviation shall be considered since the potential hazard, or its consequences, and resultant actions may be different.

Where a potential hazard is identified, remedial action may be required depending on the likelihood of the event and its consequence. If an immediate solution is available and acceptable to the team, the details of the action required must be written down in the HAZOP worksheet and the HAZOP Master shall be marked up to show the location of the action required. Where solutions are unlikely to be derived, without a technical evaluation, the Chairman shall refer the problem for a separate assessment. Discussion of problems in the meeting should be kept to a minimum.

Where proposed solutions may result in significant deviations to cost, schedule or specification such solutions shall be referred to the Project Manager and, in appropriate cases, to the client for a decision. The final decision shall be recorded formally in the Action Taken column of the HAZOP worksheet.

The review shall continue by selecting the next guideword and applying it to the system. Once all guidewords in the first set have been applied the system is marked as complete on the HAZOP Master and a line is drawn right across the page of the HAZOP Report. If no actions are required for a particular section then the statement "No actions required" is put into column 5 of the HAZOP worksheet.

The study shall continue with the selection by the Chairman of a new system, details of which are put onto the HAZOP Report as a new heading. The guidewords are then applied as before to evaluate the new system under review.

The approach is repeated until all systems on the set of P&IDs have been examined. In the event that part of an P&ID or system is incomplete, or forms a Supplier Package, the review team shall delay that part for a subsequent review and details of the section not HAZOP shall be recorded in the HAZOP Report.

If P&ID drafting errors are observed during the review the Chairman should mark the corrections in a different colour to that used for HAZOP comments without making a record on the HAZOP Report.

To complete the review the Chairman shall apply the second set of guidewords to individual vessels or the whole unit as appropriate. This approach permits the team to take an overview of the safety of the vessel or unit.

Following the review, the HAZOP Masters shall be used as the basis for the next formal P&ID issue. The HAZOP Masters shall be retained as a permanent record

The team shall follow the technique in full for process units and major offsites package unit P&IDs. For simpler non process systems and non hazardous systems the Chairman may agree to adopt a simplified approach or to dispense with the review.

The above procedure for recording responses to guidewords only when an action is required is termed "Recording by Exception". Certain Clients require responses to all guidewords to be recorded. When this requirement has been specified in writing by the Client it should be carried out, but the custom is then to record the responses only to the first set of guidewords.

An Existing Safeguards column is required. It is used when a cause and consequence are identified by the team and it is felt useful to record the existing safeguard to confirm that no action is required.

4. HAZOP Reports

Decisions affecting the scope of the review shall be recorded in the HAZOP Report. For instance, it may have been agreed to HAZOP only sections of P&ID's which have been modified as part of a revamp project. In these cases a non-standard front sheet should be used for the HAZOP Report. This non-standard front sheet should contain all the information on the top half of a normal HAZOP Report front sheet, and list all the drawings reviewed, as well as the agreed terms of reference for, and scope of, the HAZOP Study.

The HAZOP Study Report shall be distributed in accordance to any others who may need to implement the actions requested.

5. The drawback of conventional HAZOP

To conduct HAZOP successfully by the existing methods it is essential to put together a fairly large team of experts (six or more) who have to systematically and critically examine the piping and instrument diagrams (P&IDs) in relation to the process conditions and human factors. The team has to work out the various permutations and combinations of possible deviations that can occur during the operation of the plant and the adverse consequence of all such deviations. The end objective is to identify the potential problems or the ‘soft spots’.

If one has to do justice to the study as mentioned above, the HAZOP team must be multi-disciplinary and must be composed of experts who have extensive knowledge of the design, operation, and maintenance aspects of the process plant. The experts must also be insightful enough to be able to foresee all possible ways in which hazards and operational problems might arise in a process plant.

The requirement of highly paid manpower for fairly large number of man-days makes HAZOP very expensive. As HAZOP is a prelude to other major steps in risk assessment and damage prevention it is unsafe to compromise on thoroughness. It would be dangerous to cut costs at the expense of exhaustiveness of the study.

There has been difficulty in getting suitable experts. Even when a company is willing to spend the requisite money, it might be difficult to get personnel of a desired level of sophistication and experience.

Drudgery: a large number of likely deviations from normal are of routine nature yet the HAZOP team has to consider and study each one of them. This makes the team’s task rather tedious. At the same time the team can’t overlook or bypass any of the large number of routine causes as each has the potential to cause an accident.

In conclusion, a typical HAZOP analysis can take 1–8 weeks to complete, costing over $ 13 000–25 000 per week. By an OSHA estimate, approximately 25,000 plant sites in the United States require a PHA. An estimated $ 5 billion is spent annually by the chemical process industries (CPI) to perform PHAs and related activities. The estimated cost of process hazards reviews in the CPI is about 1% of sales or about 10% of profits.

Given the enormous amounts of time, effort and money involved in performing HAZOP analysis, consequently there exists considerable incentive to develop intelligent systems for automating the process hazards analysis of chemical process plants. An intelligent system can reduce the time; effort and expense involved in a HAZOP analysis, make the review more thorough, detailed, and consistent, minimize human errors, and free the team to concentrate on the more complex aspects of the analysis which are unique and difficult to automate. New approach is called automatic HAZOP. It can be as an expert human in the HAZOP meeting because it can provide all of causes and consequences for the whole process immediately. The human expert just judge this result is true of false for their process then record in the HAZOP result table. On the other hand, if there are other causes and consequences that are not in the database, human expert can add this information in the database too.

One of the important challenges in automating HAZOP analysis is handling the huge amount of process specific information which is required as the input for performing HAZOP. It is desirable to develop a system that is context-independent so that it can be used for the HAZOP analysis of a wide variety of processes and will also be able to find the process-specific hazards for the various processes. This was a major hurdle that posed difficult conceptual and implementation challenges that thwarted the earlier attempts towards automation.

To overcome these problems, there have been various researches to automate hazard analysis using computer technology, especially by developing expert system using HAZOP database techniques. However, these studies mainly dealt with automation of HAZOP study and most of the past approaches have problems in safeguard consideration, variety of identifiable accidents, variety of causes and consequence of accidents, verification of accidents propagation path. Since these attempts have almost been limited to automation of a specific hazard analysis technique, most of the suggested methodologies could not overcome the drawbacks that are contained in the technique itself. These problems of conventional researches are mainly due to their limitations in capturing and utilizing available process information, in other words, limitations in process modeling. So it is essential to establish a more efficient knowledge representation strategy to develop an enhanced hazard analysis methodology.

6. HAZOP Database system

The HAZOP database system is a computer program that uses Expertise knowledge and reasoning techniques to solve problems and make decision. The purpose of HAZOP database system is to assist a person's thinking process, not merely to provide information for a person to think about. Depending on the problem it is designed to solve, an HAZOP database system could be simple enough to operate on a personal computer.

6.1 Benefits of HAZOP database system

Some of the principal reasons HAZOP database systems are developed to replace an expert are:

- Make available expertise after hours or in other locations
- Automate a routine task requiring an expert
- Expert is retiring or leaving
- Expert is expensive
- Expertise is needed in a hostile environment

The benefits of HAZOP database system in an organization are improved productivity, staff training, retention of scarce expertise, upgrades performance of skilled and experienced personnel, improved production operations, relatively affordable expertise, increased output, smarter work in general.

Characteristics of HAZOP database system

In providing advice to someone such as advisee, an expert first obtain facts about the problem called case facts from the advisee and stores them in his short-term memory as shown in Figure 3. Then, the expert reasons about the problem by combining the short-term memory facts with the long-term. After that, the expert infers new problem information and eventually arrives at conclusion about the problem.

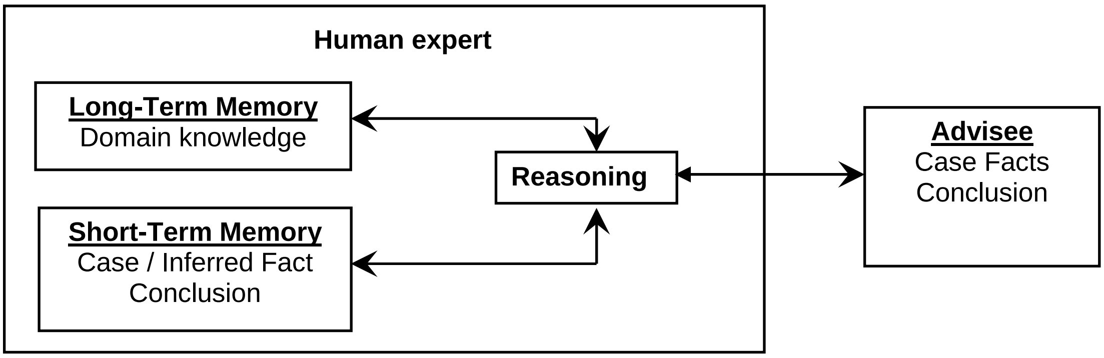


Figure 3 Human expert problem solving

From Figure 3, there are two major traits of an expert to solve problem. One is expert's knowledge and another is reasoning. Therefore, to achieve the HAZOP database system that can solve problems like an expert, the HAZOP database system must have two principal modules that are a database represented expert's knowledge and an inference engine represented reasoning. Moreover, working memory is a part of the HAZOP database system that contains the problem facts that are discovered during consultations. The problem solving of HAZOP database system is shown in Figure 4.

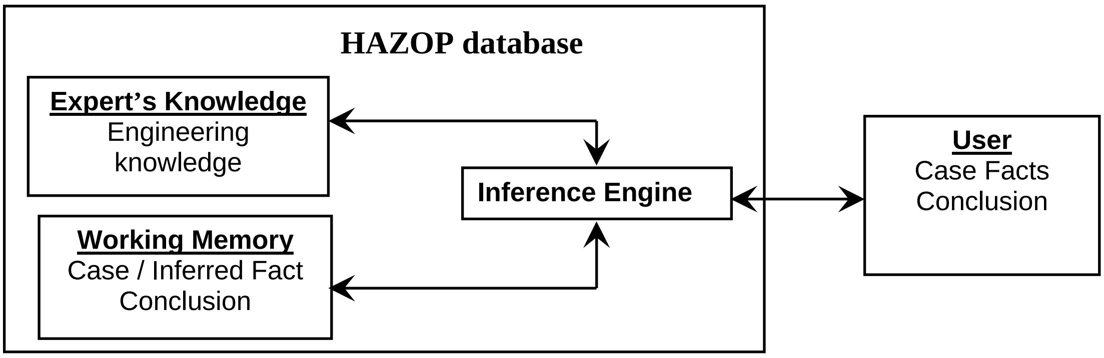


Figure 4 HAZOP database system problem solving

When the user enters information on a problem into the working memory, the system matches this information with knowledge contained in the Domain knowledge to infer new facts and enter these new facts into the working memory and matching process continues. Eventually, the system reach conclusion.

6.3 HAZOP database system structure

The structure of an HAZOP database system consists of 5 parts as shown in Figure 5.

6.3.1 Knowledge acquisition is the process of acquiring, organizing and studying knowledge to gain an understanding of the problem. The HAZOP database system obtains knowledge from Knowledge engineer who is a person that designs, builds, and tests an expert system and Domain engineer who is a person that possesses the skill and knowledge to solve a specific problem in a manner superior to others.

6.3.2 Knowledge database is a part of the HAZOP database system that contains the Engineering knowledge. Therefore, the knowledge obtained from expert will be code in the knowledge database.

