Catalyx : Journal of Process Chemistry and Technology
E-ISSN : 3063-508X
Volume. 1 Issue 2 October 2024
Page No: 113-124

Fault Tree Analysis of Increased Pressure Drop in Hydrotreater Reactor

Zahru Wilda Pratiwi[1], Budi Sulistiyo Nugroho[2], Lian Safitri[3], Abdul Jalil[4], Wanda Trihadi[5], Ramli[6]
Polytechnic of Energy and Mineral Akamigas, Indonesia[1,2,3]
Dumai Oil and Gas Company, Indonesia[4,5,6]
Correspondent: nbudi.nugroho@gmail.com

Received : September 22, 2024
Accepted : October 16, 2024
Published : October 28, 2024

Citation: Pratiwi, Z, W., Nugroho, B, S., Safitri, L., Jalil, A., Trihadi, Wanda., & Ramli. (2024). Fault Tree Analysis of Increased Pressure Drop in Hydrotreater Reactor. Catalyx : Journal of Process Chemistry and Technology, 1(2), 113-124. https://doi.org/10.61978/catalyx.v1i2

ABSTRACT: The treating stage in a Catalytic Reforming Unit (CRU) is a critical process to ensure the longevity and efficiency of the reforming catalyst. However, anomalies like sudden and significant increases in reactor pressure drop, as observed in this case, can disrupt operations and reduce the unit's overall performance. It is crucial to identify the root cause of the observed pressure drop anomaly using the Fault Tree Analysis (FTA) method to systematically investigate the issue from multiple perspectives, enabling the identification of both minor and significant contributing factors. The FTA results indicate that external debris introduced during a recent catalyst changeover (COC) activity is the most likely cause. This allegation is supported by the analysis of equipment operation data and feed condition records, which did not reveal any significant changes. Given the absence of internal factors, the external influence of the COC activity emerges as the primary explanation for the pressure drop increase. To prevent similar occurrences in the future, it is crucial to implement rigorous cleaning and inspection procedures during turn-around (TA) activities to minimize the risk of debris entering the system. Monitoring reactor pressure drop and feed quality can also help detect and address potential issues early on. By taking proactive measures, the reliability and efficiency of the treating stage can be maintained, ultimately improving the overall performance of the CRU.

Keywords: Hydrotreater, Pressure Drop, Reactor, Troubleshooting

INTRODUCTION

In an oil refinery, catalytic hydrotreating units are typically employed to desulfurize multiple oil streams to produce ultra-low sulfur products, including gasoline, diesel, and jet fuel. These units are operated under high temperature and pressure conditions to promote the catalytic cleavage of the S–C bond and S–S bond of organic sulfur compounds to H2S, which is removed together with other H2S formed during the process in the gas absorption section. However, high temperature and pressure harm the catalyst (Subagjo & Ulfah, 2013). The metal is an active site associating hydrogen with sulfur (Cui et al., 2021). The metal particle size can grow faster for some metals, such as Mo and Nickel, on alumina support under high temperature and pressure, leading to the disappearance of active sites. This metal decay function is the primary factor in the rising pressure drop (Kohli et al., 2019). Another important factor contributing to the increasing pressure drop is plugging. Due to the highly active catalyst, carbon deposition appears in the pores of the catalyst. Catalytic desulfurization under milder conditions, such as lower temperature, pressure, and hydrogen flow, can mitigate catalyst decay in service and reduce the adverse impact of the desulfurization reactions, such as hydrogen consumption and the generation of the hydrogen sulfide pollutant. However, these conditions will inevitably compromise the desulfurization performance(Novaes et al., 2021). All of these contradictory requirements must be accommodated in the active life of the hydrotreating catalysts. The only way to achieve this balance is to have the capability to remove the blocked catalyst in bypass mode periodically. Supporting multiple reactors would contingently enhance this capability (Samimi et al., 2019). Marked changes in the pressure drop signal the requirement for the switch to the fresh or regenerated catalyst, which is the critical factor in casting.

The catalytic reforming unit (CRU) is established in the petroleum processing unit to increase the octane amount of naphtha through reforming reactions. The CRU is always accompanied by a naphtha hydrotreater unit (NHT), which prepares the feed, especially for sulfur removal from naphtha feed because sulfur acts as a poison for the CRU catalyst(Korenev et al., 2022). The Hydrotreating process is a process to remove impurities such as sulfur and nitrogen from distillates such as (naphtha, kerosene, and diesel) by treating feed using the addition of hydrogen at high temperature and pressure and the use of catalysts. Hydrotreating has been expanded in recent years to process residual atmospheric distillates to reduce the sulfur and metal content of the residual distillates and produce low-sulfur fuel oil. The main impurities removed in hydrotreating units are sulfur, nitrogen, oxygen, olefins, aromatics, halogens, and metals (Kooperen et al., 2018).

