Risk level Assessment of the Desalter and Preflash Column of a Nigerian Crude Distillation Unit

Henry O. Orugba¹*, Samuel E. Ogbeide¹, Christian Osagie²

¹Department of Chemical Engineering, University of Benin, Benin City, Nigeria
²Faculty of Environmental and Natural Sciences, Brandenburg University of Technology, Cottbus, Germany

Email: *orugbahenry@yahoo.com

Abstract

A study of operability and assessment of the safety level of a crude distillation unit in a Nigerian refinery has been carried out. In a crude distillation unit of a refinery, the desalter and preflash column, as well as their associated pipe works and pumps, are considered to have high-risk factors that can present operability problems and possibly hazardous conditions. Applying the HAZOP methodology, a total of 25 guide words were suitably applied on 4 nodes to study the possible deviations that may occur. The 89 causes of these deviations identified in the study could be classified under human errors and equipment malfunctioning. From the nature of the 46 consequences identified, the plant is likely to experience more of operability problems and less of deadly hazardous scenes. Suitable recommendations that will improve the operability and safety levels of the plant were however presented in the study and presented in tables. If the 61 recommendations given in this study can be incorporated into the design with the few safeguards already present in the original design of the plant, the operability problems of the plant will be greatly minimized and safety level will improve drastically.

Keywords

Hazard, Operability, HAZOP, Guide Word, Nodes, Refinery

1. Introduction

Building and operating a chemical plant without accident-preventive measures can cause an unquantifiable magnitude of hazards. Over the years, a good number of hazards have been recorded in the chemical industry around the world.
and most of the recorded accidents were largely due to human error. The 1974 Flixborough disaster that was initiated by a reactor leak killed 28 persons, injured other 36 and destroyed properties [2]. The 1976 Seveso disaster led to the pollution of a vast area of land and water bodies. Thousands of people were killed and properties worth billions of dollars destroyed in the 1984 Bhopal disaster which was a direct consequence of human error [3]. Facilities worth billions of dollars were also destroyed in the 2005 Buncefield disaster while the 2010 BPL refinery disaster caused much pollution to water bodies [4]. The accidents that have occurred in the process industry have prompted owners and operators of modern day’s chemical plants to incorporate safety measures to prevent accidents. The major industrial accidents recorded between 1956 and 1998 showed a decline in accidents in the chemical and process industries. This decline is traceable to the recent attention given to the study of accident forecasting and loss prevention in the chemical and process industries [5] [6]. Preventive-mechanism entails recognizing possible hazardous scenes within the plant which may vary in size and which may be noticeable or not noticeable [7]. Accident in the chemical and process industries can arise from the process itself, properties of the chemicals and their handling such as fire, explosion and exposure to toxic substances. For example, over temperature can lead to over pressure which can cause fire, explosion or toxic release that can cause accident. The predictions and prevention of accidents can be done by recognizing the hazards and the corresponding actions to be taken [8]. The use of certain process schemes or materials in production in order to maximize profit may result in operability problems and increase accident risks in the plant. For example, steam stripping is very effective in the vapourisation of more products in refineries [9] but due to cost of steam, some refiners have employed the use of water steam which is less expensive [10] [11] but with its associated hazards and operational problems.

