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Abnormal Vibrations of a Regeneration Tower in Amine Gas Treatment Unit and Applicable Recommendation to Reduce it

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Abstract

The regeneration tower in the amine cycle of a gas treatment unit and its inlet pipe containing rich amine have visible abnormal vibrations. Excessive vibrations can lead to fatigue and then, economic losses with serious damages and injuries. Therefore, it is so important to find the root cause of the vibrations and fix it. This article focuses on identifying the cause of the vibrations of the regeneration tower and provides a practical solution to prevent possible failures. In this regard, all documentations including technical information, maintenance records, and operating conditions are examined. Then, the vibration data are collected in different locations on the tower and its pipe, assessed based on the relevant standards and guidelines, and compared with vibrational behavior of a similar refinery unit. Furthermore, the impact hammer modal testing technique is implemented to find the natural frequencies of the regeneration tower. The root cause of vibrations is identified as the fluid-structure interaction and resonance using the fishbone diagram. The vibrations of two refinery units are detected the same with a difference of less than 15%. The design of two viscoelastic dampers at two high-amplitude locations is proposed as a practical strategy to reduce vibrations.

Keywords: Vibrations Analysis, Resonance, Flow-Induced Vibrations, Amine Cycle.

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1. Introduction

Natural gas, in most cases, in addition to heavy hydrocarbon compounds and water vapor, contains harmful substances such as H_2S, CO_2, and sulfur compounds, which are necessary to separate them to the optimal extent. The compounds of H_2S and CO_2 in water produce sulfuric acid and carbonic acid, respectively, which are very toxic and corrosive. These compounds reduce the heat of combustion of gas and cause serious damages to the equipment and the environment. Depending on the concentration and exposure time to H_2S, this toxic substance causes swelling and bruising of the body, irritation of the respiratory organs and eyes, coughing, respiratory disorders, blurred vision, drowsiness, dizziness, fainting, palpitations, severe tremors, bleeding, and even death [1].

Natural gas containing H_2S and other sulfur compounds is called sour gas, which by reducing them to the permissible limit, the sweet or treated gas is produced in the treatment process. The most common method of natural gas treatment is absorption by a liquid solvent (like, alkanol amine - a mixture of alcohol and ammonia) at high pressure and low temperature in an absorption tower. The spent solvent is recovered in another tower called the regeneration tower at low pressure and high temperature. The separated amine is pumped back into the absorber tower (Figure 1) [1].

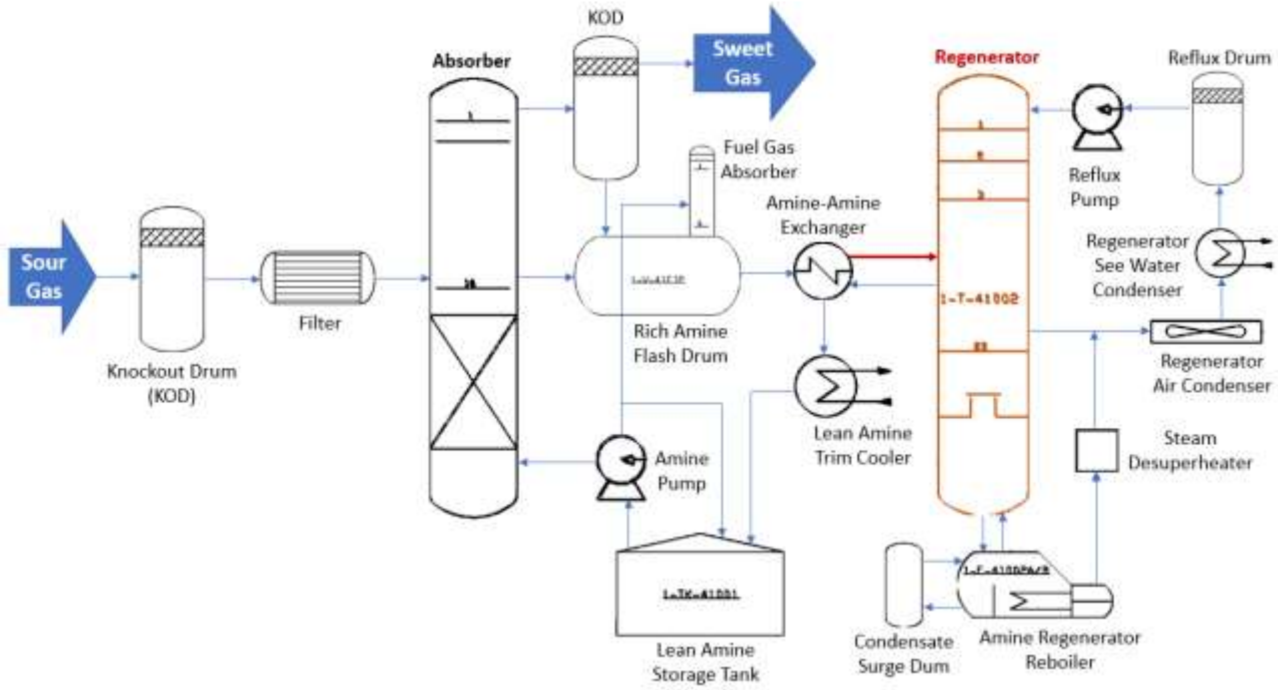


Figure 1. Process flow diagram of an amine gas treatment unit.

