

<p>KLM Technology Group</p> <p>Practical Engineering Guidelines for Processing Plant Solutions</p>	 <p>Engineering Solutions</p> <p>www.klmtechgroup.com</p>	Page : 1 of 66
		Rev: 01
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<p>KLM Technology Group P. O. Box 281 Bandar Johor Bahru, 80000 Johor Bahru, Johor, West Malaysia</p>	<p>Kolmetz Handbook Of Process Equipment Design</p> <p>Natural Gas Sweetening Systems Selection, Sizing and Troubleshooting</p> <p>(ENGINEERING DESIGN GUIDELINES)</p>	<p>Co Author: Rev 01 Aprilia Jaya</p> <p>Editor / Author : Karl Kolmetz</p>

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INTRODUCTION

Scope

This guideline provides how to design a gas sweetening system especially when utilizing alkanolamines. This design guideline can assist engineers in understanding the basic design of a gas sweetening system including suitable sizing of equipment, material selection and suitable amine selection. This guideline also includes the engineering calculations for sizing of the gas sweetening systems.

The choice of amine and equipment design is crucial to give the best performance of a gas sweetening system. The performance of gas sweetening system is influenced by the choice amine used to treat the acid gas and all the equipment used in the system, such as absorber, regenerator, and reboiler. This guideline will assist in calculating the size, heat duty, area, and power requirements of the various pieces of equipment. Additionally acid gas absorbed, circulation and bulge temperature will be calculated.

The design of gas sweetening system may be influenced by factors, including process requirements, economics and safety. There are tables that assist in making these factored calculations from the various referenced sources. All the important parameters use in the guideline are explained in the definition section which help the reader more understand the meanings of the parameters or the terms utilized.

The theory section explains the correct selection of equipment which is used in gas sweetening systems, how to calculate equipment sizing, and selection of the best amine solution for each application. The application of the gas sweetening system theory with the examples will assist the engineer to understand the concepts of gas sweetening and then be prepared to perform the actual design of the gas sweetening.

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General Design Consideration

In some hydrocarbon processing plants acid gas such as Hydrogen sulfide (H₂S) and carbon dioxide (CO₂) are present in the gas streams. They can also be organic sulfur in the form of carbonyl sulfide (COS). The streams can be natural and associated gases such as propane and butane, and products from upgrading of heavy oils, bitumen or coal.

Gas sweetening technology using alkanolamines to remove acid components from hydrocarbon rich gases have been in operation for many years. The alkanolamine processes are particularly applicable where acid gas partial pressures are low or low levels of acid gas are needed in the sweet gas. Alkanolamines are used because they form basic solutions when mixed with water and chemically enhance the absorption of H₂S and CO₂ in the aqueous solution. Several alkanolamines solutions have been widely used in gas sweetening system.

1. Monoethanolamine (MEA)
2. Diethanolamine (DEA)
3. Diglycolamine (DGA)
4. Di-isopropanolamine (DIPA)
5. Methyl diethanolamine (MDEA)
6. Triethanolamine (TEA)
7. Glycol plus amine solution.

MEA and DGA react with H₂S, CO₂ and COS directly. DEA and DIPA react with H₂S, CO₂ and some COS directly. While MDEA and TEA are reacted with H₂S directly, CO₂ indirectly and a little COS. The following factors should be considered for evaluation and decision making as a general approach to all sour gas sweetening treatment installations:

1. Air pollution regulations regarding H₂S removal;
2. Type and concentration of impurities in sour gas;
3. Specification of treated gas (sweet gas);

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4. Temperature and pressure at which the sour gas is available and at which the sweetened gas should be delivered;
5. Volume of the gas to be treated;
6. Hydrocarbon composition of sour gas;
7. Selectivity required for acid gas removal;
8. Capital cost and operating cost;
9. Liquid product specifications (where application).

Below is discussed some alkanolamines which use in gas sweetening systems

A. Monoethanolamine (MEA)

MEA is the strongest base of alkanolamines and reacts most rapidly with acid gasses, and this is why MEA is the first choice in gas sweetening system. MEA have 1.7 times more capacity for acid gases on a weight basis than DEA or DGA. Therefore a lower amine solution circulating rate can be used when amine treating with MEA compared to treating with DEA or DGA. MEA has a good thermal stability, can easily be reclaimed from contaminated solutions, good COS removal and less expensive than DEA and DGA. There some things that should be considered when using MEA:

1. MEA should commonly be used as a 10 to 20% solution in water.
2. The acid gas loading should usually be limited to 0.3 to 0.4 moles acid gas per mole of amine for carbon steel equipment.
3. MEA's degradation products are very corrosive. COS, CS₂, SO₂ and SO₃ can partially deactivate MEA, which may essentially require to be recovered with a reclaimer.
4. MEA has a high pH that makes MEA produce gas containing less than ¼ grains H₂S per 100 S.ft³ of acid gas at very low H₂S partial pressures.
5. MEA will easily reduce acid gas concentrations to Pipeline Specifications (0.25 grains per 100 S.ft³). By proper design and operation, the acid gas content can be reduced as low as 0.05 grains per 100 S ft³).