Over the years, experts in process plant safety have developed risk-assessment procedures to enhance safety levels of process plants. Some of the many risk-assessment procedures developed so far include the Preliminary Hazard Assessment (PHA), the Fault Tree Analysis (FTA), the Energy Tree and Barrier Analysis (ETBA), the Failure Mode and Effects Analysis (FMEA) as well as the Hazard and Operability (HAZOP) [12]. Each of these mechanisms has strengths and weaknesses and is specialized in handling a particular type of risk. Although HAZOP is time-consuming as it requires a considerable amount of time of preparation, it gives a proper, organized and critical examination of the process of new or existing facilities to evaluate the potential for equipment malfunctioning in terms of the resultant impacts [13]. HAZOP performs a structural investigation of each unit in a process to depict what kind of deviation from the ideal operation can occur and what harm may be caused by such deviation. It is adopted in HAZOP study that a system is safe when key operability parameters such as temperature, pressure, flow or levels are in their normal conditions. Operability problems if not identified in HAZOP can result in production losses
due to inferior product quality or process inefficiency. This means properly conducted HAZOP can help not just in plant and personnel safety but also prevents loss of continuity or loss of the product specification [14]. Initial HAZOP study helps identify suitable protection on measures that may be implemented to avoid impending accidents [5] [15]. HAZOP involves a study on how a plant might deviate from the intents while taking notes of the resulting appropriate solutions to these deviations. Since it is a group study, it creates a brainstorming environment that brings creativity and generates ideas. In HAZOP, a flow sheet on piping and instrumentation diagram (PID) for the plant is obtained. Each node on the PID is numbered where a series of disturbances are proposed. For each disturbance, potential causes and consequences are described and noted. Guide words are used to ensure that the design is explored in every conceivable way. It is paramount that a HAZOP team focuses only on consequences with serious effects since numerous consequences can be obtained. In this paper, the concept of HAZOP was applied to study the safety level of a crude distillation unit of a petroleum refinery.

2. Description of the Facility

Figure 1 shows the P & ID of the desalter while Figure 2 shows the P & ID of the preflash column of the refinery under study. The main units in the plant considered in this work are the desalter, the preflash furnace that uses fuel gas and fuel oil with medium steam and the preflash column as well as its associated pumps, controls and piping.

Crude from storage tank is pumped at 30°C and 30 kg/sqcm through a valve into the first preheat train where its temperature is raised to about 125°C and pressure reduced to 11 kg/sqcm. Water is injected into the crude both at upstream and downstream of the first preheating train to dissolve salts contained in the crude. Water injection upstream of preheating is manually controlled at

Figure 1. P & ID of the Desalter and its associated pipe work.
1% - 1.5% volume of feed while downstream injection is controlled by a valve and kept at 3.5% - 4% volume of feed. If the desalter water is acidic, it enhances corrosion hence a 0.06% of NaOH is injected into the desalter water to keep its pH at 7.5 - 8.0. Demulsifier chemicals are injected at 3 - 5 ppm of feed upstream of preheating to break oil/water emulsion and promote oil/water separation in the desalter.

Due to low velocity and long residence time, water can settle in the bottom of the desalter. Electrodes and electric grid are installed to generate an electric field in which water droplets too small to settle can electrically attract each other, coalesce in bigger drops and separate. Oil/water separation is also helped by demulsifier injection and significantly basic pH (caustic injection).

Downstream the first preheating train, crude flows through the mixing valve where mixing is promoted due to the pressure drop in the valve. Then the crude and water mixture enters the desalter and the salty water from the desalter bottom goes to waste water treatment unit while the desalted crude enters the second preheat before it proceeds to the preflash heater to raise its temperature up to the temperature required in the preflash column. The preflash heater uses fuel gas and fuel oil while atomizing steam is used to break up the fuel oil. The crude enters the preflash column and light fractions like LPG and light naphtha vaporized and are separated as overhead products, water and some hydrocarbons are withdrawn as side cuts while the crude heavier fractions remain in the bottom. Liquid fraction mainly heavy naphtha is also withdrawn as side cut and sent into the atmospheric column and the bottom sent to the atmospheric heater to raise its temperature to 350°C before it enters the atmospheric column flash zone.

