MAKING AMINE SYSTEMS SING

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ABSTRACT

Acid gas (CO_2, H_2S, and SO2) scrubbing systems are intended to operate trouble-free, but rarely do. Contaminants (heat stable salts, amine degradation products, solids, hydrocarbons, surfactants) cause a variety of maintenance and operational difficulties resulting in reduced capacity, product quality, system longevity, etc. Various methods of removing the several contaminants from amine solutions have been developed and improved over the years. These are discussed in view of practical experience that has shown that contaminant removal methods improve operations and throughput.

Introduction

Operators of acid gas scrubbing units are continually challenged to maintain throughput and quality as the feedstock changes. Alkanolamine systems have been scrutinized more and more closely over the last 15 to 20 years, because of capacity, throughput, and costs concerns. Operating companies can purchase mobile reclaiming services and permanent add-on reclaiming units for any number of dissolved, entrained and suspended contaminants anywhere in the world. Product specifications and environmental concerns have also changed. Lower sulfur specs in finished products coupled with sourer feed stocks press ever-increasingly on the capacity of amine systems.[I,II] Amine system downtime and upsets have a more visible connection to throughput and profits. The disposal of contaminated amine is hindered by fewer available options and higher costs.

Reclaiming – removing the contaminants from amine solvents – generally results in smoother operations, which, more and more visibly, translates to improved bottom line. Table 1 shows the bottom-line benefits of reclaiming to low impurity levels that four refiners documented. The positive effects of reclaiming seen by these refiners included reduced amine losses/consumption/replacement, reduced anti-foam usage, reduced foaming, reduced filtration costs, reduced heat exchanger fouling, reduced amine unit operating costs, fewer production curtailments, fewer upsets of waste water treatment plant, record crude, coker, cracker runs, increased overall production, ability to run sourer crude, increased sulfur production.

Table 1. Annual Benefit to Bottom Line of Maintaining Low Impurity Level in Amine Systems

Refinery bbl/day	Annual Benefit
230,000	$30 million
170,000	$6 million
58,000	$1 million
50,000	$2 million

This paper is a review of advances and limitations of reclaiming options organized by contaminant type.

Heat Stable Salts

Heat stable salts (HSS) have become identified as a leading cause for reduced capacity in amine systems. They also contribute to corrosion, increased viscosity, and foaming. HSS are salts which do not decompose and release acids in the amine regenerator (stripper).

For example, Formic acid (HO_2CH):

Absorber reaction:

$$R_3N + HO_2CH \rightarrow (R_3NH)^+ + (O_2CH)^- \qquad \text{[amine plus acid} \rightarrow \text{salt]}$$

Regenerator non-reaction:

$$(R_3NH)^+ + (O_2CH)^- + \text{Heat} \rightarrow \text{No Change}$$

Notice that the cation of all these salts is the protonated amine (an amine bound to a hydrogen ion). The complete name of a salt includes the name of the cation and the name of the anion. However, HSS are typically called by the name of the anion. For example, the salt of formed by methyldiethanolamine (MDEA) and formic acid, is correctly named methyldiethanolammonium formate. MDEA and hydrochloric acid form methyldiethanolammonium chloride. Rather than repeat the awkward cation name ("….ammonium"), people call out only the name of the anion. Commonly recognized alkanolamine heat stable salts include formate, acetate, propionate, glycolate, oxalate, chloride, thiocyanate, thiosulfate, and sulfate salts.

Heat stable salts accumulate in the amine, resulting in a loss of acid gas absorbing capacity, because the amine can hold but one hydrogen ion. If additional amine is added to compensate for the capacity loss, water content is sacrificed; viscosity increases, and absorption and stripping efficiencies can suffer. Additionally, HSS contribute to corrosion, which reduces material life and produces solids (corrosion products such as iron sulfide), which can result in fouling, plugging, erosion, and foam stabilization.[iii] Recommendations for acceptable levels of HSS anions in amine systems range from 500 to several thousand ppm, depending on ion identity and the disposition of the author. Our experience servicing hundreds of amine systems world wide leads us to recommend, as a general rule, total HSS anion of 5000 ppm or less for the most trouble-free operations.

Here are the common approaches to remove HSS from amine solutions.

