Journal of Materials Science and Chemical Engineering, 2019, 7, 31-41
https://www.scirp.org/journal/msce
ISSN Online: 2327-6053
ISSN Print: 2327-6045

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

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How to cite this paper: Orugba, H.O., Ogbeide, S.E. and Osagie, C. (2019) Risk level Assessment of the Desalter and Preflash Column of a Nigerian Crude Distillation Unit. *Journal of Materials Science and Chemical Engineering*, 7, 31-41.
https://doi.org/10.4236/msce.2019.711004

Received: October 15, 2019
Accepted: November 25, 2019
Published: November 28, 2019

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 [1] 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

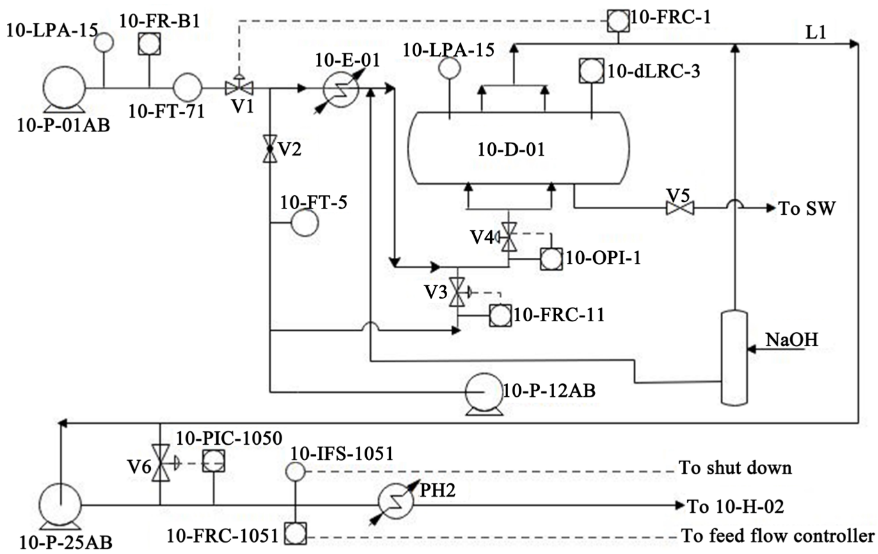

Figure 1. P & ID of the Desalter and its associated pipe work.

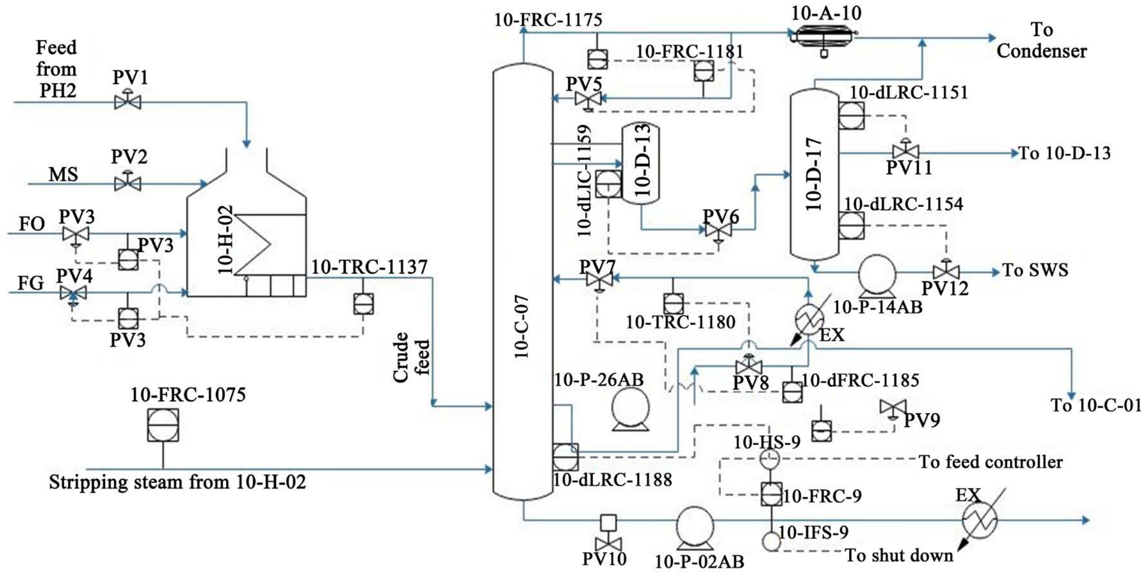

Figure 2. P & ID of the Preflash distillation column and its associated pipe work.

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 vapourized 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 examined 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 corrosion 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 malfunctioning 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 given for possible changes to be made to the system to eliminate or minimize hazard. 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 identified. 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).