3. Methodology

Selected lines and plant units in the P & ID in Figure 1 and Figure 2 were ex-
amined one after the other. For clarity, not all lines and units were considered in
the study but only units like the desalter, the furnace and the preflash column as
well as their associated pipe work that pose significant risks. Fouling and corro-
sion of equipment, increasing electrical conductivity of the crude oil, material
losses, reduction in the efficiency of furnace and chocking of furnace tubes and
flow lines are some of the major consequences that can arise from the malfunc-
tioning of these selected units which can pose severe operability problems. Guide
words were applied to each study node. In each node, a process parameter was
identified and an intention was created for the node. For example, if the process
parameter being considered was temperature, the first guide word like “low” was
applied and a meaningful deviation like “low temperature” was developed. All
the possible causes of low temperature as well as the likely consequences were
determined. The study also identified existing operational safeguards but when a
consequence is likely to pose a hazardous situation, recommendations were giv-
en for possible changes to be made to the system to eliminate or minimize h a-
zard. The same process was carried out repeatedly for all the guide words on the
same node. The next node was selected and the same activity was repeated on it.

3.1. Guide Words

The guide words used in the HAZOP study were as follows:

- FLOW—high, low, no, reverse;
- LEVEL—high, low;
- PRESSURE—high, low;
- TEMPERATURE—high, low;
- CONTAMINANT.

3.2. HAZOP Study of the Desalter

The P & ID of the desalter in Figure 1 was used to perform the HAZOP study
and the details are presented in Table 1 and Table 2 as follows.

3.3. HAZOP Study of the Preflash Column

The P & ID of the preflash column of the crude distillation unit in Figure 2 was
used to perform the HAZOP study and the details are presented in Table 3 and
Table 4 as follows:

4. Results and Discussions

The main equipment of the crude distillation unit of the refinery considered in
this work was the desalter, the preflash furnace, the preflash column and their
associated pipe works and equipment like pumps. Using the method of HAZOP
to evaluate the operability and safety level of the unit, 4 study nodes were identi-
fied. In the study of possible deviations that can occur in the nodes, 25 guide
words were suitably applied on the nodes and 89 causes were identified. Most of
the causes were due to equipment malfunctioning and a few may be classified as
### Table 1. HAZOP minute sheet for the Crude Feed line and associated pipe work (Node 1).

| Guide Word | Cause | Consequence | Safeguards | Recommendation |
|------------|-------|-------------|------------|----------------|
| 1. High Flow | 1. Crude feed pump 10-P-01AB increased pumping capacity | 1. High ratio of crude to water mixture causing low dissolution of salt from crude oil | 1. Frequently check and maintain feed pump | 1. Frequent check and maintain feed flow controller |
| | 2. Low level alarm 10-LPA-15 faulty | | 2. Check and maintain feed flow controller | |
| | 3. Crude feed flow regulator 10-FR-B1 faulty | | 3. Frequent check and maintain water pump | |
| | 4. Valve V1 fully opened | | 4. Frequent checking of all flow valves and flow lines | |
| | 5. Water pump 10-P-12AB increased pumping capacity | | | |
| | 6. Valve V2 fully opened | | | |
| | 7. Valve V3 fully opened | | | |
| | 8. Flow controller 10-FRC-11 faulty | | | |
| 2. Low Flow | 1. Crude feed pump 10-P-01AB fails | 1. Low crude in oil-water mixture increasing conductivity and consequent tripping off of desalter transformer | 1. Install spare crude feed pump to auto start when feed pump fails | |
| | 2. Low level alarm 10-LPA-15 faulty | 1. Low level alarm comes up | 2. Inspect and maintain crude feed flow controller | |
| | 3. Crude feed flow controller 10-FR-B1 faulty | | 3. Inspect and maintain feed flow lines and valves | |
| | 4. Valve V1 partially blocked | | 4. Frequent cleaning of heat exchangers tubes | |
| | 5. Heat exchanger 10-E-01 tubes partially blocked | | 5. Install a spare water pump to auto start when pump 10-P-12AB fails | |
| | 6. Water pump 10-P-12AB fails | | 6. Check and maintain water flow controller and valves | |
| | 7. Valve V2 partially blocked | | | |
| | 8. Valve V3 partially blocked | | | |
| | 9. Flow controller 10-FRC-11 faulty | | | |
| 3. No Flow | 1. Feed pump 10-P-01AB faulty | 1. Desalter volume falls and crude oil loss in effluent water | 1. Regular checking and maintenance of feed flow lines and valves | |
| | 2. Valve V1 fully closed | 1. Low level alarm comes up | 2. Install a spare pump to auto start when pump 10-P-12AB fails | |
| | 3. Heat exchanger 10-E-01 tubes fully blocked | | | |