Bleed and Feed

Bleed and feed (purging contaminated amine and replacing it with fresh amine) is the most widely practiced method of "cleaning" the amine systems. Bleed and feed does have the advantage of being easiest way of dealing with HSS. This method is probably supported by your amine supplier. It is more economical if used to maintain very high levels of HSS – the higher the salt concentration the less solvent must be discarded to remove a given amount of salt. Higher salt concentrations lead to more operational problems and shorter mechanical life. Other disadvantages of bleed and feed are well known. There are amine replacement costs and disposal costs, which have risen through the years. Another difficulty with bleed and feed is large quantities of amine can cause difficulties to the site waste water facilities and can cause waste water plant upsets. This "pump and dump" also suffers from poor environmental image.

Neutralization

The addition of NaOH or KOH, or analogous carbonates, quickly and easily recovers the capacity of the amine. The stronger base (OH^-) takes the hydrogen ion away from the alkanolammonium ion, converting it to free amine available again to react with acid, but the formed sodium or potassium salt remains in the amine solution.

"Neutralization" reaction, hydroxide:

$$(R_3NH)^+ + (O_2CH)^- + NaOH \rightarrow R_3N + Na^+ + O_2CH^- + H_2O$$

[amine salt plus stronger base → free amine plus sodium salt]

"Neutralization" reaction, carbonate:

$$(R_3NH)^+ + (O_2CH)^- + Na_2CO_3 \rightarrow R_3N + Na^+ + O_2CH^- + Na^+ + HCO_3^-$$

[amine salt plus stronger base → free amine plus sodium salts]

One disadvantage to neutralization is the false sense of security that it lends to the operator. While amine capacity is maintained, the amine solution becomes more and more polluted with salts which are not "seen" by the more common plant analytical methods. These salts likewise contribute to higher solution density and viscosity, reduced surface tension, and possible "soap" formation. Eventually the solution either self purges through an upset, or it must be discarded. Neutralization's affect on corrosion has received mixed reviews – some saying it reduced corrosion; others saying it actually increased corrosion rates. Finally, it is easy to add too much caustic, which then creates heat stable salts with the acid gases, causing higher lean loadings and less efficient acid gas scrubbing.

Neutralization is easily misunderstood or wrongfully reputed to be a HSS eliminator or HSS preventative. As the neutralization reaction shows, it simply converts amine HSS to sodium or potassium HSS. There no reduction in salt content of the solution and certainly no prevention of salt formation.

Ion Exchange

Ion Exchange is a chemically clean and environmentally friendly way to remove HSS and maintain the necessary low levels of HSS in amine systems. Ion Exchange literally exchanges a friendly ion for the HSS ion. For example, anion exchange removes the HSS anion, replacing it with hydroxide ion, which frees the amine and returns free amine and water to the amine system.[IV,V,VI]

Anion exchange reaction:

$$(R_3NH)^+(O_2CH)^- + (Resin)^+(OH)^- \rightarrow R_3N + (Resin)^+(O_2CH)^- + H_2O$$

[Amine salt plus Resin-base → free amine plus Resin-salt]

The HSS anions are later removed from the resin by regeneration with caustic, which produces biodegradable sodium salts, which are friendly to the waste water treatment system.

Cations, such as sodium, potassium, calcium, etc are similarly removed from amine systems by cation exchange.

While ion exchange seems chemically simple, the practice of removing HSS from amine systems by ion exchange has presented many technical and operational challenges. Several have reported the belief that it will not work effectively for amine reclamation, based on actual attempts. MPR Services, on the other hand has been providing successful amine ion exchange reclaiming services world-wide since 1991.

Distillation

The virtue of distillation has long been recognized for MEA and DGA. Many MEA and almost all DGA amine systems have permanent thermal reclaimers as an integral part of the amine system. Other amines require vacuum to prevent thermal degradation upon distillation. Other companies have offered distillation reclaiming of amines shipped to their central reclaiming operations. Improvements in distillation have reduced amine in waste and allowed for permanent units.

One important advantage of distillation is that distillation has an economic advantage when dealing with very high concentrations of HSS. Secondly there are low quantities of waste generated and it has low water and chemical consumption (close to 1 mole caustic per mole HSS). Distillation works better with the amines with low boiling points. The major disadvantage of distillation is the energy consumption needed to vaporize and distill over the amine solution. Distillation sends the most amine to waste of the discussed reclaimer methods. Other disadvantages include that it generates a concentrated waste which is considered potentially hazardous in many jurisdictions. The waste contains amines and amine degradation products, as well as salts and other contaminates. Distillation has poor economics for maintaining low concentrations of HSS, because such a large volume of solvent must be distilled to remove a small amount of salts.