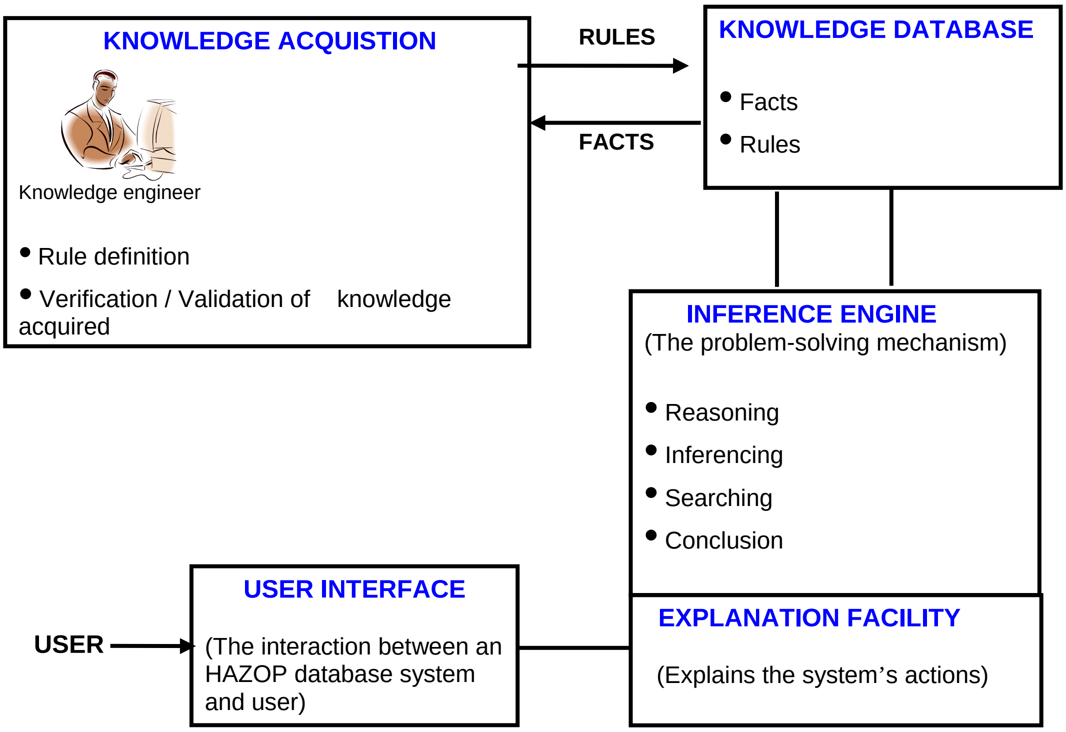


Figure 5 HAZOP database system structures

6.3.3 Inference Engine is processor in an HAZOP database system that matches the facts contained in working memory with the engineering knowledge contained in the knowledge database to reach conclusions about the problem. This part uses reasoning, inferencing, searching and conclusion to solve problem.

6.3.4 Explanation facility is ability to explain the system's action and reasoning

6.3.5 User interface is a part of HAZOP database system that used to communicate between HAZOP database system and user. A basic design requirement of the interface is to ask questions to obtain reliable information from the user.

6.4 Expert system shell

The shell has been presented as a set of knowledge representation schemes, an inference mechanism, and a way to determine the status of a problem domain while it is being solved. It is a reasoning system without the knowledge. The expert system shell is easy to addition and modifying a new rule.

6.5 HAZOP database system and HAZOP

HAZOP is associated in part of knowledge database and inference engine as shown in Figure 6.

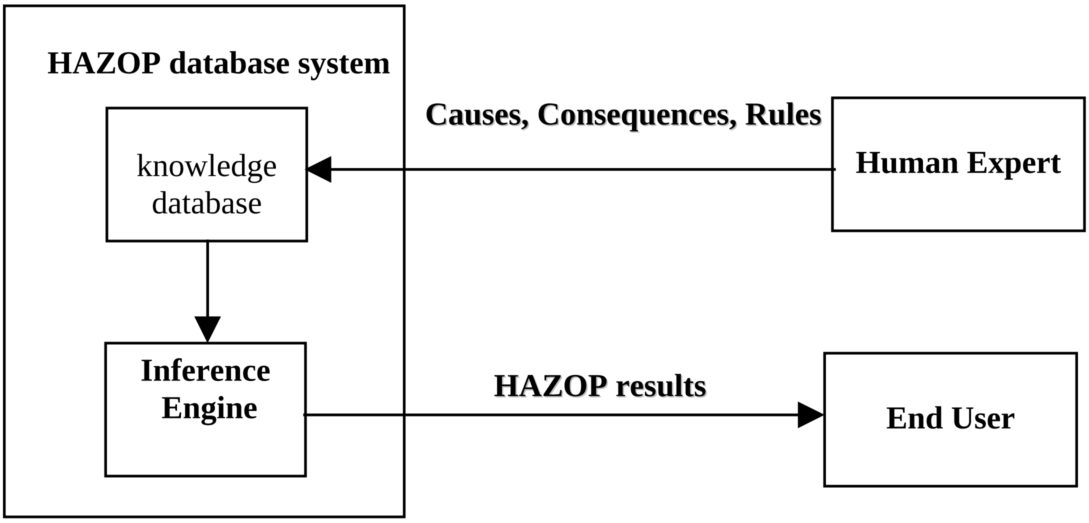


Figure 6 Relationship between HAZOP database system and HAZOP

From Figure 6, human expert enters causes, consequences, and rules in knowledge base. Then, inference engine infers and conclude the HAZOP results to end user.

MATERIALS AND METHODS

Materials

1. High performance computer

2. Program Microsoft access 2000 or 2003

3. Process flow diagrams of steam/ condensate system and cooling water system.

4. Design basis of steam/ condensate system and cooling water system.

5. Piping and Instrument diagrams of steam/ condensate system and cooling water system.

6. Conventional HAZOP reports of steam/ condensate system and cooling water system.

Methods

This part would describe about designing and verifying the HAZOP database of Utility system of Petrochemical Plant. The HAZOP database system requires information such as P&IDs, process flow diagram, process description, cause and effect diagram, etc. The most important art of HAZOP database is relationship between cause, consequence table and safeguarding table.

1. Designing HAZOP database

The HAZOP database system will collect the information and analyst from HAZOP reports.

1.1 Programming Idea

The conventional HAZOP is quite expensive and it takes a long time to find the results. Consequently, the conventional HAZOP is developed to be a HAZOP database in order to reduce time and cost. In the program, firstly, end user has to construct the flow sheet of the process by choosing the equipment, which is already prepared in the program and then put the deviation into the interested equipment. After that, the HAZOP results will find by automatically.

1.2 Information

As a basis for the HAZOP database, the following information should be available:

- Process flow diagrams
- Piping and instrumentation diagrams (P&IDs)
- Cause and Effect diagram.
- Process description

1.3 Structure of HAZOP database system

The structure of HAZOP analyzer database was show as Figure 7.

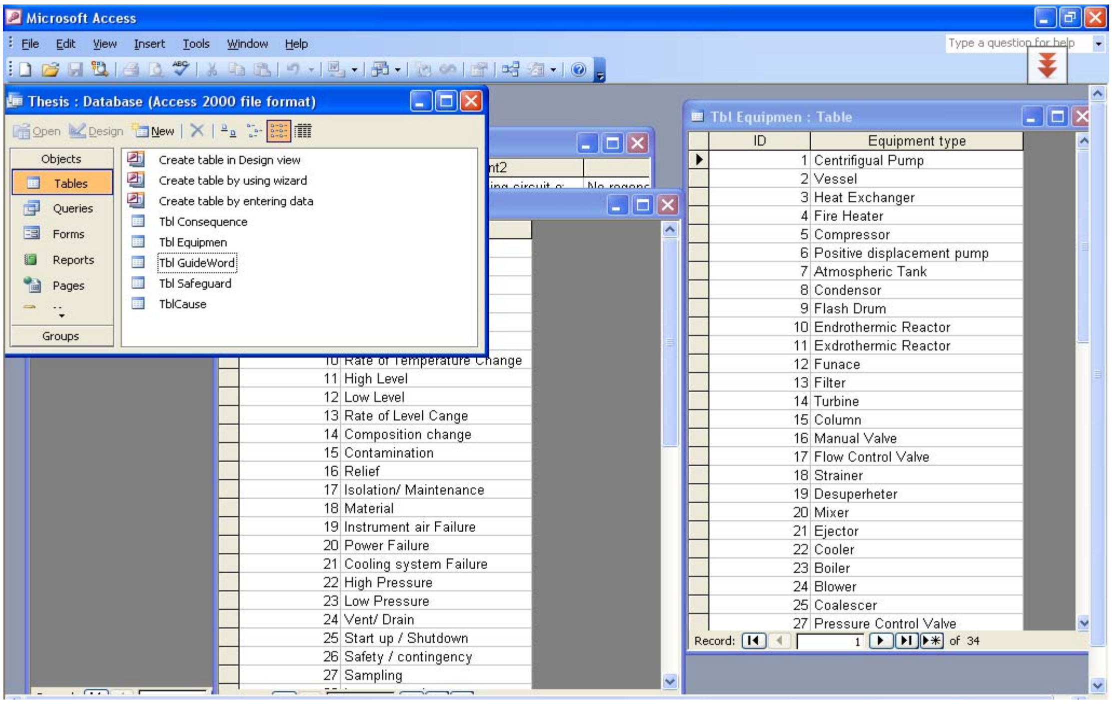


Figure 7 The components of HAZOP database system

The HAZOP analyzer database system consists of equipment table, Guideword table, safeguarding table, cause table and consequence table.

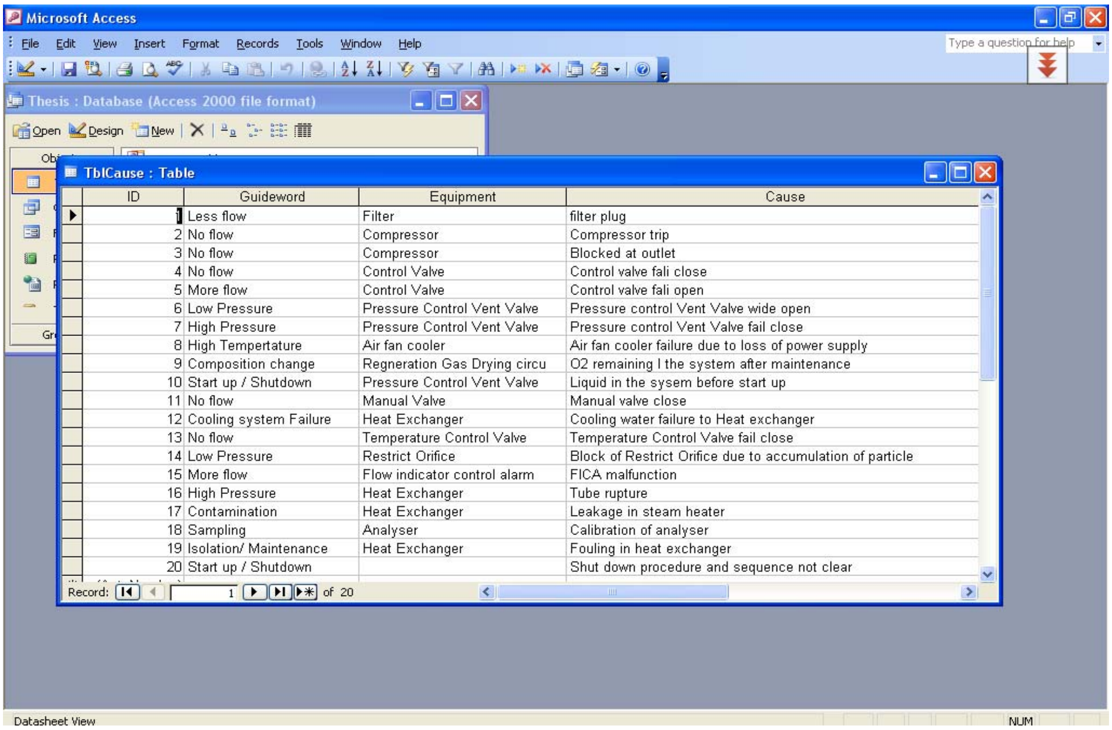
The equipment table will list all equipments in P&IDs and include part of piping and instrument. The equipment table is use as input for cause and consequence table.

