Original Article

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Application of a Hazard and Operability Study Method to Hazard Evaluation of a Chemical Unit of the Power Station

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Abstract

Background: The aim of this study was to identify the hazards, evaluate their risk factors and determine the measure for promotion of the process and reduction of accidents in the chemical unit of the power station.

Methods: In this case and qualitative study, HAZOP technique was used to recognize the hazards and problems of operations on the chemical section at power station. Totally, 126 deviations were documented with various causes and consequences.

Results: Ranking and evaluation of identified risks indicate that the majority of deviations were categorized as "acceptable" and less than half of that were "unacceptable". The highest calculated risk level (1B) related to both the interruption of acid entry to the discharge pumps and an increased density of the acid. About 27% of the deviations had the lowest risk level (4B).

Conclusion: The identification of hazards by HAZOP indicates that it could, systemically, assess and criticize the process of consumption or production of acid and alkali in the chemical unit of power plant.

Keywords: *Hazard and operability, HAZOP, Risk assessment, Chemical unit*

Introduction

The incidence of major industrial accidents around the world led to the innovation of various hazard identification techniques including Fault Mode Effective Analysis (FMEA), Fault Tree Analysis (FTA), Hazards and Operability Study (HAZOP) and Energy Trace and Barrier Analysis (ETBA) (1-4). Potential hazards and accidents for personnel, equipments and the environment can be recognized and prevented by special process (5). HAZOP, as a multidisciplinary team effort, was initially developed since 1960 for analy sis of risk factors and safety measures and can be considered as one of the most accurate methods for identifying hazards in the various industries, especially chemical plants (1, 6-10). In this approach, members use their innovation and initiative according to the basis of simulation and brain storming for identification of deviations from the main process design, their relative causes, effects and finally to present the method of control (11, 12). To determine the deviation of parameters from the main aim of process design, guide words including temperature, pressure, conductivity, water flow, services failure, utilization of instruments and others are also applied (2, 7, 13). The qualitative matrix methods, as an instrument for adopting a logical decision, have also been used for determining of any relative risk level (14, 15). There have been few scientific studies in the field of hazard identification either in Iran or other countries using HAZOP,

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but nothing found on chemical unit of power station (10, 12, 16-20).
This study therefore, was conducted to: 1) identify the hazards; 2) evaluate their risk factors; 3) determine the priority and estimation of qualitative hazards and 4) to propose the measure for promotion of the process and reduction of accidents in the chemical unit of the power station.

Materials and Methods

The present study as a case and qualitative study were conducted at the chemical unit of the power station in northwest of Yazd Province. Briefly, very pure and non ionized water are produced for high pressure boilers of the power station. Different processes including chlorination, removal of suspended particles larger than 5 microns by sand filters and creasy cartridges, removal of chlorine, reverse osmosis and exchange of ions were taken place to decrease water conductivity. In addition, to restore saturated resins during the process, acidic and alkaline sections have been designed in which Ca, Mg and SO_4^{2-} ions are replaced with H^+ and OH^- ions in the resins, respectively (Fig. 1). Initially, all the required documents including maps, details of operations and systems, piping and instruments diagrams, technical details and directions for implementation of systems were gathered by main team members who were familiar with the design of Chemical Unit. The nodes of the processes including entry of raw water till the entrance of the sand filters, tanks of the sand filters, cartridge filters, high pressure pumps, reverse osmosis system, permeate tank, caution resin tank, resin catcher, degasser, acid discharge, acid tank and mixing T shaped were recognized. Some of the nodes were altered during the study. The scenarios of deviation from the main process were also recognized by team members using guiding words (Table 1) and process parameters (Table 2). Despite of initial aim of the study, some of the operational pathways were not included due to similarity in the procedures. The priority and estimation of the qualitative hazards, risk management in the form of risk assessment matrix were also determined. The risk factors were also classified in three following stages and then results were entered in the HAZOP work documents:
Determination of the probability of the consequences of deviation in 5 groups from frequent to rare.
Severity of accident in 4 groups from catastrophic to marginal.
Combination of severity and probability of each risk to determine the danger levels and the priority of control measures, qualitatively.