Each amine molecule contains a hydroxyl group (OH) to increase the molecular weight, thereby reducing the vapor pressure and then increasing the solubility of the amine, which combines with an amino group (NH_2 or NH) to increase the capacity to absorb acid gases. The inlet of the regeneration tower, which is a mixture of liquid amine and acid gases absorbed by it, is called a rich amine. The rich amine pathway is highlighted in red in Figure 1.

Flow-induced vibrations (FIV), which occur at frequencies below 50 Hz, are the result of the instability of the fluid passing over the mechanical barriers. Two-phase flow, fluid-structure interaction (FSI), the presence of rotating parts in the fluid, change in the flow direction (ring, elbow, and tee), pressure fluctuations, pressure drop in control valves, and temperature stimulation can be among the factors of turbulence and as a result of creating vibration in the pipes. FIV is possible for both single-phase and two-phase flow, but in two-phase flow, these vibrations are more destructive, because this type of flow itself is oscillatory in nature [2]. Since the rich amine pipe contains liquid amine in combination with acid gases, the two phases may separate and cause excessive vibrations.

Some studies have raised the problem of vibrations of the rich amine pipe in the gas treatment process or other process pipings and have provided solutions for it. Designing new piping supports is an implemented solution to strengthen the supports and thus increase the natural frequency of the system to prevent resonance caused by FSI. Using supports for short pipes with two elbows close to each other can eliminate the vibration of these pipes that may be transmitted to the long pipes. In 2017 [3], supports for the outlet pipe of the control valve, where rich amine enters the regeneration tower, were designed to eliminate the vibrations of the pipe due to the two-phase flushing flow in it. Modification of piping geometry is another solution for vibration elimination. In a case study in 2019 [4], slug flow velocity decreased as the pipe diameter increased from 26" to 30" and the elbow angle decreased from 90° to 45°. With these changes, not only the vibration peak has been reduced, but also the corresponding frequency has been moved to a higher frequency. Reducing the porosity ratio of the two-phase flow by decreasing the outlet temperature of rich amine is the other suggested solution that can change the flow regime and thus reduce the vibrations [3].

The control valve at the outlet of the absorber tower and before entering the flash drum can be subjected to high vibration and noise due to the severe pressure drop. To solve this problem, it has been recommended to use Fisher Whisper Trim III, consisting of several orifices, in the structure of the valve. This part controls the rapid expansion of the fluid inside the valve and reduces vibrations [5]. If the root cause of vibrations of the rich amine pipe before entering the regeneration tower is related to the control valve, this solution can be effective.

The first refinery of South Pars Gas Complex (SPGC) has two amine gas treatment units. The rich amine pipe in these two units has abnormal visible vibrations in the flow direction. In one of these units, the regeneration tower is also vibrating along with the piping. Following the concern created in the company regarding the vibration of this tower containing acid gases, it has been decided that its vibration level be evaluated based on standard criteria, and if it exceeds the permissible limit, a practical solution be provided to reduce it. Examining technical documentation, inspection and maintenance records, and process behavior of two units as well as measuring and evaluating vibrations, identifying the cause of vibration, and providing a solution to reduce it to the permissible limit are the subjects of this research. In this regard, in addition to collecting vibration data, modal analysis is performed by impact hammer testing during overhaul. To identify the main cause of vibrations, the fishbone method, which is one of the common methods of root cause failure analysis (RCFA), is used.

The rest of the paper is organized as follows: Section 2 provides technical information about the studied refinery unit and describes the available maintenance records. Section 3 focuses on vibration measurements, modal analysis, and interpretation of their results. Section 4 attempts to find the cause of vibrations employing RCFA. Section 5 presents a practical solution to eliminate the vibration. Finally, conclusions and future interests are given.

2. Problem Definition

In this section, technical and process information and then, maintenance reports are presented for two amine gas treatment units of the first SPGC refinery.

2.1 Technical Information

According to the technical specifications, the regeneration tower has a diameter of 2.7 meters and a height of 22.5 meters with 23 valve trays at 60 cm intervals. The tower shell consists of 10 transverse sheets welded together and made of ASTM A516 Gr.60N carbon steel with a maximum allowable corrosion of 3 mm. The upper part of the tower up to the fifth tray has a 3 mm thick Clad SS316 coating. The thickness of the upper part of the tower is 15 mm and the minimum thickness of the lower part is 16 mm. According to the minimum thickness recommended in the tower's technical specifications, the shell thickness is only 1 mm higher than the minimum allowed.