The guideword table will list all guidewords (refer Table 1). The guideword table also use as input for cause and consequence table.

The safeguarding table will list all the existing protections that showed in P&ID. The safeguarding table use as input for consequence table and consider the requirement of addition the protection layer.

The cause table consists of equipments (select from equipment table), guideword (select from guideword table) and cause column. The cause column is cause message that result in the deviation (GUIDEWORD + PROCESS-PARAMETER) at position of equipment. The cause table has been show in Figure 8.

The consequence table consists of equipments (select from equipment table), guideword (select from guideword table), consequence and recommendation. The consequence will identify the potential failure of selected equipment related to selected guideword. The recommendation is the suggestion/ additional the protection to improve the design or the requirement. The recommendation will check against with the existing safeguard. If the design has sufficient protection(s), the recommendation will show "No action required". The cause table has been show in Figure 9.



ID	Guideword	Equipment	Cause
1	Less flow	Filter	filter plug
2	No flow	Compressor	Compressor trip
3	No flow	Compressor	Blocked at outlet
4	No flow	Control Valve	Control valve fali close
5	More flow	Control Valve	Control valve fali open
6	Low Pressure	Pressure Control Vent Valve	Pressure control Vent Valve wide open
7	High Pressure	Pressure Control Vent Valve	Pressure control Vent Valve fail close
8	High Tempertature	Air fan cooler	Air fan cooler failure due to loss of power supply
9	Composition change	Regneration Gas Drying circu	O2 remaining I the system after maintenance
10	Start up / Shutdown	Pressure Control Vent Valve	Liquid in the sysem before start up
11	No flow	Manual Valve	Manual valve close
12	Cooling system Failure	Heat Exchanger	Cooling water failure to Heat exchanger
13	No flow	Temperature Control Valve	Temperature Control Valve fail close
14	Low Pressure	Restrict Orifice	Block of Restrict Orifice due to accumulation of particle
15	More flow	Flow indicator control alarm	FICA malfunction
16	High Pressure	Heat Exchanger	Tube rupture
17	Contamination	Heat Exchanger	Leakage in steam heater
18	Sampling	Analyser	Calibration of analyser
19	Isolation/ Maintenance	Heat Exchanger	Fouling in heat exchanger
20	Start up / Shutdown		Shut down procedure and sequence not clear

Figure 8 Table of cause.

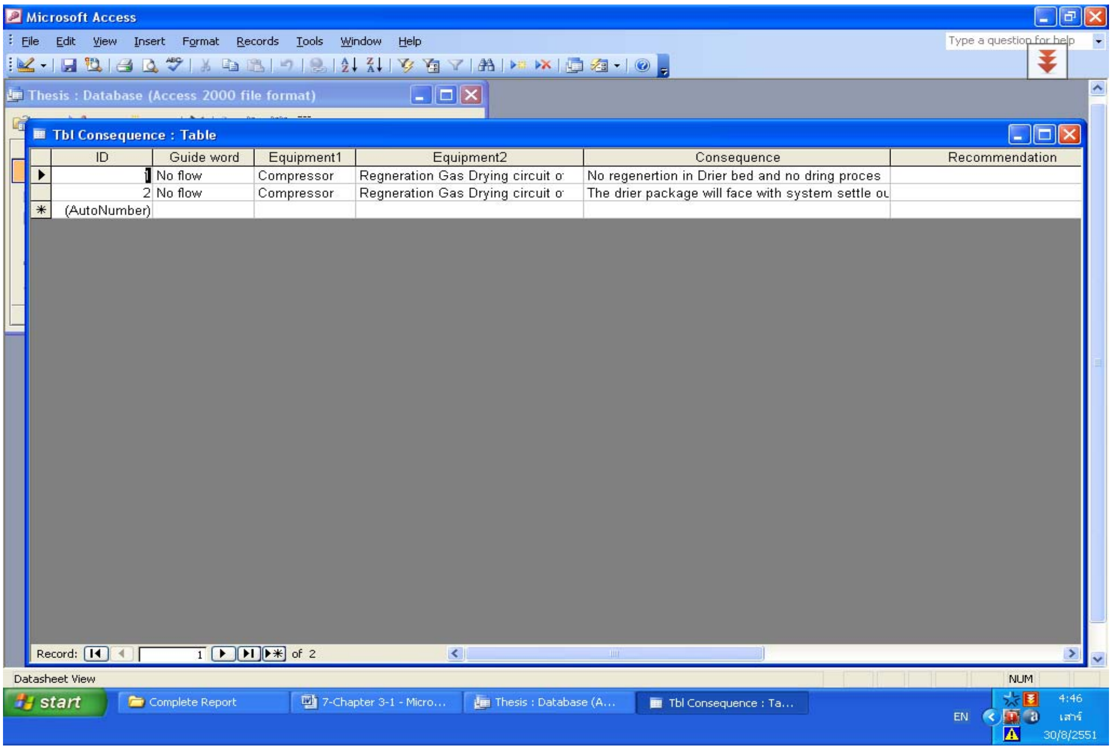


Figure 9 Table of Consequence

1.4 The Model causes identify.

Equipment cause deviations needed in hazard analysis is to describe the causal influences of variable deviations in every process unit. Among many variables showing states of process, the interested variables in hazard analysis are pressure (P), temperature (T), flow rate (F), composition (C), level (L). Using these variables, fault propagation relationship can be identified. Each variable has three states (MORE, LESS, and No) and is separated as input, status, and output according to locations within a process unit. For each variable, classes are defined. The locations and kinds of variables are identified independently by equipment. To derive unit deviation model of a unit, meaningful input, status, output variables are identified. Then, causal relationships between these identified variables are specified. Status variable and output variables are assumed to be effect variable and, high and low deviation states of these variables are connected to their immediate causal variable deviations that are elicited from the specified causal relationships.

2. Method for Finding Result

As mention, HAZOP database collect in cause and consequence library then method for finding result is concerned to get exactly result. In this program, procedure and rules are used to find HAZOP result of each equipment. If equipment gets deviation value, procedure will activate. In addition, procedure will bring deviation to find result in cause and consequence library after that it will record and show result.

2.1 Process of HAZOP database

The HAZOP database provides the causal models and consequential models of chemical process systems in a transparent manner to the user. In this HAZOP database model, each unit in this model is independent because it will only obtain a deviation which is used to evaluate the causes, consequences, and actions from connected equipments.

Algorithm for finding a solution of HAZOP database model consists of transferring the process variable deviation, looking for causes and consequences storing and showing them. Therefore, the performed algorithm in the Automatic HAZOP model can be divided to 4 steps as following:

The first step: Select a study node that will be performed the Automatic HAZOP.

The second step: Draw the P&ID of the chemical process on a workspace by using any equipment such as pump, tank, heat exchanger, valve, pipe, etc. from the unit class definition.

The third step: Initiate any process variable deviation in the interested equipment.

The fourth step: After the value at the status deviated from the normal, Automatic HAZOP will automatically perform HAZOP analysis by creating procedures called to search for causes and consequences. The process variable deviation will be sent to both upstream and downstream until the end points of the P&ID are reached. While the process variable deviation is sent to both upstream and downstream equipment, the HAZOP results which are causes from upstream and consequences from downstream are also stored in array which can be automatically reported into to workspace.

The overall architecture of the Automatic HAZOP expert system is shown in Figure 10.

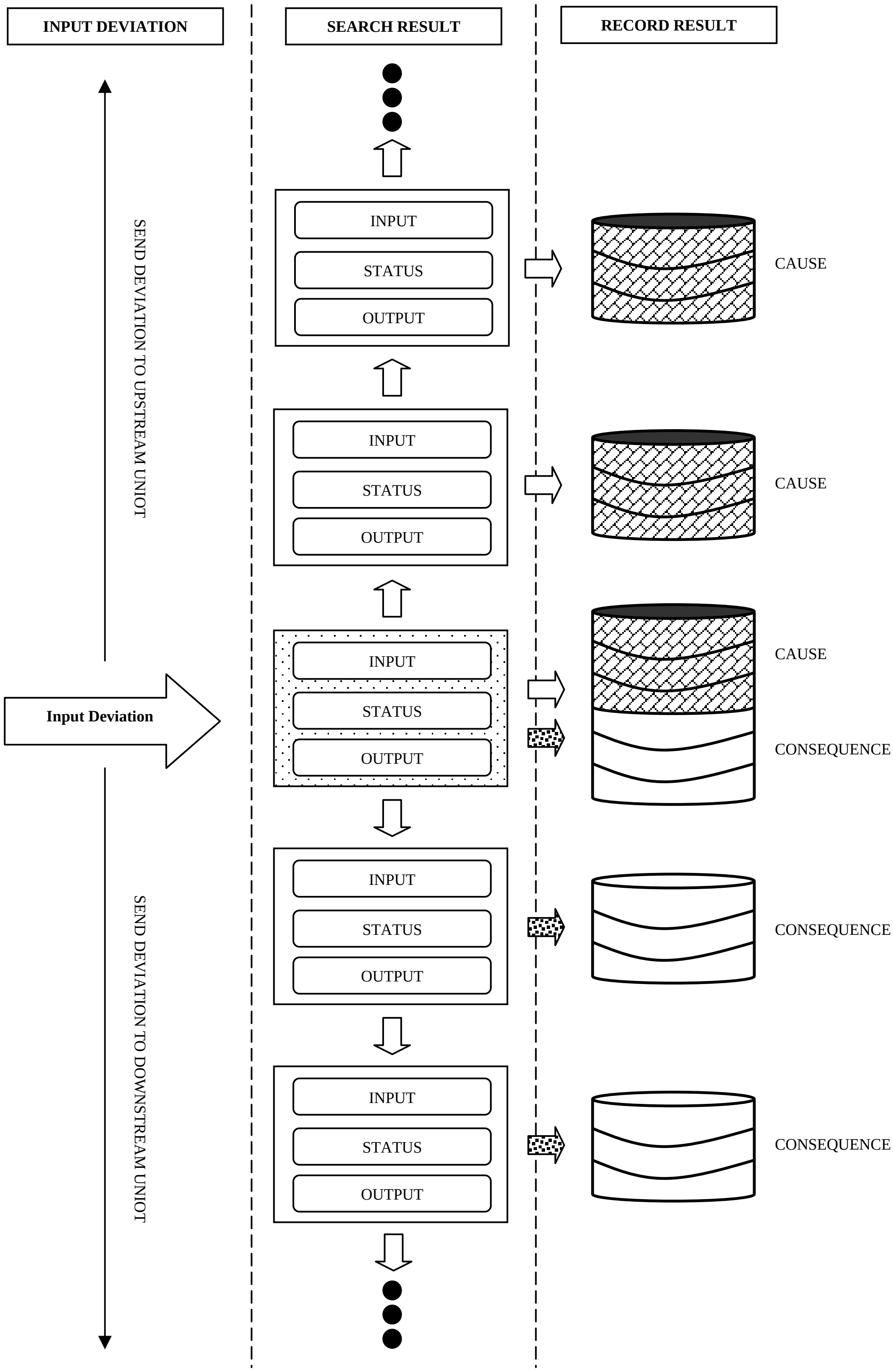


Figure 10 Process system of search result

3. Method for verifying the result

After HAZOP analysis on study node was performed, the HAZOP result must be verified significantly to make sure that the HAZOP database is correct. The methods for verifying the result are check the process variable deviation of each unit and check cause, consequence, and recommendation from that Conventional HAZOP report result.