Results

A total of 14 nodes were recognized, evaluated and then documented in a 45-page which summarized in Table 3, 4. The operational problems were mainly focused by team members and more attention paid on the deviations with negative impact on the operations of the system resulting in financial losses and personal injuries.
Generally, in this study, 126 deviations were identified in which 15% were related to nodes from the entry of raw water to entry of the sand filters, 15% filter tanks, 12% cartridge filters, 5% high pressure pumps, 10% reverse osmosis, 3% permeate tanks to the DEMIN PLANT FEED PUMP, 9% entry of the cation exchange chamber to entry of the resin catcher, 7% resin catcher to degasser, 8% acid injection pathway from the exit of the daily storage to entry of the mixing T shaped and 4% were related to the mixing T.
As the results show, one deviation can have several causes and effects. In the study, 293 causes of deviations were identified of which the main causes included; failures in the level measurement instruments, simultaneous starting of the pumps, non regulation of valves, presence of air in the water flow pathway, performance of production processes manu-

ally, torn reverse osmosis membrane, corrosion of the acid pathway, defective check valves, failures in course of acid pump, blockage of pathways, mechanical problems of valves, increased or decreased the amount of injection of pumps and increased corrosion. The causes were mainly related to the equipments (43.5%), manual or operator (35.8%), logic control panel (9.2%) and 12% to other causes.

A total of 175 suggestions were proposed and, there were no any proposals for some of deviations. Suggestions were mainly related to the modification and improvement of equipments or processes (42%), regular maintenance of equipment (35%), and the use of correct operational methods (23%).

According to the results, 10.4% of deviations were not acceptable, 35.7% were undesirable, 24.6% were acceptable but needed reconsideration and 29.3% were acceptable and no need any correction act. The maximum calculated risk level, however low percent, (1.5% of the deviations) was related to interruption of acid entry to the discharge pump and increased density of acid (1B). The lowest risk levels of deviations was related to 4D(27%) followed by 3D(2%), 4C (9.5%), 4B (4%), 2D(12%), 3C (8%), 3B(6.5%), 2B(5%), and 7% of the deviations had other risk levels.

Table 1: Some of key word used in HAZOP methodology

Key Words	Description
No	Negation of the design intent
More than	Quantitative increase
Less than	Quantitative decrease
As Well As	Qualitative increase
Part of	Qualitative decrease
Reverse	Logical opposite of the intent
Other than	Other than Complete substitution or the operational procedures occur abnormally

Table 2: Some of process parameters

Parameter	**Deviation**	**Parameter**	**Deviation**
Flow	No flow, reversed flow, more & low flow	Pressure	More or low or no pressure
Opacity	More & low opacity	Temperature	More or low Temperature
Pollution	Route blockage	conductivity	More Conductivity
Corrosion	More corrosion	Abnormal operation	Valve, pump and etc failure
Pressure difference	P Δ More	Contaminants	Increase or decrease CL or oil in water
Recovery	Low Recovery	PH	More PH
Concentration	More or low concentration	Level	More or low Level

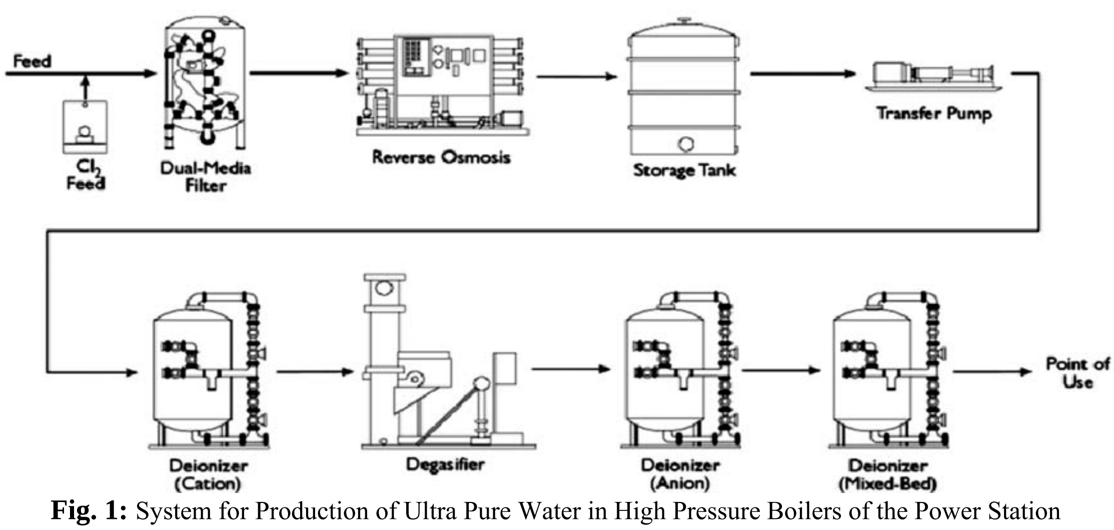

Fig. 1: System for Production of Ultra Pure Water in High Pressure Boilers of the Power Station

