HIGH EFFICIENCY CONTAMINANT REMOVAL IMPROVES NEW AND EXISTING SWEETENING PROCESSES

Laurance Reid Gas Conditioning Conference
February 26 - March 1, 2017 – Norman, Oklahoma USA

Robert James, P. Eng.
Pall (Canada) Ltd
3450 Ridgeway Drive, Unit 6, Mississauga, Ont., Canada L5L 0A2
+1 647-271-6607
robert_h_james@pall.com

Dr. Ali Arshad
Pall Corporation
2901 W Sam Houston Parkway, Suite A-150, Houston, TX USA 77043
+1 832-506-7278
Ali_arshad@pall.com

ABSTRACT

Gas sweetening processes using amine solvents are often challenged to meet productivity and reliability targets due to the impact of solid and liquid contamination. Commonly seen issues are foaming, fouling and corrosion, leading to production loss from unscheduled downtime, reduced flowrate capability, regeneration issues, increased maintenance labor and equipment costs. Installation of high efficiency liquid/gas (LG) coalescers before contactors, rich side liquid/liquid (LL) coalescers and lean and rich side particulate filters are recommended to remove liquids and solids - related process variability. Benefits are seen both in new and existing sweetening systems. New systems will achieve full production rates very quickly, as opposed to the long commissioning phase so common with most startups. They will also usually maintain these high production rates for the long term. Existing systems will typically go through a cleanup phase where lower solids levels lead to reduced foaming, fouling and corrosion at an attractive cost of filtration vs. that experienced under high solids conditions. Case studies of actual new plant startups and existing plant upgrades demonstrate and quantify the impact of high efficiency coalescing and filtration on optimizing and improving plant productivity and reliability with economically viable CAPEX and OPEX investments.

HIGH EFFICIENCY CONTAMINANT REMOVAL IMPROVES NEW AND EXISTING SWEETENING PROCESSES

Robert James, P. Eng., Pall (Canada) Ltd., Mississauga, Ontario, Canada
Dr. Ali Arshad, Pall Corporation, Houston, TX, USA

Introduction

The acid gas removal unit (AGRU) performs an important industrial process to sweeten sour gas in gas plants, LNG facilities, refineries and chemical processes that is critical in achieving profitable economics. Consider a few examples of how unreliable operation can have significant financial impact. If a 100 MMSCFD gas plant is running 10% below capacity due to AGRU issues, with natural gas selling at $2.50/MMBTU, the daily gas revenue loss is $25,800. In a refinery, inability of the AGRU to treat acidic refinery fuel gas (RFG) coming from unit operations may reduce the ability of that unit to run at capacity, cutting back on refinery output of final products such as gasoline and diesel. If a 50,000 bbl. /day fluid catalytic cracker is forced to 10% below capacity due to AGRU issues so that refinery gasoline output is reduced by 5000 bbl. /day, with gasoline selling at $2/gallon, revenue loss is in the range of $420,000/day.

With this financial leverage on so many AGRU users, there is strong motivation to optimize AGRU operation. However, the complexities of this unit operation have shown that this can be a difficult challenge. In this paper, we will summarize a number of these key challenges, the impact that high efficiency contaminant removal can have on improving both old and new sweetening processes, and present case studies that document these improvements.

Plant Needs from AGRU Operation

All sites with acid gas treatment units share similar needs for productivity, reliability, low operating costs, safety and environmental protection. However, different plants have specific needs based on the type of facility, gas being treated and its end use. Noted below are several key needs for gas/LNG plants and refineries.

Gas/LNG Plant Needs

- Achieve or exceed natural gas production quotas via reliable treatment of acid gases
- Maintain process reliability for production consistency and minimization of downtime
- Provide consistent sales gas specification quality for H_2S and CO_2 levels
- Minimize off gas emissions through effective acid contaminant removal from the sour gas
- Minimize operating and maintenance costs from fouling, corrosion and filtration

Refinery Needs

- Achieve refined products unit production quotas via reliable treatment of acid gases
- Provide consistent refinery fuel gas quality to ensure reliable operation of all burner operations
- Minimize refinery off gas emissions through effective acid contaminant removal from the RFG
- Minimize operating and maintenance costs from fouling, corrosion and filtration

Challenges with AGRU Operation

The most common issues with AGRU operation include foaming, corrosion, fouling, the corrosion /fouling cycle, and the impact these have on productivity, reliability, emissions control and operating costs.

Foaming

Foaming in the contactor can result in huge amine losses, reduced operating capacity, and off-spec product. Amine carried over into the sweet gas can result in fouling of downstream equipment including compressors and burners. The AGRU requires efficient protection to prevent the ingression of liquid and solid contaminants into the contactor with the sour gas, as they negatively impact foaming tendency and foam stability, as measured by foam height and foam stability measurements. Liquid hydrocarbons are typically non-polar, low surface tension fluids that are strong foaming promoters, as they lower the surface tension of the polar, high surface tension amine, making easier bubble formation. Foam stability is impacted when the normally elastic, rapidly stretching and rupturing bubble wall that breaks foams readily becomes a gelatinous, stronger wall that resists rupturing. Hydrocarbons contribute to the formation of a gelatinous layer, and so they also contribute to foam stability. Particles further reinforce bubble skins by increasing viscosity of the fluid in the bubble wall and therefore reducing its ability to drain and rupture, increasing the foam stability of the amine and contributing to the build-up of a thicker foam layer. Even very small contaminants with sizes in the micron range can be extremely detrimental as they can cause severe increases in foam stability leading to foaming in the absorber, reduced flow capacity, loss of amine due to carryover, excessive use of anti-foams, and process upsets in the sulfur plant. Consequently, it is critical to effectively remove them down to very low levels prior to entering the contactor.