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- The heat of reaction for CO₂ in MEA is about 1930 kJ/kg of CO₂ (460 kcal/kg of CO₂).

B. Diethanolamine (DEA)

DEA is a secondary alkanolamine, it has a reduced affinity for H₂S and CO₂. DEA has very low vaporization losses and good stability in the presence of CO₂, COS and CS₂. Degradation reaction with CO₂, COS, and CS₂ proceed at a much slower rate and the products are non corrosive, thus reclaiming is not need to control the level of DEA degradation products.

DEA is not selected when the absorber feed stream contains high levels of strong acid (chlorides, SO₂, SO₃, thiocyanic acids), organic acids (formic, acetic, nepthanic acids), CO, oxygen and cyanides. Because they are react with DEA to form heat stable salts (HSS) which are stable at regenerator conditions. HSS can cause loss of DEA, solution foaming and localized corrosion. DEA is seldom chosen for application where reclaiming will be needed to control the buildup of HSS due to DEA's low volatility need a high vacuum reclaiming to avoid excessive reclaiming temperature. There some things that should be considered when using DEA:

- DEA is commonly used in the 25 to 35 mass percent ranges.
- The loading for DEA is limited to 0.3 to 0.4 mole/mole of acid gas for carbon steel equipment.
- When using stainless steel equipment, DEA can safely be loaded to equilibrium. This condition can be considered for carbon steel equipment by adding inhibitors.
- The degradation products of DEA are much less corrosive than those of MEA.
- COS and CS₂ may irreversibly react with DEA to some extent.
- DEA has a reduced affinity for H₂S and CO₂. As a result, for some low pressure gas streams,
- DEA cannot produce Pipeline Specification gas.
- DEA will be selective toward H₂S and will permit a significant fraction of CO₂ to remain in the product gas.

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- The heat of reaction for DEA and CO₂ is 151 kJ/kg of CO₂ (360 kcal/kg of CO₂) which is about 22% less than for MEA.

C. Diglycolamine (DGA)

DGA is a primer alkanolamine, it has much high molar concentration that can be used in solution without excessive DGA losses due to degradation and without excessive corrosion rates. This allows more acid gases to be absorbed per gallon solution in lower solution circulation rates (cost saving and investment savings). DGA has a very low freezing point which is good for cold climates. Also provides partial dehydration of the stream being treated. DGA has good thermal stability, can be reclaimed from contaminated solutions, and good COS removal. DGA is better mercaptan removal due to of high concentrations of DGA in solution which increases the solubility for higher molecular weight mercaptans in the DGA solution.

The advantages of DGA are its high solubility of gaseous and liquid carbon especially in C₅⁺ hydrocarbons. It will result in higher hydrocarbon losses in the vapor from the rich solution hydrocarbon flash/skimming drum and in regenerator overhead acid gas stream. Higher hydrocarbon levels in the DGA regenerator overhead acid gas increase the risk of operating problems in the downstream sulfur recovery unit. There some things that should be considered when using DGA:

- DGA is generally used as 40 to 60 mass percent solutions in water.
- For gas streams with acid gas partial pressures, absorber bottoms temperatures as high as 82°C and above can occur. This will reduce the possible loading.
- DGA has a tendency to preferentially react with CO₂ over H₂S.
- DGA has a higher pH than MEA and thus can easily achieve 6 mg H₂S/ Sm³ gas (0.25 grains per 100 S.ft³) except in some cases where large amounts of CO₂ are present relative to H₂S.

