EFFECT OF OPERATING AND DESIGN VARIABLES ON STRIPPED SOUR WATER QUALITY

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Abstract As technology evolves, the environmental legislations on pollutant concentrations in aqueous effluents tend to tighten and increase. As a result, sour water must be handled and processed properly in order to high quality of stripped water with insignificant traces of NH3 and H2S. This must be achieved within the minimum operating costs.

This work analyses the effect of operating/design variables (such as feed temperature, feed location, number of stages, and steam flow rate) on the stripped water quality in two cases (A refluxed absorber without a reboiler and an absorber with a side-compressor). HYSYS V.8 simulation tool was used to accurately simulate the two cases. The feed data was acquired from the factory of POSCO (Pohang Iron and Steel Corporation) in South Korea.

It was found that the best stripping efficiency in the refluxed absorber was when the feed was fed at the first stage, with maximum feed temperature, number of stages and steam flow rate. For the absorber with compressor, the feed was fed in the first stage and the reflux split and the pressure ratio were changed to monitor their effect on the tower efficiency. Results showed that increasing the reflux split increases the flow rate of NH3 and acid gases in the off gas, while increasing their concentration in treated water (200 ppm) restricting the use of reflush split. It also proved that increasing the pressure ratio carries more energy to the sour water feed heat exchanger. The effect of changing the pressure ratio on the compressed gas temperature and the compressor duty was also studied. Results of the treated wastewater streams guarantee that the effluent sour water owes by standard environmental regulations.

KEYWORDS: SOUR WATER, STRIPPING, AMMONIA, ABSORBER, HYDROGEN SULPHIDE

1. Introduction

Refineries are considered the primary producers of sour water, when compared to other oil and gas processes [1,2]. Sour water has also many other sources within petrochemical plants and all the units that consumes live steam and heat, along with the presence of nitrogen and hydrogen containing compounds; for instance: fluid catalytic reactors [3], thermal and catalytic cracking units [4], coker units [5], amine regenerators, hydro-sulphurisation units [6], crude desalting units, drums and the washing of hydrocarbons introduced with caustic operations [6]. Sour water is also found extensively in iron and steel factories [7].

Usually, steam stripping process is used for sour water treatment, since it helps in stripping light elements from the sour waste water. Industrially, some technical problems are encountered such as plugging, extreme usage of steam and maintaining the column pressure [7].

In sour water stripping, an external heat source either live steam or steam production by a reboiler is used to reverse the chemical equilibrium by warming (if not boiling) sour water. The produced vapor acts as a gaseous solvent that extracts ammonia and hydrogen sulfide from the sour water by the following implementations [2]: the elevation of sour water feed temperature to the boiling point, the reversal of chemical equilibrium reactions, and diluting the partial pressure of stripped ammonia, hydrogen sulfide and carbon dioxide by furnishing excess vapor.

It was stated that the variation of steam rate had a considerable influence on the stripped water composition [6], where the hydrogen sulfide concentration declines as the steam rate inclines. Same goes for ammonia to a certain limit, where hydrogen cyanide reacts with it, until the concentration of ammonia becomes adequately low, then the ammonia and hydrogen cyanide are both stripped [4,5].

2. Literature Review

Bellen [1] suggested a scheme where the sour water is fed to a flash drum in order to separate the present hydrocarbons and sour water. The sour water is then heated via hot stripped treated water. It is then fed to the sour water stripper with decreased pressure. The required heat for stripping could be achieved either from live steam or from a low pressure steam reboiler. The process was modeled using HYSYS and PRO/II as simulation tools. In the PRO/II, two approaches were employed in the system's model: SOUR and GPSWAT [2].

In 2011 a software package with the ability to simulate sour water strippers including all of the side reactions have been initiated which goes by the name of Pro Treat [2]. Weiland [6] used Pro Treat to simulate a refluxed absorber for sour water treatment. Fixed valve trays were used to avoid fouling, since the gas acts as a valve cleaner.

