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Scientific & Technical Report

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Predicting Contamination Levels Of Upset Conditions In Amine Sweetening Systems

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Predicting Contamination Levels Of Upset Conditions In Amine Sweetening Systems

Presented by: Robert L. Brown, Jr. and Reza Hashemi, Pall Corporation, Hydrocarbon, Chemical, Polymer Group, East Hills, New York, to the: American Institute of Chemical Engineers, Spring Meeting, Houston, Texas, March 30 - April 1, 1993

Abstract

The need for filtration systems in an amine unit has been well documented. Filtration provides the following benefits: reduction of hot spots in the regenerator reboiler, reduced heat exchanger fouling, longer carbon bed life, and reduction of foaming tendency in the amine absorber. Of these operating problems, foaming is the least desirable. It results in reduced gas treating capacity, increased energy consumption, and excessive amine losses. Foaming can be greatly reduced by maintaining a clean amine solution.

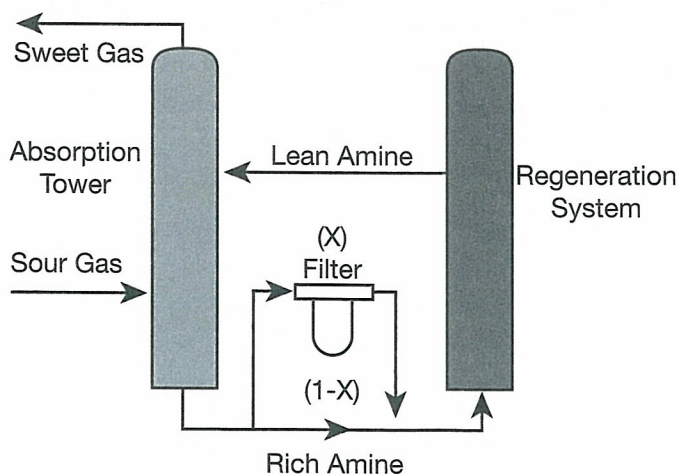
Many amine systems operate by filtering a 10% slipstream of the recirculating amine. This slipstream convention is based on little or no scientific evaluation. In addition, the amine process is subject to upsets that tend to increase the contamination level of the amine. Because amine is recirculated, the process is particularly vulnerable to an upset. An upset can result in damaged downstream equipment and increased incidence of foaming in a 10% slipstream. This study uses a mathematical model to predict the effect of upset conditions, in terms of recovery time and equilibrium contamination levels, at different levels of sidestream filtration.

Body

For many years filtration has been used to keep the recirculating amine system clean. The conventional amine unit design calls for filtration of a 10% slipstream of the recirculating amine. (See Figure 1.) This design convention is based on little or no scientific evaluation.

This paper will evaluate the effects of upset conditions on an amine system at different levels of sidestream filtration. We will investigate three upset cases and evaluate the effect of filtration of sidestreams at 10%, 25%, 50%, and 100% flow. This study uses a mathematical model to predict the effect of upset conditions.

Figure 1
Schematic of simplified gas sweetening system.



Background on Amine Filtration

Filtering of recirculating amine provides the following benefits: reduction of hot spots in the regenerator reboiler, reduced heat exchanger fouling, longer carbon bed life and reduction of foaming tendency in the amine absorber.

The source of contaminants in the amine is dirty inlet gas which contains solid particles like iron sulfide and aerosols like hydrocarbon condensate, free water, and chemicals and corrosion particles which form when H₂S comes in contact with the equipment metallurgy.

In the regenerator reboiler, particle fouling results in increased energy consumption and the formation of "hot spots" in the reboiler. Hot spots result in a weakness in the reboiler tubes and can cause the tubes to rupture. This can result in water leaking into the recirculating amine causing dilution.¹

Fouling of the regenerator trays can also occur causing flooding. This results in carryover of amine into the acid gas which can cause contamination of the catalyst in the sulfur plant.¹

Heat exchangers are used to heat the rich amine and cool the lean amine. If exchangers are fouled, the heat transfer efficiency is reduced, requiring increased energy requirements in the regenerator and reduced absorber efficiency.