### Table 2. HAZOP Minute sheet for the Desalter and associated pipe work (Node 2).

| Guide Word | Cause | Consequence | Safeguards | Recommendation |
|------------|-------|-------------|------------|----------------|
| 1. High Pressure | 1. Automatic pressure controllers 10-FRC-1 failed | 1. Poor salt dissolution from the crude transformer | 1. Pressure safety valve will pop open and transformer will trip | 1. Frequently check and maintain pressure controller |
| | 2. Discharge line L1 partially blocked causing low discharge rate | 2. Formation of more stable oil-water emulsion difficult to separate | | |
| | 3. Low discharge rate of pump 10-P-25AB | | | |
| 2. Low Pressure | 1. Automatic pressure controller 10-PRC-1 failed | 1. Vapourisation of light ends from desalter | 1. Frequently check and maintain pressure controller | |
| | | 2. Transformer trips off | 2. Install low pressure alarm | |
| 3. High Temperature | 1. High crude residence time in heat exchangers | 1. Loss of light ends from crude | 3. Frequently check and maintain flow lines and pumps | 1. Frequently check and maintain pressure controller |
| 4. Low Temperature | 1. Fouling of heat exchangers | 1. Poor settling and oil loss in the effluent water | 1. Install temperature regulator | |
| | 2. Preheat train network failed | | 2. Install High temperature alarm | |
| 5. High Level | 1. Level controller 10-DLRC-3 faulty | 1. Carryover of interface with oil into tower causing fouling and corrosion of downstream equipment | 1. Install high level alarm | |
| | 2. Discharge pump 10-P-25AB failed | 2. Level rises to electrode causing dissolution of downstream equipment | 2. Frequently check and maintain pumps and valves | |
| | 3. Waste water valve V5 blocked | | | |
| 6. Low Level | 1. Level controller 10-DLRC-3 faulty | 1. Carryover of crude with effluent water | 1. Install low level alarm | |
| | 2. Mixer valve V4 partly blocked | 2. Check mixer valve | 2. Check mixer valve | |
Table 3. HAZOP Minute sheet for the Preflash furnace (Node 3).