Corrosion, Fouling, and the Corrosion/Fouling Cycle

Most amine units contain large amounts of carbon steel internal surfaces in contact with the amine solution which are prone to attack from the acidic environment created by the sour gases. This leads to the formation of fine iron sulfide and iron oxide particulates, often less than 10 micron in size. Ideally, the hydrogen sulfide present in the sour gas reacts with the carbon steel to form an iron sulfide protective layer on the carbon steel interior surfaces that resists further rapid chemical attack from the acid gases. If total suspended solids (TSS) levels in the amine solution are allowed to increase, the combination of high velocity of the recirculating amine coupled with the abrasive nature of the hard iron sulfide and iron oxide particulates moving over the protective iron sulfide layer causes erosion of the protective layer. This continuous exposing of bare carbon steel to the corrosive environment of the acid gases creates rapid generation of new solids that increases TSS levels in the amine, leading to further erosion and generation of new solids. A ‘corrosion/fouling’ cycle establishes where higher TSS leads to increased erosion of the iron sulfide protective layer, creating higher TSS. We will see later in the paper how effective filtration can be used to break the corrosion fouling cycle by removing enough of the TSS that the iron sulfide layer can re-establish, reducing the corrosion rate and generation of new solids.

Solids in the amine loop also encounter many slower moving locations where they can settle out and accumulate, such as the lean/rich exchanger, contactor or regenerator columns. This equipment fouling can result in reboiler tube heat transfer loss, tray plugging in both the contactor and the regenerator, and loss of heat exchanger efficiency. Each of these will reduce acid gas removal efficiency, leading to off-spec product or the need to reduce capacity to ensure quality specs are met.

As heat exchange surfaces foul, higher temperature steam in the reboiler can be used to offset the loss in heat transfer efficiency. This can have a negative effect, as the partially fouled reboiler tubes create hot spots for the amine, with temperatures sufficient to create acidic amine breakdown products that further contribute to the corrosion/fouling cycle. Some of acidic breakdown reactions and products are shown in Table 1. These acidic breakdown products can then react with the amine to form new heat stable salts (HSS) that further reduce the amine loop's capacity for effective sweetening.

A serious problem with equipment fouling is that the accumulated solids tend to have different chemical properties than the rest of the system, leading to concentration cell or pitting corrosion. This type of corrosion tends to be very localized, creating deep pits or holes in surfaces that otherwise appear sound. If not noticed, the result can be unscheduled equipment failure, leading to production loss, equipment and labor costs and the potential for serious safety issues.

The good news is that the majority of the common, reoccurring problems that appear as a result of contamination and the corrosion/fouling cycle can be diagnosed, fixed, and prevented with a high efficiency filtration solution.

Table 1 - Some Amine Degradation Reactions and Products

Reactions	
Oxidation of amine to form carboxylic acids and ammonia	
Internal dehydration of amine carbonate to form HEOZD	
Simultaneous dehydration and decarboxylation of HEOZD to form THEED	
Internal dehydration of THEED to form DEP	
Double dehydration of DEA in presence of MEA to form HEP	
Condensation of two MEA molecules to form Piperazine	
Acylation of tertiary amines to form Quaternary Ammonium Salts	
Products	
HEOZD	N(hydroxyethyl) oxazolidone
THEED	Tri(hydroxyethyl) ethylenediamine
DEP	Diethanolpiperazine
HEP	N(hydroxyethyl) piperazine

The Additional Challenges of Increased Production or AGRU Loading

Increased production and tighter product specifications lead to a greater demand on the amine plant. This often results in increased stress on the system in the form of solids and liquids contamination. As this contamination continues without the proper control, it manifests itself in high amine loss, high corrosion rates, high energy costs, and challenges to sweetening capacity and reliability.

Many amine plants are struggling to handle the increased loads. As activities to increase amine solution loadings and circulation rates are undertaken, it is critical that suitable filtration, separation and heat-stable salts management are employed to ensure operational reliability.

Products to Control AGRU Challenges

A. High Efficiency Liquid/Gas Coalescers (HE LGCs)

To control ingression of liquid and solid contamination into the amine loop, placement of a high efficiency liquid/gas coalescer (HE LGC) upstream of the contactor is recommended, as shown in Figure 1. Liquid contaminants, or aerosols that are present in gas streams are very small in size, typically in the micron and sub-micron range. Although they are small, they are detrimental to all gas treating units and must be removed effectively before entering the amine loop. Conventional separators such as filter-separators may not be able to remove fine aerosols and may not protect the equipment properly, causing severe operating issues leading to reduced plant capacity and loss of revenue. HE LGCs are capable of separating both the large droplets and the sub-micron size aerosols, and are a proven solution. They remove entrained liquids (such as hydrocarbons, water, additives and other chemicals) as well as solid aerosols in the sour inlet gas to reduce amine contamination and resulting contactor foaming, corrosion rates, and equipment fouling. Other benefits include increases in carbon bed absorption efficiencies.

HE LGCs can also be applied on the sweet gas or refinery fuel gas (RFG) exiting the contactor to prevent amine carry-over from passing downstream to contaminate pipelines, burner tips, glycol dehydrators, molecular sieve driers, or recycle compressors. They can also be used to debottleneck contactors running at higher gas flow rates than original specification design, where mechanical losses have started to occur due to the higher gas velocities. The amine recovered from the HE LGC can be returned to the process, reducing amine make-up cost.

Figure 2 shows a typical layout for a vertical high efficiency liquid/gas coalescer. Flow passes into the lower chamber, where liquid slugs are removed. An optional internal pre-separator such as a demisting pad may be used to reduce liquid loading on the coalescing elements for size and cost optimization. The flow then passes up through standoff pipes and into the coalescing elements. As the flow passes from inside to outside, the process of initial capture, coalescing, release, drainage and separation from the media occurs, with clean, aerosol-free gas exiting the top of the housing.