The regeneration tower has three main inputs from the amine exchanger, reboiler, and reflux pump and three main outputs to the amine exchanger, reboiler, and condenser, according to Figure 1. The output line from the amine exchanger has significant vibrations. The mentioned pipe has a diameter of 10 inches and a length of approximately 60 meters, which has 12 elbows on its way from the exchanger to the regeneration tower. In this route, there is only one safety valve at the entrance of the pipe to the tower. Table 1 shows the process characteristics of the vibrating pipe in two gas treatment units of SPGC. It can be seen that the operating conditions of the two units are almost the same.

Table 1. Process information of rich amine pipe in two units of SPGC.

Parameter	1st Refineray Unit	2nd Refineray Unit
Volumetric flow rate [m^3/h]	165	165
Rich amine temperature at the outlet of the amine exchanger [ºC]	23.8	23.0
Rich amine temperature at the entrance to the regeneration tower [ºC]	104.5	103.5
Concentration (vapor phase/liquid phase) [%]	42	42

2.2 Maintenance Reports

According to the engineering records, the second unit had a stronger vibration than the first unit in 2013. The reason for this difference was found in the different support installations under the rich amine pipe in the two units. In 2014, the support points of the second unit were modified to equalize this support with the corresponding pipe in the first unit. At the end of 2016, the tower shell of the first unit leaked and these areas were fixed with Blazona and SS316 sheets and their welding was confirmed by penetration test (PT). In the technical inspection in 2018, scattered localized corrosion was observed on the shell of the first unit tower, which was fixed with Ceramium coating. According to records in 2019, by modifying the supports, the vibrations of the second unit have been reduced, but not eliminated. Even though the supports of the two units are the same now, the vibrations of the first unit seem more evident than the second unit.

3. Vibrations Analysis

In this section, the measurement points are introduced. Then the vibration measurement results are presented, analyzed, and evaluated based on the introduced criteria. Finally, modal analysis is performed to find the natural frequency of the tower and better interpret the results.

3.1 Measurement

Vibrations have been measured using the STD 3300 device and 603C01 accelerometer sensor with a sensitivity factor of 11.04 mV/m/s^2. Measurements have been carried out in the frequency range of 1 to 500 Hz with a sampling rate of 1.28 kHz. The names of the points from which data collection have been recorded on the tower, pipe, and valve are indicated in Figure 2.

3.2 Vibration Results

Figure 3.a shows the vibration speed of the measured points on the regeneration towers and the amine pipes in two units. It can be seen that the vibration is dominant at frequencies below 30 Hz. Therefore, cavitation, flushing, and high-frequency acoustics, associated with relief and control valves, are not the source of vibrations. The abnormal vibration can be due to turbulence or vortex shedding, according to the probable excitation frequency ranges of different sources, which are given in the reference [6]. Figure 3.b depicts the time waveform of the axial vibration at two points on the pipe. It can be observed that the random vibrations at point P7 turn into oscillatory vibrations with an envelope frequency of 0.2 Hz at point P12, and its amplitude increases up to 12 times.