Therefore, uncovering the fundamental factors leading to these phenomena is necessary. Only when the phenomenon's origin is clearly understood can reasonable solutions, such as extending the catalyst replenishment cycle, increasing the activity of the catalyst, and adjusting the operating parameters, be undertaken in further research. However, very few resources on this topic can be found because of the confidential status of petroleum refining technology and the complexity of these phenomena. This paper examined several possible reasons that can lead to the increasing pressure drop of the catalytic hydrotreating process (Wallnofer-Ogris et al., 2024).

The increasing pressure drop in hydrotreating reactors can be attributed to several factors. Catalyst fouling, caused by the accumulation of particulates, asphaltenes, or coke deposits, is a common culprit. This fouling can be exacerbated by operational inconsistencies, such as low hydrogen partial pressures (Ishiyama et al., 2019). Additionally, particulate accumulation, particularly iron sulfide and colloidal clays, can contribute to pressure drop by creating blockages in the reactor's lower beds (Chang & Chou, 2011). Operational conditions, including inadequate gas distribution, temperature fluctuations, and changes in feed composition, can also increase pressure drop.

Conducting a comprehensive analysis to identify the root causes of increasing pressure drop is paramount for ensuring efficient and reliable refinery operations. High-pressure drops can lead to operational disruptions, unplanned shutdowns, and significant financial losses. By understanding the underlying causes, refiners can implement effective strategies to mitigate these issues. Furthermore, addressing pressure drops proactively can enhance safety, reduce maintenance costs, and improve overall profitability. Regular monitoring and analysis are essential to maintain optimal reactor performance and avoid costly problems.

METHOD

The method used in this study is the Fault Tree Analysis (FTA) method to find out the detailed aspects of the problems that occur so that the root of the problem can be determined and can be used as a recommendation to improve the issues that arise. Fault Tree Analysis (FTA) is an analytical technique used to identify and evaluate potential causes of system failures. FTA presents a graphical model that illustrates the interconnectedness of various failures, including hardware failures, human errors, and external factors. Using Boolean logic, FTA can demonstrate the cause-and-effect relationships between primary and undesirable top events. Analysts can pinpoint critical points within the system by thoroughly understanding the fault tree structure and developing effective risk mitigation strategies (Ferdiana & Priadythama, 2016; Kartika et al., 2016). This fault mode will be analyzed for its effects, causes, and the preventive measures that the company has implemented. Once determined, the Risk Priority Number (RPN) is calculated by multiplying the severity, occurrence, and detection rankings for each root cause. The root causes can be attributed to various sources: people, machines, methods, materials, and the environment. Each source factor will have its root causes and corresponding improvement recommendations (Commision, n.d.).

The procedure for conducting an FTA on the pressure decrease in the hydrotreater reactor is as follows:

1. Identify the most significant event
2. Recognize and comprehend the System and Components
   - Comprehend the hydrotreater reactor's operation, including its operating process, critical parameters (such as pressure, temperature, and flow rate), and the components involved (such as pipes, valves, and pumps).
   - Determine the typical operating conditions, and - Record all pertinent components
3. Recognize Fundamental Events

   Conducted a brainstorming session or analysis with the team to identify the potential causes of the flagship event.

   Causes can be classified into two primary categories:

   a. Equipment malfunction: - Leaks in valves or pipework.
      - Compressor/pump damage at excessive pressure.
      - Reactor mechanical degradation, including corrosion and attrition.

   b. Operational Failure:
      - Error in the operation of the pressure setting.
      - Insufficient upkeep.
      - Interference with the autonomic control system

4. Probability Analysis and Data Collection
   a. Obtain quantitative data for each fundamental event (e.g., component failure rate and frequency or historical incidents)
   b. Utilize the logic principles of the diagram to determine the probability of the top event by combining the probabilities of the fundamental events
   c. Data sources may originate from:
      - Failure reports.
      - Database of equipment reliability.
      - Modeling simulations.
5. Analysis and Evaluation
   a. If data is available, determine the likelihood of the top event using a quantitative approach.
   b. Determine the factors that have made the most significant impact on the most significant event.
   c. Identify the system's vulnerabilities in order to develop a mitigation strategy
   d. Offer technical and operational solutions to mitigate the risk of the primary causes, including:
      - Periodic maintenance.
      - System upgrade for pressure monitoring (real-time monitoring).
      - Redundancy of critical components.
   e. simulated the effect of mitigation on the probability of the top event.
6. Validation and Documentation
   a. Coordinate with the technical staff to document the analysis results and recommended mitigation measures.
   b. The results of the document will be utilized as a reference for future risk planning and evaluation.

