Process Design of Ammonia Separation for Nitrification Control in Aeration Basins at an IKORC’s Oily Wastewater Treatment Unit

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ABSTRACT: In the current decades, water shortage is well understood as one of the main limiting factors for oil industry development all over the world. One of the available and reasonable solutions is reusing wastewater. The oily wastewater treatment unit of the IKORC refinery provides a portion of the makeup water for cooling towers, applying physical, biological, and chemical treatments. Ammonia shocks are the only crisis that disrupts the nitrification process. This condition eventuates in destroying the microorganisms of aeration basins and leads to a high ammonia containing effluent. In order to protect the aeration process, it is mandatory to apply a suitable system for removing excess ammonia. In this study, at first, ammonia removal history is reviewed. Then quantity and quality of the oily sewer are investigated. Because of high volatility of ammonia contamination and high TDS, a stripping tower with air is selected among diverse solutions. Taking into account the principles of project econometrics, operating parameters such as stripping factor, pressure drop, tower volumetric flow rate, and number of towers are determined. Then, the process is designed and its environmental survey is conducted. Finally, calculating indices proved that this project is economically profitable in addition to its environmental benefits.

1. INTRODUCTION

Development of living standards and the emergence of new industries followed by a rapid and continuous growth in population have eventuated in increasing the global concerns about the supply of new water resources around the world. Over the past 10 to 15 years, renewable water resources have declined by 80%, making water a limited resource and forcing people to search for more low-quality water resources. This requirement has led to significant development in the water and wastewater treatment (WWT) industry.1–6

The inlet feed of the IKORC refinery is composed of oily sewer water (OSW) outlet routes from various operating units, which are combined with the excessive stripped sour water of the refining units. Both sources are capable of carrying quantities outside the permitted range of various oil pollutants. Most of these pollutants are toxic and can cause adverse changes in the bacterial population of the biological treatment plant.7

Upon the emergence of novel technologies such as membrane technology and also by increasing the efficiency of the treatment plants in the physical and biological phases, the removal capacity of many pollutants, such as CO2, H2S, NO2, and ammonia, has increased substantially.8–16 The treated wastewater is used to supply part of the makeup water for cooling towers. The quality of the cooling water is controlled by injecting various chemicals. The pH is controlled by injecting acid, controlling the sedimentation and corrosion properties of the water with the relevant chemicals, and in wet towers by adjusting the concentration cycle. The discharged effluent in the refineries is one of the nonoil effluent sources that is usually injected into the relevant network.17–20

Providing the adaptation of bacterial population, the nitrification process has the ability to withstand shocks and is controlled with precise monitoring and more chemical use. However, in the case of more than 70 ppm ammonia, the process is uneconomical and impossible to control.21–23 In an experimental investigation, Sabbah et al. studied the potential application of tuff as a matrix for ammonia removal in an intermittent flow biofilter in comparison with sand. They perceived from the research that the tuff filters possess...
superior performance in ammonia removal compared to sand filters, which is able to be justified because of better adsorption capacity of tuff for ammonia compared to sand because its specific surface area is 50 times higher than the specific surface area of the sand. The surface area of solid adsorbents was shown to be a crucial parameter for efficient separation of pollutants. The surface area of solid adsorbents was shown to be a crucial parameter for efficient separation of pollutants. The surface area of solid adsorbents was shown to be a crucial parameter for efficient separation of pollutants.

Li et al. developed a novel technology to attain efficient partial nitrification at relatively low temperatures, which was able to appropriately decline the aeration cost and had the capability to treat an extensive range of ammonium-rich wastewaters with low chemical oxygen-demand-to-nitrogen (COD/N) ratios. They found out that after a 7 day start-up period, stable partial nitrification was obtained in the reactor for a period of up to 180 days.

In this investigation, quantitative and qualitative dimensions of pollution are evaluated applying flow monitoring and also performing the necessary tests with the aim of technical and economic feasibility study. Then, according to the results of feed conditions, the most appropriate operational option is selected and designed to remove ammonia. Indeed, the main objectives of this study include the following:

1. Wastewater analysis and explanation of qualitative and quantitative characteristics
2. Feasibility study of the process to remove ammonia shocks in the IKORC oil refinery
3. Designing the equipment process by providing engineering calculations
4. General economic analysis of the plan and determination of sensitive economic parameters for project implementation.