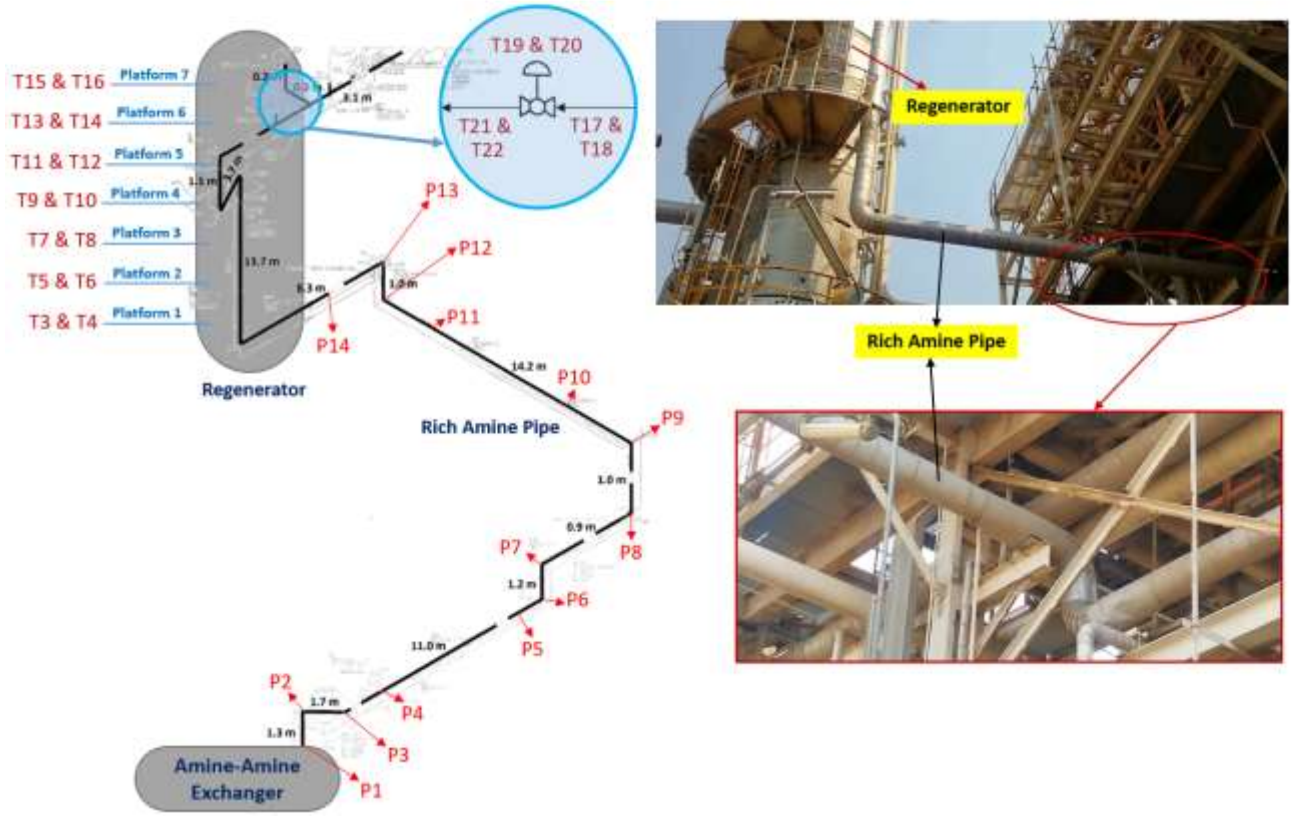


Figure 2. Vibration measurement points on regeneration tower, rich amine pipe, and safety valve.

a) b)

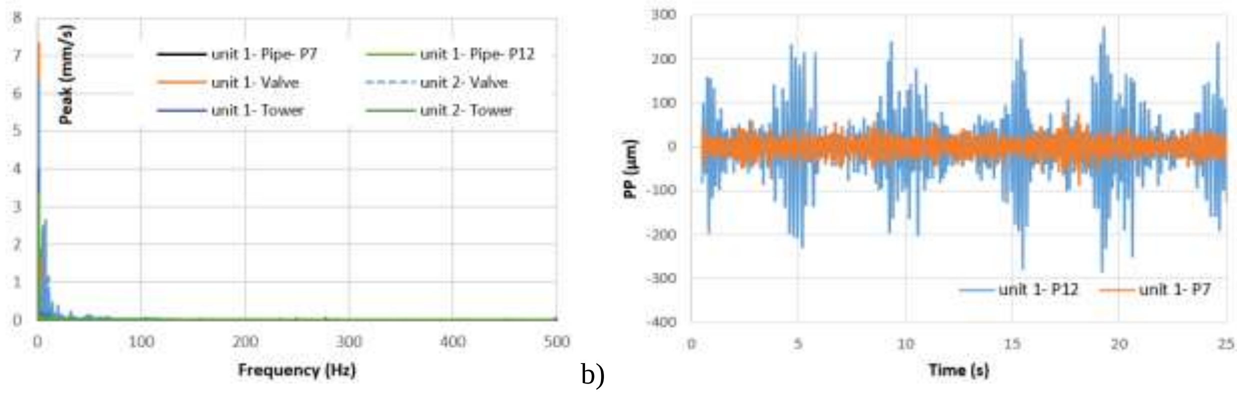


Figure 3. a) The vibrational velocity of the points with the highest amplitude to find the dominant frequency range b) Comparison of the time waveform of two points on the rich amine pipe- The point index numbers are in Figure 2.

Measurements made at the inlet and outlet of the safety valve before the amine pipe enters the tower show that the vibrations at the valve inlet are approximately 1.5 times the vibrations at the outlet (Figure 4.a). It can also be seen that the vibrations of this valve in the two units have a difference of less than 15%, which is insignificant.

The bar chart of Figure 4.b, which illustrates the maximum vibration amplitude of the two units' towers, admits that the maximum vibration is at the place where the pipe reaches the tower. The amplitude of vibration in one of these points for the first unit is more than the other, and in other places on the tower, no significant difference between the vibration of the two units is observed. Therefore, the hypothesis that the two units have significant vibration differences is rejected.