Check process deviation guideword of each equipment: For process deviation database in HAZOP database, the deviation of process variable in the study equipment shall be match with causes, consequences, and recommendation from that deviation. To ensure that the sending of process variable deviation on study equipment to downstream equipment is correct, the abnormal process variable that showed in the attribute table of upstream and downstream equipment must be compared with the deviation from Conventional HAZOP report result.

Check cause, consequence, and recommendation from process variable deviation: From process variable deviation on the interested matching equipments, the relationship of matching equipments, will select causes and consequences and recommendation. The result of causes consequences, and recommendation from HAZOP database can be verified by comparing with the data of conventional HAZOP report. The verifying cause, consequence, and action will be performed until the match all equipments of study nodes are complete.

RESULTSAND DISCUSSION

Results

The key purpose of this thesis is to analyst hazardous of Utility system (steam/ condensate system and cooling water system) in petrochemical plant based on basic engineering P&ID by using HAZOP analyzer database program. In this work, the study node is Steam/ condensate system and cooling water system.

1. The steam and condensate distribution system.

The steam and condensate distribution system separated to 3 nodes.

Node 1: HP and LP Desuperheating (include Boiler feed water line to desuperheater) and distribution system.

Node 2: Condensate return from users to Condensate return tank

Node 3: Condensate to deaerator

1.1 Node 1 start from Steam supplier plant 1 to desuperheater

Node 1 consist of Steam supply header, Pressure control valve and desuperheater and Temperature control valve on Boiler feed water line

After P&ID node 1 of Steam and condensate distribution unit was created on a Hazop database foam, by select equipment in list of combo box of equipment 1 for fail equipment and select equipment 2 from equipment 2 combo box and select the existing safeguard from the safeguard combo box, the Hazop P&ID creating foam were as shown in Figure 11.

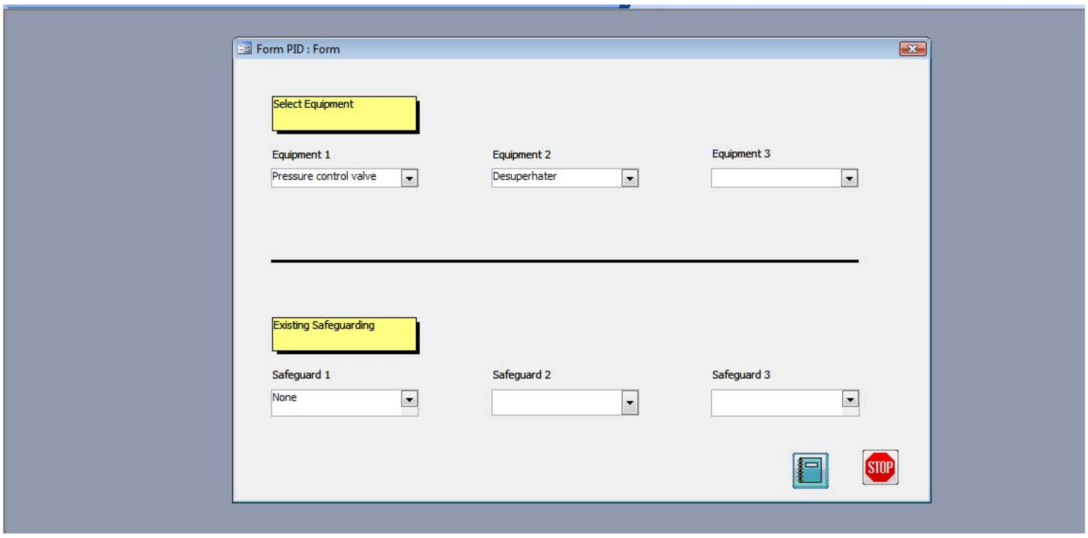
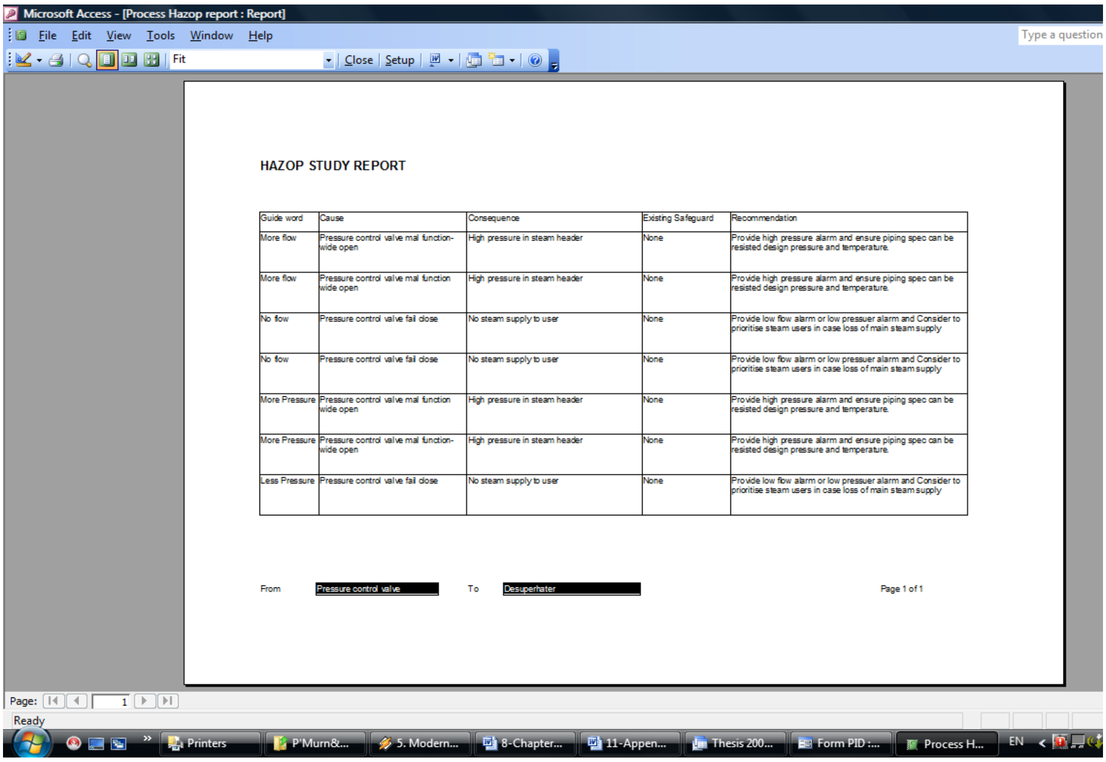


Figure 11 Foam for create P&ID

The HAZOP report results for node 1 would show causes, consequences, and actions on Hazop report as illustrated in figure 12, 13 and 14

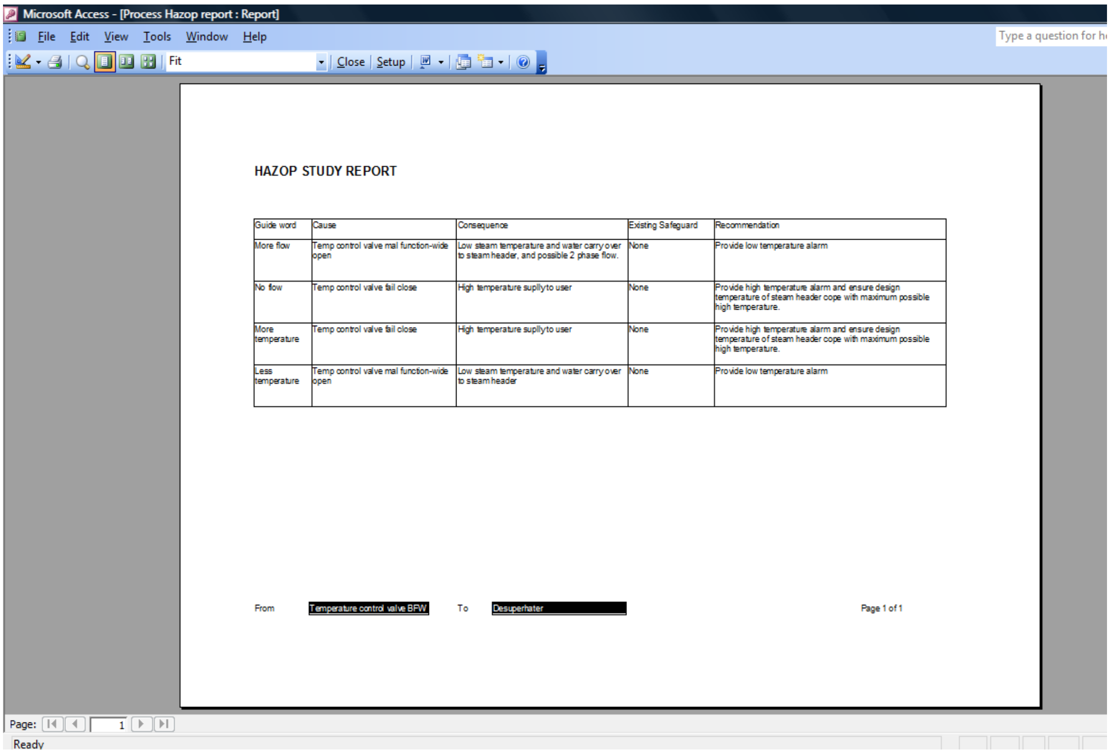


HAZOP STUDY REPORT

Guide word	Cause	Consequence	Existing Safeguard	Recommendation
More flow	Pressure control valve mal function-wide open	High pressure in steam header	None	Provide high pressure alarm and ensure piping spec can be resisted design pressure and temperature.
More flow	Pressure control valve mal function wide open	High pressure in steam header	None	Provide high pressure alarm and ensure piping spec can be resisted design pressure and temperature.
No flow	Pressure control valve fail close	No steam supply to user	None	Provide low flow alarm or low pressuer alarm and Consider to prioritise steam users in case loss of main steam supply
No flow	Pressure control valve fail close	No steam supply to user	None	Provide low flow alarm or low pressuer alarm and Consider to prioritise steam users in case loss of main steam supply
More Pressure	Pressure control valve mal function wide open	High pressure in steam header	None	Provide high pressure alarm and ensure piping spec can be resisted design pressure and temperature.
More Pressure	Pressure control valve mal function-wide open	High pressure in steam header	None	Provide high pressure alarm and ensure piping spec can be resisted design pressure and temperature.
Less Pressure	Pressure control valve fail close	No steam supply to user	None	Provide low flow alarm or low pressuer alarm and Consider to prioritise steam users in case loss of main steam supply