| Guide Word          | Cause                                                                 | Consequence                                             | Safeguards                                                                 | Recommendation                                                                 |
|---------------------|-----------------------------------------------------------------------|----------------------------------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| 1. High Flow of feed| 1. Increased pumping capacity of feed pump 10-P-25AB                  | 1. High level in preflash column causing column offset   | 1. High flow alarm should be installed                                    | 2. Frequent checking and maintenance of flow controllers and valves            |
|                     | 2. Crude feed line valve PV1 fully open                               | 2. Low temperature of preflash column feed               |                                                                           |                                                                                |
|                     | 3. Crude feed flow controller 10-FRC-1051 faulty                       |                                                                                                         |                                                                           |                                                                                |
| 2. Low Flow of feed | 1. Low head of crude feed pump 10-P-25AB                              | 1. Low level in preflash column                         | 1. Low flow alarm installation suggested                                   |                                                                                |
|                     | 2. Feed valve PV1 partly blocked                                       | 2. Pump cavitations and leaks                           | 2. Check and clean furnace tubes when choked with coke                     |                                                                                |
|                     | 3. Feed flow controller 10-FRC-1051 failed                            |                                                                                                         | 3. Regular checking and maintenance of flow controller and valves          |                                                                                |
|                     | 4. Fouling of preflash furnace tubes                                   |                                                                                                         | 4. Clean heat exchangers tubes when blocked                               |                                                                                |
|                     | 5. Ruptured heater tubes                                               |                                                                                                         |                                                                           |                                                                                |
| 3. No Flow of feed  | 1. Pump 10-P-25AB fails                                               | 1. Furnace pipe will be choked with coke                 | 1. Install spare feed pump to auto start if pump 10-P-25AB fails            |                                                                                |
|                     | 2. Feed valve PV1 fully blocked                                        | 2. Low level in preflash column causing pump cavitations and leaks                                   | 2. Check and maintain flow controller and valves                           |                                                                                |
|                     | 3. Feed flow controller 10-FRC-1051 faulty                             |                                                                                                         | 3. Regularly check and clean furnace tubes when dirty                      |                                                                                |
|                     | 4. Fouling of preflash furnace tubes                                   |                                                                                                         |                                                                           |                                                                                |
|                     | 5. Ruptured heater tubes                                               |                                                                                                         |                                                                           |                                                                                |
| 4. High Flow of fuel| 1. Temperature controller 10-TRC-1137 faulty                           | 1. Coking in furnace tubes                               | 1. Regular inspection of fuel valve and circulation system                 |                                                                                |
|                     | 2. Fuel oil flow controller FR-1146 faulty                             | 2. Fouling of furnace tubes                              | 2. Check temperature controller regularly                                  |                                                                                |
|                     | 3. Fuel gas flow controller FR-1149 faulty                             |                                                                                                         |                                                                           |                                                                                |
|                     | 4. Fuel oil valve PV3 fully open                                       |                                                                                                         |                                                                           |                                                                                |
|                     | 5. Fuel gas valve PV4 fully open                                       |                                                                                                         |                                                                           |                                                                                |
| 5. Low flow of fuel | 1. Temperature controller 10-TRC-1137 faulty                           | 1. Low coil outlet temperature                          | 1. Frequent inspection of fuel valves                                      |                                                                                |
|                     | 2. Fuel oil flow controller FR-1146 faulty                             |                                                                                                         | 2. Check and maintain temperature controller                               |                                                                                |
|                     | 3. Fuel gas flow controller FR-1149 faulty                             |                                                                                                         |                                                                           |                                                                                |
|                     | 4. Fuel oil valve PV3 partially blocked                                |                                                                                                         |                                                                           |                                                                                |
|                     | 5. Fuel gas valve PV4 partially blocked                                |                                                                                                         |                                                                           |                                                                                |
| 6. Low Flow of atomizing steam | 1. Steam control valve PV2 faulty                                      | 1. Incomplete combustion                                 | 1. Install steam-air ratio with low steam rate alarm                       |                                                                                |
|                     | 2. Smoke generation                                                   |                                                                                                         |                                                                           |                                                                                |
| 7. As well as High | 1. High draught                                                       | 1. Increased stack loss                                 | 1. Install air-fuel ratio controller                                       |                                                                                |
| Flow of primary air |                                                                       | 2. Reduced furnace efficiency                           |                                                                           |                                                                                |
| 8. As well as Low | 1. Low draught                                                        | 1. Incomplete combustion                                 | 1. Install air-fuel ratio controller                                       |                                                                                |
| Flow of primary air |                                                                       | 2. Loss of fuel                                         |                                                                           |                                                                                |
| 9. High Temperature| 1. Furnace temperature controller 10-TRC-1137 faulty                   | 1. Cracking of crude feed                               | 1. Regular checking and maintenance of heater temperature controller       |                                                                                |
|                     | 2. Fuel oil flow controller FR-1146 faulty                             | 2. High crude temperature may cause pressure build up and rupture furnace tubes | 2. Install high temperature alarm                                         |                                                                                |
|                     | 3. Fuel gas flow controller FR-1149 faulty                             |                                                                                                         | 3. Frequent checking of heater fuel valves                                 |                                                                                |
|                     | 4. Fuel oil valve PV3 fully open                                       |                                                                                                         |                                                                           |                                                                                |
|                     | 5. Fuel gas valve PV4 fully open                                       |                                                                                                         |                                                                           |                                                                                |
| 10. Low Temperature| 1. Temperature controller 10-TRC-1137 faulty                           | 1. Low coil outlet temperature into preflash column     | 1. Regular check and maintain temperature controllers                       |                                                                                |
|                     | 2. Fuel oil flow controller FR-1146 faulty                             |                                                                                                         | 2. Check fuel flow valves frequently.                                      |                                                                                |
|                     | 3. Fuel gas flow controller FR-1149 faulty                             |                                                                                                         | 3. Inspect crude preheat train regularly                                   |                                                                                |
|                     | 4. Fuel oil valve PV3 partially blocked                                |                                                                                                         |                                                                           |                                                                                |
|                     | 5. Fuel gas valve PV4 partially blocked                                |                                                                                                         |                                                                           |                                                                                |
|                     | 6. Fouling in heater tubes                                             |                                                                                                         |                                                                           |                                                                                |
| 11. High Pressure   | 1. High temperature in furnace causing release of light ends           | 1. Expansion of hot oil and consequent rupture of furnace tubes | 1. Install pressure controller                                             |                                                                                |
|                     |                                                                       |                                                                                                         | 2. Install high pressure alarm                                             |                                                                                |
Table 4. HAZOP Minute sheet for the Preflash column (Node 4)