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The following factors should be considered when selecting an amine for a sweetening application as outlined here in under:

1. The pressure and acid gas content of the sour gas as well as the purity specification for the product gas.
2. MEA is used for plants where the inlet gas pressure is low and Pipeline Specification gas or total removals of the acid gases are required. MEA is not preferred for its high heat of reaction and lower acid gas carrying capacity per unit volume of solution.
3. DEA is used for its lower heats of reaction, higher acid gas carrying capacity and resultant lower energy requirements. Its potential for selective H₂S removal from streams containing CO₂ has not fully been realized.
4. DGA has very high gas carrying capacity usually produces very reasonable net energy requirements although has high heat of reaction. DGA also has a good potential for absorbing COS and some mercaptans from gas and liquid streams, and because of this, DGA has been used in both natural and refinery gas applications.
5. MDEA, with its some outstanding capabilities, resulting from its low heat of reaction, can be used in pressure swing plants for bulk acid gas removal. MDEA is currently best known for its ability to preferentially absorb H₂S.

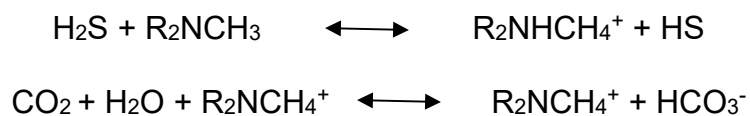


Figure 1: Reaction between acid gas and amine

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Process Flow Scheme

Typically flow scheme for gas sweetening system is shown in figure 2. The hydrocarbon or H₂ rich stream to be treated is fed into the bottom of absorber tower (scrubber) and is passed upward through the packed or trayed absorber, counter current to the amine solution to insure intimate contacting. The amine solution absorbs H₂S, CO₂, and acid gas. The treated carbon stream which has a low acid gas content (sweet) flows overhead from the top of the absorber tower.

The solution leaving the bottom of the absorber tower has a high loading H₂S and CO₂ (rich solution) is sent to hydrocarbon flash/skimming drum, which also provides rich solution surge capacity then preheated in an exchanger and fed to the low pressure regenerator near the top of tower. Reboiler adds heats to the bottom of the regenerator causing part of the solution vaporizes thereby providing an upward flow of stripping vapors in the regenerator tower, and then condense partly in the regenerator to supply heats for the endothermic acid gas desorption reactions and for heating the solution to regenerator bottom temperature.

Water vapor and acid gases striped from the rich solution flow overhead from the top of the regenerator tower and are cooled to condense a major portion of the water vapor. This condensate is collected and continually recycled back to the system to prevent water loss from the system and thereby maintain unit water balance. It is refluxed back to the top of regenerator, above the rich solution feed location, to remove traces of alkanolamine vapor from the overhead stream leaving the top of the tower.

The hot solution leaving the bottom of the regenerator tower has low loading H₂S and CO₂ (lean). After partial cooling by heat exchange with the rich solution, lean solution is cooled by heat exchange with cooling water or air and then pumped to the top of the absorber tower to complete the solution circuit. Many operating problem can be avoid if surge volume and filtering are provided for the lean solution and lean solution is fed to each absorber under flow control. With MEA and DGA, a slipstream of mine solution from the regenerator bottom is usually fed to a reclaimer purification but if using DEA, the reclaimer are seldom used.