2. MATERIALS AND METHODS

2.1. Quantitative and Qualitative Identification of Oily Sewer. In order to design the process and equipment, having precise knowledge of the feed of unit in terms of quantity and quality seems to be necessary. The volume rate of the feed in a quarterly period must be monitored and the upper, lower, and middle limits of the incoming effluent must be recorded appropriately. Chemical analysis of wastewater should also be performed on pollutants affecting the selected process over a 3 month period to obtain an accurate view of the qualitative dimensions of the contamination load. The following are the tests and standard methods of each:

1. Electrical conduction, which is an indirect method for measuring the total amount of soluble solids in an effluent. This test is performed by an electronic guidance measuring device and the results are reported in unit of µs/cm.
2. The pH measured by the pH measuring device.
3. The existed oil in the effluent is measured by the ASTM D3921 standard method and is reported in ppm.
4. The total amount of suspended solids (TSS) is measured by the ASTM 2540 standard method and is reported in ppm.
5. The amount of available ammonia that is measured by the ASTM D1426 standard method and is reported in ppm.
6. The amount of total hardness that is measured by the ASTM D1126 standard method and is reported in ppm.

Because of the existence of high volume flow rate, high feed ammonia level, and high total hardness and soluble solids, the most appropriate operational option in this regard is to use the stripping process at ambient temperature and by air.

2.2. Presentation of Some Procedures for the Release of Free Oil. Because of the fact that the stripping tower is located after physical and chemical treatment units, a large amount of free oil from the tower’s feed has already been removed from the effluent. However, because of the volumetric shocks, possible oil leakage can also cause severe problems. In the process, there is no choice but to install a uniform reservoir. Therefore, the output of the existing dissolved air flotation (DAF) units is transferred by the pump to the uniform underground tank. DAF ponds are located at a height and the transfer of oil-stripped (skimmed) flow to the underground reservoir is usually carried out in a gravitational manner. However, at this stage of the design, because of a lack of information about the location, installation surfaces, and equipment distances, the need for a pump is assumed unavoidable.

In order to remove ammonia during the tower stripping process, the existing ammonium ion must first be released into the free ammonia state. Therefore, in the process of transferring effluent flow to the underground reservoir, a pipe mixer will be installed to inject 15–20 v % NaOH in order to increase the pH of the effluent in the range of 11–11.5. Also, an analyzer is considered to evaluate the pH and send a signal to the control room to issue a command to adjust the amount of NaOH injection.

Removal of probable oil is done by the slotted pipe skimmer of the underground reservoir. This equipment compensates the possible defects of the existing DAF and API systems. Slotted pipe skimmers can be appropriately utilized in different applications such as oil and scum removal from the surface of a basin when a significant amount of oil must be eliminated and the amount of water does not considerably vary. The rotation process of slotted pipe skimmers may be done either manually or by using a mechanical system. The skimmer and its associated parts are usually manufactured from disparate grades of stainless steel.

This underground reservoir consists of two parts, skimmer and clean effluent. After the physical removal of oil by the slotted pipe skimmer, the effluent enters the clean section of the reservoir. The separated oil by the metal slotted pipe skimmer is first transferred to an oil hole next to the underground reservoir, and finally, by increasing the oil level, it will be directed to the oil collection tanks in the unit by two pumps. The sludge collected at the bottom of the tank is directed to the sludge hole according to the designed slope of 6° and is pumped to the sludge hole in the sludge hole by two slug pumps that are submerged in water. Given that this flow comes from DAF systems, placing a metal grid in the first section of the underground reservoir is optional. The effluent from the underground reservoir is transferred to the top of the disposal tower by three pumps.

2.3. Ammonia Stripping Tower with Air. Ammonia shocks to the WWT plant of an oil refinery are likely to undergo extensive changes in ammonia concentration in values higher than the economic conditions of the nitrification process (70 ppm) because of the variety of different inputs. Packed stripping towers have long been used...
in the chemical industry. Among the most important applications of this technology are the disposal of volatile organic compounds and ammonia from water resources, wastewaters, and leachate from waste disposal sites with maximum separation efficiency. This method, which is based on the mechanical removal of ammonia, can remove high levels of this contaminant in aqueous solutions at high flow rates. The contaminated water is pumped to the top of the column and slowly spreads over the area, the cross section of the column, which is filled with porous packings.\textsuperscript{35,36} An air–water stripping tower consists of the following compartments:

1. Column shell
2. Internal equipment
3. Packings’ retaining plate at the bottom of the tower
4. Liquid distribution tray at the top of the tower
5. Liquid redistribution trays in the distance between the liquid distribution tray at the top of the tower and the packings’ retaining plate at the bottom of the tower
6. Mist eliminator located above the distribution tray
7. Empty exhaust air at the top of the tower
8. Fan and air conduction channel to the tower
9. Centrifuge pump and related routes for transferring polluted water to the top of the tower.\textsuperscript{7,17}