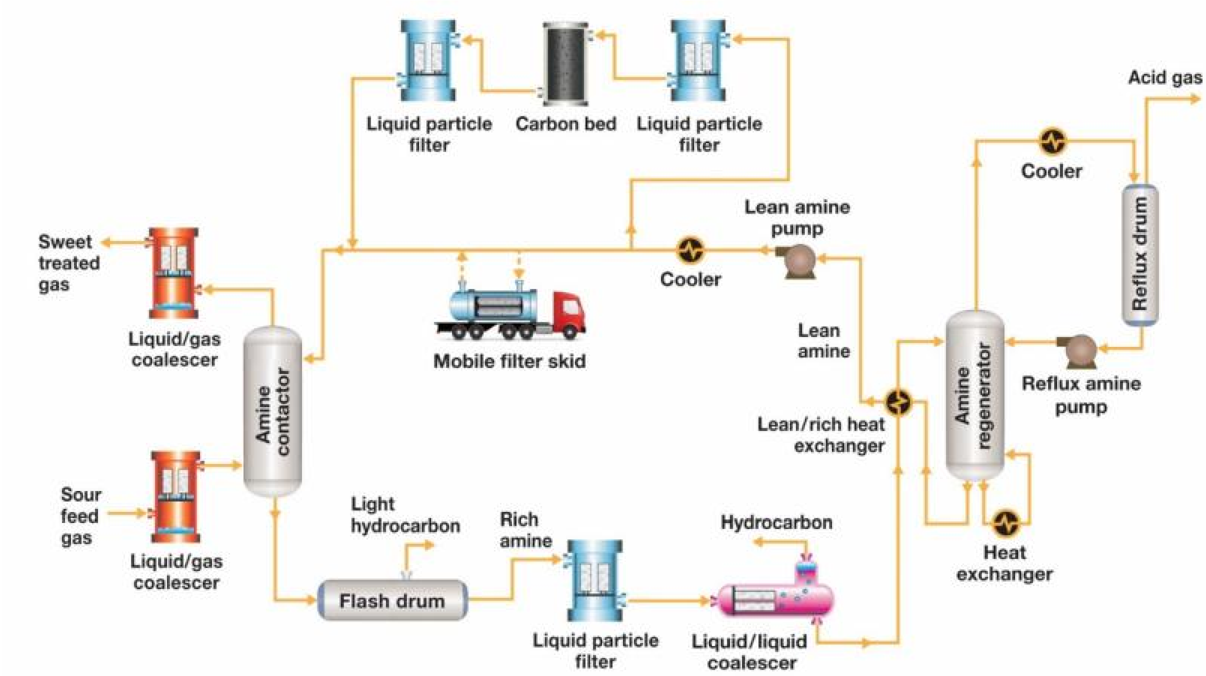

Figure 1. Typical Amine Loop Layout with Filtration/Coalescing Recommendations

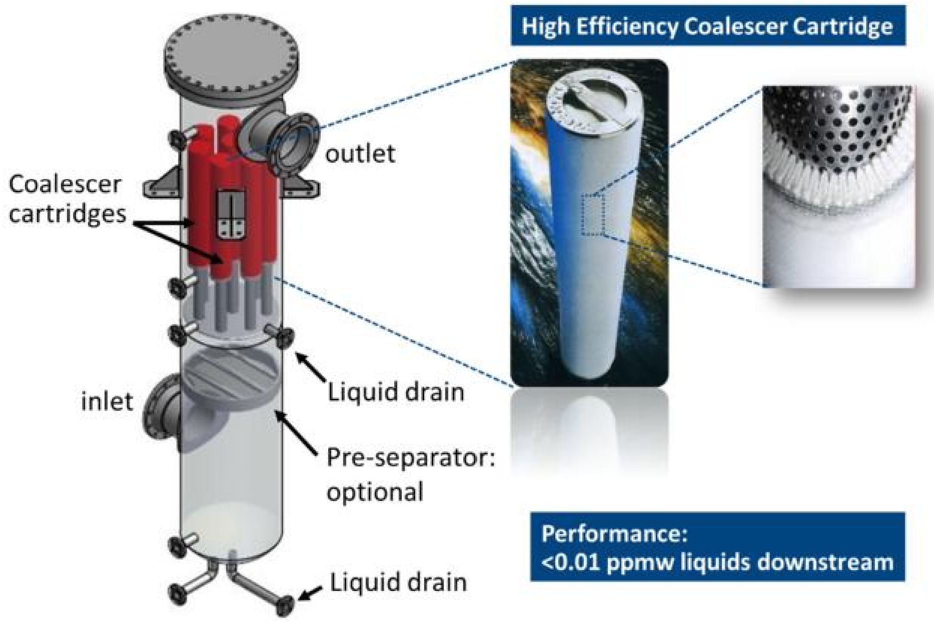

Figure 2. A Vertical High Efficiency Liquid/Gas Coalescer

Resin bonded glass fibers have been used extensively in HE LGCs due to their ability to form fine fibers down to a few microns in diameter. The use of polymeric media does not allow for the creation of fiber diameters as small as the glass fibers. Coalescer elements should be constructed with pleated media to allow for far more surface area than a cylindrical wrapped depth media to reduce the gas velocity through the media. The lower velocity allows for better coalescence and separation, resulting in a smaller sized coalescer system. The pleated configuration keeps the pressure losses to a minimum and will, therefore, reduce the energy costs of recompression. They should also be designed with a layered structure with a graded pore structure, first fine to allow for optimized aerosol capture and then coarser to provide room for the drops to coalesce into larger diameters and effectively drain before exiting the media.

The HE LGC design will ideally use hydrophobic/oleophobic surface treatment of the entire coalescer element, including all exposed media, support and drainage material surfaces. The surface treatment lowers the surface energy of all coalescer layers and prevents the drops from wetting out the coalescer, leading to rapid drainage. This greatly reduces the liquid holdup of the element, leading to smaller size vessels at lower capital cost, improved separation efficiency, reduced potential for liquid re-entrainment, faster recovery from liquid slugs, and operation at a lower cost due to the lower saturated pressure drop. Compare this to the untreated element. The lesser drainage leads to a 'flooding' of most of the media. The large volume of coalesced liquid droplets blocks most of the pores, leading to high gas velocity through the remaining open pores. This leads to droplets being atomized and re-entrained in the exiting flow. The result is a coalescer with high delta P and poor liquids removal efficiency.

The use of polymeric media (polyester or nylon) will not provide critical wetting surface tensions as low as the cartridge options with complete surface treatment and will not have the same benefits to separation.