RESULT AND DISCUSSION

Process Description

The primary purpose of the NHT process is to reduce the impurities content and separate heavy naphtha from light naphtha, which will be used as feed in CRU. The NHT feed consists of straight-run naphtha from the Crude Distillation Unit (CDU), heavy naphtha from the Hydrocracking Unibon Unit (HCU), and coker naphtha from the Delayed Coking Unit (CDU) with a capacity of 10.1 MBSD. It produces light naphtha and treated heavy naphtha products. This unit operates at a temperature of 300 – 360 °C with a reactor pressure of 52.0 kg/cm^2 and a ratio of H_2/HC = 162 Nm^3/m^3. The products produced by the NHT are gas, light naphtha, and treated naphtha.

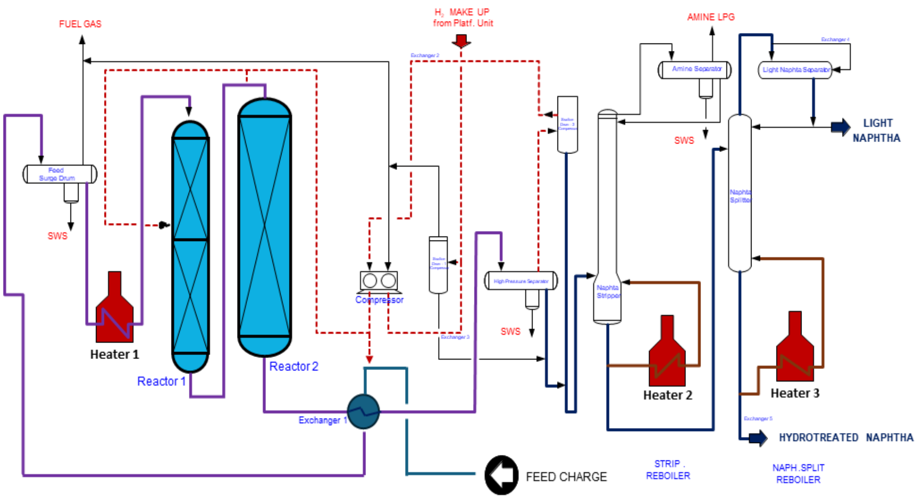

Figure 1. Hydrotreating Process Flow Diagram

The NHT feed will enter the Feed Surge Drum to be separated between oil, gas, and water. Afterward, it will be heated to around 295 □C before entering reactor 1 and 2 hydrotreating reactors. The reactions that occur in the reactor are hydrodesulfurization, hydrodenitrification, olefin saturation, deoxygenation, halide removal, and metal removal. The reactor effluent is used to heat the NHT feed and is separated again into oil, gas, and liquid at a high-pressure separator. The gas will enter the Suction Drum Compressor 1 before being compressed by the Compressor Recycle side. In contrast, the make-up gas Platforming Unit enters the Suction Drum Compressor 2 before entering the Compressor Makeup side. The separated oil will enter the Naphtha Stripper to separate treated naphtha from the reaction by-products of H2S, HCl, and NH3. The treated naphtha product will be separated again at the Naphtha Splitter into light and treated heavy naphtha.

The pressure drops in the hydrotreating unit that processes naphtha will increase rapidly when the new plant operates after the turn-around activity in June 2024. The turnaround activity in June includes cleaning the heat exchanger (HE) to overcome fouling and replacing the catalyst (COC) in the hydrotreater reactor in both reactors 1 and 2. This is an abnormal condition because the lifetime of this catalyst is 1 year, and the activity of increasing pressure drop from year to year moves slowly until the catalyst is saturated. The trend of increasing pressure drop can be seen in the graph below.