Many amine units contain a carbon bed downstream of the rich amine. The primary purpose of the carbon bed is to remove dissolved contaminants, especially degradation material. Particles, hydrocarbons, and chemicals can reduce the effectiveness of the carbon bed and result in frequent replacement. Also, small carbon particles can escape the carbon bed and contribute to the fouling problems described above.

Of all operating problems in an amine unit, foaming is the least desirable.² Clean amines do not foam. Stable foams are formed by the introduction of hydrocarbon, and particles like iron sulfides into the amine.³ Foaming causes a reduction in gas treating capacity, an increase in energy consumption, and excessive amine losses. Foaming can be greatly reduced by maintaining a clean amine solution.⁴

Guidelines

There are several commercial varieties of amines. Each of these amines has a different degree of sensitivity to particulate contamination. An accepted guideline to ensure that foaming does not occur is to maintain the solids concentration of recirculating amine at 1 mg/liter (ppm). This guideline is easily obtainable through filtration.

In terms of fouling, particulate deposition is related not only to concentration of solids, but also fluid velocity, temperature, and particle stickiness. In general, one can expect a greater tendency toward fouling at lower flow velocity. In a recirculating system, once a particle has been introduced into the system, it has a greater tendency to foul than in a "once-through" system. In a well-designed system, the 1 mg/liter guideline should provide sufficient fouling protection of amine equipment.

Mathematical Model

This study uses a mathematical model to predict the level of contamination for a recirculating system, based on several variables including the

ratio of sidestream filtration to full flow. A complete derivation of the model is shown in Appendix 1.⁵

Applying the Mathematical Model

Case 1

In the first example, an initial dirty system is assumed with recirculating amine solids concentration of 15 ppm. This case is akin to putting a filtration system on-line for the first time. The other process conditions are listed below. Figure 2 shows the results of filtering at different slipstream rates. A 10% slipstream reaches an equilibrium concentration at slightly over 5 ppm. This is well above the recommended guideline of 1 ppm. In addition, it takes the 10% slipstream nearly 5 hours to reach its equilibrium.

A dramatic difference in performance is witnessed with filtration of a 25% slipstream. In this case, the equilibrium concentration is approximately 2 ppm and the time required to reach equilibrium is under 3 hours. Though this does not meet the

guidelines recommended to eliminate foaming, this may be acceptable in many cases. A 50% filtration system in this case meets the 1 ppm solids recommendation and reaches equilibrium in less than two hours. Full flow filtration reaches equilibrium in a shorter time period and meets the 1 ppm requirement to eliminate foaming.

Table 1: Process Conditions for Case 1

A typical large gas plant

Initially contaminated amine (concentration 15 ppm)

Corrosion Rate = moderate

Solvent circulation 4000 GPM, 900,000 L/H

E=0.80 (efficiency of removing 1 μ m particles, this is equal to a 10 μ m (Beta=5000) cartridge element)

X= 10% slipstream
25% slipstream
50% slipstream
full flow filtration

Figure 2
Recovery from upset at different levels of filtration.

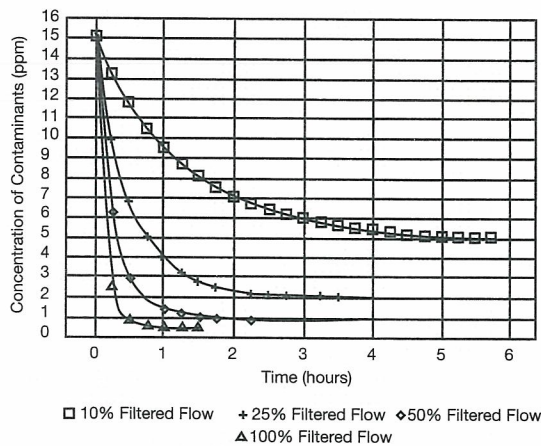
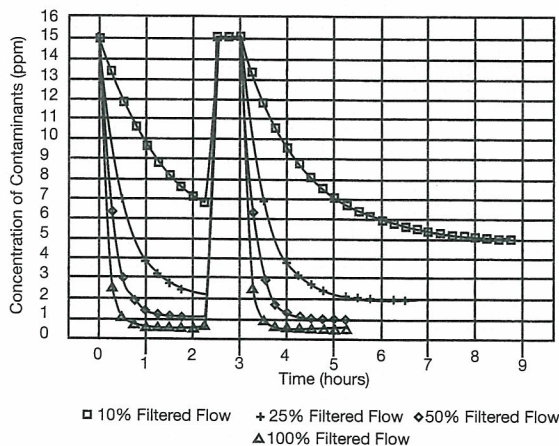


