Risk assessment of the presence of various organic and inorganic compounds in oil flows in different units of refineries by methods of FMEA and PHA

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Abstract - In this new and applied study, it has been investigated the risks of presence of Nitrogenous organic compounds such as quinoline and indole and Naphthenic acids and various inorganic compounds (S, FeS, H_2S, water, inorganic salts, Sediment) in oil flows in different units of refineries. Hazards, their effects and related causes were identified. Control and preventive actions was suggested for decreasing risks. Results showed that with applying control and preventive actions, risk numbers decreased significantly for both FMEA and PHA methods. These showed that all control and preventive actions were fully effectiveness and appropriately.

Key words: FMEA, PHA, Risk assessment, Refinery, organic, inorganic components.

1. Introduction

There is often a negative attitude among the population in the society about the risk concept. They have considered it as a sign of a damage، danger and negative effects as well as fail probability toward achieving the predefined goals of the considered project [1]. While Britain Standards Institute, knows risk as combination of occurrence and results of a hazardous event [2].

Risk assessment determines the qualitative analysis of risk potential regarding the sensitivity or vulnerability of the surrounding environment [3]. In general, there are currently more than 70 risk assessment methods in the world which are divided in to two qualitative and quantitative groups [4].

Quantitative assessment focuses on risk factors and preventive measures and is done to eliminate or prevent risks [5]. Failure modes and effects analysis (FMEA) is one of the modern methods of assessment and risk management in oil, gas and petrochemical industries [6].

The purpose of FMEA is to increase process reliability by preventing the system identified failures and reducing the adverse consequences thereof. FEMA requires detailed and detailed information about the system under investigation [7-9].

Tae-guKim Jeong (2002) [10] studied focuses on the current status of risk management activities conducted by the petrochemical plants in Korea, and on the trends in the global market.

M. Jabbari Gharabagh (2009) [11] studied comprehensive risk assessment and management of petrochemical feed and product transportation pipelines. In this research, using probabilistic and indexing models, an algorithm is developed, which overcomes most of the limitations of the models. , the results of the relative risk assessment indices were used as an adjusting factor to correct the pipeline failure rate and to develop an algorithm for the comprehensive risk assessment technique. Sensitivity analysis of the algorithm was carried out. The present algorithm enables the identification of most of the pipeline failure causes.

Rong-Hwa Huang (2012) [12] studied an assessment model that examines quantity and quality factors for equipment risk management in the petrochemical industry. The proposed model had five dimensions—financial performance, logistical support, service level, learning and innovation, and risk control. Proposed model provided a valuable reference for decision-making in equipment risk management.

XU Xiaonan (2012) [13] studied Leakage frequency of ethylene horizontal tanks and its attachments and may lead to risk accident were analyzed by SAFETI and leak quantitative risk analysis software of Norwegian DNV company. Through the simulation results of four accident Scene, which gas leakage of the tank, tank rupture, leakage in the pipe from the tank to the pump, leakage in the pump and its export pipe, evaluated the effect of leakage, radiation, explosion to the staff and installations in the factory so that Determined the risk of casualties and property loss in ethylene tank farm.

Wei Wu Guang (2013) [14] studied Risk analysis of corrosion failures of equipment in refining and petrochemical plants based on fuzzy set theory. In this model, two essential parts of failure risk (i.e., failure likelihood and severity of failure consequence) are first estimated by using fuzzy synthetic evaluation. The results show that this model is effective and feasible.

In this study, for the first time, it was studied risk assessment of presence of different mineral and organic compounds in oil streams in different units of refineries with FMEA and PHA methods.

2. Methodology

2.1. PHA Methodology

Risk assessment matrix in table 1 shows severity of dangers and probabilities of occurrence.

Table 1: Risk assessment Matrix in PHA method

Risk Assessment Matrix				
Partial (4)	Boundary (3)	Critical (2)	Disastrous (1)	Severity of danger / Probability of occurrence
4A	3A	2A	1A	Repeated (A)
4B	3B	2B	1B	Possible (B)
4C	3C	2C	1C	Occasional (C)
4D	3D	2D	1D	Very little (D)
4E	3E	2E	1E	Improbable (E)

Table 2 shows the risk criteria and risk classification. Every risk criteria relates to oneself risk classification.