Figure 2. shows that the pressure drop value in October 2023-January 2024 is 0.37-0.49 kg/cm2, the average pressure drop value in reactor 1. However, this value continued to increase until June 3, 2024, at 5.78 kg/cm2. When viewed from the catalyst replacement schedule, July is the actual schedule for the catalyst to be replaced. Still, only 1 month earlier, the pressure drop had reached a high value, so a Turn Around (TA) was carried out on this reactor section to flush the exchanger before entering the reactor. The TA activity lasted for 28 days and included the start-up process. If not immediately addressed, this increase in pressure drop will hinder the unit's regular operation and cause problems with other equipment. Thus, it is necessary to immediately find out the leading cause of this increase in pressure drop by conducting an approach analysis based on equipment data records from the reactor section. The problem point that occurred was in the hydrotreater reactor, as shown in Figure 3.

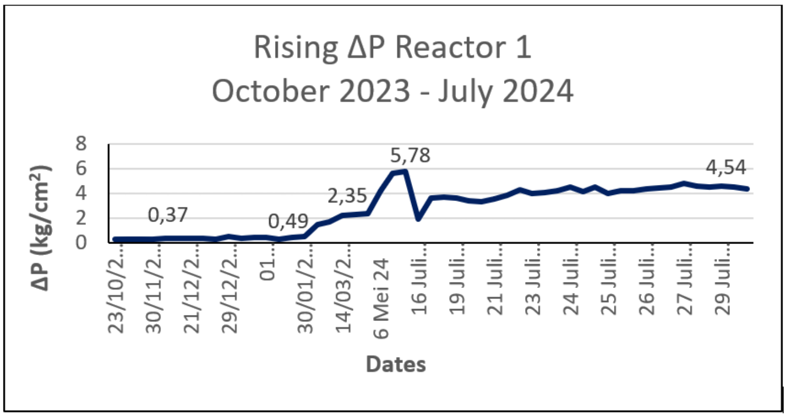

Figure 2. Graph of Pressure Drop Increase in Reactor 1 October 2023-July 2024 Period

Many aspects cause the increase in pressure drop in the reactor section of the NHT unit in Reactor 1. To facilitate the description of the aspects that affect the increase in pressure drop, a fact collection was carried out based on data recording of activities and events on the equipment and data recording of the equipment's operating conditions, especially the pressure drop from reactor 1.

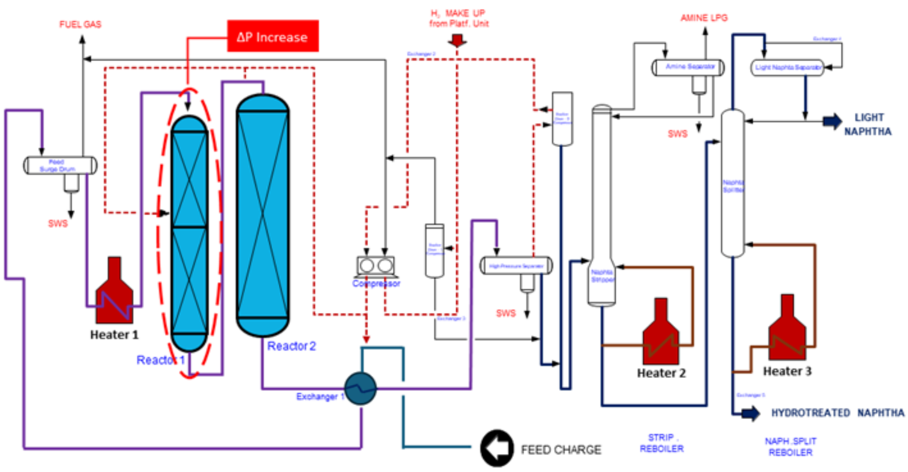

Figure 3. Problem Points that Occurred in the NHT Unit

1. Finding Facts

a. NHT Feed Changes

The initial design of the NHT unit was used to process Naphtha HCU. Currently, this unit is used to process SRN and Coker Naphtha, which are the results of cracked naphtha where the characteristics of this cracked naphtha have higher impurities and olefin content than naphtha HCU. The higher olefin content can affect the reaction heat. Thus, if there is a change in feed characteristics, an adjustment of the inlet temperature of the feed is required before entering the reactor (Centeno et al., 2012). This means that it is necessary to re-adjust the inlet temperature of the hydrotreater reactor due to changes in the quality of the NHT feed so that the reaction can run effectively and achieve the desired product specifications.

b. Gum Formation

There are many causes of increased pressure drop in this NHT reactor, one of which is the influence of the olefin content, which reacts with oxygen so that gum can form.