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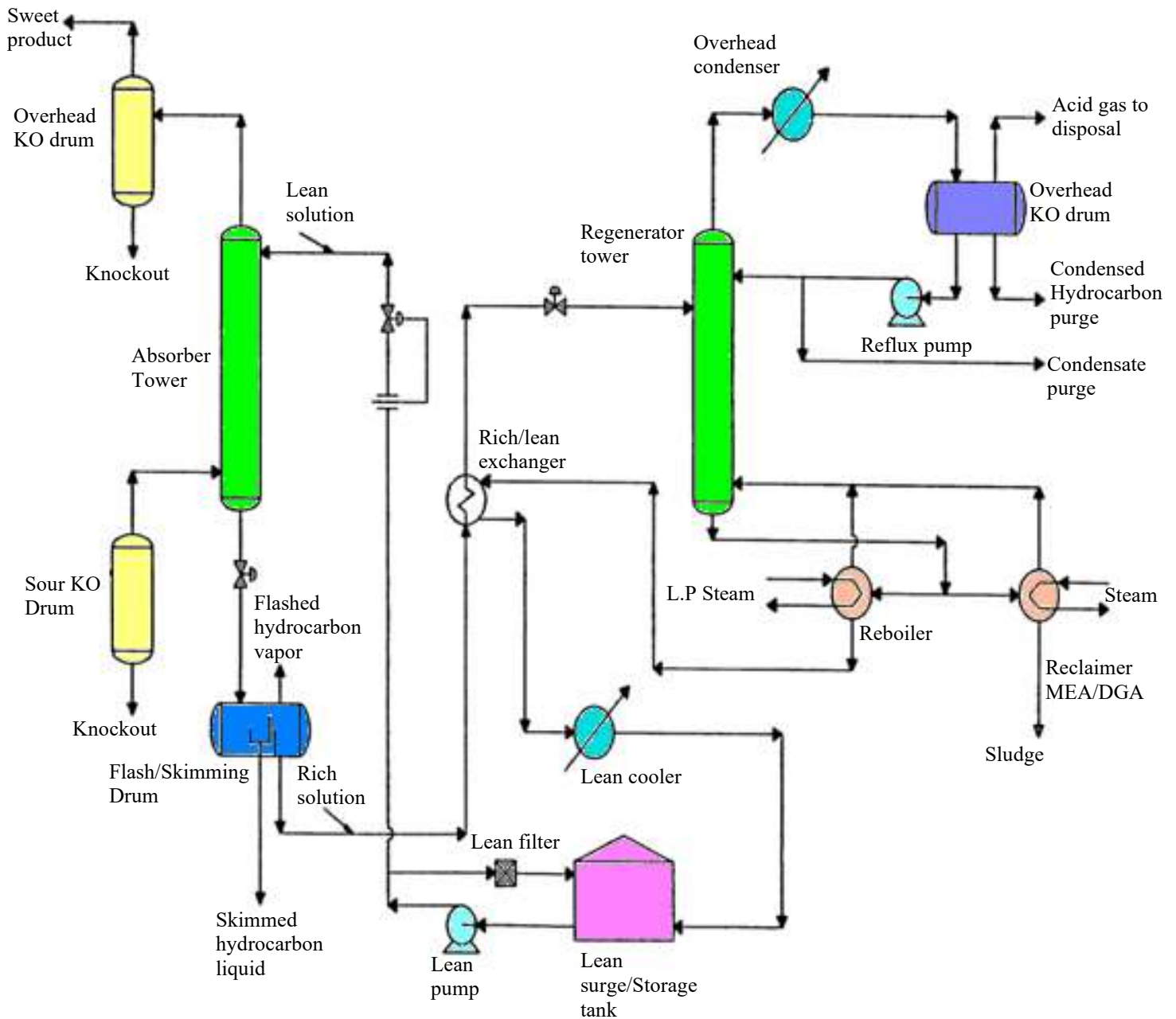


Figure 2: Process flow scheme of gas sweetening

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Good performance of a gas sweetening systems requires proper choice and control of process operating conditions. Bellows are variables which affect for gas sweetening systems:

1. **Type of alkanolamine**
2. **Alkanolamine concentration in solution**

Excessive alkanolamine have negative effects which place a practical limit on solution strength, requires the use of more stainless steel materials, temperature rise in the absorber due to exothermic heat of the absorption reactions thereby rich end pinch can occur in the absorber. Also causing higher lean solution loadings and higher acid gas levels in the absorber overhead product or higher steam requirements for the regenerator reboiler.

3. **Rich solution acid gas loading or solution circulation rate**

Increasing the rich solution loading will permit less solution to be circulated, the solubility of hydrocarbon in the rich amine solution leaving the bottom of the absorber decreases. Therefore, it is desirable to use as high a rich solution loading as is feasible. The acid gas loading in the rich solution should be limited because these factors:

- The acid gas equilibrium vapor pressure or concentration over the rich solution must be sufficiently lower than actual inlet partial pressure to continue the absorption process.
- A higher solution rate will provide a lower bulge temperature. At the bulge temperature, the equilibrium vapor pressure or concentration of acid gases over the down-flowing solution reaches its highest value. If the bulge temperature is too high, no absorption can take place at all point of the tower.
- Higher loadings tend to cause higher rates of corrosion.
- Too low a solution rate can result in blowing in trayed towers or poor liquid distribution in packed towers.

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4. Lean solution acid gas loading

Lower equilibrium acid gas concentrations in treated product leaving the absorber can be achieved by lower lean solution loadings (lower H₂S loadings in lean solution). Lower H₂S loading in the lean solution are obtained with higher regenerator reboiler heat duty, higher CO₂/H₂S ration in the absorber feed stream, higher regenerator pressure (if CO₂/H₂S ratio <0.33) and lower regenerator pressure (if CO₂/H₂S ratio ≥ 0.33). with a higher ratio of CO₂ to H₂S pickup by solution, stripping H₂S from the amine solution in the regenerator is easier.

5. Acid gas concentrations in absorber feed

When CO₂ present, the amine solutions are more corrosive but striping of H₂S is easier (CO₂/H₂S ratio higher). A lower lean solution H₂S loading is possible for a given reboiler heat duty or a lower reboiler heat duty can be used to obtain a given lean solution H₂S loading.