### 2.4. Principles and Stages of Designing the Process of Ammonia Stripping with Air

The required equipment in the process of ammonia stripping with air is divided into two categories. The first category is the tools that can be prepared from the market without the need for design and construction and only by determining the specifications and dimensions of the required process. For this category of equipment, only the relevant specifications for the tender are determined. The list and number of these equipment according to the box diagram are as follows:\textsuperscript{7,17}

- Fixed mixer (6 pieces)
- pH analyzer (6 pieces)
- Ammonia analyzer (2 pieces)
- Caustic injection pumps (4 pieces)
- Acid injection pumps (10 pieces)
- Skimming intake pumps (3 pieces)
- Skimming outtake pumps (10 pieces)
- Towers’ outlet pumps (10 pieces)

The design of the stripping tower is expanded based on the principles of mass transfer using the mathematical model of the process. Because the number of unknown parameters is greater than the number of equations, a variety of designs for the stripping tower can be determined to achieve the desired ammonia removal. In an air–water stripping machine, assuming values for some variables independent of the equations, such as the stripping factor ($S$) and the air pressure drop across the column ($\Delta P$), and also by examining economic requirements, various designs are implemented.

#### 2.5. Henry Constant

The Henry constant ($K_H$ with the unit atm·m$^3$/mol and H in the dimensionless form) is considered as a sign of the compound’s relative instability.\textsuperscript{37–39} This example expresses the abundance of the compound in the gas phase with the same amount in aqueous phase in equilibrium, which is an important parameter in the design of an effluent stripper with air. If $K_H < 10^{-7}$ atm·m$^3$/mol, there will be little tendency for stripping from the liquid phase (low volatility), if the $K_H$ values are in the range of $10^{-7} < K_H < 10^{-3}$ atm·m$^3$/mol, this compound will slowly evaporate from the water (low volatility). Compounds with $K_H$ values in the range of $10^{-5} < K_H < 10^{-3}$ atm·m$^3$/mol are relatively volatile and are often easily removed by air–water effluent stripping device (medium to high volatility). Values of $K_H$ greater than $10^{-3}$ atm·m$^3$/mol indicate that evaporation will proceed rapidly (rapid volatility). It should be noted that ammonia is present in water in the form of ammonium ions, and according to the Le Chatelier's principle, at first, by alkalinizing the effluent, ammonium ions must be converted to ammonia gas so that it can be separated from water with optimal efficiency as the follows:\textsuperscript{36,41}

$$\text{NH}_4^+ + \text{OH}^- \leftrightarrow \text{NH}_3 + \text{H}_2\text{O} \tag{1}$$

\[
\% \text{NH}_3 \text{ removed} = \frac{10^{\text{pK} + \text{pH}}/(10^{\text{pK} + \text{pH}} + 1)}{	ext{pK}_{\text{NH}_4^+}} = 9.0387 \times 10^{-2} + \frac{2.7293 \times 10^{-1}}{T (K)}
\]

\[
T = 25 \degree C
\]

\[
\text{pH} = 11
\]

\[
\text{pK}_{\text{NH}_4^+} = 9.0387 \times 10^{-2} + \frac{2.7293 \times 10^{-1}}{298} = 9.25
\]

\[
\% \text{NH}_3 \text{ removal} = \frac{10^{(11.9283 - 1.75)} \times 100}{10^{(11.9283 - 1.75)} + 1} \times 100 = \frac{10^{(1.75)} \times 100}{10^{(1.75)} + 1} \times 100 = 98\%
\]  \tag{2}

In other words, it is possible to theoretically separate 98% of ammonia gas from water by air at pH = 11. Under these conditions and a temperature of 25 °C, the Henry constant is equal to 1.6 × 10$^{-3}$ atm·m$^3$/mol, in that case ammonia is mainly in the low to moderate volatility group.

### 2.6. Criteria for Designing an Air–Water Stripping Tower

The design of the air–water effluent stripping tower is considered as a counter-current gas–liquid flow in the packed tower.\textsuperscript{36,42,43} Stripping factor ($S$) and gas pressure drop ($\Delta P$) are considered as two design variables. The overall mass transfer coefficient is estimated using the valid Onda model.\textsuperscript{44} By changing the flow rate of water, it is possible to achieve a lower cross section and a smaller diameter of the stripping tower and consider it as an initial assumption from the beginning of the project to achieve optimal conditions after approval of all design and economic criteria.\textsuperscript{45} Table 1 renders the criteria and design limitations of the stripping tower.