| Guide Word | Cause | Consequence | Safeguards | Recommendation |
|------------|-------|-------------|------------|----------------|
| 1. High Pressure | 1. Top temperature controller 10-TRC-1175 fails and top temperature rises | 1. Reduces vapourisation of light ends | 1. Install pressure controller | |
| | 2. Flow regulator 10-FRC-1181 controlling reflux valve PV5 fails | 2. Increase atmospheric furnace load | 2. Pressure indicator should be installed | |
| | 3. Reflux valve PV5 closed | 3. Entrained water from desalter still passes on to atmospheric heater which may expand and rupture heater tubes | 3. High pressure alarm should be installed | |
| 2. Low Pressure | 1. Fall in preflash top temperature as temperature controller 10-TRC-1175 failed | 1. Foaming in column, Producing black distillates as well as yield loss in atmospheric column | 1. Install pressure controller | |
| | 2. Reflux valve PV5 fully opened | 2. Flooding of column | 2. Pressure indicator should be installed | |
| | 3. Flow regulator 10-FRC-1181 fully opened | | 3. Low pressure alarm should be installed | |
| 3. Low Temperature | 1. Top temperature controller 10-TRC-1175 fails | 1. Reduces vapourisation of light ends hydrocarbons increasing atmospheric column vapour load | 1. Maintain the column temperature controllers | |
| | 2. Reflux flow control valve PV5 fully opened | 2. The high temperature in the atmospheric furnace causes the light ends and water still present in the crude to expand in the furnace tubes and rupture occurs | 2. Regular checking and maintenance of reflux flow lines and valves | |
| | 4. Feed temperature controller 10-TRC-1137 faulty | | 3. Maintain heat exchanger tubes frequently | |
| | 5. Column middle temperature controller 10-TRC-1180 faulty | | | |
| 4. Low Level | 1. Level controller 10-LRC-1188 failed | 1. Low vapourisation of light ends hydrocarbon increasing vapour loads of the atmospheric column | 1. Check level controller | |
| | 2. Discharge pump 10-P-02AB pumping capacity increased | | 2. Maintain pumps | |
| | 3. Preflash furnace feed flow controller 10-FRC-1051 faulty | 2. Cavitations of pumps | 3. Check and maintain feed flow controllers, feed lines and valves | |
| | 4. Preflash furnace feed flow valve PV1 partly closed | 3. Off spec distillates | | |
| 5. High Level | 1. Level controller 10-LRC-1188 failed | 1. Entering feed throws liquid up the column and damage wash trays Emergency valve 10-HS-1190 will open | 1. Regular checking and maintenance of level controllers | |
| | 2. Low head of discharge pump 10-P-02AB | | 2. Maintain pumps | |
| | 3. Preflash feed flow controller 10-FRC-1051 faulty. | | 3. Check and maintain feed flow controllers, feed lines and valves | |
| | 4. Preflash feed flow valve PV1 fully opened | | | |