DGA reclaimers are actually designed to convert a degradation product (BHEEU) back to useful DGA. A properly operated, clean (free of other contaminants), DGA reclaimer should ideally operate indefinitely. However, HSS and non-volatile impurities accumulate in the DGA reclaimer, which can upset the BHEEU conversion. The accumulation of HSS in the DGA reclaimer can lead to increased operating temperatures and the formation of another degradation product, morphaline.[VII] Efficiency of DGA thermal reclaimers is greatly improved by removing HSS by ion exchange.

The DGA and MEA thermal reclaimers are periodically emptied of the accumulated salts, which are sent to waste. Very commonly the reclaimer bottoms have high amine content, causing the reclaimer to be more of a bleed and feed device. Table 2 shows the results of a survey of the amine/HSS ratio in several amine systems and their reclaimer bottoms. Ideally, the amine/HSS ratio was much, much lower in the reclaimer bottoms than in the system, so less amine would be wasted via reclaimer bottoms than via direct bleed and feed. In only about 1/3 of the cases is the amine loss in the reclaimer less than half the loss that bleed & feed would have caused. MEA reclaimers also collect, and even cause formation of, amides and urea, each of which entraps an MEA molecule.

Table 2. Thermal Reclaimers Waste Good Amine

Amine	System Free Amine/HSS mol/mol	Reclaimer Bottoms Free Amine/HSS mol/mol
MEA		**50**
MEA		**10**
MEA	**17**	**3**
MEA		**1**
MEA	**82**	**2**
MEA		**26**
MEA	**3**	**4**
MEA	**3**	**2**
MEA	**5**	**6**
MEA	**4**	**4**
MEA	**5**	**5**
MEA	**6**	**3**
MEA	**3**	**4**
MEA	**11**	**2**
MEA	**23**	**1**
DGA	**62**	**77**
DGA	**29**	**44**

Electrodialysis Units (EDU)

The electrodialysis units have become more available and they have improved with new membrane technologies. Electrodialysis providers have claimed a greatly reduced need to neutralize HSS before removal of anions.[VIII] Also electrodialysis providers are able to remove HSS salts to lower levels with less amine waste than in previous years and electrodialysis units can remove thiosulfate impurities better than ever before. Membrane selection and maintenance is critical to the success of electrodialysis. The various membranes have different selectivities for different ions, so one may see some ions removed and others not.

Electrodialysis has lower energy demands than vacuum distillation. Electrodialysis has an advantage of lower chemical and water usage than ion exchange. One primary difficulty with Electrodialysis technology through the years has been dealing with solids. It is recommended that electrodialysis needs a 1 micron pre-filter. Another difficulty with electrodialysis is amine levels in the waste increase when going to low HSS endpoints. Often a trade-off has been observed between anion removal efficiency and amine losses i.e. reduce amine losses by reducing the efficiency of removal of anions from the amine.

Fouling of membranes has historically been a major cause of downtime and membrane expense. Recent advances have made this less of a problem, but dissolved iron, hydrocarbons, and suspended solids can cause fouling. Electrodialysis also has higher power consumption than ion exchange and electrodialysis generates more waste than vacuum distillation. Salt concentration in the waste runs from 3 to 20 times the salt concentration in the amine.

Amino Acids

Amino Acids have received considerable attention recently due to their corrosive nature at relatively low concentrations.[IX,X,XI,XII] Bicine $\{(HOCH_2CH_2)_2NCH_2CO_2H\}$ in MDEA and DEA systems and Hydroxyethylsarcosine (HES) $\{(HOCH_2CH_2)N(CH_3)(CH_2CO_2H)\}$ from MMEA are currently reportable by many amine analysis laboratories. Bicine strongly complexes iron, capable of holding iron in solution in the presence of some H_2S in lean amine solutions, so it is expected to contribute to corrosion. Based on laboratory corrosion studies, bicine has been recommended to be kept as low as 250 ppm in amine systems[XIII] especially where H_2S levels are low. Corrosion in gas plant amine has been clearly traced to bicine in the 1000 to 4000 ppm range. In a collection of 1739 amine samples from 273 different gas treating plants, 825 had more than 100 ppm bicine.[XIV] Because “there have not been an extraordinary number of reports from accounts of active corrosion” these authors doubt the importance of bicine corrosion. As bicine and other amino acids are found in more amine systems we will certainly hear more about amino acid corrosion.