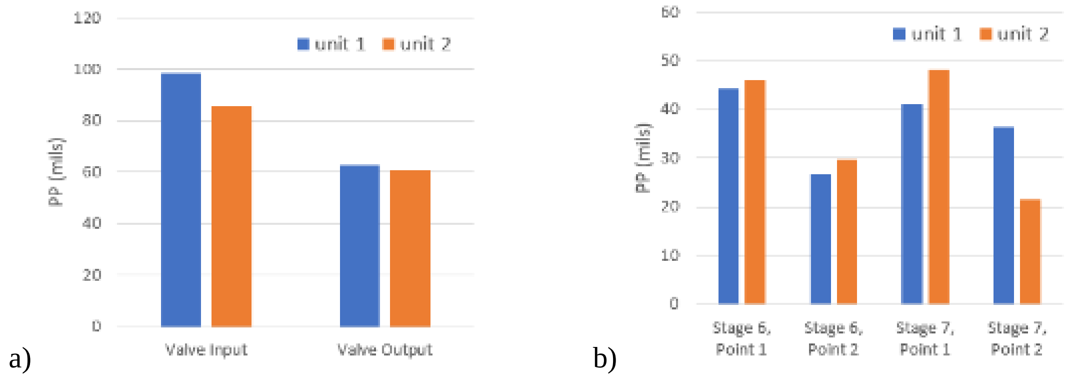


Figure 4. The vibrational velocity of the points on a) valve inputs and outputs b) regeneration tower.

3.3 Vibrations Evaluation

According to the investigations, there are no guidelines and technical standards regarding the permissible limit of vibrations of the tower or similar fixed equipment, except ISO 4866 [7], but the items mentioned in this standard do not fully match with the existing problem and so, are not used in this research.

Figure 5 evaluates the vibration displacement and velocity of points on the pipe of two units with different criteria ([8]). It can be seen that the pipe vibrations at point P12, which were evident, are within the permissible range based on all criteria, both in terms of displacement and vibration speed. In contrast, the vibrations of the point on the amine line before the safety valve with a peak frequency of 1.4 Hz are concerning in terms of the following criteria:

- Southwest Research Institute (SwRI) criterion on vibration displacement: This point is above the correction limit and fixing the vibration problem is neccessary.
- Wachel criterion on the vibration speed: The point is above the correction limit and requires corrective action.
- API standard on vibration displacement: The point has higher than permissible vibrations at low frequencies.
- API standard on vibration speed: this point has high vibrations.
- Energy Institute (EI) criterion on the vibration speed: The examined point is between the concern and problem boundaries.
- ASME standard on vibration velocity: Pipe vibrations are within the permissible range.

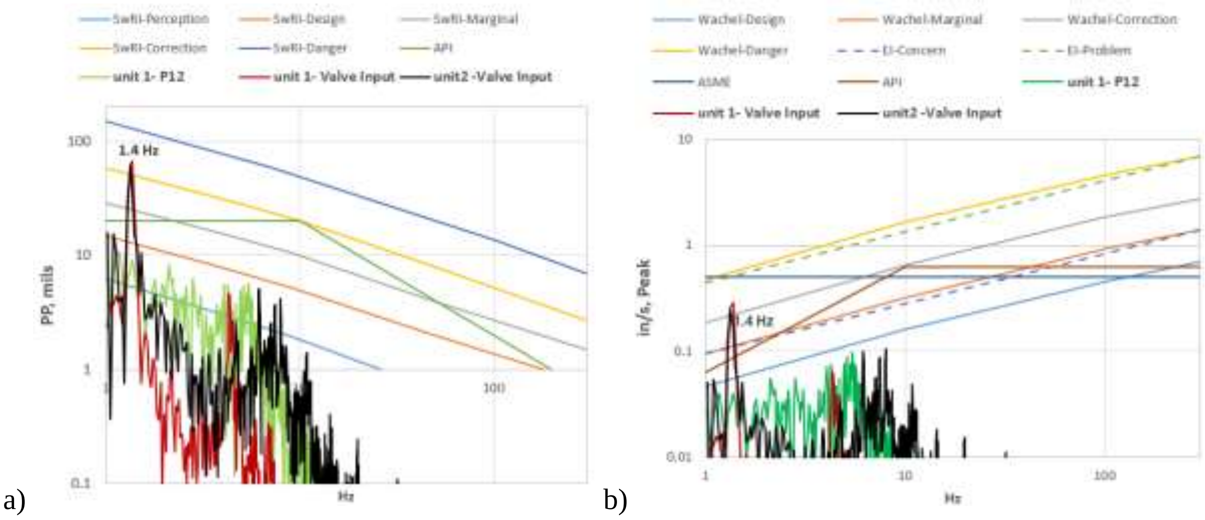
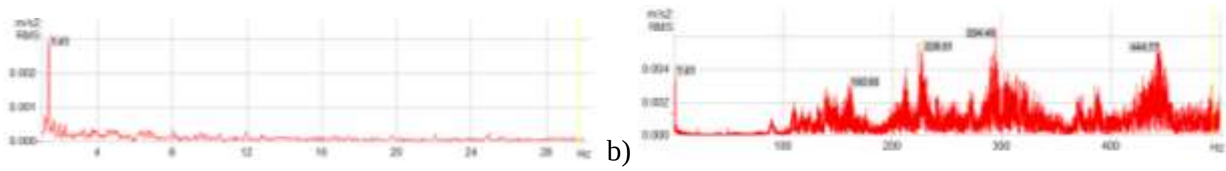


Figure 5. Vibrations evaluation of a) displacement b) velocity of points on the amine pipes in two units based on different criteria.