Table 2: Risk criteria and its related classification in PHA method

Risk classification	Risk criteria
1A, 1B, 1C, 2A, 2B, 3A	unacceptable
1D, 2C, 2D, 3B, 3C	Undesirable
1E, 2E, 3D, 3E, 4A, 4B	Acceptable but with the need for revision
4C, 4D, 4E	Acceptable without revision

2.2. FMEA Methodology

Chemical Engineer of process design is the primary responsibility for risk assessment.

Next step is identifying the Potential Failure Modes that occurs in the defined operation.

The potential impacts are the consequence and consequence of Potential Failure Modes that occur on the next level operations.

Severity is intensifying of the rating that indicates how serious the damage caused on the product.

Potential Cause/ Mechanism of Failure: Identify process deficiencies and deficiencies that can cause failure.

Occurrence: The number of occurrences is the rank associated with the probability of a crash occurring.

Current Process Control: There are methods and techniques used to prevent failure (or causes of failure) or to identify failure (or causes) at the same production facility or subsequent stations (before leaving the product out of process).

Rank detection: The diagnosis is an estimate of the probability that current process controls can detect the state of failure or the cause of the failure before leaving the manufacturing process or assembly. In determining the rating, you must examine the ability of these controls to detect the state or cause of the crash.

Table 3 shows the frequency of occurrence of defects (O) that includes rating, percentage of occurrence and check the probability of a fault.

Table 3: Occurrence of defects (O)

The frequency of occurrence of defects (O)		
Check the probability of a fault	**Percentage of occurrence**	**RATING**
Very high; The occurrence of flaw is almost certain.	1 defect per 10 items 1 defect per 20 items	10 9
High; Defects usually happen.	1 defect per 100 items 1 defect per 200 items	8 7
Medium; Fatigue sometimes happens.	1 defect per 500 items 1 defect per 1000 items	6 5
Little; Flaw rarely happens.	1 defect per 2000 items 1defect per 5000 items	4 3
Unlikely	1 defect per 10000 items 1 defect per 20000 items	2 1

Table 4 shows detection scale (D) that includes rating, detection capability and fault detection review.

Table 4: Detection Scale (D)

(D) Detection scale		
Fault Detection Review	**Detection capability**	**RATING**
There is no control over the process, or existing controls cannot determine the cause of the fault mechanism.	Absolutely impossible	10
The likelihood that existing controls can detect the fault mechanism and the occurrence of a fault is unlikely.	Very unlikely	9
The likelihood that existing controls can detect the fault and failure mechanism is very rare.	Unlikely	8
The likelihood that existing controls can detect the fault and failure mechanism is very limited.	Very little	7
The probability that existing controls can detect the fault and defect mechanism is low.	little	6
The probability that existing controls can detect the fault and defect mechanism is moderate.	medium	5
The probability that existing controls can detect the fault and defect mechanism is moderate to high.	Moderate to high	4
The probability that existing controls can detect the fault and defect mechanism is high.	High	3
The probability that existing controls can detect the fault and defect mechanism is very high.	Very high	2
The existing process controls will almost completely detect the cause of the fault and fault mechanism.	Almost complete	1

RPN, Risk number is calculated by following formula:

$$RPN= S*O*D \tag{1}$$

Where: S is Severity, O is Occurrence, D is Detection and RPN is degree of risk.