Table 1. Data Component Feed Reactor NHT

Analysis of Feed Component							
Parameter	**Unit**	**SRN**	**Naphtha Coker**	**Feed NHT**	**Light Naphtha**	**Feed PL**	**Reformate**
Sulfur	ppm	30,63	497,05	108,68	6,5	0,5	6,2
Nitrogen	ppm	0,91	19,77	6,42	0,67	0,082	0,65
(%vol) PONA							
Paraffin	%vol	66,73	61,52	60,7	93,9	62,9	39,4
Olefin	%vol	4,96	25,33	13,1	3,6	0,3	3,5
Naphtha	%vol	19,72	9,53	18,1	2,1	28,6	0,8
Aromat	%vol	7,54	3,62	5,9	0,3	6,7	55
Total		**98,95**	**100**	**97,8**	**99,9**	**98,5**	**98,7**

Based on the feed composition of the NHT unit, a value of 13.1% vol was obtained for the olefin content in the NHT feed. This does not support the theory that gum formation is in the NHT reactor section unit because there is no Olefin cracking process in the reactor, and the percentage of Olefin is lower than the naphtha content in the feed. Gum formation can occur in the compressor because there is contact between the feed and hydrogen gas, where the gas may contain oxygen. In addition, the feed tank used to store the feed is a floating roof tank where the tank can minimize the occurrence of vapor space so that there is no opportunity to react with oxygen and react to form gum.

c. Coke Formation

It is suspected that the formation of coke or carbon deposits on the catalyst surface may be one of the causes of the increase in pressure drop in reactor 1. When opening the reactor bed during TA activities (catalyst replacement or skimming), coke was found on the catalyst surface, thus supporting the theory of :

1) The feed used is Straight Run Naphtha & Naphtha Coker (SRN cut temperature 90-140 °C; Naphtha Coker cut temperature 315-360 °C).
2) The reaction temperature of coke formation is 290 °C.
3) The reaction takes place in the gas phase by adding hydrogen gas.

Thus, this assumption supports the assumption that pressure drop can increase due to coke formation on the catalyst. The NHT reaction temperature is maintained at 295°C, which is the temperature of coke formation. Thus, catalyst performance decreases and can increase the pressure drop in the reactor (Topsoe, 2009). However, if the cause of the increase in pressure drop is from coke formation, this is contrary to the graph of the drastic increase in pressure drop in figure 2. Therefore, coke formation is a minor possibility of increasing pressure drop in this hydrotreater reactor, and there may be other significant causes of increasing pressure drop in this hydrotreater reactor(Scotti et al., 2024; Yang et al., 2024).

d. External Particles (Debris)

Another possible cause of this increase in pressure drop is that foreign particles may have settled in the catalyst bed, clogging the space and increasing the pressure drop in the top bed of the reactor. These particles can be produced due to deposit formation in the Exchanger and residual external material after TA. However, this increase in pressure drop increased drastically, as seen in Figure 2. There is a graph break on May 30, 2024. When viewed from its value, the graph shows a drastic increase in pressure drop, not gradually or exponentially, with the conditions in that month being the time after TA. Thus, the deposit formation option was not used, and it is suspected that there is external material after TA. Further study of this option is needed, namely the series of processes and the history of TA procedures that have been carried out.

2. Fault Tree Analysis

Analysis using the Fault Tree Analysis method (FTA) diagram as in Figure 4. Fault Tree Analysis offers advantages over other problem analysis methods through its structured approach, effective visualization, comprehensive root cause identification, risk quantification capabilities, proactive problem-solving orientation, and broad applicability across industries. These strengths make FTA an invaluable tool in reliability engineering and safety assessments (Wibowo et al., 2018).

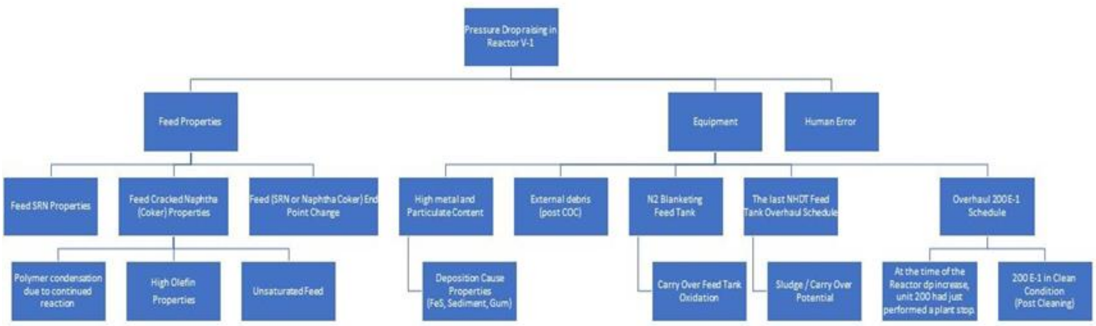

Figure 4. Fault Tree Analysis (FTA) of Pressure Drop Rising in Hydrotreating Reactor 1