From Pressure control valve To Desuperhater Page 1 of 1

Figure 12 Causes and actions from Pressure control valve to Desuperheater

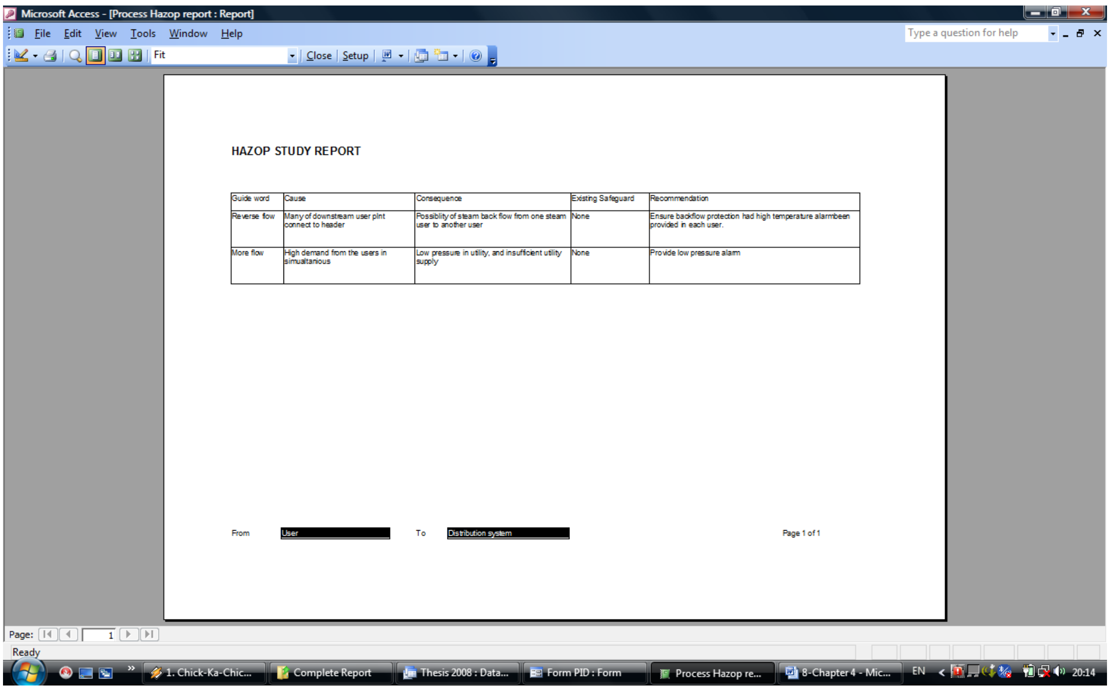


HAZOP STUDY REPORT

Guide word	Cause	Consequence	Existing Safeguard	Recommendation
More flow	Temp control valve mal function-wide open	Low steam temperature and water carry over to steam header, and possible 2 phase flow.	None	Provide low temperature alarm
No flow	Temp control valve fail close	High temperature supllyto user	None	Provide high temperature alarm and ensure design temperature of steam header cope with maximum possible high temperature.
More temperature	Temp control valve fail close	High temperature supllyto user	None	Provide high temperature alarm and ensure design temperature of steam header cope with maximum possible high temperature.
Less temperature	Temp control valve mal function-wide open	Low steam temperature and water carry over to steam header	None	Provide low temperature alarm

From Temperature control valve BFW To Desuperhater Page 1 of 1

Figure 13 HAZOP report from the Temperature control valve to Desuperheater



HAZOP STUDY REPORT

Guide word	Cause	Consequence	Existing Safeguard	Recommendation
Reverse flow	Many of downstream user plnt connect to header	Possiblity of steam back flow from one steam user to another user	None	Ensure backflow protection had high temperature alarmbeen provided in each user.
More flow	High demand from the users in simualtanious	Low pressure in utility, and insufficient utility supply	None	Provide low pressure alarm

From User To Distribution system Page 1 of 1

Figure 14 HAZOP report from the Temperature User to Steam distribution

The HAZOP results from the Hazop database as shown in Table 2, we found that the HAZOP Database will display the HAZOP results in each equipment, therefore the Automatic HAZOP can cover all of cause, consequence, and action. In contrast, the conventional HAZOP will give the HAZOP results that do not cover all of cause, consequence, and action.

Table 2 Steam/condensate system Hazop report from HAZOP database for node 1

Guide word	Cause	Consequence	Safeguard	Recommendation
Pressure control valve to Desuperheater				
More flow	Temp control valve mal function-wide open	Low steam temperature and water carry over to steam header, and possible 2 phase flow.	None	Provide low temperature alarm
No flow	Temp control valve fail close	High temperature supply to user	None	Provide high temperature alarm and ensure design temperature of steam header cope with maximum possible high temperature.
More temperature	Temp control valve fail close	High temperature supply to user	None	Provide high temperature alarm and ensure design temperature of steam header cope with maximum possible high temperature.

Table 2 (Continued)

Guide word	Cause	Consequence	Safeguard	Recommendation
Less temperature	Temp control valve mal function-wide open	Low steam temperature and water carry over to steam header	None	Provide low temperature alarm
Temperature control valve to Desuperheater				
More flow	Temp control valve mal function-wide open	Low steam temperature and water carry over to steam header, and possible 2 phase flow.	None	Provide low temperature alarm
No flow	Temp control valve fail close	High temperature supply to user	None	Provide high temperature alarm and ensure design temperature of steam header cope with maximum possible high temperature.
More temperature	Temp control valve fail close	High temperature supply to user	None	Provide high temperature alarm and ensure design temperature of steam header cope with maximum possible high temperature.
Less temperature	Temp control valve mal function-wide open	Low steam temperature and water carry over to steam header	None	Provide low temperature alarm

Table 2 (Continued)

Guide word	Cause	Consequence	Safeguard	Recommendation
Users to steam distribution				
Reverse flow	Many of downstream user plant connect to header	Possibility of steam back flow from one steam user to another user	None	Ensure backflow protection and high temperature alarm had been provided in each user.
More flow	High demand from the users in simultaneous	Low pressure in utility, and insufficient utility supply	None	Provide low pressure alarm

1.2 Node 2 Condensate return from user to condensate tank

Node 2 consist of condensate return header, Air cooler and condensate tank

The HAZOP report results for node 2 would show causes, consequences, and recommendation on Hazop report as Table 3

Table 3 Steam/condensate system Hazop report from HAZOP database for node 2

Guide word	Cause	Consequence	Safeguard	Recommendation
Air cooler to Condensate tank				
More temperature	Failure of inlet air cooler	Possible flashing and high pressure in tank	None	Provide high pressure and high temperature alarm

1.3 Node 3 Condensate tank to deaerator

Node 3 consist of condensate tank, condensate feed pump, desuperheater feed pump and deaerator

The HAZOP report results for node 3 would show causes, consequences, and recommendation on Hazop report as table 4

Table 4 Steam/ condensate system HAZOP report from HAZOP database for node 3

Guide word	Cause	Consequence	Safeguard	Recommen-dation
Condensate tank to condensate feed pump				
Less level	Tank low level	No feed to system, and potential pump damage due to loss of suction	None	Provide low level alarm
Condensate feed pump to deaerator				
No flow	Pump trip	No condensate feed to deaerator	None	Provide low level alarm
Pressure control valve (Steam line) to Deaerator				
More flow	Pressure control valve mal function-wide open	High pressure and high temperature in deaerator	None	Provide high pressure alarm and ensure pressure relief valve design for pressure control valve fail open

Table 4 (Continued)

Guide word	Cause	Consequence	Safeguard	Recommendation
No flow	Pressure control valve fail close	No deaeration. Oxygen contain in steam, leading to piping line corrosion for long term. Low temperature and low pressure in deaerator	None	Provide low pressure alarm, low flow alarm and low temperature alarm
More Pressure	Pressure control valve mal function wide open	High pressure and high temperature in deaerator	None	Provide high pressure alarm and ensure pressure relief valve design for pressure control valve fail open
Less Pressure	Pressure control valve fail close	No deaeration. Oxygen contain in steam, leading to piping line corrosion for long term. Low temperature and low pressure in deaerator	None	Provide low pressure alarm, low flow alarm and low temperature alarm
More temperature	Pressure control valve mal function wide open	High pressure and high temperature in deaerator	None	Provide high pressure alarm and ensure pressure relief valve design for pressure control valve fail open

Table 4 (Continued)

Guide word	Cause	Consequence	Safeguard	Recommendation
Less temperature	Pressure control valve fail close	No deaeration. Oxygen contain in steam, leading to piping line corrosion for long term. Low temperature and low pressure in deaerator	None	Provide low pressure alarm, low flow alarm and low temperature alarm
More Pressure	Pressure control valve mal function wide open	High pressure and high temperature in deaerator	None	Provide high pressure alarm and ensure pressure relief valve design for pressure control valve fail open
Level control valve to Deaerator				
More flow	Level control valve mal function wide open	Low temp in deaerator and poor process performance to deaerator, Oxygen contain in steam leading to piping line corrosion for long term operation	None	Provide low temperature alarm and provide oxygen analyser with high oxygen alarm
More flow	Level control valve mal function wide open	High level and flooding /overflow in deaerator, potential deaerator or internal part (tray) damage	None	Provide high level alarm and link to open drain valve, provide high high level alarm and close feed block valve

Table 4 (Continued)

Guide word	Cause	Consequence	Safeguard	Recommendation
More flow	Level control valve mal function wide open	Hot water overflow to the vent line, possible personal injuries	None	Ensure deaerator vent to safe location to avoid hot water shower to operators (away from working area, platform).
No flow	Level control valve fail close	No condensate feed to deaerator	None	Provide low level alarm and low low level alarm
More level	Level control valve mal function wide open	Low temp in deaerator and poor process performance to deaerator, Oxygen contain in steam leading to piping line corrosion for long term operation	None	Provide low temperature alarm and provide oxygen analyser with high oxygen alarm
More level	Level control valve mal function wide open	High level and flooding /overflow in deaerator, potential deaerator or internal part (tray) damage	None	Provide high level alarm and link to open drain valve, provide high high level alarm and close feed block valve
More level	Level control valve mal function wide open	Hot water overflow to the vent line, possible personal injuries	None	Ensure deaerator vent to safe location to avoid hot water shower to operators (away from working area, platform).

Table 4 (Continued)

Guide word	Cause	Consequence	Safeguard	Recommendation
Less level	Level control valve fail close	No condensate feed to deaerator	None	Provide low level alarm and low low level alarm
Deaerator Less Pressure	Steam condense when deaerator trip	Vacuum condition in the deaerator	None	Consider design deaerator with full vacuum

2. Cooling water system

The cooling water system was separated to 4 nodes as following:

- Sulfuric acid storage and distribution
- Sodium Hypochlorite dosing system
- Dispersant and corrosion inhibitor system
- Cooling tower and distribution system

2.1 Node 1: Sulfuric acid Storage and injection system for cooling water system

Design intent of node 1:

To store and inject 98% sulfuric acid to adjust pH of cooling water. And design condition of acid storage is 3.5 barg and 65 degree C and operating pressure is 0.04 barg and ambient temperature.

Node 1 consists of 98% sulfuric acid storage tank, acid transfer pump, acid distributor.

The HAZOP report results for node 1 would show causes, consequences, and recommendation on Hazop report as Table 5

Table 5 Cooling water system Hazop report from HAZOP database for node 1

Guide word	Cause	Consequence	Safeguard	Recommendation
More flow	pH control loop mal-function	Low pH in water and corrosion of piping line	None	Provide low pH alarm and low low pH close isolation valve and trip dosing pump
More flow	Pressure regulator failure-wide open	Possible over pressure in acid tank	None	Provide venting facility and ensure the venting facility design for pressure regulator fail open
No flow	Pressure regulator failure close	Possible vacuum condition in acid tank	None	Provide PVRV, low pressure alarm and design tank for vacuum condition
No flow	Pump trip	High pH in cooling water system and potential scaling in downstream system	High pH alarm	No action required.
More level	Stop loading too late when the tank is full. (Batchwise operating)	Tank overfill and chemical spillage, potential tank over pressure and tank damage	None	Provide high level alarm, ensure the local indicator is readable from unloading area, operating procedure to address the requirement of operator attendance and monitor and stop unloading at a level before high level alarm and review design pressure of tank.