The chemical pathways for forming bicine in amine systems have not been determined. Proposed pathways include:

a. Reaction of cyanide with formaldehyde
b. DEA with Glyoxal
c. Direct degradation of DEA with oxygen
d. Disproportion reaction of MDEA to TEA and further oxidation of TEA to Bicine
e. Reaction of cyanide with imide of MDEA (from DEA or MDEA)
f. Thiosulfate ($S2O3^{=}$) assisted reaction with MDEA or DEA (observed in tail gas units).

Bleed and Feed

Pump and dump is not normally used to lower a bicine contamination because of the poor economics of addressing a low concentration impurity by throwing away amine.

Neutralization

Although claims have been made, and rationale published that neutralization help reduce corrosion by amino acids operator testimony and further theoretical scrutiny show neutralization to be of no value for “masking” bicine corrosion. Fully de-protonated amino acid is stronger in chelating of iron than partially de-protonated, so caustic “neutralization” of bicine serves only to assure more of the bicine is in its strongest form.

Because bicine can complex cations, it has been suggested that sodium or potassium from caustic addition (neutralization of amine HSS and amino acids) might divert bicine from complexation of iron. This theory was supported by calculations of Bosen and Bedell.[XIV] Our literature search led us to complexation constants which, when applied to the Bosen and Bedell theoretical calculations, yielded clear evidence that bicine strongly enhances iron solubility in H2S systems, and that this enhanced solubility is insignificantly affected by the presence of very high concentrations of sodium or potassium. Bicine’s effect on the solubility of iron in CO2 systems is orders of magnitude higher.[XV] Sodium and potassium cannot be relied upon to significantly reduce bicine complexation of iron.

Field experience in gas plants and refineries attests to amino acid corrosion and ineffectiveness of caustic addition. A Texas gas plant identified bicine as the root cause of amine system corrosion, correlated dissolved iron increases and decreases with bicine increases and decreases, found no reduction in corrosion attack upon 'neutralization' by caustic addition. A Gulf Coast Refinery added caustic to the amine solution to control escalating bicine levels. No impact on measured corrosion rates was observed, but unit performance continued to deteriorate. A Gulf Coast gas plant encountered escalated corrosion rates and high bicine levels. Sodium was added in an effort to control the corrosion. Minimal impact was observed.

Ion Exchange

MPR's HSSX® ion exchange process has had considerable success for bicine removal. Ion exchange can work well for bicine removal especially when addressing low level bicine concentrations. [XVI, XVII] Other ion exchange providers have had difficulty in removing bicine due to their process conditions that result either in poor bicine removal or adding sodium to amine system.

Distillation

It has been suggested that distillation can remove amino acids[XVIII] but it may not be practical due to the fact the distillation is at its best with high concentration impurities and most bicine applications begin at relatively low concentrations (1 wt% or less) and are seeking to reduce bicine to 250 ppm or lower.

Electrodialysis

Electrolysis has shown some positive results, but amino acids removal is still being developed.

Amides

Primary and secondary amines form amides with carboxylic acids. For example, MEA and formic acid form a MEA-formamide called Formyl-MEA (also FMEA or MEAF). Similarly for DEA, DIPA, DGA, etc. Other amides, such as acetamide (e.g., Acetyl-DEA from DEA and acetate) may also form. For simplicity, the following discussion mentions only formamide, but it applies to other amides.

Formation of formamide results in a loss of one mole of useful amine per mole of formamide. The equilibrium formation of formamide may be depicted as follows:

$AmineH^+ + Formate^- \leftrightarrow Formyl\text{-}amine + H_2O$

Temperature, time, pH and concentration affect the formation of amides. Since the first two factors are usually fixed in the system, attention must be given to concentration. There is an equilibrium relationship between formate and amine formamide in primary or secondary amines. The molar ratio of formamide to formate varies with amine type and degree of contamination, with higher ratios typically seen at higher contaminant concentrations. Formamide have been seen in operating amine systems from less than 1 wt% to 15 wt%.

Of the common alkanolamines, the formamide to formate ratio is highest in DIPA, typically around 2:1. The ratio in DEA is typically about 1:1.

In an operating amine system, formamide may be converted back to useful free amine by removing the formate from the amine solution. As formate concentration is reduced, the equilibrium causes the formamide to convert back to protonated amine and formate. Further removal of formate results in further reduction in formamide concentration.

Bleed and Feed

Purging contaminated amine and replacing it with fresh amine works to remove amides but has the same advantages and disadvantages that were discussed for HSS.