The opinion of most of the criteria, especially the criteria that have a more precise division about pipe vibrations such as SwRI and Wachel, is that the vibrations of the amine pipe in both units need to be corrected. Therefore, the following sections deal with finding the main cause of vibrations and providing solutions to reduce them.

3.4 Modal Analysis

The impact test has been conducted on the two tower platforms of the first unit of the refinery during its overhaul. The frequency spectra of the acceleration measured by the impact of the tower at two points in different heights on platforms 4 and 5 are demonstrated in Figure 6. The only common frequency in these two points is 1.4 Hz, which has also seen in Figure 5. Therefore, this frequency corresponds to the first natural frequency of the regeneration tower.



a) b)

Figure 6. Impact response of a point on the regeneration tower at the a) fourth b) fifth platform.

4. Root Cause of Vibrations

Considering the many influencing factors, the complex nature, and the specific subtleties in industries, finding a solution to prevent the recurrence of many unpleasant incidents requires detailed technical investigations using a standard, efficient, and specialized method. One of the standard and reliable methods in this field is RCFA. RCFA refers to a systematic process that identifies the causes involved in the occurrence of an event, which is often indicative of underlying causes and may not correspond to apparent causes [9].

The fishbone diagram is one of the RCFA techniques using brainstorming that examines and analyzes all the branches and components of the problem [9]. This technique is used in the current research to discover the root cause of the vibrations of the regeneration tower along with its amine inlet pipe.

4.1 Fishbone Diagram

A fishbone diagram to identify the main causes of visible vibrations in the regeneration tower along with its inlet amine pipe in the first refinery unit is presented in Figure 7. The main causes of the visible vibrations of the tower of this unit can be related to the difference between pipes, towers, operating conditions, or process conditions compared to another unit. Reasons whose effectiveness is less complex are listed near the fish's head.

By checking the geometry of the structure and the pipe according to the isometric drawing, it has been concluded that the class of the pipe and the number of elbows in its path are the same in the two units. Regarding the operating conditions (temperature, pressure, and flow rate), according to the received information from the control room (Table 1), the operating conditions of the two units along the pipe and at the inlet of the towers are almost the same. Therefore, the cause of vibrations can be related to the difference in tower structure or fluid dynamics. In the next two subsections, these issues are discussed and then the conclusion is provided.

4.2 Corrosion and Cracks Causes in Regeneration Tower

The amine used in the SPGC gas treatment units is methyldiethanolamin (MDEA), which reduces energy consumption due to its low regeneration heat and is less waste than other amines due to non-foaming. Pure amine is not corrosive, but its combination with acid gases can cause corrosion. Amine pollution, insoluble solid particles, and fluid turbulence due to the flushing phenomenon when the fluid enters the tower or passes through the valve tray plates inside the tower are some of the factors affecting the corrosion rate [10]. By using amine several times in the gas treatment cycle, the corrosion potential increases over time [11].

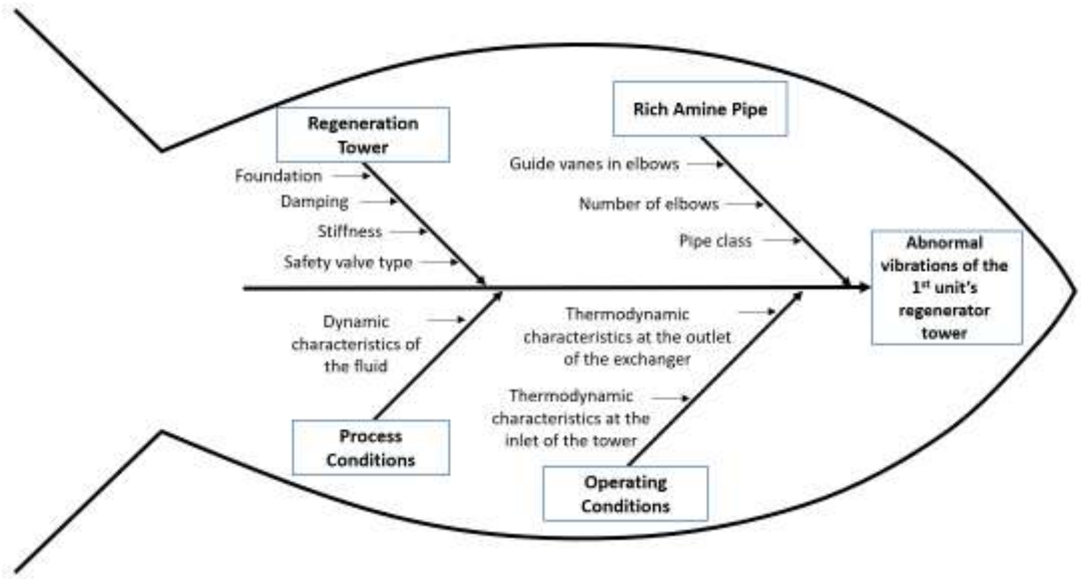


Figure 7. Fishbone diagram for the root cause analysis of the vibrations of the regenerator tower in the first unit.