From the findings and facts collected, an analysis can be carried out to find the root of the major problem from the existing data records. From all the findings, it can be seen that there are two significant factors suspected of the problem of increasing pressure drop in reactor one hydrotreater: external debris (post-COC) and the potential of sludge carryover potential. Not many supporting fact findings can prove that both of these things did not occur in reactor one after TA activities, so they became the primary cause of this problem. Therefore, further checks are needed to determine the following steps to improve this condition.

3. Recommendation

From the FTA that has been done, there are several options to improve this condition, either temporarily or requiring further TA activities to obtain the original condition. Here are some recommendations for activities that can be done, such as :

a. Feed Composition
   The composition of this feed is very diverse and fluctuating. It is not sure what the characteristics of the feed to be processed are, but the equipment design has determined the characteristics of the feed that can be processed. The treatment process must meet existing standards. Therefore, the feed composition from this hydrotreater reactor needs to be further studied against the percentage of components in the feed. If at specific operating conditions and capacities, what percentage and characteristics of feed are most optimal for

treating in the hydrotreater reactor, especially in reactor 1? This can help limit the impurity components that will be treated by reactor one so that the catalyst works more optimally in treating the feed, the products produced are on spec, and the catalyst's lifetime following its time can even be longer. The percentage of feed composition, operating conditions, and capacity can also be further studied to optimize the catalyst's lifetime in reactor 1. However, this also depends on the available feed and the needs and targets of the factory in producing products.

b. Check Feed & Product Properties Analysis
Checking these properties is necessary not only for the hydrotreating products produced to find out whether the products produced have reached the standard or on spec but also for each feed; periodic testing needs to be carried out according to changes in conditions and capacity. So, data recording can be carried out on the performance of the hydrotreating catalyst of this reactor. The properties check that needs to be carried out is the content of impurities that will be removed from this naphtha hydrotreating process(Jackowski et al., 2015). The properties that need to be tested include sulfur, oxygen, nitrogen, metal, silica compounds, and saturation of the olefin ratio. The data recording shows operating conditions, capacity, and percentage of optimal composition with the hydrotreating performance. This is closely related to the feed composition in the previous point, so reviewing this point cannot be done to find the optimal point if it is not carried out together with checking these properties, both from the feed and the hydrotreating products.

c. N2 Blanketing Settings on Feed Tank
The influence of this blanketing is crucial to this problem. The feed used in this process has a high olefin content, and if the olefin content meets oxygen, it will oxidize and form sludge. Furthermore, if the sludge is formed, the quality of the product will change, and if it is carried through the piping to the process area, this sludge can hinder the process and cause problems that have occurred, such as increasing pressure drop. Therefore, this activity is very crucial to be monitored and checked regularly. With this blanketing, the feed stored in the tank will be protected from contact with oxygen from the outside air, and the quality of the feed will be maintained until the product is processed in the processing unit (Aznarez et al., 2024). In addition to blanketing, the tank used to store feed with this olefin content must also have a design so that the stored feed has minimal contact with air or other materials in open spaces such as fixed roof tanks or fixed floating roof tanks. Thus, blanketing can be carried out optimally on the stored feed.

d. Use of Chemical Injection
From the problems, the increase in pressure drops only occurred in reactor 1 of the hydrotreating reactor series. This indicates that the treatment in reactor 1 was in less-than-optimal conditions. Therefore, before the turnaround for short-term mitigation, the chemical injection can be used to reduce impurities in the feed so that the pressure drop due to this treatment does not increase further. This chemical injection can be done specifically based on the impurity content you want to minimize. This relates to the chemical injection point and the optimum conditions for the chemical to react with the feed (Yusuf et al., 2020). Further studies are needed regarding the type of chemical, conditions, and amount of chemical that must be injected into the feed and its effects on the process. Thus, this mitigation is a mid-term and cannot be used permanently.

e. Skimming
   Effectively managing pressure drop in hydrotreating reactors is crucial for maintaining operational efficiency and prolonging catalyst life. One promising solution to address rising pressure drops is the implementation of skimming techniques. Skimming involves the removal of fouled catalyst material from the reactor, which can accumulate due to various factors such as coking, corrosion, and the deposition of foreign particles. This process not only helps alleviate pressure buildup but also allows for the introduction of fresh catalyst material, thereby enhancing the overall catalytic activity within the reactor. However, skimming is often seen as a temporary fix rather than a comprehensive solution, as it does not address the underlying causes of catalyst fouling (Huda et al., 2022; Kolitcheff, 2021).