Table 5 (Continued)

Guide word	Cause	Consequence	Safeguard	Recommendation
Less level	Tank low level/ empty	High pH in water and scaling in downstream system and potential pump damage due to loss of suction	Low level alarm	Operating procedure to address routine check acid tank and refill before low level alarm.

2.2 Node 2: 10% Sodium Hypochlorite dosing system.

Design intent: To store and inject Sodium hypochlorite as biocide for cooling tower system and 10% Sodium Hypochlorite storage tank design at ATM and 65 degree C.

10% Sodium Hypochlorite dosing system consist of Sodium Hypochlorite storage tank, Sodium Hypochlorite dosing pump and distribution system.

The HAZOP report results for node 2 would show causes, consequences, and recommendation on Hazop report as Table 6

Table 6 Cooling water system Hazop report from HAZOP database for node 2

Guide word	Cause	Consequence	Safeguard	Recommendation
No flow	Pump trip	No Sodium Hypochlorite dosing to system, organism growing up and water off spec	Analyzer Low HClO concentration alarm	Provide dosing pump running status to DCS

Table 6 (Continued)

Guide word	Cause	Consequence	Safeguard	Recommendation
More Pressure	Tank loading line and Tank venting line is same size	Possible positive pressure in tank, if loading rate to the tank to high	Vent open to ATM	Check loading rate and venting line size will not over pressure in tank
More level	Stop loading too late when the tank is full. (Batchwise operating)	Tank overfill and chemical spillage, potential tank over pressure and tank damage	None	Provide high level alarm, ensure the local indicator is readable from unloading area, operating procedure to address the requirement of operator attendance and monitor and stop unloading at a level before high level alarm and review design pressure of tank
Less level	Tank low level/ empty	No Sodium Hypochlorite dosing, organism growing up and water off spec, potential pump damage due to loss of suction	Low level alarm	Operating procedure to ensure routine check tank level and refill at a level before low level alarm and consider provide low low level trip pump

2.3 Node 3: Dispersant and Corrosion inhibitor dosing system.

Design intent: To store and inject dispersant and corrosion inhibitor for cooling system

Dispersant and Corrosion inhibitor dosing system consist of Dispersant storage tank, Corrosion inhibitor storage tank, Dispersant dosing pump, Corrosion inhibitor dosing pump and distribution system.

The HAZOP report results for node 3 would show causes, consequences, and recommendation on Hazop report as table 7

Table 7 Cooling water system Hazop report from HAZOP database for node 3

Guide word	Cause	Consequence	Safeguard	Recommendation
More Pressure	Tank loading line and Tank venting line is same size	Possible positive pressure in tank, if loading rate to the tank to high	None	Check loading rate and venting line size will not over pressure in tank
More level	Stop loading too late when the tank is full. (Batchwise operating)	Tank overfill and chemical spillage, potential tank over pressure and tank damage	high level alarm	Ensure the local indicator is readable from unloading area, operating procedure to address the requirement of operator attendance and monitor and stop unloading at a level before high level alarm and review design pressure of tank to avoid overpressure in tank

Table 7 (Continued)

Guide word	Cause	Consequence	Safeguard	Recommendation
Less level	Chemical storage vessel low level/ empty	No chemical feed to system and potential pump damage due to loss of suction	None	Provide low level alarm, operating procedure to ensure routine check tank level and refill at a level before low level alarm and consider provide low low level trip pump
No flow	Pump trip	No chemical dosing to cooling system	None	Provide dosing pump running status to DCS

The Hazop result for node 3 was applied for Dispersant and Corrosion inhibitor dosing system due to two systems have same configuration.

2.4 Node 4: Cooling tower and distribution system

Design intent:

1) To cool down the returning cooling water and supply cooling water to users.

2) Cooling water return temperature is 39 degree C and cooling down to 32 degree C.

3) Design pressure of cooling water system is 7 Barg (The design pressure cover pump shut off pressure.

4) Cooling water pumps, 3 pumps running, 1 stand by.

Cooling tower and distribution system consist of Cooling tower, cooling water pump, and piping distribution system.

The HAZOP report results for node 4 would show causes, consequences, and recommendation on Hazop report as Table 8.

Table 8 Cooling water system Hazop report from HAZOP database for node4

Guide word	Cause	Consequence	Safeguard	Recommendation
More flow	Flow control valve malfunction-wide open	High level in cooling tower basin and local flooding	None	Provide high level alarm
No flow	Flow control valve fail close	Low level in cooling tower basin, potential 3 pumps damage and force to downstream users shut down.	None	Provide low flow alarm
No flow	Blow down control valve fail close	Poor water quality, and cooling water user fouling	None	Provide low flow alarm and high conductivity alarm
Less level	Partial pump suction screen blockage	Low level in cooling water pump basin.	None	Provide level deviation alarm and operating procedure to require regular clean up of pump suction screen

Table 8 (Continued)

Guide word	Cause	Consequence	Safeguard	Recommendation
Less flow	Cooling water pump trip	Low cooling water supply pressure to user, high temperature in cooling water return header	None	Provide high temperature alarm, cooling water supply pump selection should have right pump curve range to allow running 2 pumps when high water demand (before operator start stand by pump)
More Pressure	Pump cut out, pump trip.	Potential surge problem in the system	None	Evaluate the possibility of surge in cooling water system and design accordingly.
More flow	High demand from the users in simultaneous	Low pressure in utility, and insufficient utility supply	None	Provide low pressure alarm
More Pressure	Loss of downstream users.	Less cooling water demand, high pressure in cooling water system	None	Provide high pressure alarm and operating procedure to address criteria to shut down/ start up of cooling water pump.
Less Pressure	Siphon effect	Possible vacuum in piping line (esp in cooling water return line, 64 inch)	None	Ensure piping design layout will not create vacuum condition due to siphon effect from high elevation to low elevation

Discussion

1. Verifying Hazop database result

To make sure that the Hazop database is correct and accurate, the results from Hazop database must be verified significantly by check process variable deviation of each unit that changed from the Conventional HAZOP result.

1.1 Verifying cause and consequence

From process guideword deviation on the interested equipments, the relationship between equipments will be used to finding process deviation guideword, causes, consequences and recommendation. Safeguard will be used to screen the recommendation. The result of causes consequences, safeguard and recommendation from Hazop database can be verified by comparing with the data of conventional HAZOP to confirm the HAZOP results from Hazop database are correct.

2. Improvement from Automatic HAZOP

In this thesis, there are 3 improvements from Automatic HAZOP

Firstly, the Hazop database had been improved by include existing safeguard as a one criteria for screening the recommendation.

Secondary, the general guideword had been considered as one option in Hazop database. For the general guideword recommendation shall be updated and input by operators/ maintenance group.

Finally, the access database programming is general application for every company, easy to develop and input the data Hazop database, and the Hazop database can create the Hazop report after select equipments and existing safeguard from Hazop database P&ID foam

3. Limitation of Hazop database

The Hazop database has limitation as shown below.

1. This program allows the user input 2 equipments, and 1 safeguard on the Hazop database programming.

2. The cause and consequence library is inadequate and specific only in utility plant. As a result, it is generic for only operator of this plant because the name of equipment in cause and consequence library still to be a code used in this plant.

3. This program need to improve the interface and graphic for create P&ID.

CONCLUSION AND RECOMMENDTIONS

The HAZOP database is a computer programming for identification hazard analysis. Utility system of Petrochemical Plant was selected to be a case study of HAZOP database. The HAZOP results were shown in form of access report. All causes and consequences from deviation changed from deviation changed were represented in their access report.

Conclusion

Application of HAZOP database, the end user can arrange the equipment in their locations to set up the interesting of Utility system of petrochemical process plant. Moreover, the end user has to define study node and put deviation at that point. Subsequently, HAZOP database will send deviation by unit deviation model to the close equipment. Finally, the program will find out HAZOP results using method for finding result and report results.

These results can be mutually complemented; consequently HAZOP database can detect the potential accident more exhaustively than other hazard analysis system with narrow viewpoint. As the HAZOP database result was shown in causes and consequences pattern in their workspace to represent results for the end user.

Recommendations

HAZOP database system still has limitation. Therefore it should be developed to be easy for the end user. In addition, the development will help this program works well with a widely HAZOP results in whole process. It should be expanded its ability to use with general chemical process plant. Consequently, HAZOP database should be enhanced by amplify detailed of program as following:

1. Improving and adding database table of cause and consequence library to cover whole plant.

2. Adding more equipment in process equipment use with several process plants.

3. Adding information of material that concern with process due to different materials will give different deviation profile of equipment.

4. The P&ID graphic should be developed for convenient to the end user.

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APPENDICES

Appendix A

Process Flow Diagram (PFD) and Design basis of Steam/ Condensate System

STEAM AND CONDENSATE SYSTEM

1. Design objective

The steam system is a part of Utilities Project. It is designed to meet the utility requirement of Plant A. This design basis provides the design requirement of the steam system, which consists of low pressure steam, high pressure steam distribution system, condensate collection system, boiler feed water generation & distribution system.

1.1 Battery Limit Conditions

The distribution system is designed to meet the required operating conditions at the battery limits, see Appendix Table A1 below.

Appendix Table A1 Battery Limit Conditions

	Location	Pressure, barg				Temperature, ^oC			
		Minimum	Normal	Maximum	Process Design	Minimum	Normal	Maximum	Process Design
Steam – high pressure (SH)	Steam Supply Plant 1	21	22	24	26.7	235	235	300	325
Steam – high pressure (SH)	Steam Supply Plant 2	21	22	24	26.6	225	225	300	325
Condensate return (CL)	Plant A	2	2.5	3	7.5	134	139	144	170
Condensate return (CL)	Steam Supply Plant 1		6		13.5		90		130
Boiler Feed water	Plant A		30		46		134		160

The steam distribution systems are designed to meet the required operating conditions at the downstream of desuperheaters, see Appendix Table A2 below.

Appendix Table A2 High pressure steam header and low pressure steam header conditions

	Location	Pressure, barg			Temperature, °C		
		Normal	Maximum	Process Design	Normal	Maximum	Process Design
Steam – high pressure (SH)	Downstream of SH desuperheater	22	24	28	235	250	275
Steam – low pressure (SL)	Downstream of SL desuperheater	5	35	7.5	200	220	245

High Pressure steam supplied from steam supply plant shall be within the following specification, see Appendix Table A3.

Appendix Table A3 Steam condition

Parameter	Limit	Unit
Conductivity	≤ 10	μS/cm
Sodium	≤ 20	ppb
Chloride	≤ 20	ppb
pH	9.0 – 9.6	
Silica	≤ 20	ppb
Total Iron	≤ 20	ppb
Total Copper	≤ 10	ppb
Total Organic Carbon	≤ 300	ppb

Condensate for the entire site will be collected and returned to the Utilities block for BFW make up and returning to steam supply plant. Each plant must install appropriate monitoring equipment to ensure that the quality of condensate return meets the following specifications, see Appendix Table A4.