Walker [8] also implied normal and refluxed strippers with realistic operating data, as well as studying numerous operating factors on stripping performance. Melin [9] contributed in studying further operating variables on stripping performance. Furthermore, it was illustrated that the injection of a caustic base in the lower segment of the tower could help to achieve the desired ammonia removal [9,10]. It was Darton [10] who observed that the stripping efficiency is dependent on steam rate as well as number of trays though experimental studies. On the other hand, Isla [11] proposed a developed design in sour water strippers that lowered the required heating energy of the reboiler. He also made trials to reach the optimal operating conditions.

Lee [7] studied a sour water treatment system, taken from a real life case study of a steel corporation named POSCO (Pohang Iron and Steel Corporation) in South Korea. His main target was minimum energy consumption, while achieving treated water criteria of ammonia concentration less than 100 ppm and hydrogen sulfide 23 ppm. He discussed the dynamics of the sour wastewater stripping process, as well as controlling the column pressure.

3. Variables Affecting the Stripping Efficiency

This work aims at studying the variables affecting the stripping efficiency in sour water stripping plants for two different cases. The first case is a refluxed absorber without a reboiler, while in the second case, a new compressor is added resulting in the creation of new variables; the pressure ratio and the reflux split. The designs will achieve Weiland's treated water criteria (30-80 ppm ammonia and less than 0.1 ppm hydrogen sulfide) [6]. Those cases were built using HYSYS simulating program. The operating data and feed composition was acquired from Lee [7] from the factory of POSCO.

4. Case #1

In this case, only a refluxed absorber (shown in Figure 1) is used in investigating the variables affecting the stripping efficiency.
It was observed that as the feed temperature increases, the amount of liquid NH$_3$ and acid gases decreased in the effluent stream. This means that the stripping efficiency is enhanced on the expense of the cost of feed heating.

Figure 1: Case #1, Refluxed absorber
80700 kg/h of sour water was fed to the refluxed absorber at 64°C with a pressure of 160 kPa. The concentration of NH$_3$, H$_2$S, CO$_2$ & HCN was 13000, 2500, 8000 & 100 ppm respectively. 10810 kg/h of stripping steam was fed at 170°C, with a pressure of 200 kPa. The sour water was fed at the 2nd stage of the 12 staged refluxed absorber. The top pressure of the refluxed absorber was 129 kPa, while the bottom pressure was 155 kPa. The feed location was changed from stage 1 to stage 10, the feed temperature was changed from 64°C to 110°C, the number of the stripper stages was changed from 3 to 20 stages, while the steam flow rate was changed from 10809 kg/h to 20000 kg/h. For every variable changed, the flow rate of each component is obtained at each of the column trays. All variables were kept constant unless its variation is being studied.

5. Results of Case #1

5.1 Feed stage location
The effect of changing feed stage location from stage 1 to stage 10 was studied. Feeding at stages 1, 4, 7 and 10 results are illustrated in Figure 2.

![Figure 2](image)

It has been noted that the NH$_3$ and H$_2$S are at their highest concentration in their vapor phase after the feeding tray. As for the liquid phase, the highest concentration was on the feeding tray. It was also concluded that when the feed is fed on the first tray; the lowest mass flow rate of NH$_3$ and acid gases in the liquid effluent stream is achieved.

5.2 Feed Temperature
In this section, the effect of changing feed temperature from 64°C to 110°C was tested. The minimum feed temperature is 64°C (Lee [7]), while the highest temperature is 110°C, which is the maximum temperature HYSYS can converge at. The effect of changing feed temperatures at 64°C, 80°C, 95°C and 110°C on the mass flow rates of all components is illustrated in Figure 3.

![Figure 3](image)

Figure 3: Effect of changing feed temperature on the mass flow rate on each stage
(a) Feed temperature 64°C, (b) Feed temperature 80°C, (c) Feed temperature 95°C, (d) Feed temperature 110°C

5.3 Number of Stages
The investigation of changing number of stages (from 3 to 20 stages) on the off gas flow rate was implemented. Three stages are the least possible number to achieve conversion, while twenty is the maximum number of stages, beyond which, HYSYS does not converge. Mass flow rates of all components for towers with 3, 8, 15 and 20 stages are illustrated in Figure 4.

![Figure 4](image)

Figure 4: Effect of changing the number of stages on the mass flow rate on each stage
(a) 3 stages, (b) 8 stages, (c) 15 stages, (d) 20 stages

It is obvious that increasing the number of stages enhances the separation; which agrees with the mass transfer theory, as it allows more mass transfer to take place.