The formation of primary cracks on the surface of metals such as the steel used on the shell of the regenerator tower is mainly caused by three mechanisms, including the creation of an acidic environment on the surface of the metal, the expansion of fine cracks, and stress corrosion caused by the penetration of hydrogen into the steel structure [12]. Small internal cracks expand due to vibrations and create larger cracks, thereby reducing the strength of the structure. According to the explanations provided, it is clear that the cause of the tower's vibrations is not because of the corrosion and cracks, although the vibrations is effective on the growth of cracks.

Despite the repairs done on the tower of the first unit (mentioned in Section 2.2), the attached patches do not affect the stiffness, dynamic behavior of the tower, and vibration response. It is praise to note that corrective actions have been taken on this tower to fix the cracks and leaks since 2016, while the towers have been vibrating since the beginning of its installation.

4.3 Flow-Induced Vibrations

The primary effects of fluid vibrations are fluctuations in fluid mass, momentum, and energy, which can cause pressure fluctuations and ultimately, fluid disturbances. As a result of FSI, fluid vibrations cause structure stimulation and structure excitations increase flow vibrations [2]. The rich amine pipe at the entrance of the regeneration tower in the refinery units is relatively free and without support, due to thermal expansion. This problem may have caused the coupling of low-frequency vibrations of the structure with fluid vibrations.

The two-phase flow inside the pipe can have several regimes based on the operating conditions. In vertical pipes, bubble flow occurs at low vapor phase flow rates and causes FIV due to the presence of bubbles in the fluid. At higher vapor phase flow rates, the slug flow may exist, where the coalescence of bubbles produces larger bubbles. Density fluctuations in this type of flow are the cause of FIV. As the gas flow rate increases, the churn flow is created with fluctuations. In horizontal pipes, the flow is similar to vertical pipes, except that the gas phase accumulates in the upper part of the pipe more than the lower part [2].

The flow rate of the vapor phase in the regeneration towers of the SPGC first refinery is higher than the flow rate of the liquid phase. Therefore, the flow regime in the amine pipe may be of a two-phase slug type. Moreover, considering that the frequency content of the slug flow is narrower with higher amplitude than the bubble flows [13], the stimulation of the structure by the slug flow is expected to be in a narrower frequency range. According to the results of Section 3, the slug flow in the amine pipe is probable.

4.4 Daignosed Cause of Vibrations

Putting together the results and documentation presented in the previous sections, it is concluded that due to the rich amine fluid dynamics, piping and then the tower is excited by the random vibrations of the slug flow. The natural frequency of the tower is in the range of the excitation frequency of the slug flow, and when this pipe reaches the tower, resonance occurs and causes abnormal vibrations. The effect of resonance can be seen as a reaction force on the pipe vibrations.

By comparing the vibrations of two units, it can be said that since the vibrations of the pipe and the fluid inside it are slightly higher in the first unit than the other unit (Figure 4.a), this unit is subjected to a slightly higher excitation and as a result, its tower experiences more vibrations (Figure 4.b). Comparing the results with the standard criteria (Figure 5) shows that the piping vibrations of both units are out of the allowed range and need to be corrected.

5. Practical Recommentadation for Vibration Reduction

The solutions used in previous research to reduce the vibrations of the amine pipe fall into four categories, including piping modification, operating conditions changes, support design, and using vibration absorbers. They can be effective in reducing the excitation effect or reducing the vibration response. In the following, the applicability of each of these solutions for the current project is examined.

5.1 Piping Modification

Changing the position or structure of the control valve or piping geometry affects the excitation force and then the response. Piping modification, such as increasing its diameter at the entrance of the tower, reduces fluid velocity and vibrations, but due to the need to change the piping design and the complexity of this solution, this solution is not prioritized.

Considering that in the present problem, the vibrations have decreased after the safety valve at the top of the tower (Figure 4.a), adding the Fisher Whisper Trim III element to the amine inlet valve cannot help to reduce the vibrations.

5.2 Operating Conditions Changes

Changing the operating conditions such as reducing the pressure drop in the control valve and reducing the temperature of rich amine by reducing the porosity ratio can change the flow regime and reduce its vibrations. But this solution affects process issues as well, which is not desirable in this research.