Figure 3
Recovery from upset at different filtration ratios.



Case 2

In the next example, an initial dirty system is again assumed with recirculating amine solids concentration of 15 ppm. As the system is being cleaned, suddenly a slug of material is introduced for one hour into the unit raising the concentration back to 15 ppm. The other process conditions are listed below. Figure 3 shows the results of filtering at different slipstream ratios.

In all cases, the equilibrium concentration is the same as in Case 1. It is important to consider the length of time required to reach equilibrium. The longer it takes to reach equilibrium, the greater possibility of equipment fouling and foaming. A 10% slipstream reaches an equilibrium concentration in approximately 8 hours and the 25% slipstream reaches equilibrium concentration in approximately 5-1/2 hours. Both the 50% slipstream and full flow filtration reaches an equilibrium at or below 1 ppm in less than 4-1/2 hours.

Table 2: Process Conditions for Case 2

A typical large gas plant
Initially contaminated amine (concentration 15 ppm)
Corrosion Rate = moderate
Slug introduced after 2.5 hours for one hour raising the concentration to 15 ppm
Solvent circulation 4000 GPM, 900,000 L/H
E=0.80 [efficiency of removing 1 µm particles, this is equal to a 10 µm (Beta=5000) cartridge element]
X= 10% slipstream
25% slipstream
50% slipstream
full flow filtration

Case 3

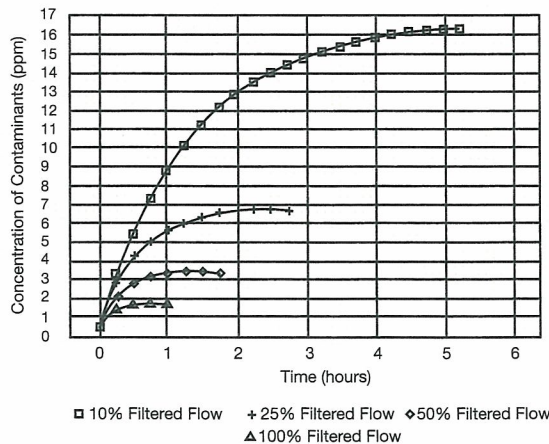
In the Case 3, an initial clean system is assumed with recirculating amine solids concentration of 0.5 ppm. In this case, a high concentration of continuous contaminants is assumed to be in the inlet gas. A moderate corrosion rate is also assumed. This case is akin to the beginning of processing dirty gas. The other process conditions are listed below. Figure 4 shows the results of filtering at different slipstream rates. In all cases, the equilibrium concentration is above 1 ppm. The 10% slipstream reaches an equilibrium concentration at slightly over 16 ppm.

One can conclude from this simulation that filtration alone may not be able to overcome the effects of a dirty inlet gas stream.⁴ In this particular case, it would be recommended that the inlet gas be cleaned before it is introduced into the system. Since the inlet gas contains both solids and liquid contaminants, a liquid/gas coalescing system is recommended to clean the gas.

Table 3: Process Conditions for Case 3.