6. Other contaminants in absorber feed

7. Absorber temperature

The absorber should be run as low as possible. Lower temperature shift the equilibrium of exothermic reactions allowing more acid gas absorption to occur at a given acid gas partial pressure or concentration over the solution. Large changes in the absorber temperature may indicate a serious operating problem. Absorber temperatures are affected by:

- Feed stream temperature at absorber inlet should be maintained as low as possible
- Low lean solution temperature but do not too low in hydrocarbon gas treating, hydrocarbon will condense in absorber result foaming.
- Heat released by acid gas absorption reactions
- Ratio of solution circulation mass rate to feed mass rate. If feed content very low acid gas, the feed mass rate may be large relative to the solution mass rate.

8. Absorber pressure

The absorber pressure is selected to meet the needs of the upstream and downstream units. For gas treating, increasing the absorber pressure decreases the ratios of acid gas partial pressure to total pressure in the absorber overhead which

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results in lower acid gas concentrations in the overhead product thus improve acid gas removal by the amine solution. For liquid hydrocarbon treating, the absorber operating pressure must be sufficiently high to prevent hydrocarbon vaporization in the absorber, including at the bulge temperature.

9. Regenerator temperature

Regenerator is desirable to operate at the lowest practical temperature to minimize alkanolamine decomposition and corrosion. The regenerator reboiler must be design to ensure that metal temperatures in the reboiler do not exceed 300°F and that local hot spots do not occur in the tube bundle. The regenerator tower bottom temperature must be sufficiently high to boil the amine solution, at the regenerator bottom pressure, to generate stripping steam flow up the tower.

10. Regenerator pressure

The regenerator is operate at a pressure as low as practical to minimize the temperature in the tower thereby reduce corrosion and alkanolamine degradation. Also lower acid gas partial pressure favors desorption of the acid gases from amine solution and reduce the MEA and DGA reclaiming temperatures. Higher regenerator pressure increase the regenerator bottom temperatures resulting in easier solution regeneration. A typical design regenerator operating pressure is 10 – 15 psig at the tower top.

11. Regenerator reboiler heat duty

The regenerator reboiler heat duty should be minimize to reduce costs and grassroots units. Regenerator reboiler heat duties typically equivalent ponds of 60 psig saturated steam (905 Btu/lb) per gallon circulating amine solution. The reboiler heat duty includes: 1) the sensible heat required to raise the temperatures of the rich amine feed, the reflux, and the makeup water to the temperature of the reboiler, 2) the heat of reaction to break chemical bonds between the acid gas molecules and the amine, and 3) the heat of vaporization of water to produce a stripping vapor of steam.

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Reducing the solution circulation rate reduces the reboiler duty by maximizing the acid gas absorbed per volume of rich solution.

a. Minimum duty for stripping acid gases

Stripping steam must be provided at a sufficient rate to the bottom of the regenerator in order to give very low acid gas partial pressure in the vapors above the regenerator bottom trays. These acid gas partial pressure must be lower than the equilibrium must be lower than the equilibrium acid gas vapor pressures over the lean amine solution on the bottom trays to provide a driving force of absorption of acid gases from solution. The reboiler steam ratio must be high enough to meet the regenerator heat balance criterion, otherwise stripping will be impaired.

b. Minimum duty for regenerator heat balance

The heat supplied to the regenerator reboiler must satisfy the regenerator heat balance to providing adequate stripping of the amine solution. If heat supplied is less than required, solution regeneration will degenerate. If more than required, the additional heat input will pass overhead from regenerator tower and be removed by the regenerator overhead condensers. Two conditions must be met to satisfy the regenerator heat balance: the vapor temperature cannot be less than the rich solution feed temperature, the steam partial pressure in the vapor stream cannot be less than the equilibrium steam vapor pressure over the rich solution feed.

The minimum heat duty is a function of regenerator pressure, the difference between the acid gas loading in the rich and lean solution, and the temperature difference between the hot lean solution entering the rich/lean exchanger and the hot rich solution leaving the rich/lean exchanger.

12. Regenerator reflux

The regenerator is operated at total reflux, all the liquid condensed from the overhead is pumped back to the top of the tower above the rich amine solution feed point. Recycle of this condensate back to the amine unit helps reduce alkanolamine losses.