3. Results and discussions

Table 5: PHA risk assessment

PHA						
Risk level after control actions	**Control and preventive actions**	**Risk level**	**Effects**	**Causes**	**Hazards**	**Row**
3E	**Sulfur pre-purification operations (desulphurization)**	**3D**	**Reducing the useful life of the unit reforming Catalyst**	**The presence of sulfur compounds in the flow of feed to the reforming unit**	**Creating poisoning in the Reforming unit Catalyst**	**1**
3E	**Sulfur removal from the final product with separation operation**	**3D**	**Decrease the quality of final products due to color change**	**Absence of complete purification of sulfur compounds in pre-treatment stages**	**Presence of low amounts of sulfur compounds in the final product**	**2**
2E	**Covering the external wall of the pipelines with irreversible and non-oxidizing coatings with air**	**2D**	**fire**	**The presence of iron sulfide compounds in the tube wall**	**Contact iron sulfide pipelines and air**	**3**
3E	**The use of a cover on the inner side of the storage tank that does not react with hydrogen dioxide**	**3D**	**Corrosion in the walls of storage tanks**	**Presence of more than 6 ppm Hydrogen sulfide dissolved in oil**	**Formation of iron sulfide deposits**	**4**
3E	**Injectable non-harmful acid for the catalyst to adjust its acidity**	**3D**	**Reduced acidity of refined catalysts in conversion units such as cracking and reforming**	**The degradation of nitrogen compounds such as quinoline and indole**	**Creating organic bases or ammonia**	**5**
2E	**Pre-treatment of crude oil before entering the reactor**	**2D**	**Equipment destruction**	**Presence of low amounts of water, sediment and mineral salts**	**Creation of corrosion, abrasion, sedimentation, blockage and catalyst poisoning**	**6**
2E	**Use the appropriate gender for the piping system and the connections in such a way that the oil flow does not corrode the fluid transfer system**	**2D**	**Blockage of pipelines and contamination of products**	**Abrasion of pipelines, storage tanks, valves and plumbing systems**	**Formation of free compounds such as iron, copper, lead, nickel and vanadium**	**7**
2E	**Water injection**	**2D**	**Reduce production**	**The presence of sodium chloride salt precipitation**	**Reducing the internal diameter of the extraction pipe**	**8**

				due to partial evaporation of water due to the drop in pressure between the head and bottom of the well in the exhaust pipe wall		
3E	**Prefiltration before the flow inlet into the heat exchangers of the shell and pipe**	**3D**	**Formation of hot spots and formation of coke, especially in warmer heat exchangers**	**In refining processes, salt sedimentation in the heat exchanger tubes**	**Reduce heat transfer**	**9**
3E	**Pre-treatment of salt with filtration and precipitate**	**3D**	**Reduce heat transfer**	**The presence of salt in the supply of heavy fuel**	**Eclipse burners**	**10**
3E	**Pre-treatment of salt with filtration and precipitate**	**3D**	**Lack of proper asphalt formation**	**The presence of salt in the asphalt unit feed**	**Disturbance of asphalt emulsions**	**11**
3E	**Pre-treatment of salt with filtration and precipitate**	**3D**	**Reduce the quality of coke production**	**The presence of salt in the input feed of petrochemical coke production unit**	**Coming down the percentage of coke in the final product**	**12**
3E	**Injection of alkaline materials at points in the distillation column where water is condensed**	**3D**	**corrosion of the distillation tower and corrosion of the condenser shell or wall of the condenser pipes**	**The presence of magnesium chloride salts and calcium chloride in the distillation tower**	**Hydrolysis of magnesium chloride and calcium chloride at a temperature above 120 ° C, resulting in the release of dissolved hydrogen chloride in the top of the distillation tower of crude oil or condenser**	**13**
3E	**Pretreatment**	**3C**	**Reducing the quality of products produced from catalytic cracking and refining units**	**The presence of salts in the feed into catalytic cracking and refining units**	**Deactivation of catalysts of catalytic cracking units and refinement**	**14**
3E	**The use of irreplaceable materials-by the use of naphthenic acid-in the equipment**	**3C**	**Corrosive**	**The presence of naphthenic acids in crude oil and oil cuts**	**Formation of stable emulsions with caustic solution during desalination or oil production**	**15**