Table 3: Sample of the HAZOP Results Summary (For Chemical Plant

Deviation	Possible causes	Consequences	Action Required
No Pressure	1- Blocked inlet and outlet of the pump 2- Ingress of air in pump 3-Pump Failure 4- Blockage at route and clogging before pump 5- Fouling of check valves 6- Manual valve failure	Line Trip, and no produce permeate water	1- Install switch on manual valve as safety lock 2- Install auto vent on line 3- Set up a filter with tiny mesh on the entrance of water 4- Periodical inspection & maintenance
Low Pressure	1- Decrease in level of Raw Water Vessel regard to inlet suction 2- Strainer blockage 3- Pipe or Vessel Rupture 4- Flange failure 5- Pump Corrosion	Line Trip, and no produce permeate water	1- Placed start and stop key of raw water pump in PLC[a] 2- Installing moisture sensor near sand filter pump 3- Controlling of manual valves 4- Periodical inspection & maintenance
Low Flow	1- No regular manual valve in outlet of Raw Water Pump, Concentrate of Reverse Osmosis, High Pressure Pump 2- Failure in pump suction 3- Check valve blockage 4- Finishing using time of sand filter	Line Trip, and no produce permeate water	1- Controlling of manual valves 2- Regular backwash of sand filter 3- Periodical inspection & maintenance
High Flow	1- No regularize manual valve 2- Mechanical failure in flange 3- Start accidental pump	Line Trip, and no produce permeate water and cracking pipe	Programming on PLC that no start additional pump when one pump is running
Water without chlorine	1- Electrical or mechanical failure on chlorine pump 2- Unloading of chlorine vessel 3-Bblockage on chlorine injection rout 4- No standard percentage chlorine solution	Growing micro organisms & algae on raw water & sand filter vessel & RO	1- Weekly inspection of chlorine vessel 2- Maintenance & repairing of chlorine pump 3- Full dissolving of hypochlorite solution
Water with additional chlorine	1-Increase at injection dose of chlorine pump 2- Decrease in raw water flow 3- Percentage of chlorine solution is more than standards	Increase corrosion, affect on RO[b] membrane & more consuming of SMBS[c]	1- Install chlorine sensor on the entrance of water that measure chlorine rate and regulate injection dose of chlorine pump automatically 2- Install flow meter 3- Chlorine pump start automatically of PLC
Service failures	1- Tow phase in Acid pump in cause electrical failure 2- Acid Pump corrosion 3- Mechanical failure in Acid instrument	No unloading of Acid, diffusion of Acid on place	Maintenance & periodical repairing

[a] Panel Logic Control
[b] Reverse Osmosis
[c] $Na_2S_2O_5$

Table 4: Sample of the HAZOP Results Summary (For Chemical Plant)