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13. Alkanolamine losses/makeup

Minimizing alkanolamine losses is important to minimize alkanolamine makeup operating costs. There are several factors which causing alkanolamine losses:

- a. Vapor losses can occur in the rich solution hydrocarbon flash.skimming drum overhead, in the regenerator overhead acid gas and in the absorber vapor overhead. For MEA and DGA, the vapor losses can be reduced by washing this stream with slipstream of cool regenerator reflux or lean solution.
- b. Solution entrainment and alkanolamine solubility in the absorber overhead product stream resulting liquid hydrocarbon treating losses. The losses can be minimized by proper design of the absorber top: adequate liquid-liquid disengaging time, low hydrocarbon velocities, and large holdup time above the low liquid-liquid interface level.
- c. Foaming and other upsets in the absorber or regenerator resulting entrainment losses. Foaming can be controlled by using anti-foam agent and clean solution.
- d. Reactions with contaminants in the feed, makeup water, and thermal decomposition resulting chemical losses. The losses can be reduced by proper choice of alkanolamine, water washing of the absorber feed to remove acids, reclaiming MEA and DGA, for unit without reclaiming by occasional caustic addition to the circulating solution. To prevent reaction between oxygen and alkanolamine can using an internal floating roof or inert gas blanketing in surge tanks and using only deaerated water.
- e. Cleaning of equipment (reclaimers, solution filters, carbon treaters, and heat exchanger)
- f. Leaks, spills, solution purge steam, unit startups/shutdowns. The losses can be minimized by proper equipment design and maintenance, proper procedures, and proper unit monitoring.

14. Water balance – water losses/purging/makeup

The net water flow into or out of the amine treating unit must be controlled to maintain the desired alkanolamine concentration in the circulating amine solution. Makeup water or steam add to the amine treating unit must be pure (free oxygen, salts, chlorides, organic chemicals, minerals, particulates, iron, etc). Steam, steam condensate (demineralized) and deaerated are recommended for rated makeup

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15. Solution purification

The advantages of the amine process are:

1. It is a continuous circulating system of smaller rate than some other processes
2. Theoretically, it is a simple exothermic-endothermic reversible chemical reaction
3. It will remove all hydrogen sulphide from the gas to lead standards, below 0.05 grains, at contact pressure of about 100 psi and above. At lower pressure, complete removal of sulphide from the gas stream is not always achieved because of partial pressure equilibrium limitations

The disadvantages of amine process are:

1. The amine is subject to vaporization and other losses that can be expensive replenish.
2. Like any hydrogen sulphide removal plant, the amine process is subject to expensive corrosion problems. A well designed amine plant will have less corrosion than a poorly designed plant, but nevertheless, will have some corrosion.
3. Amine will remove carbon dioxide that might better be left in the gas.

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DEFINITIONS

Absorption - A separation process involving the transfer of a substance from a gaseous phase to liquid phase through the phase boundary.

Acid gases - Impurities in a gas stream usually consisting of CO₂, H₂S, COS, RSH and SO₂. Most common in natural gas are CO₂, H₂S and COS.

Acid gas loading - The amount of acid gas, on a molar or volumetric basis, which will be picked up by a solvent.

Adsorption - A separation process involving the removal of a substance from a gas stream by physical binding on the surface of a solid material.

Antifoam - A substance, usually a silicone or long-chain alcohol, added to the treating system to reduce the tendency to foam.

Absorber/Contactor/Scrubber - Tower in which aqueous amine solution is contacted with hydrocarbon or H₂ rich phase to remove contaminants, mostly H₂S and CO₂.

Alkanolamine - Organic amine which contains at least one alcohol group and one amine group, e.g. MEA, DEA DGA.

Amine Treating - Process in which an aqueous alkanolamine solution is used to remove components mostly H₂S and CO₂ from hydrocarbons.

Anti Foam - Surface active agents used to suppress foaming of a solution. Usually used in small concentrations (typically 10 wppm or less).

Blowing - Condition in a tower in which a fine dispersion or fog of liquid is entrained from one tray to tray above. It is caused by excessive vapor velocities through tray openings at relatively low liquid rates. Blowing causes poor vapor/liquid contacting which reduces tower efficiency.

Bubble Point - Temperature (for a given pressure) or pressure (or a given temperature) at which the first bubble of vapor appears from a liquid.

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Bulge Temperature - Maximum amine solution temperature in an absorber tower. The temperature of amine solution increases as it flows down due to heat released by acid gas absorption.

Degradation - Loss of desirable alkanolamine properties which occurs during usage. Alkanolamines degrade by reacting with CO₂, COS, CS₂, O₂, etc. to form undesirable products.

Degradation products - Impurities in a treating solution which are formed both reversible and irreversible side reactions.