Appendix Table A4 Condensate Return Quality

Parameter	Limit	Units
Conductivity	≤ 12	µS/cm
Sodium	≤ 20	ppb
Chloride	≤ 20	ppb
pH	9.0 – 9.6	
Silica	≤ 20	ppb
Total Iron	≤ 20	ppb
Total Copper	≤ 10	ppb
Total Organic Carbon	≤ 300	ppb

The quality of Boiler Feed Water feed to desuperheater shall be within the following specification, see Appendix Table A5

Appendix Table A5 Boiler Feed Water Quality

Parameter	Limit	Units
Oxygen as O_2 max [1)]	0.007	ppm
Total Iron	0.02	ppm
Total Copper	0.01	ppm
Total hardness as $CaCO_3$ max	0.3	ppm
pH @ 25 ^{o}C	7.5 - 10	
Total Organic Carbon	0.3	ppm
Oil	Not detecAppendix Table	

2. Process Description and Equipment Design Considerations

Steam is distributed within the plant at two pressure levels, high pressure (SH) and low pressure (SL).

SH is from 2 sources; Steam supply plant 1 and Steam supply plant 2. It will be let down through pressure let down valve and SH Desuperheater to meet the site requirement and distributed in SH header. BFW from deaerator will be used as desuperheating water.

SL is generated by letting down SH through pressure let down valve and SL Desuperheater and then sent to SL distribution header. BFW from deaerator will be used as desuperheating water.

Condensate return is collected and sent from each user to the header. It is cooled down by an air cooler to 90 ^{o}C before it is stored in the condensate tank.

Condensate return is then pumped by condensate return pump and distributed into 2 systems;

- Send to deaerator to produce boiler feed water.

- Return to Steam supply plant 1.

During normal operation condensate return is sent to deaerator for BFW makeup. However, if condensate is off-spec, it will be dumped to Waste Water Treatment Plant by each ISBL plant and demineralized water will be used for BFW make up instead.

Dissolved gases in condensate return is removed at deaerator by scrubbing with SL. BFW is then pumped to desuperheater by BFW feed pump. The common chemical treatment of the boiler feed water is carried out to both suction lines of BFW Pump. The dosing systems and dosing chemical storage will be supplied as a Boiler Feed Water Dosing Package. The dosing is not required for desuperheating water pump.

3. Equipment Design Considerations

Equipment summary is shown below

3.1 SH desuperheater.

SH from Steam supply plant 1 is desuperheated in the SH Desuperheater and distributed to users. SH from Steam supply plant 2 needs not to be desuperheated at SH Desuperheater. Desuperheating is achieved using boiler feed water supplied from deaerator. The water flow to the desuperheater is controlled to achieve the required steam outlet temperature (235 oC). SH main header pressure (22 barg) is controlled by the pressure let down valve at the upstream of SH desuperheater.

3.2 SL desuperheater.

SH is desuperheated in the SL Desuperheater and distributed to users. Desuperheating is achieved using boiler feed water supplied from deaerator. The water flow to the desuperheater is controlled to achieve the required steam outlet temperature (200 oC). SL main header pressure (5 barg) is controlled by the pressure let down valve at the upstream of SL desuperheater.

3.3 Condensate Return Cooler.

Condensate Return Cooler will be designed to cool down the condensate return temperature of 130 ^{o}C to 90 oC before it is stored in the condensate tank. The storage temperature is limited as recommended by API standard (200 oF maximum); It also needs to meet the steam supplier's requirement of condensate return temperature (90 ^{o}C).

3.4 Condensate Collection Tank.

The cooled condensate return is routed to store at ATM in the condensate tank. The capacity of the tank will be based on the working volume which provides hold-up time 24 hours.

3.5 Condensate Pumps.

2 condensate pumps will be installed: 1 in operation, 1 standby. Pump type is electric motor driven. Differential Head of the pump is estimated at 10 barg.

3.6 Deaerator.

The deaerator shall be a spray/tray type. The storage capacity shall provide at least 15 minutes of storage at the maximum flow rate.

3.7 Boiler Feed Water Dosing Package.

It is anticipated that a conventional component treatment regime will be required comprising:

- Oxygen scavenger
- pH control

The dosing chemicals shall be Hydrazine-free.

The supplier shall supply a package including the followings;

- All necessary equipment for the storage (30 days chemical storage)

- The delivery system of the dosing chemicals into the suction lines of boiler feed water pumps.

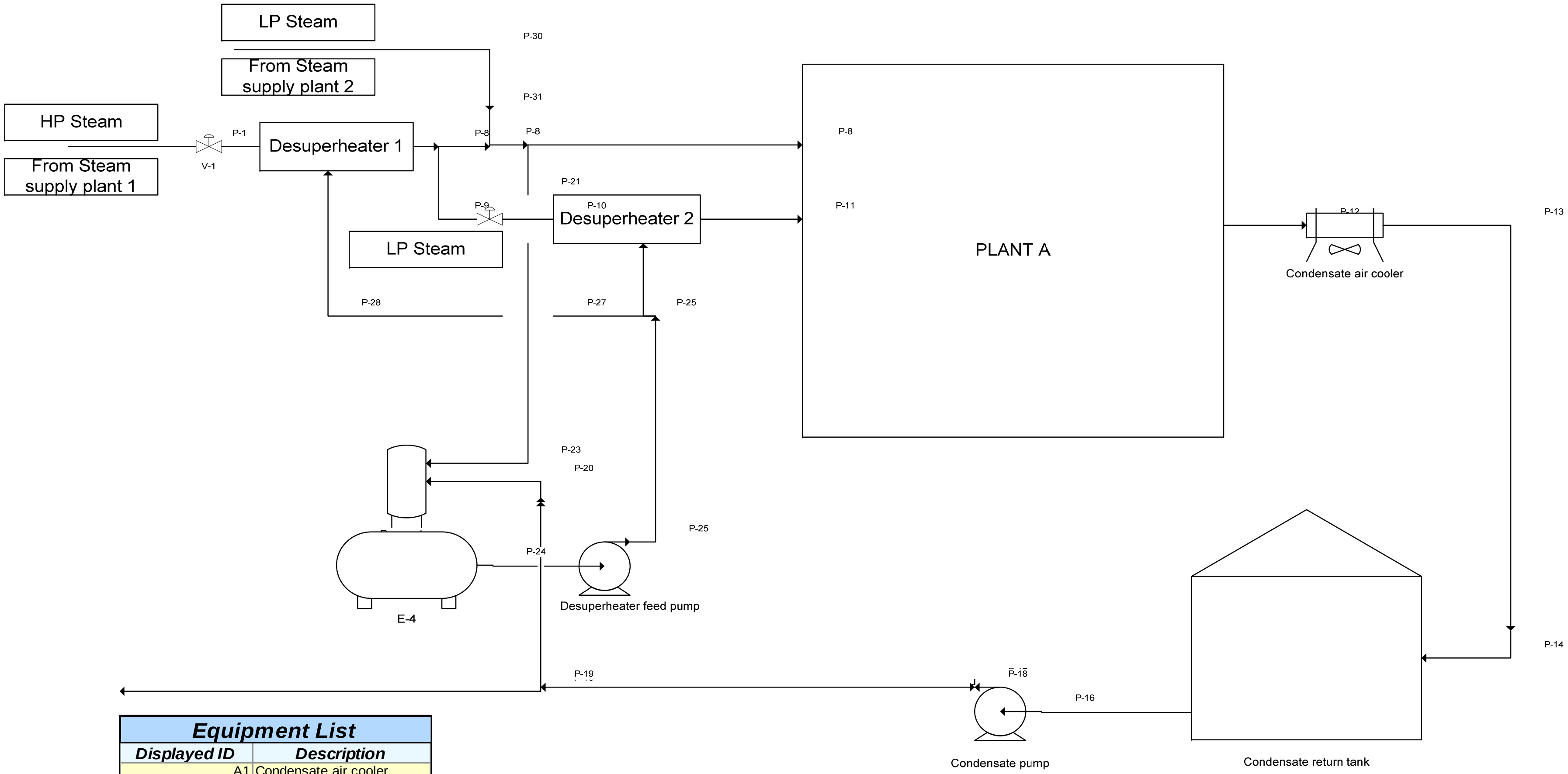
- All necessary instrumentation, sampling arrangements and all other equipment required for continuous operation.

3.8 Boiler Feed Water Pumps.

2 BFW pumps will be installed: 1 in operation, 1 standby. Pump type is electric motor driven. Head of the pump is estimated at 30 barg.

3.9 Desuperheating Water Pumps.

2 Desuperheating Water Pumps are required for deaerator. 2 desuperheating water pumps will be installed: 1 in operation, 1 standby. Pump type is electric motor driven. Head of the pump is estimated at 25 barg.



Equipment List	
Displayed ID	***Description***
A1	Condensate air cooler
P1	Condensate pump
T1	Condensate return tank
D1	Deaerator
P2	Desuperheater feed pump

Appendix Figure A1 Process Flow Diagram of Steam/ Condensate System

Appendix B

Process Flow Diagram (PFD) and Design basis of Cooling Water System

Cooling Water System.

1. Basis Of Design

Cooling water is used for the cooling of process streams in the exchangers. The cooling water supply system provides 32 ^{o}C maximum for use in exchangers within the process units. The cooling water return temperature is 39 ^{o}C. Cooling water is circulated to the users by Cooling Water Pumps. The returned cooling water is cooled down by the Cooling Tower.

The cooling water make up source is utility water from Raw Water Treatment. The concentration of dissolved solids in the water is increased by evaporation and, therefore, a chemical dosing package and cooling water blowdown is required to prevent dissolved solid build-up and precipitation. The chemical dosing will typically comprise of acid, dispersants, corrosion inhibitor and biocides. The continuous blowdown from the cooling water supply header is sent to Waste Water Treatment Plant.

Part of the cooling water from the Cooling Water Pump will go through a filtration to remove suspended solids, sand, silt and other airborne material entrained into the cooling water. The filtered water is returned to the Cooling Tower Basin. The filter is back washed with cooling water periodically with the washings being sent to Waste Water Treatment Plant through blowdown header.

1.1 Circulating Cooling Water Quality

It is anticipated that the circulating water will have the following characteristics see Appendix Table B1:

Appendix Table B1 Circulating Water Characteristics

Parameter	Limit	Unit
pH	7.8~8.4	
Conductivity	< 4500	µS/cm
Iron as Fe	< 3	ppm
Total dissolved solid (TDS)	< 3000	mg/l
Turbidity	< 30	NTU
Total suspended solid	< 30	mg/l
Chloride (as Cl^-)	< 455	ppm
Sulphate (as $SO4^{2-}$)	< 1200	ppm
Silica (as SiO2)	< 150	ppm
Calcium hardness (as CaCO3)	< 700	ppm
Total Chlorine residual	< 0.4	ppm
Sessile Organisms	No detectable slime	
Planktonic Organisms	< 10,000	CFU/ml

1.2 Cooling Tower

The cooling tower shall be induced draught, counter flow type, field erected, fibreglass reinforced plastic (FRP) framed and film fill. The design heat load is 133 MW, normal heat load is 115 MW. Number of cells is 5 (preliminary, to be confirmed by vendor), no spare cell required.

Rate of blowdown is to be based on 5 cycles of concentration of the make-up water. Drift loss of cooling tower should be less than 0.02%.

1.3 Cooling Tower Basin

Cooling water basin should be sized to contain the quantity of liquid found in the piping system. It should be sloped toward a low point drain to facilitate ease of cleaning. The basin volume accommodates 7 minutes of circulating flow (1900 m3), which is equivalent of 7 hours of make-up water, from Low Liquid Level to Normal Working Level in order to ensure security of Cooling Water supply in the event of loss of make-up flow. The volume of the pond includes an allowance of 1050 m3 from Normal Working Level to Maximum Working Level in order to accommodate the draining down of the Cooling Water exchangers and piping. This volume is subject to confirmation during Detailed Engineering.