Table 6: FMEA risk assessment

FMEA											
RPN=72 After control actions RPN=24											
Action Results				Preventive and control actions	Degree of risk (RPN)	Detection coefficient (D)	Occurrence (O)	Severity (S)	Causes of occurrence	Hazards	Row
RPN	DET	OCC	SEV								
21	3	1	7	Sulfur pre-purification operations (desulphurization)	63	3	3	7	The presence of sulfur compounds in the flow of feed to the reforming unit	Creating poisoning in the Reforming unit Catalyst	1
12	4	1	3	Sulfur removal from the final product with separation operation	36	4	3	3	Absence of complete purification of sulfur compounds in pre-treatment stages	Presence of low amounts of sulfur compounds in the final product	2
27	3	1	9	Covering the external wall of the pipelines with irreversible and non-oxidizing coatings with air	81	3	3	9	The presence of iron sulfide compounds in the tube wall	Contact iron sulfide pipelines and air	3
18	3	1	6	The use of a cover on the inner side of the storage tank that does not react with hydrogen dioxide	72	3	4	6	Presence of more than 6 ppm Hydrogen sulfide dissolved in oil	Formation of iron sulfide deposits	4
12	3	1	4	Injectable non-harmful acid for the catalyst to adjust its acidity	36	3	3	4	degradation of nitrogen compounds such as quinoline and indole	Creating organic bases or ammonia	5
28	4	1	7	Pre-treatment of crude oil before entering the reactor	84	4	3	7	Presence of low amounts of water, sediment and mineral salts	Creation of corrosion, abrasion, sedimentation, blockage and catalyst poisoning	6
24	3	1	8	Use the appropriate gender for the piping system	72	3	3	8	Abrasion of pipelines, storage tanks, valves	Formation of free compounds such as	7

				and the connections in such a way that the oil flow does not corrode the fluid transfer system					**and plumbing systems**	**iron, copper, lead, nickel and vanadium**	
21	**3**	**1**	**7**	**Water injection**	**63**	**3**	**3**	**7**	**The presence of sodium chloride salt precipitation due to partial evaporation of water due to the drop in pressure between the head and bottom of the well in the exhaust pipe wall**	**Reducing the internal diameter of the extraction pipe**	**8**
18	**3**	**1**	**6**	**Prefiltration before the flow inlet into the heat exchangers of shell and tube**	**54**	**3**	**3**	**6**	**In refining processes, salt sedimentation in the heat exchanger tubes**	**Reduce heat transfer**	**9**
15	**3**	**1**	**5**	**Pre-treatment of salt with filtration and precipitate**	**45**	**3**	**3**	**5**	**The presence of salt in the supply of heavy fuel**	**Eclipse burners**	**10**
18	**3**	**1**	**6**	**Pre-treatment of salt with filtration and precipitate**	**54**	**3**	**3**	**6**	**The presence of salt in the asphalt unit feed**	**Disturbance of asphalt emulsions**	**11**
21	**3**	**1**	**7**	**Pre-treatment of salt with filtration and precipitate**	**63**	**3**	**3**	**7**	**The presence of salt in the input feed of petrochemical coke production unit**	**Coming down the percentage of coke in the final product**	**12**
18	**3**	**1**	**6**	**Injection of alkaline materials at points in the distillation column where water is condensed**	**54**	**3**	**3**	**6**	**The presence of magnesium chloride salts and calcium chloride in the distillation tower**	**Hydrolysis of magnesium chloride and calcium chloride at a temperature above 120 ° C, resulting in the release of dissolved**	**13**

										hydrogen chloride in the top of the distillation tower of crude oil or condenser	
21	**3**	**1**	**7**	**Pretreatment**	**63**	**3**	**3**	**7**	**The presence of salts in the feed into catalytic cracking and refining units**	**Deactivation of catalysts of catalytic cracking units and refinement**	**14**
18	**3**	**1**	**6**	**The use of irreplaceable materials-by the use of naphthenic acid- in the equipment**	**54**	**3**	**3**	**6**	**The presence of naphthenic acids in crude oil and oil cuts**	**Formation of stable emulsions with caustic solution during desalination or oil production**	**15**