For proper sizing of a coalescer, the following parameters need to be supplied by the EPC or end user. Estimates are to be provided if exact values are unknown:

- Gas flowrate – normal and maximum
- Gas temperature – minimum, normal and maximum
- Gas pressure – minimum, normal and maximum
- Gas composition
- Liquid composition
- Anticipated liquid loading – minimum, normal, and maximum
- Nature of solids and solids loading
- Additional contaminants and anticipated loading (e.g. waxes, asphaltines, etc.)

In designing and sizing a HE LGC, the following parameters are taken into account:

- Gas velocity through the media
- Annular velocity of gas exiting the media
- Solid and liquid aerosol concentration in the inlet gas
- Drainability of the coalescer
- Surface tension

Each of these factors with the exception of the inlet aerosol concentration can be controlled. For example, in order to correctly size a liquid/gas coalescer, one must insure that the media and annular velocities at the operating conditions never exceed the maximum media or maximum annular velocity of the system. The reason for this concern is that an undersized coalescer will dramatically lose its efficiency when the gas flow rate and/or inlet aerosol concentration exceeds the original design conditions, causing potential downstream carryover and contamination.

It is important to consider the size of typical liquid and solid aerosol challenges to a HE LGC. Figure 3 shows that liquid aerosols in a typical pipeline are formed in three peaks of droplet size based on condensation, atomization, or re-entrainment from upstream equipment. Condensation almost always forms very stable, fine aerosols in the 0.1µm to 5.0µm range. These aerosols do not easily fall out of the gas stream, and therefore, require a high quality coalescing medium for their efficient removal. Aerosols between 0.1µm and 0.6µm are particularly difficult to remove and cannot be coalesced by conventional Liquid/Gas separators because they are easily "buoyed" by system flow and tend to follow the flow paths of the gas. Based on field measurements at many amine sites, over 90% of liquid aerosols entrained in process gas streams are typically in the 0.1µm to 5.0µm range, as demonstrated in Figure 4. Such aerosols cannot be removed efficiently by knock-out drums, mist eliminators, vane packs, filter-separators or conventional coalescers due to poor capture efficiency. If not removed by the separator technology, these aerosols will contaminate the outlet flow. For example, the amine loop will be hit with hydrocarbon liquids and solids, contributing to foaming, fouling and shortened amine filter life. If on the downstream side, the sweetened gas will be contaminated with amine.

The most effective high efficiency liquid/gas coalescers are designed to remove all solid and liquid aerosols in these critical ranges and are laboratory-rated at 0.3µm. This means maximum removal of liquid contaminants, and provides the clean gas streams essential to efficient operation.

Field measurement of liquid aerosols downstream of an L/G separator is very challenging due to the lack of reliable field equipment to measure droplet quantities at different size ranges. We find it more effective to evaluate total liquids removal performance that accounts for all droplet sizes. The field test is performed with a small scale coalescer to measure the mass of remaining liquids vs. the gas flow, with validation via a submicron filter test disc downstream of the test coalescer to confirm no carryover of fine mists. Typical field downstream effluent concentrations of the HE LGC are 0.01 ppmw or less, vs. legacy technologies at tens, hundreds or thousands of ppmw.

The HE LGCs are also designed to remove solid particulates – namely pipe scale and rust, which can also cause downstream problems – from gas streams. The additional removal efficiency of 99.9% of 0.1 micron assures that only the highest quality gas products are supplied.

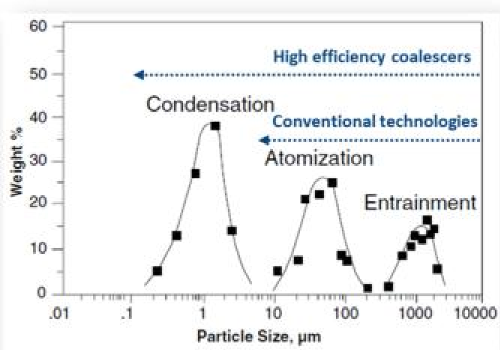

Figure 3. Typical Droplet Size Distribution in a Pipe

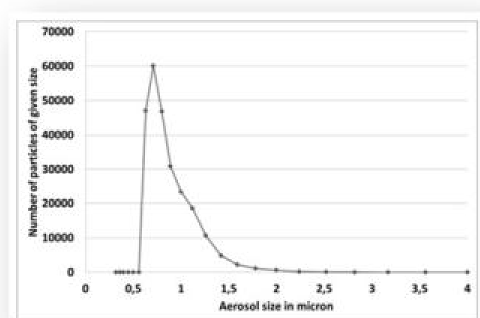

Figure 4. Actual Field Test Results Showing Most Droplets Finer Than 2 Micron in Size

B. Amine Particulate Filters

The particulate separation products on the amine loop should be selected to ensure consistent contaminant control and reliable amine system performance, as shown in Figure 1. The proper use of high efficiency state of the art technologies will minimize contactor foaming upsets, ensure regenerator reliability, reduce or eliminate sulfur plant excursions, and consistently meet gas specifications for H_2S and CO_2.

i) Stable Pore Filtration / Fixed Medium Pore Structure:

For consistent solids removal performance in the amine loop, it is essential to use particulate filters that exhibit fixed pore media structure. These filters are designed to depend heavily on the mechanism of direct interception to achieve the separation, and are so constructed that the flow path through the medium is tortuous. These filter media contain sufficient thickness that the release of collected particles that are smaller than the removal rating is minimized, even under impulse conditions. The fixed pore filters typically have absolute and/or Beta ratings, as defined below.

Non-fixed pore filter media, on the other hand, rely principally on the filtration mechanisms of inertial impaction and/or diffusional interception to trap particles within the interstices of their internal structure. Non-fixed pore filters have no absolute ratings, are subject to media migration, and unload particles very badly under impulse conditions. A sudden increase in flow and/or pressure can overcome the retentive forces and cause the release downstream of some of the particles, or the medium fibers can move to release previously removed contaminants. This unloading will frequently occur after the filter has been in use for some time and can give the false impression of long service life for the filter. Nominally rated elements do not have fixed pore structures, and hence, cannot guarantee absolute particle cutoffs leading to serious downstream problems.