A medium sized gas plant
Initially contaminated amine (concentration 0.5 ppm)
Corrosion Rate = moderate
Introduce dirty gas
Solvent circulation 400 GPM, 90,000 L/H
E=0.80 [efficiency of removing 1 µm particles, this is equal to a 10 µm (Beta=5000) cartridge element]
X= 10% slipstream
25% slipstream
50% slipstream
full flow filtration

Figure 4
Contamination effect at different filtration ratios.



Benefits of Cleaner Filtration

In order to optimize the system, it is important for an operator of an amine plant to know the source of contamination. If the majority of the contamination is the result of corrosion occurring within the process, increasing the slipstream from 10% to 50% or above should be considered. The effect of increasing the slipstream size in this situation is demonstrated in Case 1.

If the contamination is the result of dirty feed gas, increasing the slipstream size does not necessarily bring the system into an acceptable contamination level. In this situation, illustrated in Case 3, the gas must be cleaned before it enters the system. Since contaminants are both liquid and solid, a coalescing filter system should be used to clean the gas.

Tables 4 and 5 show an example of filtration and contamination costs associated with a 20 MMScf/D gas plant. It is important to realize that all costs will vary widely depending on inlet gas quality, design conditions and specifications, type of solvent used, and utility and environmental costs. The purpose of this exercise is to illustrate all of the factors that should be considered in determining the cost of contamination.

Table 4 illustrates the cost of filtration at a 20 MMScf/D gas processing facility. The annual costs of an absolute rated filter system is approximately \$11,000 for a 10% slipstream. This

is the type of system that is simulated in all three cases. An additional \$4000 would be required for annual maintenance and disposal costs.⁶ Each of the three cases, however, shows that filtration of a 10% slipstream leaves the unit vulnerable to foaming, frequently changed out carbon beds, and fouled exchangers, reboilers, and towers.

Filtration costs will increase no more than proportionally with the increasing size of the slipstream. The three cases indicate, however, that by increasing the size of the slipstream to be filtered or cleaning the incoming gas with a coalescer, the concentration of the contaminants in the recirculating amine will decrease. These steps will reduce the probability of a foaming incident, a carbon bed changeout, or an unscheduled shutdown of equipment for cleaning. Fewer contaminants also improves energy efficiency by reducing fouling.

Table 5 summarizes the cost of contamination. If a 20 MMScf/D unit is capacity limited and capacity is reduced by 10% due to foaming, the cost is \$760/day. This is a reasonable estimate for capacity limitation. There are documented cases of foaming reducing gas processing capacity by over 40%.⁶

In a 20 MMScf/D unit, fouling caused by particle deposition can reduce the efficiency of the regenerator reboiler and the heat exchanger in

Table 4: Cost of Filtration for 20 MMScf/D Gas Processing Plant.

Cartridge Filtration

Slipstream Ratio	10%	25%	50%	100%
Annual Filter Cost	\$11,000	≤ \$27,500	≤ \$55,000	≤ \$110,000
Maintenance/Disposal	\$4,000	≤ \$10,000	≤ \$20,000	≤ \$40,000
Total	\$15,000	≤ \$37,500	≤ \$75,000	≤ \$150,000
Incremental From 10% Filtration	\$0	≤ \$22,500	≤ \$60,000	≤ \$135,000

Coalescer System (to clean inlet gas)

Initial Costs	\$50,000
Annual Costs	\$3,700
Annual Maintenance/Disposal Costs	\$1,000

an amine unit. A 5% reduction in efficiency of both of these pieces of equipment costs approximately \$123/day and a 10% efficiency reduction costs \$246/day.⁶ An average efficiency reduction of 5-10% due to particle deposition is a reasonable estimate.

Excessive fouling may also require an unscheduled shutdown of equipment. Often a plugged regenerator must be acid washed to eliminate plugging.¹ Exchangers also are subject to shutdown if fouling is too high. This may require a shutdown of the entire unit for a short period of time. For a 20 MMScf/D, the cost of shutting down the unit for a shift to clean equipment is approximately \$15,000. This includes maintenance, labor, cleaning, and disposal costs as well as the cost of not processing gas for one shift.