Human error. These causes gave rise to 46 consequences. All the consequences can only pose operability problems that may lead to shut down but none of the consequences can really be termed as very hazardous and life-threatening. The plant can, therefore, be said to have a high safety level. This may be due to the existing safeguards designed into the plant. 61 recommendations were given in the study to further improve the operability and safety level of the plant.

5. Conclusion

Based on the nature of recommendations given in the HAZOP study, in order to prevent operability problems and hazardous conditions in the plant, there should be regular inspection; regular maintenance of flow lines and equipment and possibly replace faulty equipment. It is highly recommended that more safeguards be incorporated into the design to further improve the safety level of the plant. However, it is highly recommended that a thorough HAZOP study should preferably be carried out during the design phase of a plant so as to have much influence on the design.
Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Goharrokhi, M. (2005) Hazard Identification by HAZOP method and Qualitative Risk Analysis in Process Industries. Daneshgaran Sanat Pajouh, Tehran, 67-72.

[2] Lees, F.P. (2005) Lee’s Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control. 3rd Edition, Elsevier, Oxford, UK.

[3] Abbasi, T. and Abbasi, S.A. (2005) The Expertise and the Practice of Loss Prevention in the Indian Process Industry. *Process Safety and Environmental Protection*, **83**, 413-420. https://doi.org/10.1016/j.psep.2004.12.005

[4] Abbasi, T., Pomapathi, V., Tauseef, S.M. and Abbasi, S.A. (2017) An Assessment of the Prevailing Codes/Standards and Models for Determining Safe Spacing between Two or More Hazardous Storage Tanks. *International Journal of Engineering, Science and Mathematics*, **6**, 255-268.

[5] Khan, F. and Abbasi, S. (1997) Mathematical Model for HAZOP Study Time Estimation. *Journal of Loss Prevention in Process Industries*, **10**, 249-251. https://doi.org/10.1016/S0950-4230(97)00010-7

[6] Rigas, F. and Amyotte, P.R. (2013) Myths and Facts about Hydrogen Hazards. *Chemical Engineering Transactions*, **31**, 913-918.

[7] Gholami, M. and Aryani, G. (2008) Safety Management and Hazards Identification methods and Consequences Analysis in the Oil, Gas and Petrochemical Industries. Oil National Company of Petrochemical Industries, First Congress of Safety Health, Bander Abbas, 28-35.

[8] Sedegheh, A., Shakiba, B., Mansour, Z. and Shirazeh, A. (2015) Comparison of Risk Assessment Using HAZOP and ETBA Techniques: Case Study of a Gasoline Refinery Unit in Iran. *Journal of Human, Environment and Health Promotion*, **1**, 19-27.

[9] Mamdouh, G., Dina, K., Fatima, A. and Hemdan, N.E. (2013) A New Optimization Based Retrofit Approach for Revamping an Egyptian Crude Distillation Unit. *Energy Procedia*, **36**, 454-464. https://doi.org/10.1016/j.egypro.2013.07.051

[10] Li, X.G., Lin, C.W., Wang, L. and Li, H. (2013) Exergy Analysis of Multi-Stage Crude Distillation Units. *Frontiers of Chemical Science and Engineering*, **7**, 437-446. https://doi.org/10.1007/s11705-013-1349-y

[11] Samborskaya, M.A., Gusev, V.P., Gryaznova, J.A., Vdovushkina, N.S. and Volf, A.V. (2014) Crude Oil with Superheated Water Steam: Parametrical Sensitivity and Optimization. *Procedia Chemistry*, **10**, 337-342. https://doi.org/10.1016/j.proche.2014.10.057

[12] Mohammadfam, I. and Kianfar, A. (2010) Application of Hazard and Operability Study (HAZOP) in Evaluation of Health, Safety and Environment (HSE) Hazards (Case Study: Oil Storage of National Iranian Oil Products Distribution Company). *Journal of Environmental Science and Technology*, **12**, 39-49.