The absolute-rated cartridges are manufactured from medium fibers that are locked in place to ensure consistent removal efficiencies and the structural integrity of the element. The removal efficiencies of these filter elements will not change due to sudden increases in flow or pressure.

ii) Filter Rating Systems – Nominal, Absolute, Beta (β):

Various rating systems have evolved to describe the filtration capabilities of a variety of filter technologies, all of which continue in use today due to their applicability to different types of construction and application, as demonstrated in Figure 5.

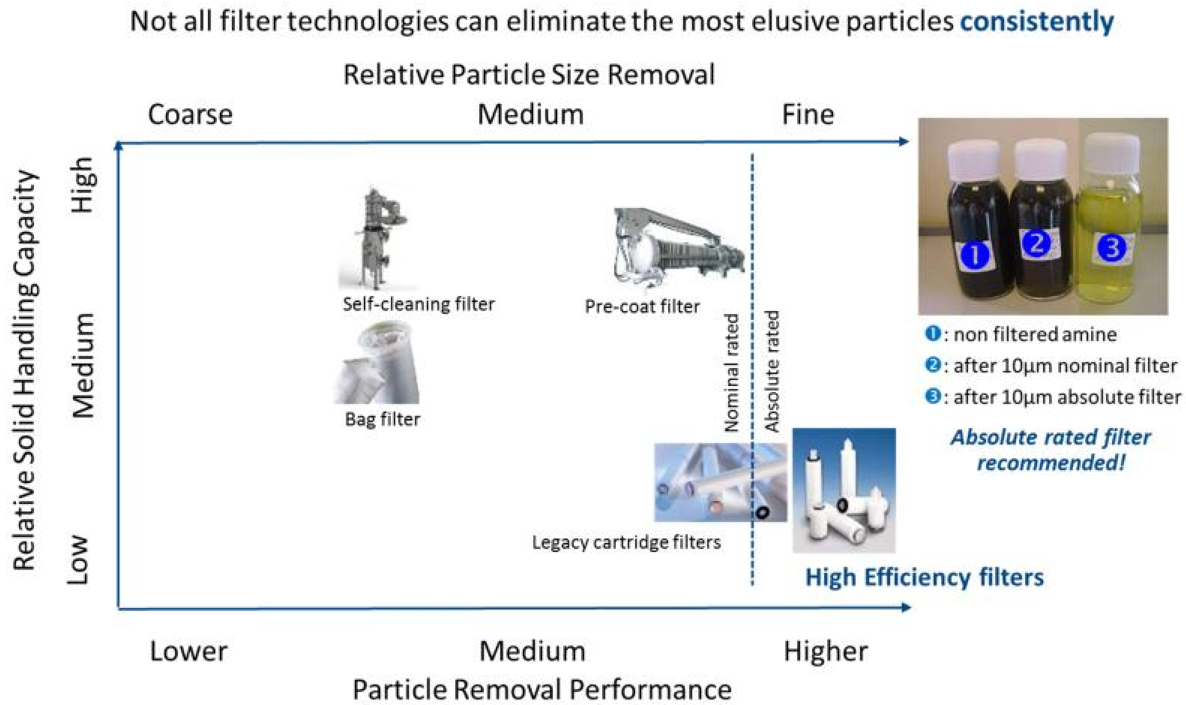

Figure 5. A Sampling of Nominal through Absolute Filter Technologies Used on Amine Systems

iii) Nominal Rating:

Non-fixed pore filters are typically nominally rated. The rating is based on a gravimetric (% weight removal) test rather than a particle count test. Counting particles upstream and downstream is a more meaningful way to measure filter effectiveness, however this type of test is not applicable to a non-fixed pore filter, as the removal efficiency can change significantly during service life as conditions cause shifting of fiber positioning that greatly modify the efficiency rating, typically to a lower removal efficiency. An example is a large particle initially stopped that is gradually pushed through the filter medium under increasing differential pressure by shifting fibers side to side without breaking, as they are not held in place. The particle eventually pushes through the medium and exits the far side, leaving behind a larger diameter hole or channel that continues to allow larger particles to pass downstream.

- Nominal Rating definition: Arbitrary value given by the filter manufacturer based on the removal of a % of the total particles, often in weight. If a filter is specified by a micron rating with no other descriptor, it is a nominal rating.

iv) Absolute Rating:

An Absolute rating refers to the diameter of the largest hard spherical particle that will pass through a filter under specified test conditions. It is an indication of the largest opening in the filter element.

v) Beta (β) Rating:

Beta ratios are determined using the Oklahoma State University, "OSU F-2 Filter Performance Test". The test, originally developed for use on hydraulic and lubricating oil filters as a multi-pass test and was adapted for single-pass filtration use as a rapid semi-automated testing of filters for service with aqueous liquids, oil, or other fluids. The β values allow the comparison of removal efficiencies at a range of different particle sizes for different cartridges in a meaningful manner.

- The Beta ratio, $ß_x$: An indicator of how well a filter controls particulate. It is the ratio of the number of particles (>x µm) entering the filter to the number (>x µm) that pass through. If one out of every two of the particles (>x µm) in the fluid pass through the filter, the filter's Beta ratio at x µm is "2." If only one out of every 200 of the particles (>x µm) pass through the filter, the Beta ratio at x µm is "200." Therefore, filters with a higher Beta ratio provide better particulate control and hence better system protection.
- For Process filtration, Beta values of 5000 or 1000, with corresponding removal efficiencies of 99.98% and 99.9% respectively are commonly used as operational definitions of the absolute removal rating of a fixed pore filter. So, a process filter rated $\beta_{10} = 5000$ will allow 1 particle in 5000, 10 µm or larger to pass downstream, a close approximation to the largest hard, spherical particle that will pass per the absolute rating definition. This functionally meets and quantifies the absolute rating with a removal efficiency that has been shown to provide predictable and reliable performance in the field.

vi) Absolute-Rated Filters in Amine Loop Service

Absolute-rated particulate filters will effectively remove corrosion products that may enter the amine system through the inlet sour gas or sour LPG, or are formed in the amine circuit. They also provide adequate protection for the activated carbon bed in the lean amine and capture any carry-over carbon bed fines to prevent fouling of the amine contactor.