Many amine units have carbon beds to absorb hydrocarbons and dissolved solids. A high concentration of suspended contaminants will increase the frequency of changing out the carbon bed. In general, a carbon bed is changed out every 4-6 months. For a 20 MMScf/D, the change out cost will be approximately \$20,000. This includes maintenance, labor, and material costs. Experience has shown that high solids concentration can reduce the life of the carbon bed by up to 50%.

All contamination costs listed in Table 5 can virtually be eliminated if the contaminant concentration remains at 1 ppm or below. In this case, the annual cost of filtration is less than the annual cost of contamination. Depending on the source of contamination, the purchase of a coalescer system or the increase in the size of the slipstream to be filtered or a combination of both systems is justified.

Table 5: Annual Costs of Contamination for a 20 MMScf/D Gas Plant.

Item	Cost per Day	Annual Cost *
Amine Losses from Foaming ⁴ (1)**	\$50-600	\$17,500-210,000
Reduced Capacity (10% reduction) ⁷ (2)	\$760	\$266,000
Reduced Energy Efficiency (10%) includes: ⁵ (3) Reboiler Heat Exchanger Cooling Water	\$246	\$86,100
Carbon Bed Replacement (1 additional replacement per year) (4)		\$20,000
Acid Washing Regenerator or Heat Exchangers (1 additional replacement per year) (5)		\$15,000
Total Annual Cost (if capacity limited)		\$404,600-597,100
Total Annual Cost (if not capacity limited)		\$138,600-331,100

* Assumes 350 stream days per year.

(1) Indicates that losses from 16 MMScf/D were 6 lbs/MMScf processed. Amine costs range from \$0.50-5.00/lb.

** Does NOT include costs associated with added stress on the wastewater treatment system.

(2) Data obtained from Reference 7 (Figures 9-10) which projects the 1993 processing upgrade and net processing margin for the Permian Basin.

(3) Includes utility costs for a 21.3 MMScf/D amine treating facility. Assumed costs: \$0.10/kWh, \$1.50/MMBTU, \$0.07/MGal of cooling water.

(4) From discussion with plant operator.

(5) Takes into account maintenance, labor, material costs and the cost of shutting down unit for one shift.

Summary

- A simple dynamic mass balance (continuity) equation could predict the solid particle and other contamination build up in amine sweetening or similar gas processing plants.
- Field tests can reliably generate all input data required to solve the above equations. Such data will include inlet solid concentration (counts/volume), solid density, gas, and liquid flow rates. Field tests can reliably determine the source of contamination.
- By increasing the ratio of sidestream filtration to the total solvent flow, the equilibrium solid concentration is decreased. The same phenomenon is true for liquid contamination adsorption via carbon beds.
- By increasing the ratio of sidestream filtration to the total solvent flow, the recovery time from an upset is reduced.
- Increasing the ratio of sidestream filtration alone cannot guarantee maintaining a contamination level below the acceptable levels. If the contamination occurs as the result of dirty inlet gas, the gas should be cleaned before it is allowed to enter the system. A coalescing filter system can effectively reduce the contamination of inlet gas.
- Considering the drastic effect of contaminants on foaming and system fouling, it would be more economical to increase the sidestream flow to total flow rate ratio, than to allow a high equilibrium level of contamination. The cartridge filter consumption will remain the same.

Conclusion

Amines with a concentration of under 1 ppm contaminants will not foam and will minimize fouling. In order to reach this level, the source of the contamination, either as entering in the feed gas or forming internally from corrosion, must be determined. In cases where the contamination source is external, it is very difficult to reach 1 ppm level without a prefilter or coalescer. In cases where there is normal

corrosion, our model indicates that filtering a 25% slipstream will reach an equilibrium concentration of around 2 ppm and filtering a 50% slipstream will reach an equilibrium concentration of 1 ppm.

Though all systems are different, filtering a 50% slipstream should, in many cases, be sufficient to prevent foaming and significant fouling.

Appendix 1

First, we will develop a model for solid contamination and cartridge filters. We will then apply the model to liquid contamination and carbon bed adsorption.