### Table 1. Criteria and Design Limitations of the Air–Water Stripping Tower\textsuperscript{7,17}

| parameters | unit | VOC compounds removal | ammonia removal |
|------------|------|-----------------------|-----------------|
| falling liquid ratio | L·m$^{-3}$/min | 600–1800 | 40–80 |
| gas to liquid ratio | m$^3$/m$^3$ | 20–60.1 | 2000–6000:1 |
| stripping ratio ($S$) | G/(L·h) | 1.5–5 | 1.5–5 |
| permitted pressure drop ($\Delta P$) | (N/m$^2$)/m | 100–400 | 100–400 |
| height to diameter ratio ($Z/D$) | m/m | max 10 | max 10 |
| packing height ($Z$) | M | 1–6 | 2–6 |
| safety factor (SF) | D % | 20–50 | 20–50 |
| pH | 5.5–8.5 | 10.8–11.5 |
Liquid flux = 80 \left( \frac{1}{m^2 \times \text{min}} \right) = 4.8 \left( \frac{m^3}{m^2 \times \text{h}} \right) 
\begin{align*}
D &= 3 \text{ m} & A &= 7.06 m^2 & Q_{\text{wastewater}} &\approx 34 \\
D &= 4 \text{ m} & A &= 12.56 m^2 & Q_{\text{wastewater}} &\approx 60
\end{align*}

\text{(3)}

Liquid flux = 40 \left( \frac{1}{m^2 \times \text{min}} \right) = 2.4 \left( \frac{m^3}{m^2 \times \text{h}} \right) 
\begin{align*}
D &= 3 \text{ m} & A &= 7.06 m^2 & Q_{\text{wastewater}} &\approx 17 \\
D &= 4 \text{ m} & A &= 12.56 m^2 & Q_{\text{wastewater}} &\approx 30
\end{align*}

\text{(4)}

2.7. Design Stages of the Stripping Tower. The design operation of the packed stripping towers is of the filling type with the counter-current interaction of air and water for gas/liquid absorption or stripping applications with the simultaneous solution is presented as follows. To advance the design and problem solving, the input and output ammonia are assumed to be 300 and 30 ppm, respectively. Additionally, the input volume flow rate of the effluent entering the stripping tower is considered to be 50 m³/h.

2.8. Determining the Percentage of Ammonia Removal. The following equation can be applied to compute the ammonia removal:

\text{ammonia removal} = \left( \frac{C_{\text{in}}^L - C_{\text{out}}^L}{C_{\text{in}}^L} \right) \times 100

\text{(5)}

In the above-mentioned equation, \( C_{\text{in}}^L \) and \( C_{\text{out}}^L \) are defined as the influent liquid solute concentration and effluent liquid solute concentration. Assuming 300 ppm of input ammonia and 30 ppm of output ammonia

\text{ammonia removal} = \left( \frac{300 \text{ ppm} - 30 \text{ ppm}}{300 \text{ ppm}} \right) \times 100 = 90\%

\text{(6)}

Dimensionless Henry constant is an important parameter, which can be calculated by the following equation:

\begin{align*}
H_{\text{NH}_3,7} &= 0.0006 \exp \left( \frac{1}{293} - \frac{1}{T} \right) \\
H_{\text{NH}_3,7} &= 0.0006 \exp \left( \frac{1}{293} - \frac{1}{273 + 25} \right) = 0.0006
\end{align*}

\text{(7)}

Considering the amount of air flow rate to water, the stripping factor (\( S \)) is computed by the following equation

\begin{align*}
volumetric \text{ air/water ratio} &= 3000 \text{ to } 3300 \\
S &= H \times ((\text{volumetric air/water ratio}) \times Q_{\text{AM}}/L_M) \\
&= 0.0006 \times 3000 = 1.8
\end{align*}

\text{(8)}

where, \( Q_{\text{AM}}, L_M, \) and \( H \) are, respectively, interpreted as the air flow rate per unit area, liquid mass flux, and Henry’s law constant. By applying the following equation, NTU can be appropriately computed as:

\begin{align*}
\text{NTU} &= \left( \frac{S}{S - 1} \right) \ln \left( \frac{(S - 1) C_{\text{Lin}}}{S} + \frac{1}{C_{\text{out}}} \right) \\
&= \frac{2}{2 - 1} \ln \left( 2 - \frac{1}{C_{\text{in}}} \right) + \frac{1}{C_{\text{out}}} + \frac{1}{2} = 3.4
\end{align*}

\text{(9)}

According to Table 1, the allowable pressure drop, flooding velocity and the liquid mass flux can be determined by the following equation

\begin{align*}
\text{select: } &50 \text{ (1/m² min)} = 8.33 \times 10^{-4} \text{ (m³/m² s)} \\
Q_{\text{w}} &= 50 \text{ m³/h} = 0.01388 \text{ m³/s} \\
\text{cross sectional area} &= (0.01388)/(8.33 \times 10^{-4}) = 16.66 \text{ m²} \\
\text{diameter} &= (16.66 \times 4) = 3.142 \approx 4.5 \text{ m}
\end{align*}

\text{(10)}

where, \( Q_{\text{w}} \) is the liquid flow rate.