5.4 Steam Flowrate
The minimum steam flow rate required to omit the reboiler and transform the tower from a distillation column to a refluxed absorber was 10809 kg/h (according to HYSYS calculations). Lower than that value, HYSYS wouldn't converge. In this section, the results of changing the steam flow rate from 10,809 kg/h to 20,000 kg/h were depicted. Steam flow rates of 10,809 kg/h, 12,500 kg/h, 16,000 kg/h and 20,000 kg/h on the mass flow rates of all components is demonstrated in Figure 5.
Vapor NH₃, Light Liquid NH₃, Vapor H₂S, Light Liquid H₂S, Vapor CO₂, Light Liquid CO₂, Vapor HCN, Light Liquid HCN

Figure 5: Effect of changing steam flow rate on the mass flow rate on each stage
(a) 10809 kg steam/h, (b) 12500 kg steam/h, (c) 16000 kg steam/h, (d) 20000 kg steam/h.

As expected, increasing the stripping steam flow rate enhances the stripping efficiency, agreeing with the mass transfer theory.

6. Case #2
A new modification was applied in this case. A new compressor (K-100) was added and the condenser was omitted. The hot product was used to heat the sour water feed. In order to compensate the elimination of the reflux, a fraction of the cooled off gas was reintroduced to the column as reflux, revealing a new variable called the (reflux split). The reflux split stands for the portion of the off gas refluxed back to the column. Another new variable - the compressor pressure ratio - was also considered. Its effect on the compressed off gas temperature, the compressor's duty and the stripping efficiency was examined. Figure 6 illustrates the process scheme of Case #2. A HYSYS model was built to monitor the effect of changing the reflux split and the pressure ratio on the stripping efficiency.

Figure 6: HYSYS illustration of Case #2

It was obvious from the previous study on Case #1 that the best stripping efficiency was observed when the feed was fed at the first stage. This variable was fixed while changing the reflux split and the pressure ratio to monitor their effect on the tower stripping efficiency.

7. Results of Case #2

7.1 Reflux Split
The result of changing the reflux split ratios from 0.001 to 0.2 on the flow rates of all components is illustrated in Figure 7.

It was found that increasing the reflux split increases the NH₃ and acid gases flow rate in the off gas, on the expense of increasing the liquid ammonia and hydrogen sulfide concentration in treated water, reaching 200 ppm. This restricts the use of reflux split.

7.2 Pressure Ratio
Pressure ratio was altered from 1.1 to 1.85 to see its effect on the stripping efficiency. Results of pressure ratios 1.1, 1.35, 1.6 and 1.85 are illustrated in Figure 8.

Increasing the pressure ratio elevates the compressed off gas temperature (also known as heat pump). This carries more energy to the sour water feed heat exchanger. As stated in section 5.2, increasing feed temperature gives better stripping efficiency. It was also found that by increasing the pressure ratio, the number of trays required to perform a certain separation decreases.

The effect of increasing the pressure ratio on the temperature of the heat pump and the compressor duty is illustrated in Figure 9.
It is obvious from Figure 9 that increasing the pressure ratio also increases the compressor duty, which means an increase in the cost of the electricity required to operate the tower. Increasing the pressure ratio also increases the temperature of the compressed stream, which in turn increases the amount of heat transferred to the feed sour water.

8. Conclusion

From the above study, it was found that for a refluxed absorber, the best stripping efficiency was achieved when the feed was fed in the first tray with maximum available temperature. It was also found that increasing the stripping steam flow rate enhances the mass transfer operation and gives better results. Increasing the number of stages in the refluxed absorber also gave better stripping results.

After the addition of a new equipment (the compressor), new variables have appeared having a noticeable influence on the stripping efficiency and the treated water quality outcome. These new variables were reflux split and pressure ratio. It was noticed that increasing the reflux split results in the increase of NH$_3$ and H$_2$S concentrations in the treated water, up to 200 ppm, and this inhibits its usage. As for the pressure ratio, it was noticed that as it increased better separation will occur, although the electric cost of the compressor will increase.