5.3 Support Design

In most of the previous research, the support design for restraining the rich amine pipe has been proposed to reduce the vibrations. This research cannot accept the mentioned solution because the reason for the freeness of the pipe is its probabale thermal expansion and process issues inside it. Therefore, it is not possible to change the designed piping supports only with the vibration view and without paying attention to the process issues.

5.4 Using Vibration Absorbers

The main purpose of vibration absorber is to moderate the vibration response around the point of highest vibration amplitude. It is worth mentioning that changing the stiffness of the tower to change its natural frequency, despite its complexity and impracticality, cannot be an applical solution. Because the excitation caused by the fluid contains a band of frequencies due to its random nature, and even if the natural frequency of the tower changes, the frequency matching between the excitation and the system still occurs, resulting in resonance. Therefore, the proposed solution in this research is the damping of pipe vibrations, so that the vibrations taken from the fluid inside it are damped in the same place and less stimulation is introduced to the tower.

Piping systems have little damping and dynamic forces acting on them at the resonance frequency and lead to their high vibration amplitudes. Viscoelastic dampers are used to protect the piping system and industrial facilities and are very effective in increasing the reliability of the equipment. Among the advantages of these dampers compared to the usual pipe supports, the followings can be mentioned: reduction of vibration in all directions, high damping force against impact, quick response, simplicity of design, no need for maintenance, and installation without shutting down the equipment [14]. Figure 8 shows the effect of a sample viscoelastic damper in vibraiton reduction of a piping system. It can be seen that the maximum range of vibrations has been reduced by about 75% by using it.

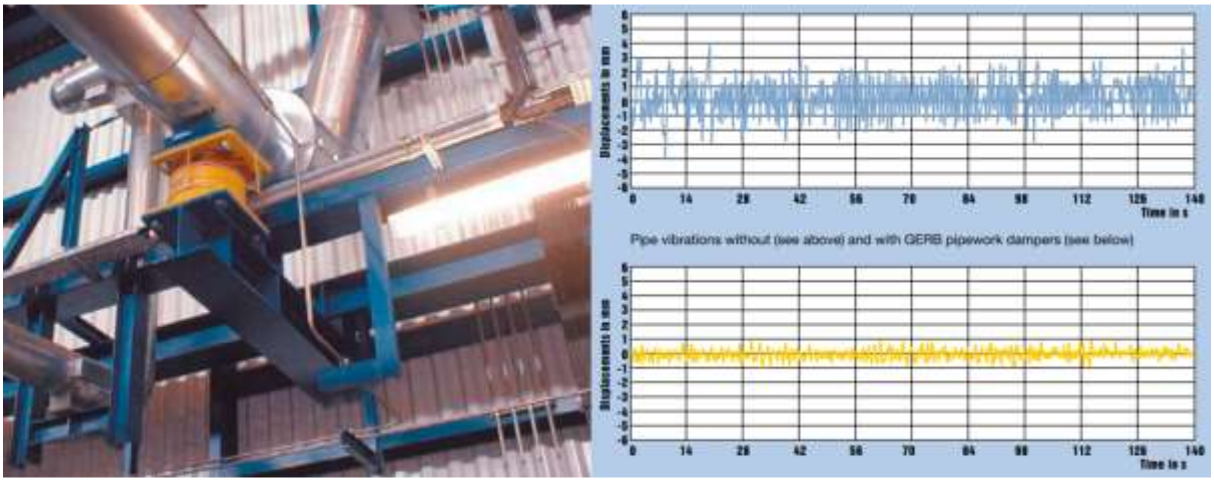


Figure 8. The effect of a viscoelastic damper on reducing pipe vibration due to FIV [14].

Viscoelastic dampers do not withstand static force and it is necessary to restrain the pipe by other supports. In the present problem, the reduction of dynamic forces is considered, and therefore these dampers can be an effective solution. It is recommended to use two dampers, one at the elbow of the pipe where vibrations are evident, and the other near the safety valve at the top of the tower and at the entrance of the amine pipe to the tower. By using two dampers in two positions, instead of one damper, more vibration modes can be suppressed.

6. Summary/ Conclusions

This article has analyzed the vibrations of regeneration towers and their inlet rich amine pipes in two similar gas treatment units of SPGC using an RCFA technique. First, the maintenance documents of the two units have been compared. Then the vibrations of two units have been measured at different points. The results have shown that the vibrations inside the pipe have a shock nature in a high-amplitude frequency range. It has been recognized that there is a possibility of slug flow in the pipe which is the source of this type of vibration. Modal analysis has depicted that the natural frequency of the regeneration tower is equal to 1.4 Hz, which is within the pipe excitation range. Employing RCFA technique, FSI and resonance are identified as the cause of vibrations. The pipe vibrations of both units have been compared with different criteria and it has been shown that the pipe vibrations of both units need to be corrected. In the end, by examining different methods of modification, the use of viscoelastic dampers in two points has been recommended to reduce the vibrations of the tower, which will be the focus of research in the future.

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