Recent innovations in hydrogenation processes have introduced methods to reduce catalyst skimming while effectively managing pressure drops. For instance, specific reactor designs incorporate specialized gas-liquid distributors and overflow systems, allowing continuous mass transport even when pressure differentials arise across catalyst beds. These systems utilize pressure rupture disks that activate under specific pressure conditions, enabling gas-liquid flow to bypass clogged areas and maintain hydrogenation reactions without necessitating reactor shutdowns for skimming (Ibrahim et al., 2005). This approach not only extends the operational cycle of the catalyst but also ensures that production safety is upheld by mitigating excessive pressure drops.

Additionally, advancements in catalyst grading technologies have emerged as effective strategies for managing reactor fouling and pressure drop. Refineries can significantly reduce the accumulation of solid contaminants that lead to increased pressure differentials by employing graded bed configurations and specialized particulate traps. These technologies are designed to capture larger particles before reaching active catalyst areas, optimizing catalyst utilization and minimizing downtime caused by skimming operations(Shaban & Khan, n.d.). Integrating skimming with innovative reactor designs and advanced filtration technologies presents a comprehensive approach to managing pressure drop issues in hydrotreating reactors.

CONCLUSION

The problem of rising pressure drop in the hydrotreater reactor is a crucial problem if not mitigated quickly. This increase in pressure drop occurs significantly with abnormal data records, namely shortly after the turnaround unit is carried out. Thus, an assessment of this problem is very urgent. Several temporary assumptions from the finding facts of the existing condition data records have been summarized with Fault Tree Analysis (FTA). The analysis's significant causes, including external debris (post-COC) and sludge carryover potential, have been obtained. Therefore, this study is limited to the troubleshooting analysis of the problem of increasing pressure drop, but there are mitigation recommendations that can be carried out and need further assessment. These recommendations can reference mitigation stages from short term to long term, including assessing the percentage of feed composition used, testing feed and product properties to process conditions, chemical injection, and the final stage, namely skimming or plant stop. These recommendations are also selected based on the needs and targets of the factory.

REFERENCE

Aznarez, A., Korili, S. A., & Gil, A. (2024). Progress and Recent Novelties in Naphtha Reforming Catalyst. *Journal of Environmental Chemical Engineering*, 1–27.

Centeno, G., Ancheyta, J., Alvarez, A., Marroquin, G., Alonso, F., & Castillo, A. (2012). *Effect of different heavy feedstocks on the deactivation of a commercial: Vol. Fuel* (pp. 73–79).

Chang, J.-C., & Chou, T.-C. (2011). Improve the operation cycle time of a naphtha hydrotreating unit by controlling the pressure drop. *Journal of the Chinese Institute of Engineers*, *73–80*.

Commision, U. N. (n.d.). *Systems and Reliability Research*. United States Government.

Cui, Q., Ma, X., Nakano, K., Nakabayashi, K., Miyawaki, J., Al-Mutairi, A., & Mochida, I. (2021). Effect of blending on hydrotreating reactivities of atmospheric residues : Synergistic effects. *Fuel*, *293*(120429), 1–7. https://doi.org/10.1016/j.fuel.2021.120429

Ferdiana, T., & Priadythama, I. (2016). Analisis Defect Menggunakan Metode Fault Tree Analysis (Fta) Berdasarkan Data Ground Finding Sheet (Gfs) Pt.Gmf Aeroasia. *Universitas Sebelas Maret Proceeding Conference*, 34–41.

Huda, H., Renanto, B., R., T., Fathoni, R., & Larasati, T. D. (2022). *Prediction Analysis of Fouling Model on Heat Exchanger In The Crude Oil Refinery*.

Ibrahim, H. A.-H., Safwat, A., & Hussany, N. (2005). Investigation of The Fouling Mechanism In The Heat Exchanger of A Hydrotreater. *Engineering Journal of The University of Qatar*, *18*, 9–14.