2.9. Determination of the Overall Mass Transfer Coefficient. The overall mass transfer coefficient can be determined by the results of pilot tests in steady-state conditions, but if the pilot is not available, this coefficient can be calculated by the valid Onda method. Two-phase resistance theory is widely used to describe mass transfer in gas–liquid transfer processes. In this theory, the solute is transferred from the one-phase mass to the interface and then is transferred from the interface to the second-phase mass. There is limited thickness on each part of the layer, and the dissolved molecules must penetrate through these layers before passing from the liquid phase to the gas phase, as shown in Figure 1.

Figure 1. Two-phase resistance model of gas/liquid mass transfer.

The overall mass transfer resistance is calculated by the summation of the two separate resistance of the liquid phase (\( K_L \)) and the gas phase (\( K_G \)). In the Onda method, at first, the value of \( D_{\text{L}} \) and \( D_{\text{G}} \) parameters must be determined. For this purpose, Wilke Chang & Hirschfelder’s equations are applied. To calculate \( D_{\text{L}} \), the following equation is derived:

\begin{align*}
\frac{D_{\text{L},AB} \mu_B}{T} &= 7.48 \times 10^{-8} (\phi_B M_B)^{1/2} \\
&= \frac{V_B^{0.6}}{T}
\end{align*}

\text{(11)}

In this equation, \( D_{\text{L},AB}, \mu_B, T, M_B, V_B, \) and \( \phi_B \) are denoted as the liquid diffusivity of solute A in solvent B, viscosity of the solvent, absolute temperature, molecular weight of solvent B, molar volume of the solute at normal boiling temperature, and association parameter for solvent B, respectively. By predicting the aforementioned parameters’ values at 298 K, the value of \( D_{\text{L}} \) is determined as
The following equation is applied to calculate the amount of $k_G$:

$$
K_G/a_D = 5.23\left[\frac{Q_M}{a_D\mu_G}\right]^{0.7}\left[\frac{\mu_G}{\rho_L D_G}\right]^{1/3}\left[\frac{a_D d_p}{t}\right]^{2}
$$

(19)
\[ Q_C = 3300 \times 0.01388 = 45.804 \text{ m}^3/\text{s} \]

density of air = 1.2041 kg/m³ at 25 °C

\[ Q_M = 45.804 \times 1.66/16.66 = 3.31 \text{ kg/m}^2\cdot\text{s} \]

\[ \mu_g = 1.86159 \times 10^{-5} (\text{kg/m} \cdot \text{s}), \; d_p = 0.0762 \text{ m} \]

\[ K_G = 5.23 \left( \frac{73.2}{(2.085 \times 10^{-4})} \right)^{1/3} \]

\[ K_G = 0.054 \text{ m/s} \]

With the aim of achieving \( k_L \), the following equation would be used as

\[ K_L = \rho_L \left( \frac{1}{\mu g} \right)^{1/3} \left( \frac{L_M}{a_m \mu_L} \right)^{2/3} \left( \frac{H}{a_D} \right)^{-0.5} \left( \frac{a_d}{d_p} \right)^{0.4} \]

Using the values:

\[ \left( \frac{998.2}{0.000891 \times 9.8} \right)^{1/3} = 0.0051 \left( \frac{20.49}{(0.000891)} \right)^{2/3} \]

\[ K_L = 0.0001383 = 1.383 \times 10^{-4} \text{ m/s} \]

The calculation of the overall mass transfer coefficient (\( K_L \)) takes place using the following equation

\[ \frac{1}{K_L} = \frac{1}{H \times K_G} + \frac{1}{K_L} = \frac{1}{(0.0006) \times (0.054)} + \frac{1}{0.0001383} = 38,191 \]

In this equation, \( k_L, K_G, \) and \( H \) are expressed as the liquid film mass transfer coefficient, gas phase mass transfer coefficient, and Henry’s law constant, respectively. By computing \( K_L \), the amounts of the overall volumetric mass transfer coefficient \( (K_L a) \) is determined as

\[ k_L a = 2.625 \times 10^{-4} \times 20.49 = 0.00053792 (1/\text{s}) \]

\[ = 5.3792 \times 10^{-4} \text{ s}^{-1} \text{ (assume } a = a_w \text{)} \]

### 2.10. Calculation of HTU and Packing Height (Z)

In order to calculate the HTU and packing height, the following equations are applied

\[ \text{HTU} = \frac{Q_m}{(K_L a) \times A} = 0.01388/(5.3792 \times 10^{-4}) \]

\[ \times (16.66) = 1.549 \]

\[ Z = \text{NTU-HTU} = 3.4 \times 1.549 = 5.26 \text{ m} \]

take 20% overdesign = 1.2 \times 5.26 = 6.3 \text{ m}
2.11. Stripping Tower Design Using ASDC Software.