We have already introduced the importance of solids control to break the corrosion fouling cycle of a typical amine loop. Experience has shown that the circulating amine should contain a maximum of 1 to 10 ppm TSS by weight (ppmw) and ideally less than 1 ppmw to effectively break the corrosion/fouling cycle. To achieve this threshold with an initially dirty system, coarser filters may need to be installed at first to clean the system of solids which have been accumulating over a period of time. Progressively finer filters are introduced to the system until a filter efficiency of 10 µm or 5 µm absolute is installed.

vii) Rich Side Amine Filtration

For enhanced solids control, addition of filtration to the rich side is strongly recommended. The particulate filter should be placed immediately downstream of the surge/flash tank and upstream of the lean/rich exchanger on the rich side. This strategy will provide long term benefits to plant operation by:

- Ensuring removal of iron sulfide solids in the precipitated state on the rich side that are in solution on the lean side
- Providing optimal protection of the lean/rich heat exchanger, regenerator and reboiler to maintain heat exchange efficiency, thus reducing steam and overall energy consumptions costs

- Minimize degradation and breakdown of the amine from reboiler hotspots caused by solid depositions on the reboiler tubes. Breakdown products can lead to corrosion or to generation of heat stable salts (HSS)
- In many cases, the efficient protection of these heat or mass transfer surfaces will ensure site productivity, as demonstrated in two of the enclosed case studies.

Depending on the site issues, rich side filtration may be the best strategy to a permanent and reliable solution. Work with your in house experts, safety personnel and an experienced filter supplier to perform an appropriate analysis. Rich side filtration always requires proper equipment, procedures and training to be done safely.

C. High Efficiency Liquid/Liquid Coalescers (HE LLCs)

Figure 6 shows the combination of prefilter and high efficiency liquid/liquid coalescer (HE LLC). The prefilter is a particulate filter that on amine applications, serves two functions:

- To protect the coalescer from solids accumulation so that it can operate effectively as a coalescer for an extended period of time, typically two or more years service life.
- To provide rich side filtration as described above.

HE LLCs provide excellent removal of liquid hydrocarbon contaminants that may have carried over from an LPG liquid/liquid contactor, or that have not been removed in the flash drum due to insufficient residence time. Removal of these hydrocarbons on the rich side is critical to ensure elimination of hydrocarbon-related fouling of the lean-rich exchanger, regenerator and reboiler, and to stop hydrocarbon carryover into the sulfur plant that can result in bed coking or fires in the sulfur plant catalyst beds.

HE LLCs are able to separate difficult oil in amine emulsions with low interfacial tension. In general, one of the most important properties to address in sizing and selecting L/L coalescers is interfacial tension. The lower the interfacial tension, the more stable the emulsion and the more difficult the liquids are to separate. Frequently, the problem is the presence of a surfactant, or surface-active chemical that lowers interfacial tension. Conventional coalescers begin to lose efficiency when the interfacial tension is below 20 dyne/cm due to the challenge of the fine droplet size encountered. In addition, a small amount of surfactant can disarm conventional coalescers, rendering them ineffective by occupying the attractive sites on the coalescing media where coalescing process begins. Surfactants are everywhere - in corrosion inhibitors, well treating chemicals, sulfur compounds, and numerous chemical additives. The HE LLCs separate liquids with interfacial tensions as low as 0.5 dyne/cm without disarming to exhibit multi-year service life.

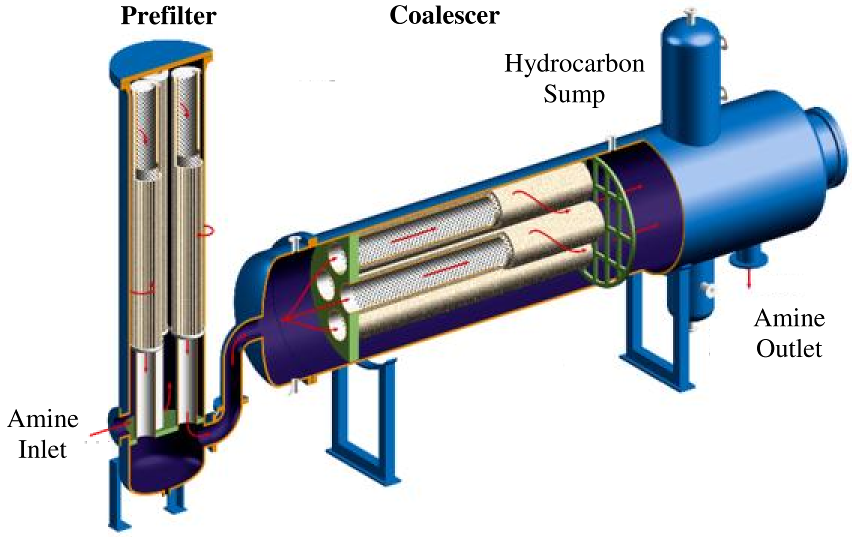

Figure 6: Vertical Prefilter and Horizontal, High Efficiency Liquid/Liquid Coalescer

D. Carbon Beds

Carbon beds are widely employed in amine regeneration circuits. We see carbon beds on full-flow rich amine streams, and more commonly on full-flow and side-stream lean amine streams. They are well suited for dissolved hydrocarbon (H/C) removal, working on the principle of surface active media having an affinity for hydrocarbon species, and provide a vital and effective purpose in removing the dissolved H/C. Carbon beds are also frequently called upon to remove liquid H/C. This is less than ideal for a few reasons. When the beds are overloaded from H/C (due to free H/C slugs, or missed regeneration or replacement cycles) operators will often add anti-foams to deal with foaming upsets. However due to surface affinities, antifoams will also be stripped by the carbon bed as they re-circulate, leading to the need for even higher antifoam addition rates that further reduce the carbon bed's capacity to adsorb H/C. A foaming incident may even be initiated if the previously removed antifoam is released from the carbon, leading to a slug of antifoam that actually becomes a foam initiator.