To prevent large solid objects from being pulled into the pump suctions, the trash screen to be installed. There shall be two screens, arranged in series at each location to enable one of the two to be removed for cleaning whilst the second remains in operation.

1.4 Cooling Water Pumps

4 cooling water pumps will be installed: 3 in operation, 1 standby. All pumps will be electrical motor driven. The design code is non- API. The normal capacity per pump is 4,810 m3/h, rated capacity is 5,600 m^3/h, which includes 285 m3/h flow through filtration and 55 m3/h blowdown.

1.5 Filtration (Package)

A pressure side stream filtration is to be provided to filter the equivalent of 2% of the cooling water normal circulated to the Users i.e. 285 m^3/h. The filter circuit shall take water from the cooling water pumps discharge and return it to the cooling tower basin. The system should contain at least 3 filters to accommodate a continuous system. This allows one filter to clean the water while the other filter is backwashing. The number of individual filter units will be confirmed by the Vendor. The system shall be provided with automatic backwash to operate either on a timed basis or when a high pressure drop is built-up. The filters will be backwashed and the washings will be sent to Waste Water Treatment Plant through blowdown header.

There is no simultaneously discharge from blowdown and backwash, once the backwash is initiated blowdown valve will be closed.

1.6 Cooling Tower Dosing System

The cooling tower dosing system will provide the following chemicals into the cooling tower basin to treat the cooling water.

- Corrosion Inhibitor;
- Dispersant;
- 98% Sulfuric Acid;
- 10% Sodium Hypochlorite;

Corrosion Inhibitor and Dispersant dosing system will be a vendor package, including the chemicals storage tanks, the dosing pumps.

The chemical storage tanks should be sized for 14 days usage in principle. Each chemical dosing pump should have an installed spare.

The construction material of storage tanks/pumps must be compatible with the chemicals. Sodium Hypochlorite storage material should be high density plastic as polyethylene, or FRP.

The chemicals storage tanks should be located in a dike area for spill containment. Moreover, the storage of Sulphuric acid and Sodium hypochlorite should have their dedicated dikes, to be isolated from the other chemicals.

1.7 Pipelines

The material of cooling water pipelines is carbon steel for aboveground and FRP for underground.

1.8 Makeup Water Specification

The make-up water of cooling water system is utility water from Raw Water Treatment. The specification is shown in Appendix Table B2

Appendix Table B2 Makeup Water Specification

Parameter	Unit	Normal	Maximum
Pressure	Barg	6.1	
Temperature	°C	Ambient	38
pH		7-8	
Turbidity	NTU	3	5
Iron (as Fe)	ppm	< 0.5	
Conductivity	µS/cm	200	308
Total Dissolved Solid (TDS)	mg/l	120	178
Chloride as Cl^-	ppm	25	43
Sulphate as SO_4^{2-}	ppm	15	46
Silica as SiO2	ppm	13	22
Manganese as Mn2+	ppm	0.5	1
Calcium Hardness as CaCO3	ppm	30	47
Mg Hardness as MgCO3	ppm	20	49
Total Hardness CaCO3	ppm	60	96
Total alkalinity	ppm	60	74
BOD	mg/l	1.5	3.6
COD	mg/l	22	5.6
TOC	mg/l	5	6.6

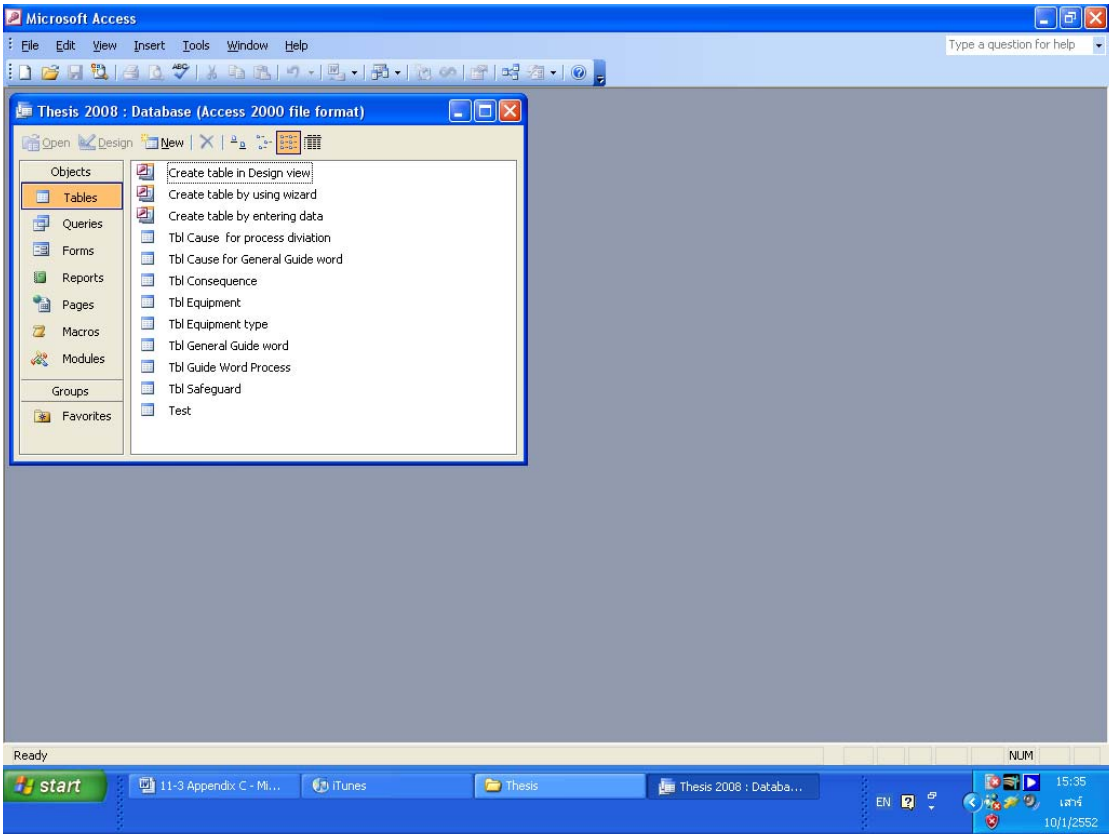
Appendix C

HAZOP Database Structure.

HAZOP database structure.

1. HAZOP Database tables.

HAZOP Database consists of tables of Equipment type, Equipment, Process Guideword, Cause, Consequence and Safeguard. Overall HAZOP database table see Appendix Figure C1.



Appendix Figure C1 HAZOP Database table.

Table Equipment type create for classify group of equipments, such as Vessel, Pump, Tank, Instrument, and other. Table equipment was created for correct equipment data, equipment data give detail of equipment following equipment type table.

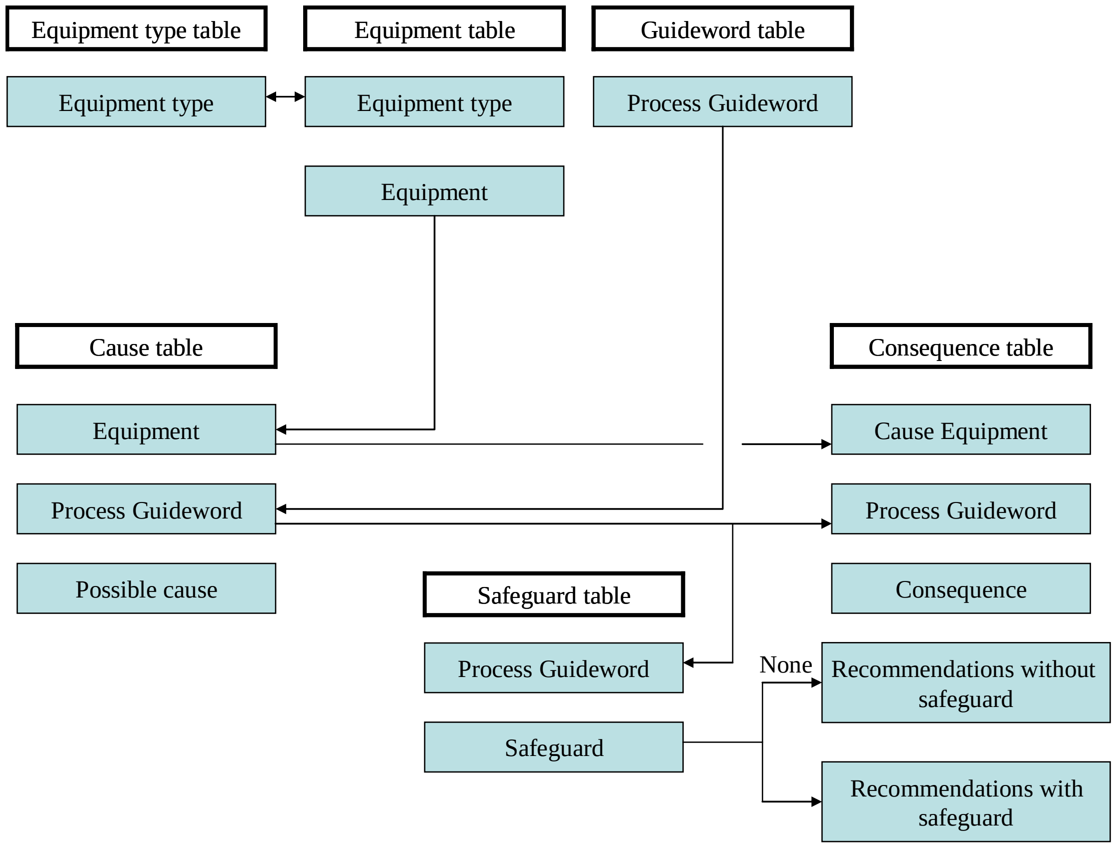
Table of process guideword corrected HAZOP guidewords related for process concern, Process guidewords see Appendix Table C1.

Appendix Table C1 List of Process Guidewords

GUIDEWORD	AREA OF APPLICATION
FLOW	
No Flow	SYSTEM
Reverse Flow	SYSTEM
More Flow	SYSTEM
Less Flow	SYSTEM
TEMPERATURE	
More Temperature	SYSTEM
Less Temperature	SYSTEM
LEVEL	
More Level	SYSTEM
Less Level	SYSTEM
PRESSURE	
More Pressure	SYSTEM
Less Pressure	SYSTEM

Cause table was design for corrected possible causes for equipments following the process guidewords. This table consists of equipment type, equipment, process guideword and possible cause data.

Consequence table consists of process guideword, cause equipments, effected equipments, possible consequence and recommendation (recommendations separate to two set, first is recommendation without safeguard and recommendation with safeguard. The data input from Foster Wheeler HAZOP review report. The relationship of each table see Appendix Figure C2.



Appendix Figure C2 HAZOP Database relationship.

CIRRICULUM VITAE

NAME	: Mr. Pisak Wichakool		
BIRTH DATE	: January 17, 1979		
BIRTH PLACE	: Petchabun, Thailand		
EDUCATION	: **YEAR**	**INSTITUTE**	**DEGREE/DIPLOMA**
	2001	Srinakarinwirot Univ.	B.Eng.(Chemical Eng.)
POSITION/TITLE	: Senior Design Safety Engineer		
WORK PLACE	: Foster Wheeler International Corporation.		