Deviation	Possible causes	Consequences	Action Required
Pump reversed	1-Enter error electrical phase into pump 2- Decrease on vessel level 3- No getting air on apparatus followed by repairing	Line Trip, and no produce permeate water	Install auto vent on routing
Increase in water hardness	1- Reduce in quality of raw water 2- Raising dust on vessel	Increase corrosion, decrease in Permeate water quality, decline in recovery, saturated of dmin vessel	Periodical water examination, regulate recovery & pressure in RO
Abnormal Operation (failure valve)	1- Fault at PLC programming 2- Mechanical failure in valves 3- Interruption air of pneumatic valves	Damage to valves	Maintenance & periodical repairing
Increase opacity	1- Deficit silica & anthracite height in sand filter 2- Creation flood channel among sand filter 3- Inappropriate granular in sand filter 4- Running away nozzle 5- Inefficient rinse after backwash 6- Use more extra of sand filter	Quick blockage of filters	1- Install opacity tester 2- Set up diffusion water
Increase Δ P Pressure difference	1-Finish normal using time of cartridge 2- corrosion in routing 3- Running away washer among piping & stick on cartridge	Change in recovery, passing suspended particles	Install resin catcher before cartridge
Increase recovery	1-Decrease draining at RO concentrate 2- RO membrane torn 3- Running away RO oaring 4- Blockage rout and concentrate check valve	Increase Conductivity and decrease water quality also reduce in advantage using time	1- Regular flow meter calibration 2- Install recovery representative in PLC 3- install automatic regulated valve instead manual valve
Flow interruption to unloading acid pump	1-Running away stride 2-Blockage in stride	Diffuse acid in the place	Maintenance & periodical repairing
Entrance acid to alkaline line	1- Operator error in connecting routes together	Explosion	1- Full isolation acid and base route 2- labeling acid and base route 3- using different flange for any route
Puncturing acid vessel	1- Chemical reaction 2- Physical failure (knocking)	Sprinkling acid and environment pollution	Install plastic curtain surrounding vessel to prevent leakage
Decrease acid concentration to below 98%	In attendance impurities like water and iron	Equipment corrosion, reduce acid potency	Periodical inspection, catching humidity in air route
Strengthen acid concentration more than 4%	1- Increase acid injection pump course 2- Low water flow in entry of Mixing Tee	Damage to resin, Equipment corrosion	1- Maintenance & periodical repairing of acid pump, valve control, 2- install flow switch high
Raised calcium and magnesium and sediment calcium sulfate	Utilizing water with more than 90 micro siemens conductivity	Affect on resin	1- Install on-line conduct meter 2- Line trip if water conduct is more than 90 micro siemens

Discussion

HAZOP was first developed and used for analysis of risk factors and safety measures by several researchers, working independently, in the 1960s. There is now a body of work describing the identification of hazards using HAZOP methodology. In spite of several studies, nothing found on chemical unit of power station. This study, therefore, has characterized and determined the hazards for the first time, as comprehensive analysis. The investigation was supplemented, as appropriate, by more conventional qualitative matrix methods. All this builds to a profile of analysis and must be considered as a whole to achieve a full interpretation of the data.

With respect to the aims of the study, a large number of risks and hazards identified in which deviations were mainly related to nodes from the entry of raw water to entry of the sand filters (14, 21). In consistent with the findings of Angela Pulley in America, more than half of the identified causes were related to equipment defects followed by operator errors (17). The manual control system may also increases the number of deviations and, therefore, the automatic control panels should be applied (22).

For prevention of deviations, attention should be, therefore, focused on the application of instructions for regular inspections and maintenance of systems. It is worth to mention that, the finding of this study is consistent to the observations of Shafaghi who worked on Absorption Heat Pump in the US (19). Some of the suggestions in various nodes were similar, so that it was impossible to propose any idea or there were no specific offer. The pattern of this study is similar to the model demonstrated by previous investigations (18). An explanation is that a number of deviations in other nodes were not used due to the similarity in their causes, effects and results. This point is also common in HAZOP procedure and have previously mentioned in other studies (18).

Ranking and evaluation of identified risks indicate that the majority of deviations were categorized as "acceptable" and less than half of that were "unacceptable". According to the results, the highest level of risk was related to deviation of acid and alkali which is considered as "unacceptable". Discharge of acid and alkali, in spite of low percent of deviation (1.5%), would increase the chance of accidents and the process, therefore, need to be modified immediately (23). Most of the deviations in the present study were classified as undesirable and need to be assessed by the top management. It is necessary to point out that, the most important problems during the study were the gathering of team members, inconvenience and difficulties for organizing of meetings and the lack of inclination during meetings (18).

The prominent suggestions were the modification and improvement of process and equipments which play an important role in the reduction of hazards. The use of acid and alkali in the workplace may increase the chance of accidents in the process and need to be modified immediately.

In conclusion, the identification of hazards by HAZOP indicates that it could, systemically, assess and criticize the process of consumption or production of acid and alkali. This technique can be, therefore, considered as an effective method for recognition and prediction of hazards and it may increase the safety levels, prevent accidents and enhance the reliability of systems via the reduction of operational problems.

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