Refining and Petrochemical Company			HAZOP Minute Sheet	
Project: Crude Distillation Unit			Node: 1	Draw No:1
Node Description: Crude Feed Line and Associated Pipe Work				
Guide Word	Cause	Consequence	Safeguards	Recommendation
1. High Flow	1. Crude feed pump 10-P-01AB increased pumping capacity 2. Low level alarm 10-LPA-15 faulty 3. Crude feed flow regulator 10-FR-BI faulty 4. Valve V1 fully opened 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	1. High ratio of crude to water mixture causing low dissolution of salt from crude oil 2.Increased corrosion and fouling of downstream equipment 3. More water in oil-water mixture causing increased crude conductivity and trips off desalter transformer		1. Frequently check and maintain feed pump 2. Check and maintain feed flow controller 3. Frequent check and maintain water pump 4. Frequent checking of all flow valves and flow lines
2. Low Flow	1. Crude feed pump 10-P-01AB fails 2. Low level alarm 10-LPA-15 faulty 3. Crude feed flow controller 10-FR-BI faulty 4. Valve V1 partially blocked 5. Heat exchanger 10-E-01 tubes partially blocked 6. Water pump 10-P-12AB fails 7. Valve V2 partially blocked 8. Valve V3 partially blocked 9. Flow controller 10-FRC-11 faulty	1. Low crude in oil-water mixture increasing conductivity and consequent tripping off of desalter transformer 2. Less water in oil-water mixture causing poor salt dissolution 3. Fouling and corrosion of downstream equipment	1. Low level alarm comes up	1. Install spare crude feed pump to auto start when feed pump fails 2. Inspect and maintain crude feed flow controller 3. Inspect and maintain feed flow lines and valves 4. Frequent cleaning of heat exchangers tubes 5. Install a spare water pump to auto start when pump 10-P-12AB fails 6. Check and maintain water flow controller and valves
3. No Flow	1. Feed pump 10-P-01AB faulty 2. Valve V1 fully closed 3. Heat exchanger 10-E-01 tubes fully blocked	1. Desalter volume falls and crude oil loss in effluent water	1. Low level alarm comes up	1. Regular checking and maintenance of feed flow lines and valves 2. Install a spare pump to auto start when pump 10-P-12AB fails

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

Refining and Petrochemical Company			HAZOP Minute Sheet	
Project: Crude Distillation Unit			Node: 2	Draw No:1
Node Description: Desalter and Associated Pipe Work				
Guide Word	Cause	Consequence	Safeguards	Recommendation
1. High Pressure	1. Automatic pressure controllers 10-PRC-1 failed 2. Discharge line L1 partially blocked causing low discharge rate 3. Low discharge rate of pump 10-P-25AB	1. Poor salt dissolution from the crude 2. Formation of more stable oil-water emulsion difficult to separate	1. Pressure safety valve will pop open and transformer will trip	1. Frequently check and maintain pressure controller 2. Install low pressure alarm 3. Frequently check and maintain flow lines and pumps
2. Low Pressure	1. Automatic pressure controller 10-PRC-1 failed	1. Vapourisation of light ends from desalter 2. Transformer trips off		1. Frequently check and maintain pressure controller
3. High Temperature	1. High crude residence time in heat exchangers	1. Loss of light ends from crude		1. Install temperature regulator 2. Install High temperature alarm
4. Low Temperature	1. Fouling of heat exchangers 2. Preheat train network failed	1. Poor settling and oil loss in the effluent water		1. Install temperature regulator 2. Install Low temperature alarm
5. High Level	1. Level controller 10-dLRC-3 faulty 2. Discharge pump 10-P-25AB failed 3. Waste water valve V5 blocked	1. Carryover of interface with oil into tower causing fouling and corrosion of downstream equipment 2. Level rises to electrode causing current flow and transformer trips		1. Install high level alarm 2. Frequently check and maintain pumps and valves
6. Low Level	1. Level controller 10-DLRC-3 faulty 2. Mixer valve V4 partly blocked	1. Carryover of crude with effluent water		1. Install low level alarm 2. Check mixer valve

Table 3. HAZOP Minute sheet for the Preflash furnace (Node 3).