Neutralization

Neutralization removes protonated amine from the equilibrium reaction by raising the pH and drives the amide to amine and formate. Thus, while caustic addition might increase the available amine concentration, neutralization replaces the relatively non-corrosive formamide with corrosion enhancing formate.

Ion exchange

Ion exchange removes the formate ion from the equilibrium reaction and drives the equilibrium to amine and formate. Ion exchange is extremely selective, removing only the formate, none of the formamide. Formamide can all be converted in the amine system to useful amine. For example, one refiner identified 90,000 lb of new DEA from formamide conversion after removing formate and other HSS from the amine system by Ion exchange.

Distillation

Because of the dehydrating aspect of distillation, amides can actually increase during the reclaiming process. Additional good amine thus becomes trapped in the reclaimer bottoms and is wasted. This can cause difficulties for waste water treatment facilities. Permitted the requisite time and operating skill, however, vacuum distillation and thermal reclaiming processes should be able to recover amine from amides. Commonly, however, amides remain in the bottom of the still and are thrown away, representing lost amine which is costly to discard and to replace.

Diamines and Ureas

Examples of diamines and ureas are:
HEEU (Hydroxyethylethylenediamine urea) found in MEA
HEED (Hydroxyethylethylenediamine) found in MEA
BHEEU (N,N-bis(hydroxyethoxyethyl)urea found in DGA
THEED (Tris-Hydroxyethylethylenediamine) found in DEA
Bis-HEP (Bis-hydroxyethylpiperzine) found in DEA
DIPA/MIPA and DIPA/DIPA dimers found in DIPA[II]

Diamines and ureas reduce capacity of amine solutions and can be responsible for corrosion, increased viscosity, and reduced water content.

Bleed and Feed

Pump and Dump have been used successfully when treating diamines and ureas. Pump and dump has the advantages and disadvantages discussed in the HSS section.

Neutralization

There are no known examples of neutralization being effective in treating diamines and ureas.

Ion Exchange

Ion exchange is not an effective way of removing diamines and ureas. However, field results indicate that continual operation of ion exchange to control HSS in refinery DEA systems prevents further formation of THEED. It is suspected that this is a side-effect of the improved regenerator conditions resulting from operating with cleaner amine.

Distillation

The value of thermal reclaimers for MEA and DGA is well known. Vacuum distillation of other amines has been successful in removing high concentrations of diamines and ureas. The advantages and disadvantages of distillation for treating diamines and ureas are similar to the advantages and disadvantages of distillation for HSS removal discussed above. The increased temperature of MEA thermal reclaimers dramatically increases the formation rate of dimers and ureas, thus additional good amine becomes trapped in the reclaimer bottoms and is wasted.

Electrodialysis

Electrodialysis is not an effective way of removing diamines and ureas.

Solids

Solids are a heterogeneous phase and normally provide different types of problems for amine operators. Solids can settle out or combine with hydrocarbons or antifoam and coat the internal components of the amine system. The "shoe polish" that coats the internals of amine systems leads to filter plugging, tray plugging, and reduced thermal transfer.[XIX] Another difficulty with solids is they can contribute to corrosion by mechanical wear that erodes the internal surfaces. It has been shown that solids can stabilize foaming. If the solids contain considerable iron sulfide, the iron sulfide can represent a fire hazard when servicing the amine system. Under normal conditions, pump and dump, neutralization, ion exchange, distillation, and electrodialysis are not used to deal with solids.

Size Exclusion Filters

Almost always solid removal is done with permanent units using size exclusion filtering. There have been advances of the filters include an increased variety in filtering technology available, and easier to use. The vast majority of filtering media is disposable (back washable media is available. The advantages of the disposable size exclusion filters are they are "easy" to use and they are readily available world wide from many suppliers. The disadvantages of disposable size exclusion filters are they can require frequent replacements in dirty systems. The filters do not remove particles below rated particle size. The consumable nature of filters can make for expensive purchase and disposal costs. Another difficulty is the potential for a fire hazard form iron sulfide. There are labor costs and personnel issues involving H_2S during filter change outs. All too often filters are bypassed during operations in to avoid dealing with a plugged filter.

SSX™ Process

The SSX™ technology is a new method where the solids are attracted to its media.[XX] This leads to the advantage that the SSX™ media normally does not plug, there is a low pressure drop, and

SSX™ units can remove particles to less than 1 micron. The media is regenerated with water and SSX™ works well on rich or lean side treating. This technology works well for refineries, where the oily waste water is easily handled. The SSX™ process rarely plugs. The disadvantage of this technology is that may not remove 100 % of particles per pass.