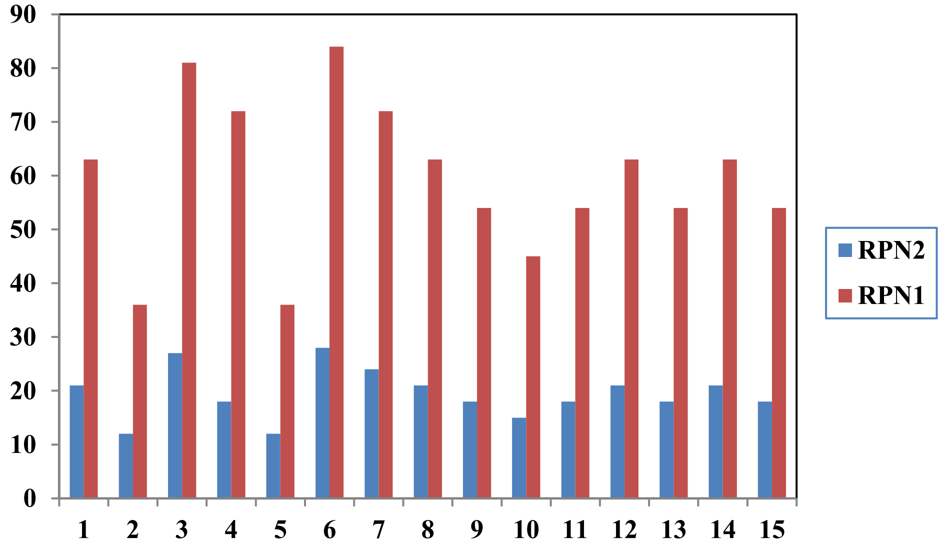

Figure 1: RPN_1, RPN_2; RPN_1 is risk numbers before control and preventive actions, RPN_2 is risk numbers after control and preventive actions.

Table 7: RPN_1, RPN_2, and Percent of decrease of risks

Decrease (%)	RPN_2	RPN_1	Row
66.67	21	63	1
66.67	12	36	2
66.67	27	81	3
75.00	18	72	4
66.67	12	36	5
66.67	28	84	6
66.67	24	72	7
66.67	21	63	8
66.67	18	54	9
66.67	15	45	10
66.67	18	54	11
66.67	21	63	12
66.67	18	54	13
66.67	21	63	14
66.67	18	54	15

Referring to the risk assessment table (table 5) with PHA method, it was identified 15 important hazards. We conclude that 40% of the risks are undesirable and 60% are acceptable but need revision which can be mitigated by the preventive and control actions mentioned in table 5. Risk surfaces decreased due to decreasing probability.

With risk assessment using FEMA method, min of risk number is 36 and max of risk number is 84 (table 6, table 7). Other risk numbers are between these two numbers.

Referring to the RPN numbers obtained in the FMEA method, we conclude that we choose RPN = 72 which corresponds to row 7 as the final RPN. The reason for this choice is why the formation of free compounds such as iron, copper, lead, nickel and vanadium due to wear of pipelines, storage tanks, valves and piping systems, resulting in the closure and blockage of pipelines and contamination of products which is a critical and undesirable state.

Figure 1 shows a comparison between risk numbers before and after applying preventive and control actions. Table 7 shows the decrease percent of different hazards after applying control actions.

Figure 1, Table 7 shows that all RPN numbers decreased with applying control and preventive actions. This decrease was significantly. This shows that all preventive and control actions are appropriate and effectiveness. Control and preventive actions shows that treating and pre-treating streams included different organic and mineral components is very necessary for preventive of hazards. Also equipment design with appropriate materials that have non-corrosive properties is completely necessary.

4. Conclusions

This study showed that a good engineered process design is very necessary and important for preventing of hazards. Also it was showed that concepts of chemistry and chemical engineering can help to a successful risk assessment. Also FMEA is better that PHA method for risk assessment in design and preventive phase. Because FMEA is completely a quantitative method but PHA is a semi-quantitative method.

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