Dew Point - For a given pressure, temperature at which the first drop of condensate forms from vapor.

Entrainment - Small droplets or particles of one phase carried in a stream of another phase, usually liquid droplets in a gas stream, due to incomplete phase separation.

Flooding - Unstable condition in which liquid (e.g. amine solution) builds up in a tower until the tower is essentially full. It is caused by excessive vapor or liquid rate through the tower.

Foaming - Condition in which amine solution froth is formed and does not collapse. Usually caused by contaminants, such as heavy hydrocarbons, in solution. Foaming decreases tower throughput capacity or efficiency.

Heat of Reaction - Heat released by reactions during absorption of acid gases amine solution or heat required by reactions during desorption of acid gases from amine solution.

Heat Stable Salts (HSS) - Salts of alkanolamine are not regenerable, i.e. do not decompose in the regenerator. HSS are formed by reaction of alkanolamines with acids stronger than H₂S or CO₂, such as SO₂, SO₃, chlorides, thiosulfates, ferrocyanates, thiocyanic, acids etc.

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Hydrocarbon Flash/Skimming Drums - Drum(s) designed to reduce hydrocarbon concentration in rich amine solution from the absorber bottom. Pressure is reduced in the drum(s) to flash off light hydrocarbon vapors. The skimming drum is designed to separate out a liquid hydrocarbon phase from amine solution.

Knockout (K.O) Drum - Drum for disengaging entrained liquid droplets from a stream of a different phase, usually a gas stream.

Lean End Pinch - Condition in the top of an absorber where the actual vapor pressure (or concentration) of acid gas over lean amine solution is very close to the equilibrium partial pressure (or concentration) of acid gas in the absorber overhead product, thus limiting absorption of additional acid gas into the amine solution.

Lean Solution - Regenerated amine solution, i.e. regenerator bottoms, which has low acid gas concentrations.

Lean Solution Cooler - Exchanger used to cool lean amine solution from the rich/lean exchanger before the lean solution is fed to top of the absorber tower.

Liquefied Petroleum Gas (LPG) - Any material having a vapor pressure not exceeding that allowed for commercial propane composed predominantly of the following hydrocarbons, either by themselves or as a mixtures: propane, propylene, butane (normal butane or isobutane) and butylene, as a by-product in petroleum refining or natural gasoline manufacture.

Mercaptan - A hydrocarbon group (usually a methane, ethane, or propane) with a sulfur group (-SH) substituted on a terminal carbon atom.

Minimum Heat Duty or Steam Rate/Requirement - Reboiler heat duty or steam rate sufficient to satisfy regenerator tower heat balance plus a small excess necessary for regenerator control.

Organic Acid - Carboxylic acid, with molecular formula RCOOH where R is a hydrogen atom or alkyl group, e.g. formic, acetic, oxalic or naphthenic acid.

Overhead - Stream exiting from top of a vessel, usually a tower or knockout drum.

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Overhead Condensate - Water, saturated with H₂S and CO₂, which is condensed out of regenerator overhead vapors by cooling. Recycle of this condensate helps maintain water material balance in the amine treating unit.

Packing - Inert solids with high surface area/volume used to improve contacting of amine solution with another phase in a tower.

Pinch - Condition in a tower where there is close approach to equilibrium, i.e. there is a small difference between the actual vapor pressure (or concentration) of acid gas over amine solution and the equilibrium acid gas partial pressure (or concentration) over amine solution.

Reboiler - Heat exchanger (usually kettle type) which takes amine solution from bottom of regenerator and boils it to supply vapors for acid gas stripping from and heating of the amine solution. Vapors from reboiler return to bottom of regenerator and liquid from reboiler is lean solution. Steam usually supplies energy to reboiler.

Reclaimer - Vessel for separating alkanolamine from degradation products, heat stable salts, and solids by batch distillation. Alkanilamine and water distilled from the reclaimer are returned to the amine treating unit.

Reflux Ratio - Molar ratio of condensed water to acid gas vapors leaving the regenerator over head condenser.

Regenerator/Reactivator/Stripper - Tower in which acid gases are desorbed from amine solution by stripping.

Rich End Pinch - Condition in the absorber bottom where the actual acid gas partial pressure (or concentration) above rich amine solution is very close (or equal) to the equilibrium acid gas partial pressure (or concentration) in the feed to the absorber, thus limiting absorption of more acid gas into amine solution.

Rich/Low Exchanger - Heat exchanger which utilizes heat from hot lean amine solution, leaving the regenerator reboiler, to preheat rich solution feed to the regenerator.