Another important consideration for carbon is its potential ability to remove amine degradation products. Carbon grades that are selected for their liquid H/C removal capabilities are typically very poor at removal of amine degradation products listed in Table 1. A more effective approach to improve amine system operation is to use alternate technologies such as HE LLCs to remove the liquid H/C, and switch to the appropriate grade of carbon that more reliably removes amine degradation products.

Carbon beds are generally protected by filtration to ensure that the depth of the bed does not plug with particles thus eliminating surface active sites, cause channeling, or general poor performance of the bed. Filtration is also usually found downstream of the carbon bed to ensure fines generated during the carbon aging process to not find their way into the main amine loop as an additional contaminant to deal with. The 5 or 10 micron absolute-rated filtration mentioned earlier to achieve 1-10 ppmw solids in the loop and to break the corrosion/fouling cycle is usually more than sufficient to serve as carbon bed pre- and after-filters.

Case Studies

Gas Plant, New Installation

A major new gas plant project in the Middle East was started on schedule in March 2013 and handed over to the owner September 2013. Very early in plant studies, a choice was made by EPC and owner for fluid contamination control during design, construction, start-up and commissioning. The goal was to implement a Faultless Right First Time Start Up (FRFTSU) strategy to ensure a trouble-free start-up of four new acid gas removal trains, two glycol dehydration trains and the sulfur recovery unit. This involved a careful examination of component selection, construction, pre-commissioning and commissioning activities.

Part of the strategy was to identify 'critical contaminant-challenged locations', where the installation of an appropriate and efficient separation technology was deemed necessary to ensure detrimental solids and liquids would be eliminated before a processing unit or critical equipment, or in a closed loop to eliminate solids forming inside the loop. In their component selection for LG separation and particulate filtration requirements, the decision was made to go with vertical HE LGCs for the Feed Gas Filter Separators upstream of the contactors, and HE beta-rated particulate filters for the Lean Solvent filtration Packages. The move to high efficiency separation was driven in part by owner history at existing plants where operational issues had been solved by modifying and replacing inefficient filtration equipment with high performance technologies. These Lessons Learned helped to settle precise specifications for the new plant:

- Feed Gas Filter Separators: a filter element type technology with the SepraSol™ Plus brand installed in a vertical housing
- Lean Solvent Filtration Packages (Amine Sump Filter, Lean Amine Filter, Carbon Fines Filter): cartridge type filters with a removal efficiency of 99.98% and a Beta ratio 5000

Fluid cleanliness control was practiced during prefabrication, fabrication, precommissioning and commissioning activities that included:

- Cleaning, inspection and preservation of large diameter pipe spools to reduce the need for difficult and expensive flushing during precommissioning
- In precommissioning, cold water and hot water washing followed by chemical flushing of the amine circuits to remove grease, then flushing many times with water until residual caustic content was negligible
- Lean Solvent Filtration packages were supplied with staged coarse to fine start-up filters to control filtration costs
- On the Feed Gas Filter Separators, start-up filters were initially installed in the first days of operation when pipeline contamination was expected, then converted to the final coalescer cartridges after a few days of operation

Following start-up, field testing of the coalescers and particulate filters was performed to validate critical equipment performance. The liquid/gas coalescers were proven to deliver a liquid content below 0.3 ppmw in the outlet gas. The particle filters were proven to maintain a solid content below 3 ppmw in the amine loop.

Since the turnover to the owner September 2013, performance has been steady and trouble-free. The plant has been operating above design capacity most of the time since January 2014. The reliability of the AGRU operation helps ensure that production targets are met. Based on a 900 MMSCFD production design capacity, and natural gas assumed selling at $2.50/MMBTU, every percent of production is worth approximately $23.2k/day, or $8.1 million/year in revenue. With filter service life averaging 6 to 12 months, the annual change out cost is in the tens of thousands of dollars. The leverage of filtration costs to maintain or increase productivity is enormous.

50 Year Old Refinery AGRU with 10 Year Old Filter Upgrade Installation

In 2006, as part of a 50% expansion project, a major Canadian refinery complex chose to install the latest technology available to meet stringent requirements for plant reliability and performance by eliminating particulate and hydrocarbon ingression/contamination issues that were previously reducing plant efficiency due to fouling.

A critical area in the redesign analysis was flash drum residence time, as the original drum was maintained. Before the expansion, the average residence time was 22 minutes vs. 19 minutes original design. Following the expansion, residence time dropped to 13 minutes at normal operating level, 9 minutes at 50% level. This was considered insufficient time to adequately separate liquid hydrocarbons from the amine, leading to concerns about the reliability of the new plant.

On-site testing in October 2004 revealed that even with the original residence time, a hydrocarbon/amine emulsion was found that remained stable, with samples remaining hazy for 3 weeks. A HE LLC was capable of breaking the emulsion in a single pass, as demonstrated in Figure 7. The left and center bottles show the impact of 10 micron absolute filtration – color improvement from grey/green to straw color, with a haze still remaining. The bottle on the right shows the coalescer outlet – straw color, clear and bright, where clear and bright provides a qualitative indication of free oil concentration of 30 ppmw or less. During the period of the test, the coalescer was removing between 43 and 88 ppmw of liquid hydrocarbon from the amine solution.

As part of the expansion in 2006, rich side filter and L/L coalescer units were started up. Prior to rich side filtration, TSS in the circuit would reach 30 ppmw. After start-up of the new rich side filter, TSS dropped to the 1 ppmw range on average. The combination of original flash drum and HE LLC was shown to effectively remove free oil, as demonstrated by follow up testing in October 2007 and January 2008 that showed straw colored, clear and bright amine both upstream and downstream of the coalescer. Presence of coalesced liquid hydrocarbon in the coalescer sump indicated that the fine hydrocarbon emulsion was being effectively removed. More critically, when hydrocarbon spikes occur, the L/L coalescers responds immediately by separating and removing the liquid hydrocarbon slugs, keeping levels low and preventing amine loop contamination.