ASDC software, along with operational corrections, will design the stripping tower. ASDC software is one of the fewest types of software, which is able to estimate the cost of investment and operating costs. Figure 2–4 shows the design process for the effluent with a volume flow rate of 50 m³/h, input ammonia of 300 ppm, and output ammonia of 30 ppm at 25 °C. Figure 5 uses an Iranian 3 in. plastic Pall Ring packing according to what was included in the manual calculations.
The software output is shown in Figure 5. As can be seen, the implemented design using software is in brilliant agreement with the results of the manual design. Therefore, instead of manual calculations, this software can be used to design other specifications and different packings.

By obtaining the experimental results and determining the qualitative conditions of the effluent and the amount of ammonia load associated with it, as well as monitoring the volume flow rate, feed specifications are obtained for entering software. On the other hand, choosing the most appropriate type and size of packing, the best pressure drop for the tower and the desired amount of the stripping factor, and considering the cost of the whole process leads to different design scenarios that must be considered with economic and operational considerations to choose the best option.

2.12. Principles of Performing Economic Calculations of the Project. The cost model introduced in ASDC software can comprehensively perform all economic calculations. In this software, according to the available resources in the field of project economics, the total cost of the investment is obtained from the sum of direct and indirect costs.58

As shown in Figure 6, direct costs include the cost of equipment, which is divided into two parts: process equipment and ancillary services. Process equipment, which includes tower shells, internal accessories, packings, blowers, and mist eliminators, is calculated by software. The packing cost is one of the key parameters of the tower’s direct cost. If the tower’s packing height is more than 6 m, 2 water distribution trays are required. Also, the cost of redistribution trays is considered equal to 5% of the main water distribution tray. Approximately every 1.5 to 2 m of filling height, a water redistribution tray is required. The pressure drop of the channels and internal components inside the tower (water distribution tray, redistribution trays, and mist eliminator) is generally considered to be 0.05 psi.58

Indirect costs include workshop equipment costs, land preparation, engineering, installation, and construction. Based on information from project design authorities, the indirect cost is calculated as follows65

\[
\text{site works} = 0.15 \times \text{direct cost} \tag{27}
\]
\[
\text{engineering} = 0.27 \times \text{direct cost} \tag{28}
\]
\[
\text{construction} = 0.20 \times \text{direct cost} \tag{29}
\]

Operating costs consist of the total cost of electricity, personnel, and maintenance. In order to correct the basic prices in software, an update factor is used. The factor used
in the ASDC computer program is related to the ENR construction cost index, which is an internationally valid factor. Figure 7 shows how to enter the information needed for economic calculations.

If water is not hot, the sedimentation problems related to the packings will be negligible, and the computer program considers the maintenance cost to be equal to 5% of the direct costs.

Maintenance cost = 0.05 × direct cost  \hspace{1cm} (30)

### 3. RESULTS AND DISCUSSION

The most important information needed to design the ammonia separation process is to know the average and high volume flow rate entering the process. Because the stripping process by the using stripping tower is located between DAF units and aeration reactors, its feed is DAF output. The flowmeters in the wastewater treatment (WWT) unit are installed at the inlet and outlet of the whole system, and regardless of the small volume of oil and sludge separated from the effluent, it can be considered as a criterion for measuring the flow of the system’s internal components such
Figure 9. Rate of ammonia fluctuations in the autumn quarter of 2016.

Table 3. Tower Design Results with Different Packings for Similar Operating Conditions

|                  | USA plastic | Germany plastic | European plastic | Iranian plastic |
|------------------|-------------|-----------------|------------------|-----------------|
|                  | Q-Pac Lantec | Novalox Saddle | Pall Ring        | Pall Ring       |
| stripping factor | 4"          | 3"              | 3/5"             | 3"             |
| packing factor   | 2           | 2               | 2                | 2               |
| tower diameter (m)| 3.6        | 4.08            | 4.14             | 4.71            |
| tower height (m) | 16.7        | 10.3            | 11.32            | 7.94            |
| liquid mass flux (kg/m³·s) | 1.314 | 1.06            | 1.028            | 0.793           |
| air mass flux (kg/m³·s)   | 4.744   | 3.827           | 3.712            | 2.862           |
| air to water flowrate ratio | 3039    | 3039            | 3039             | 3039            |
| overall mass transfer coefficient (s⁻¹) | 3.6 × 10⁻⁴ | 4.57 × 10⁻⁴ | 4.04 × 10⁻⁴ | 4.44 × 10⁻⁴ |
| allowed pressure drop (N/m²·m) | 250      | 400             | 400              | 400             |