[13] Dunjo, J., Fthenakis, R., Dabra, R., Vichez, J. and Arnaldos, J. (2011) Conducting HAZOPs in Continuous Chemical Processes: Part I. Criterial, Tools and Guidelines for Selecting Nodes. *Process Safety and Environmental Protection*, **89**, 224-233. https://doi.org/10.1016/j.psep.2011.03.002

[14] Sikandar, S., Ishtiaque, S. and Soomro, N. (2016) Hazard and Operability (HAZOP)
Study of Waste Water Treatment Unit Producing Biohydrogen. *Sidh University Research Journal (Science Series)*, *48*, 131-136.

[15] Ashok, S. and Prakas, J. (2014) HAZOP Study of Sewage Treatment Plant at Educational Institution. *International Journal Research of Engineering Technology*, *3*, 2319-2321.
### Nomenclature

| Code     | Description                                           |
|----------|-------------------------------------------------------|
| 10-C-07  | Preflash column                                       |
| 10-D-01  | Desalter                                              |
| 10-dLRC-3| Desalter level controller                              |
| 10-E-01  | Heat exchanger 01                                     |
| 10-FR-B1 | Flow regulator in crude feed line to desalter        |
| 10-FRC-1051| Flow regulator controlling preflash furnace crude feed |
| 10-FRC-1075| Flow regulating flow of preflash column bottom steam  |
| 10-FRC-11 | Desalter water flow controller regulator              |
| 10-FRC-1181| Preflash column reflux flow controller                |
| 10-H-02  | Preflash furnace                                      |
| 10-IFS-1051| Flow controller to shut down                          |
| 10-LPA-15| Low pressure alarm in crude feed line to desalter    |
| 10-LRC-1188| Level regulator in preflash column                   |
| 10-P-01AB| Crude storage pump                                    |
| 10-P-02AB| Discharge pump from preflash bottom                   |
| 10-P-12AB| Pump supplying desalter water                         |
| 10-P-25AB| Desalted crude discharge pump                         |
| 10-P-26AB| Preflash column pumparound pump                       |
| 10-PRC-1 | Desalter pressure controller                          |
| 10-PRC-IV| Pressure controller in crude feed line to desalter    |
| 10-TRC-1137| Preflash coil out temperature regulator               |
| 10-TRC-1175| Preflash column top temperature controller            |
| FR-1146  | Preflash furnace fuel oil flow regulator              |
| FR-1149  | Preflash furnace fuel gas flow regulator              |
| L1       | Desalted crude flow line from desalter                |
| MPA      | Middle pumparound                                      |
| PH1      | First preheat train                                    |
| PH2      | Second preheat train                                   |
| PV10     | Emergency valve in preflash bottom                    |
| PV2      | Control valve in preflash furnace medium steam supply line |
| PV3      | Control valve in preflash furnace fuel oil supply line |
| PV4      | Control valve in preflash furnace fuel gas supply line |
| PV5      | Preflash column reflux control valve                  |
| PV7      | Control valve regulating flow from preflash pump around |
| PV8      | Control valve regulating temperature in preflash pump around |
| PVI      | Control valve in preflash furnace crude feed line     |
| SS       | Stripping steam                                        |
| SW       | Sore water                                             |
| V1       | Control valve in crude feed line to desalter          |
| V2       | Flow valve in upstream desalter water feed line       |
| V3       | Control valve regulating downstream desalter water    |
| V4       | Desalter mix valve                                     |
| V5       | Valve in sore water flow line                         |