Now on line for ten years, the combination of rich side filtration and L/L coalescence to control amine loop contamination has proven effective. For the last few years, amine recirculation rates have been roughly halved, creating a potential for fouling corrosion due to low flowrates allowing for solids accumulation in the system. This has not happened. The system operates without major incident, with average L/L coalescer life of 2.5 years, and filter service life of 4 to 8 weeks.

Figure 7 – Visual Examination of Amine Samples

Refinery, Major AGRU Upgrade

A major gulf coast refinery processing in excess of 500,000 bbl/day of sweet and sour crudes installed high efficiency high flow particulate filters during a major upgrade forming two new AGRUs. Full flow amine filtration was installed on the rich side, slipstream filters on the lean side upstream and downstream of the carbon bed, and filtration on the amine sump. All filters are 10 micron absolute.

Performance of the AGRU since the upgrade has been excellent, with no foaming or fouling issues impacting refinery production since 2009. Initially, they would use 40 micron filters during start-up, and then move to 10 micron absolute. They have progressed to 10 micron absolute filters at all times, including start-ups and upset conditions, to accelerate recovery to steady state and minimize amine loop fouling. They are achieving the intended result. For example, during a recent scheduled turnaround, while filter changeout frequency increased slightly during start-up, they maintained amine visual clarity the entire time, with no onset of foaming and effectively no deposition of solids in the amine loop. They have been very pleased with the rapidity and ease of filter changeout of the high flow filter element and horizontal housing design equipped with quick opening closures. This configuration minimizes maintenance costs – both through rapid filter changes and ease of access – and also minimizes potential personnel exposure. Filter service life on the rich side is in excess of two months on average.

Consistent performance of the AGRU helps the refinery achieve its production targets of millions of dollars per day in final products with minimal chance of environmental exceedances from the AGRU or sulfur plant.

Refinery with AGRU Foaming Resulting in FCC Production Losses

A European refinery had an AGRU train on the fluid catalytic cracker unit (FCCU) off-gas. Repeated foaming issues were causing issues with the H_2S spec and heavy hydrocarbon carryover in the treated refinery fuel gas (RFG). The refinery had to limit AGRU capacity from 40 ton/h to 35 ton/h, a reduction of 12.5%. This reduction directly limited refinery fuel gas (RFG) production, with the potential to restrict FCCU output at significant financial risk to the refinery.

A range of nominally rated filter technologies such as bag, pre-coat and self-cleaning filters had been trialed unsuccessfully. An amine loop clean-up or 'depollution' was tried with high efficiency filter, liquid/liquid coalescer and carbon bed mobile rental units connected to the rich amine loop to reduce the solids and hydrocarbon liquids recirculating in the amine. Foam tests were used to evaluate progress. As a benchmark, new amine solution foam collapse time was measured at 7 seconds. The amine solution before depollution measured at 60 seconds. Within 24 hours of depollution, collapse time improved to 20 seconds. After 72 hours it was down to 9 seconds. More importantly, the refinery was able to return the train to its design capacity of 40 ton/h. Testing also demonstrated that the carbon bed installed downstream of the coalescer did not bring a further reduction in the collapse time of the foam, meaning that the contaminants leading to the foaming were effectively removed by the particulate filter and coalescer.

After a few months, the refinery decided to permanently install a filter on the rich side to maintain low levels of solid contamination. An Ultipleat High Flow, 10 micron absolute-rated filter was installed.

A few years later, the refinery initiated an upgrade project to address continued foaming sensitivity on the FCCU AGRU. They went back to the excellent depollution results that demonstrated the reducing amine foaming with improved liquid hydrocarbon removal. The refinery decided to upgrade by installing high efficiency liquid/gas coalescers upstream of the contactor to eliminate condensed hydrocarbons from the FCCU before mixing with the amine solution. Risk assessment validated the reliability of this solution based on the positive feedback from another refinery in the group where the same high efficiency coalescer technology was successfully installed on a similar application. Lastly, 10 micron absolute-rated Ultipleat High Flow lean side filters were installed up and downstream of the carbon bed.

They are very pleased with the results – very satisfactory operation of the filters and coalescer, no more foaming incidents, no more antifoam consumption, stable quality of the amine solution, minimal risk of FCCU restrictions due to AGRU issues. Rich side filters are changed every 3 months on average, lean side filters every 12 months. Yearly costs for coalescer and filter elements is below $25,000. These benefits were realized as a result of the strong long term relationship between the refiner and the filter supplier, and the process knowledge of both parties to develop and implement a cost effective and reliable solution.

Summary

Case studies of new and old AGRUs have demonstrated that proper application of high efficiency filtration and coalescence is an important part of AGRU system productivity, reliability and cost effectiveness. New installations exhibited excellent operability for many years by maintaining the original cleanliness of a new system. Old units saw a cleanup driving performance improvement. It is recommended that AGRU users consider upgrading to high efficiency filters and coalescers as an excellent investment in their plant to maximize top line and bottom line performance.

References

1. Pauley, R., "Face the Facts About Amine Foaming", *Chemical Engineering Progress,* July 1991
2. Pauley, R., Hashemi, R. "Analysis of Foaming Mechanisms in Amine Plants", paper presented at the *AICHE Summer Meeting*, Denver, CO (Aug 1988)
3. Wines, T.H., Whitney, S., Arshad, A., "Liquid-Gas Coalescers: Demystifying Performance Ratings", *Chemical Engineering*, July 2011
4. Meusburger, K.E. and Segebrecht, E.W., "Foam Depressants for Gas Processing Systems", presented at the *1980 Laurance Reid Gas Conditioning Conference (LRGCC)*, Norman, Oklahoma, March 1980
5. Janas, Jane, and Meenan, Sean, "Guidelines for Choosing the Optimum Process Filter", *Chemical Processing,* 1991
6. Swiezbin, J and Janas Jane, "Using beta rating tests to compare filter performance", *Chemical Processing,* 1995
7. Raymond, A., Levesque, F. Lakhani, H., "Separation Technologies to Improve Amine System Reliability: A Case Study", presented at *LRGCC*, February 2008