as DAF input and output. However, in order to eliminate possible errors of flow measuring instruments, the output flow of the DAF unit was measured five times each month by calculating the level change of the outlet pool. The reason for monitoring the flow is to ensure that all fluctuations of the flow are recorded and finally to select the correct volume flow rate for the design. The result graph is shown in Figure 8. As can be seen, except two cases, in most cases the flow rate fluctuates between 215 and 233 m³/h, which means that a volume flow rate of 240 m³/h is suitable for process design. The direction of the effluent to the stripping tower should be done during the design stage of the tower along with the relevant economic calculations. The results of these calculations show that the entire effluent enters a large tower or must be divided into several branches and enter the smaller towers.

3.1. Experimental Analysis. Another important parameter needed for the design is the analysis of the feed input to the process. The average results are shown in Table 2. Because the most important pollutant discussed in this investigation is ammonia, the graph of its changes is also shown in Figure 9. Given that the operational changes of the refining units can be significantly extensive, considering a time period of three months can provide a suitable and comprehensive view of the qualitative behavior of the oily sewer. Unplanned or emergency exit of units and their service, permanent and occasional discharges of various tanks, and changes in the operating conditions of one or more refining units are among the items that can cause qualitative fluctuations in wastewater. The amount recorded for electrical conductivity, as well as the overall hardness of the effluent indicates that the dissolved solutes are high, making it unavoidable for the stripping tower to operate at ambient temperature. In fact, although the increase in the temperature eventuates in faster ammonia removal, it causes corrosion because of the impurities dissolved in the effluent, and eventually leads to the premature failure of the tower and related equipment. This issue removes the hot steam stripping tower process from the list of options and demonstrates the need to use an air stripping tower at ambient temperature. Once the effluent pH has been determined, the amount of NaOH required to increase the alkalinity of the feed of the stripping tower is determined and the conditions for ammonia removal is calculated. Consequently, the injection volume of NaOH and the coordinates of the injection pumps are determined. The results show that the pH entering the system should be considered 6 and the injection pumps should be designed based on it so that the process is completely flexible against pH changes. The measured values for this parameter include a wide range from 16 to 432 ppm. The design of the refinery’s oily sewer recovery unit is based on 23 ppm of input ammonia, but the nitrification process is economically viable and operationally controllable in the amount up to 50 ppm.

As shown in Table 2, during the 3 month period, the ammonia level was above 50 ppm in 80% of cases, and this issue necessitates the design of an ammonia removal system before aeration basins. As can be seen from Figure 9, the major fluctuations of the output ammonia during this period were between 200 ppm and 300 ppm. Therefore, the best option for input ammonia for designing a stripping tower is 300 ppm.

3.2. Determining the Packing Type and Size. Due to the fact that the flooding rate strongly depends on the packing type and size and the liquid mass flux, and also because of the high ratio of air to liquid in the ammonia stripping process, it is clear that using larger packings with a smaller packing index is more appropriate. Packing index,
provided by the manufacturer, includes all the characteristics of the packing. Different designs for the effluent with the value of ammonia contamination 300 ppm were performed using different packings with a size of about 3 in. To assure the validation of the results, except packing type, other conditions were considered the same in all designs and limitations related to the design criterion are considered according to Table 1. The effluent temperature is 25 °C, the ambient pressure is 1 atm, and the pH is 11. Also, the removal efficiency required to reduce ammonia load to 30 ppm is 90%.

Determining the optimal capacity of each tower unit and stripping factor should be considered in the next steps, but at this stage, to create the possibility of comparison between different packings, these parameters were assumed to be 50 m³/h and 2, respectively. The results are given in Table 3.

The results of Table 3 show the importance of the effect of the packing and its corresponding factor on the fluid flux of the tower. Because of the lack of easy access to the modern Q-Pac Lantec packing and the proximity of the German Novalox saddle packing model with the European Pall Ring and the better benefits of the Pall Ring than the Saddle, such as more empty space and less pressure drop during sedimentation, an economic study of the project for two Pall Ring models of approximately the same size as the Iranian and European ones is conducted in order to select the appropriate option for this project. If the height of the packing is more than 6 m, in order to observe the symmetrical design criterion, two packing beds with two separate liquid distribution trays have been used. The specifications of these two packings are shown in Table 4 and the design results along with the economic feasibility are shown in Table 5.