Refining and Petrochemical Company			HAZOP Minute Sheet	
Project: Crude Distillation Unit			Node: 3	Draw No:2
Node Description: Preflash Furnace (10-H-02)				
Guide Word	Cause	Consequence	Safeguards	Recommendation
1. High Flow of feed	1. Increased pumping capacity of feed pump10-P-25AB 2. Crude feed line valve PV1 fully opene 3. Crude feed flow controller 10-FRC-1051 faulty	1. High level in preflash column causing column offset 2. Low temperature of preflash column feed		1. High flow alarm should be installed 2. Frequent checking and maintenance of flow controllers and valves
2. Low Flow of feed	1. Low head of crude feed pump 10-P-25AB 2. Feed valve PV1 partly blocked 3. Feed flow controller 10-FRC-1051 failed 4. Fouling of preflash furnace tubes 5. Ruptured heater tubes	1. Low level in preflash column 2. Pump cavitations and leaks		1. Low flow alarm installation suggested 2. Check and clean furnace tubes when choked with coke 3. Regular checking and maintenance of flow controller and valves 4. Clean heat exchangers tubes when blocked
3. No Flow of feed	1. Pump 10-P-25AB fails 2. Feed valve PV1 fully blocked 3. Feed flow controller 10-FRC-1051 faulty 4. Fouling of preflash furnace tubes 5. Ruptured heater tubes	1. Furnace pipe will be chocked with coke 2. Low level in preflash column causing pump cavitations and leaks		1. Install spare feed pump to auto start if pump 10-P-25AB fails 2. Check and maintain flow controller and valves regularly 3. Inspect heat exchangers and flow lines and clean them when dirty
4. High Flow of fuel	1. Temperature controller 10-TRC-1137 faulty 2. Fuel oil flow controller FR-1146 faulty 3. Fuel gas flow controller FR-1149 faulty 4. Fuel oil valve PV3 fully opened 5. Fuel gas valve PV4 fully opened	1. Coking in furnace tubes 2. Fouling of furnace tubes		1. Regular inspection of fuel valve and circulation system 2. Check temperature controller regularly
5. Low flow of fuel	1. Temperature controller 10-TRC-1137 faulty 2. Fuel oil flow controller FR-1146 faulty 3. Fuel gas flow controller FR-1149 faulty 4. Fuel oil valve PV3 partially blocked 5. Fuel gas valve PV4 partially blocked	1. Low coil outlet temperature		1. Frequent inspection of fuel valves 2. Check and maintain temperature controller
6. Low Flow of atomizing steam	1. Steam control valve PV2 faulty	1. Incomplete combustion 2. Smoke generation		1. Install steam-air ratio with low steam rate alarm
7. As well as High Flow of primary air	1. High draught	1. Increased stack loss 2. Reduced furnace efficiency		1. Install air-fuel ratio controller
8. As well as low Flow of primary air	1. Low draught	1. Incomplete combustion. 2. Loss of fuel		1. Install air-fuel ratio controller
9. High Temperature	1. Furnace temperature controller 10-TRC-1137 faulty 2. Fuel oil flow controller FR-1146 faulty 3. Fuel gas flow controller FR-1149 faulty 4. Fuel oil valve PV3 fully opened 5. Fuel gas valve PV4 fully opened	1. Cracking of crude feed 2. High crude temperature may cause pressure build up and rupture furnace tubes		1. Regular checking and maintenance of heater temperature controller 2. Install high temperature alarm 3. Frequent checking of heater fuel valves
10. Low Temperature	1. Temperature controller 10-TRC-1137 faulty 2. Fuel oil flow controller FR-1146 faulty 3. Fuel gas flow controller FR-1149 faulty 4. Fuel oil valve PV3 partially blocked 5. Fuel gas valve PV4 partially blocked 6. Fouling in heater tubes	1. Low coil outlet temperature into preflash column		1. Regular check and maintain temperature controllers 2. Check fuel flow valves frequently. 3. Inspect crude preheat train regularly
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)

Refining and Petrochemical Company			HAZOP Minute sheet	
Project: Crude Distillation Unit			Node: 4	Draw No:2
Node Description: Pre flash column (10-C-07)				
Guide Word	Cause	Consequence	Safeguards	Recommendation
1. High Pressure	1. Top temperature controller 10-TRC-1175 fails and top temperature rises 2. Flow regulator 10-FRC-1181 controlling reflux valve PV5 fails 3. Reflux valve PV5 closed	1. Reduces vapourisation of light ends 2. Increase atmospheric furnace load 3. Entrained water from desalter still passes on to atmospheric heater which may expand and rupture heater tubes		1. Install pressure controller 2. Pressure indicator should be installed 3. High pressure alarm should be installed
2. Low Pressure	1. Fall in preflash top temperature as temperature controller 10-TRC-1175 failed 2. Reflux valve PV5 fully opened 3. Flow regulator 10-FRC-1181 failed	1. Foaming in column, Producing black distillates as well as yield loss in atmospheric column 2. Flooding of column		1. Install pressure controller 2. Pressure indicator should be installed 3. Low pressure alarm should be installed
3. Low Temperature	1. Top temperature controller 10-TRC-1175 fails 2. Reflux flow controller 10-FRC-1181 faulty 3. Reflux flow control valve PV5 fully opened 4. Feed temperature controller 10-TRC-1137 faulty 5. Column middle temperature controller 10-TRC-1180 faulty	1. Reduces vapourisation of light ends hydrocarbons increasing atmospheric column vapour load 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		1. Maintain the column temperature controllers 2. Regular checking and maintenance of reflux flow lines and valves 3. Maintain heat exchanger tubes frequently
4. Low Level	1. Level controller 10-LRC-1188 failed 2. Discharge pump 10-P-02AB pumping capacity increased 3. Preflash furnace feed flow controller 10-FRC-1051faulty 4. Preflash furnace feed flow valve PV1 partly closed	1. Low vapourisation of light ends hydrocarbon increasing vapour loads of the atmospheric column 2. Cavitations of pumps 3. Off spec distillates		1. Check level controller 2. Maintain pumps 3. Check and maintain feed flow controllers, feed lines and valves
5. High Level	1. Level controller 10-LRC-1188 failed 2. Low head of discharge pump 10-P-02AB 3. Preflash feed flow controller 10-FRC-1051faulty. 4. Preflash feed flow valve PV1 fully opened	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. Maintain pumps 3. Check and maintain feed flow controllers, feed lines and valves

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.

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Nomenclature

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 into preflash column
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