Hydrocarbons

Hydrocarbons are associated with plant upsets and they are frequently blamed as a source of foaming. Hydrocarbons and antifoam combine with solids that may result in plugging. Hydrocarbons are a poison to Claus catalysts. Hydrocarbons are not normally addressed with pump and dump, neutralization, ion exchange, distillation, or electrodialysis. Most amine systems have a permanently installed phase separator (knock-out drum) to deal with hydrocarbons that are not miscible with the amine solution. Hydrocarbons which make it past the phase separator require a reclaiming method.

Activated Carbon

Most amine systems use a tank filled with activated carbon to address dissolved and entrained hydrocarbons. In practice activated carbon bed performance suffers from the problems of being undersized and neglected. The activated carbon also needs to be regularly replaced leading to purchase and disposal costs as well as the labor required. Monitoring the condition of an activated carbon filter is also difficult.

HCX™ Process

The HCX technology uses a surface attraction of hydrocarbon that removes immiscible, entrained, and dissolved hydrocarbons from the amine systems.[XXI] The advantage is the HCX media normally is back washed about every 2 to 5 days to regenerate its surface. This technology works well for refineries, where the oily waste water is easily handled.

Foam Abatement

Foaming in amines systems cause system upsets that leads to an off spec product, loss production and amine losses. Foaming is caused by an impurity or impurities that act as surfactants in the amine system that allows the stabilization of the gas in liquid dispersion. Foaming has been attributed to number contaminants such as hydrocarbons, HSS, and solids.[XXII,XXIII,XXIV]

De-foaming Chemicals

There is a wide variety of anti-foaming or de-foaming agents available. These additives are believed to break the foam by being a heterogeneous droplet or solid enter entering the foam bubble and weakening the wall until the bubble ruptures.[XXV]

There have been advances in choices, effectiveness, and stability of these de-foaming additives. The advantages of de-foaming agents are their ease of use and low initial capital expense. The primary disadvantage of antifoam agents is that they do not remove impurities that cause the foaming in the amine system. The de-foaming agents can give operations a false sense of security and hide the underlying problem/impurity that could lead to a cycle of repeated foaming. Also de-foaming additives can become inactive at high concentrations and fail break the foam.

SigmaPure™ Process

The SigmaPure™ cleaning system has a unique method of effectively removing the foaming agents and any impurities which travel with the foam.[XXIV,XXVI] The SigmaPure system intentionally causes controlled foaming of a slip-stream of amine outside of the amine unit. Amine is drained from the foam and the foam it is carried over into a waste container. The amine is returned to customer with the foam causing contaminates removed.

Summary and Conclusion

Benefits of reclaiming have been widely demonstrated to reduce operational upsets, reduce amine losses and reduce corrosion. A variety of reclaiming options are now available to the amine system operator to remove troublesome contaminants. A comparative summary of these options is presented in Appendix A.

Appendix A

Comparison of Reclaiming Methods

	Ion Exchange	Distillation	Electrodialysis
Applicability	Removal of Ionized impurities	Removal of solids and non-volatile species	Removal of ionized impurities
Operation Principle	Ions captured by ion exchange resin	Vaporization of volatile species (water, amine, etc) from salts and degradation products	Ions removed by electrodialysis
Limitations	Can not remove non-ionic species (other than amides)	Energy intensive; most amines need vacuum;	Can not remove non-ionic species; membranes selection and durability
Forte	best option for low conc. Salts; works for all conc.	high conc. salts and degradation products	Amine concentration remains the same
Waste Products	Dilute aqueous stream containing removed ions and excess regeneration chemicals	Reclaimer bottoms, containing salts, non-volatile organics, and some amine. Normally hazardous waste	Aqueous brine containing removed ions
Volume of Wastes	High to moderate	Low	Moderate
Amine Recovery	>99%	95-85%	98%
Amine Feed Requirements	Lean cool amine	HSAS neutralized	Lean, cool, hydrocarbon free, particle free amine HSAS neutralized
Special Requirements	Regeneration chemicals as low as 1 mol/mol	Fuel gas or high temp. heat source; chemicals 1 mol/mol	DC power; chemicals 1 mol/mol
Operating Mode	Batch or on-line	Batch or on-line	Batch or on-line
Unit Availability	Permanent and mobile units available	Mobile units available (many DGA and MEA units have permanent thermal reclaimers)	Permanent and mobile units available

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