### Table 4. Specifications of Two European Pall Ring Fillers and Iranian Production

| Material          | Nominal Size (mm) | Surface Area (m²/m³) | Packing Factor (ft⁻¹) |
|-------------------|-------------------|----------------------|----------------------|
| Polypropylene     | 76.2              | 73.2                 | 28.6                 |
| Plastic           | 88.9              | 85                   | 17                   |

It can be seen that both packings, especially with stripping factor 2, are able to remove ammonia under favorable conditions and in accordance with the allowed design range according to Table 1. Also, in addition to the benefits of easier access to the Iranian sample, the above economic study shows the significant superiority of Iranian packing.

### 3.3. Determining the Pressure Drop and Stripping Factor

The choice of the pressure drop and stripping factor are two important factors in the design that both affect the operational conditions of the process and play an important key role in determining the dimensions of the tower. By combining a process study with economic considerations, the optimal values of these two parameters can be determined. By using the maximum allowed pressure drop, the diameter of the tower can be reduced. The best model based on which the effect of these two factors on interaction with each other can be examined is that different designs are performed in the total allowable range. According to Table 1, the allowed range of ammonia stripping tower’s pressure drop is between 100 to 400 (N/m²) m and the allowed range of stripping factor is between 1.5 and 4. Figure 10 shows the relationship between these two factors and the total cost of the investment (including initial investment and annual operating cost) based on the US dollar per year.

### 3.4. Determining the Number of Stripping Towers

The total amount of the effluent entering the ammonia removal system was determined 240 m³/h. What should now be determined based on this amount of flow is the number of...
required towers. The most important factor in determining the number of towers is economic considerations. Ease of operation, ease of maintenance and supply of parts, and considering the capacity of the excess process for repairs are the other influential factors in this regard. To keep the process going, it is necessary to have at least one tower similar to the main towers for unexpected repairs or overhauls. According to the proposed cases, the total inlet flow can be divided into two equal parts of 120 m$^3$/h. In the same way, four towers with a capacity of 80 m$^3$/h, five towers with a capacity of 60 m$^3$/h, or six towers with a capacity of 50 m$^3$/h can be considered. The best economic option for each of the above cases has to be chosen while examining the process parameters. Table 6 renders the process and economic results of the stripping tower design for different states of volume flow distribution.

Examination of the design results shows that, as expected, with the correct selection of variables based on the findings of the previous steps, all process specifications in all eight of the above modes are within the allowable range. Regarding the dimensions of the tower, the $L/D$ parameter mostly fluctuates in the range of 1.5–2.5, which indicates the dimensional fit of the tower. The volume fluxes of the falling liquid and air-to-liquid ratio are also suitable in all eight modes. Values of the overall mass transfer coefficient, the ratio of wet surface to volume and liquid flux in the cases where the stripping factor is equal to 1.5 have a relative advantage over other modes, and this advantage is well reflected in the project econometrics. Economic comparison of different scenarios for the volume flow rate shows that a flow rate of 60 m$^3$/h has the lowest initial investment, annual operating costs, and the lowest total annual investment. The comparative chart of the total annual capital for these different cases is shown in Figure 11. Therefore, the final selection of the stripping tower is based on the flow rate of 60 m$^3$/h and the stripping factor of 1.5, and the data of this case are applied to perform calculations and determine the remaining specifications of the devices.

4. CONCLUSIONS

The presence of high amounts of ammonia in the oily sewer sent to the IKORC oil refinery’s WWT unit and consequently the disruption of the nitrification process of the aeration basins of this unit causes significant amounts of the treated effluent to be wasted. In this research, in a quarterly period, the monitoring of the volume flow rate of oily sewer entering the aeration basins of the WWT unit was performed to evaluate the fluctuations and determine the amount of the inlet feed. Then, by performing the required analyses in order to identify the types of pollution and its amount, the type and dimensions of the stripping tower and its related equipment were determined. Based on the results of quantitative effluent monitoring, a flow rate of 240 m$^3$/h
was considered for the inlet feed. Experiments have shown that an effluent with an average electrical conductivity of 1360 mS/cm and a total hardness of about 190 ppm exist, which means that due to the potential of sedimentation, it is not possible to use processes above ambient temperature. By evaluating the results of the ammonia test, 300 ppm was considered for the input feed. The best design option for the stripping tower is to use five identical parallel towers with a capacity of 60 m³/h for each of them, with “Iranian Pall Ring 3” packing for the effluent with a temperature of 25 °C, ambient pressure of 1 atm, and pH equal to 11. Considering a pressure drop of 400 N/m².m and a stripping factor of 1.5, the removal efficiency is 90%.

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**Notes**
The authors declare no competing financial interest.

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