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Rich/Lean (Temperature) Approach - Difference between the temperatures of rich solution leaving and lean solution entering the rich/lean exchanger(s).

Rich Solution - Amine solution which has passed through the absorber, i.e. absorber bottoms, and has high concentration of acid gas.

Sour gas - Any gas stream which containing acid gas components H₂S and/or NH₃, e.g. absorber feed, regenerator overhead condensate, wash water etc.

Steam Ratio - Ratio of regenerator reboiler steam rate to circulating lean solution rate. The reboiler steam rate is frequently converted to the equivalent rate of 60psig saturated steam (905 Btu/Lb).

Stripping Steam - Steam, due to amine solution vaporization in the reboiler, entering the regenerator bottom from the reboiler. Stripping steam rate is set by the reboiler steam rate.

Surge/Storage Drum or Tank - Vessel which provides amine solution holdup capacity for the amine treating unit.

Sweet gas - A gas stream which has acid gas components removed to an acceptable level

Water balance - Maintenance of desired inventory of water in amine treating unit. It requires controlling net flow of water into or out of unit to give desired concentration of water in amine solution circulating through unit.

Weeping - Condition in a tower in which liquid continuously leaks through tray openings to the tray below. It is caused by vapor velocities through tray opening which are too low to support the liquid level on the tray. Excessive weeping reduces vapor/liquid contacting and therefore tower efficiency.

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NOMENCLATURES

a	Heat carrying capacity of amine solution, btu/h°F
A _{cooler}	Amine cooler Area, ft ²
A _{HX}	Rich/lean heat exchanger Area, ft ²
A _R	Reboiler (Direct Fired) Area, ft ²
A _{reflux}	Reflux condenser Area, ft ²
b	Heat carrying capacity of the absorber feed stream, btu/h°F
C _{AG}	Acid gas concentration in sour gas, mole%
C _{AGout}	Acid gas concentration in overhead product, mole%
C _{pfeed}	The absorber feed specific heat, btu/mole °F
%CO ₂	CO ₂ concentration in sour gas, %
D _a	The diameter of an amine plant absorber, in
D _{RA}	The diameter of the regenerator above the feed point, in
D _{RB}	The diameter of the regenerator below the feed point, in
F _{AP}	Main amine solution pumps, HP
F _{BP}	Amine booster pumps, HP
F _R	Reflux pumps, HP
F _{AC}	Aerial cooler, HP
GLS	Lean solution rate, gph
GPM	Amine circulation rate, gpm
ΔH _{abs}	Heat released in absorber, btu/h
ΔH _{Bulge}	Heat released in absorber due to H ₂ S plus CO ₂ absorption into amine solution below bulge temperature location, btu/h
ΔH _{H₂S}	Heat reaction of H ₂ S, btu/mol
ΔH _{CO₂}	Heat reaction of CO ₂ , btu/mol
H _{HX}	Rich/lean heat exchanger Heat Duty, Btu/hr
H _{cooler}	Amine cooler Heat Duty, Btu/hr
H _R	Reboiler (Direct Fired) Heat Duty, Btu/hr
H _{reflux}	Reflux condenser Heat Duty, Btu/hr
%H ₂ S	H ₂ S concentration in sour gas, %
L _{H₂S lean}	H ₂ S loading in lean solution, mol/mol
L _{CO₂ lean}	CO ₂ loading in lean solution, mol/mol
L _{H₂S rich}	H ₂ S loading in rich solution, mol/mol
L _{CO₂ rich}	CO ₂ loading in rich solution, mol/mol
L _{H₂S lean}	H ₂ S loading in lean solution, mol/mol

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$L_{CO_2 \text{ lean}}$	CO ₂ loading in lean solution, mol/mol
$L_{H_2S+CO_2 \text{ rich}}$	Rich H ₂ S + CO ₂ load (estimated), mol/mol
$M_{W \text{ amine}}$	Amine molecular weight, lb/mol
P	Contact pressure, psia
Q	Sour gas to contactor, MMscfd
T_{bulge}	The bulge temperature, °F
T_{Rich}	Rich solution temperature, °F
T_{Feed}	Feed solution temperature, °F
T_{Lean}	Lean solution temperature, °F
$\%W_{\text{Amine}}$	Amine concentration in liquid solution, wt%
Z	Amine solution specific heat

Greek Letters

ρ_{Lean}	Lean solution density, lb/gal
β	Bulge temperature correlation factor

Superscript

A	Area, ft ²
H	Heat Duty, Btu/hr
L	Load, mol/mol
T	Temperature, °F

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