Ishiyama, E. M., Kennedy, J., & Pugh, S. J. (2019). Modelling Fouling In Hydrodesulfurization Unit Heat Exchangers. *Heat Exchanger Fouling and Cleaning*, 1–9.

Jackowski, L., Risse, P. J., & Smith, R. O. (2015). Impact of Non-Uniform Fouling on Operating Temperatures in Heat Exchanger Networks. *Proceedings of International Conference on Heat Exchanger Fouling and Cleaning*, 191–198.

Kartika, W. Y., Harsono, A., & Permata, G. (2016). Usulan Perbaikan Produk Cacat Menggunakan Metode Fault Mode And Effect Analysis Dan Fault Tree Analysis Pada Pt.Sygma Examedia Arkanleema. In *Jurnal Online Institut Teknologi Nasional* (pp. 345–357). Jurusan Teknik Industri Itenas.

Kohli, K., Prajapati, R., Maity, S. K., Sau, M., & Sharma, B. K. (2019). Deactivation of a hydrotreating catalyst during hydroprocessing of synthetic crude by metal bearing compounds. *Fuel*, 579–589.

Kolitcheff, S. (2021). Sulphur Spiking Agents for Hydroprocessing Units Activation. *Digital Refining*, *al*, 1–3.

Kooperen, A. V, Esteban, J., & Murphy, B. (2018). *Hydroprocessing Rate Increase Using Shaped Charges*. Digital Refining.

Korenev, V. V, Tomin, V. P., Zhdaneev, O. V, & Kapustin, V. M. (2022). Phase Equilibriums of Ammonium Chloride Systems as Model Hydrogenolysis Products of Organochlorine

Compounds under Naphtha Hydrotreating Conditions. *Petroleum Chemistry*, *62*(4), 376–382. https://doi.org/10.1134/S0965544122020177

Novaes, L. R., Secchi, A. R., Salim, V. M., & Resende, N. S. (2021). Enhancement of hydrotreating process evaluation: correlation between feedstock properties, in-line monitoring and catalyst deactivation. *Catalysis Today*, *1–13*.

Samimi, A., Zarinabadi, S., Kootenaei, A. H., Azimi, A., & Mirzaei, M. (2019). Optimization of The Naphtha Hydrotreating Unit (NHT. In *in order to Increase Feed In The Refinery. Eurasian Chemical Communications* (pp. 150–162).

Scotti, K. L., Voorhees, P. W., & Dunand, D. C. (2024). Lamellar structures in directionally solidified naphthalene suspensions. *Journal of Materials Research*, *39*(15), 2228–2235. https://doi.org/10.1557/s43578-024-01381-x

Shaban, H. I., & Khan, A. R. (n.d.). Pressure-related operational problems and their remedies in hydrotreating reactors in petroleum refineries. *Journal of Petroleum Science and Engineering*, *14*, 79–88.

Subagjo, & Ulfah, M. (2013). *KINETIKA HIDRODESULFURISASI DIBENZOTHIOPHENE (HDS DBT) MENGGUNAKAN KATALIS NiMo/γ-Al2O3*. Reaktor.

Topsoe, H. (2009). Pressure Drop Control. *Lyngby*.

Wallnofer-Ogris, E., Poimer, F., Koll, R., Macherhammer, M.-G., & Trattner, A. (2024). Main Degradation Mechanisms of Polymer Electrolyte Membrane Fuel Cell Stacks-Mechanisms, Influencing Factors, Consequences, and MItigation Strategies. *International Journal of Hydrogen Energy*.

Wibowo, K., Sugiyarto, & Setiono. (2018). *Analisa dan Evaluasi : Akar Penyebab dan Biaya Sisa Material Konstruksi Proyek Pembangunan Kantor Kelurahan di Kota Solo, Sekolah, dan Pasar Menggunakan Root Cause Analysis (RCA) dan Fault Tree Analysis (FTA*. Matriks Teknik Sipil.

Yang, Y., Li, C., Yang, L., Zhu, H., Xie, Z., Falandysz, J., Weber, R., Qin, L., & Liu, G. (2024). Linking industrial emissions and dietary exposure to human burdens of polychlorinated naphthalenes. *Science of the Total Environment*, *951*. https://doi.org/10.1016/j.scitotenv.2024.175733

Yusuf, A. Z., John, Y. M., Aderemi, B. O., Patel, R., & Mujtaba, I. M. (2020). Effect of hydrogen partial pressure on catalytic reforming process of Naphtha. *Computers and Chemical Engineering*, 1–15.