Let:

- t = Time (H)
- Q_g = Gas flow rate L/H (standard condition)
- Q = Solvent circulation rate (L/H)
- C_g = Solid concentration in inlet gas (No. of particles/L)
- C_r = Solid concentration in rich solvent (No. of particles/L)
- C_1 = Solid concentration in lean solvent (No. of particles/L)
- E = Filter removal efficiency on count basis
- V = Volume of solvent in the system (L)
- W = Rate of solids generated within the system (e.g. corrosion) (No. of particles/H)
- K = Rate of total solids added to the system (No. of particles/H)
- X = Ratio of sidestream to full flow

Note: "No. of particles" refers to solid contaminants 1 micron and larger.

In deriving the solid mass balance, the following assumptions have been made:

1. Homogeneous concentration of solids throughout the system.
2. Inlet gas contamination rate remains constant.
3. Internal solid generation rate including corrosion remains constant.

4. The regeneration system does not alter the solid concentration.
5. Filtration efficiency (E) remains constant.
6. Constant flow and circulation rates.

Mass Balance:

Let:

$$K = Q_g C_g + W \quad (\text{Eq. 1})$$

$$Q C_r + Q X C_r (1-E) = Q X C_r + Q C_1 \quad (\text{Eq. 2})$$

$$C_1 = C_r (1-EX) \quad (\text{Eq. 3})$$

Dynamics of the System:

$$K + C_r Q - C_r Q = V \frac{dC_r}{dt} \quad (\text{Eq. 4})$$

Substituting Eq. (3) in Eq. (4):

$$K - QEX - C_r = V \frac{dC_r}{dt} \quad (\text{Eq. 5})$$

with initial condition:

$$\text{at } t=0, C_r = C_r^{\circ}$$

The solution to Eq. (5) becomes:

$$C_r = \frac{1}{QEX} [K(1 - e^{-QEXt/V}) + C_r^{\circ} QEX e^{-QEXt/V}] \quad (\text{Eq. 6})$$

when $t = \infty$ (after several hours)

$$C_{eq} = \frac{K}{QEX} \quad (\text{Eq. 7})$$

C_{eq} = Solid concentration at equilibrium.

Liquid Contaminants

Liquid contaminants, similar to solids, gradually build up in the amine system and must be removed by activated carbon beds. Equation #6 can still represent the dynamics of carbon bed adsorption, if the following adjustments are made:

- K = Liquid contamination rate (KG/L)
- E = Liquid removal efficiency of carbon bed which is assumed to be constant

The numerical solution to this equation will also show that more than 10% sidestream flow rate through carbon bed is needed to maintain the system cleanliness.

Particle Concentration

Weight of particles = Particle volume x density
of particles

$$W = V_p \rho \quad (\text{Eq. 8})$$

$$W = \rho p \sum N_i V_i = \frac{\pi \rho p \sum (D_i^3 N_i)}{6} \quad (\text{Eq. 9})$$

Where:

W = weight of particles (G)

ρ = average density of particles (KG/L or G/ML)

ϕ = Shape factor (=1 for a sphere and 0.4 to 0.8 for granular particles)

N_i = # of particles in given size range/ML

D_i = average particle diameter in given size range (CM)

V_i = Particle volume in given size range (ML)

Size Range: 1-5 μ m, 5-15 μ m, 15-25 μ m, 25-50 μ m and >50 μ m

A typical particle size distribution in amine or similar solvent system contaminated with iron sulfide is:

$N_{(1-5)}$ = 0.85 N (N is total number of particles in 1 to 50+ μ m range)

$N_{(5-15)}$ = 0.10 N

$N_{(25-50)}$ = 0.03 N

$N_{(50+)}$ = 0.01 N

ρ = 2KG/L (mostly iron sulfides)

ϕ = 0.6

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Pall Corporation


Pall Corporation
516.484.5400 phone
888.873.7255 toll free in the USA
+01 516 484 0364 fax
fuelsandchemicals@pall.com email

Pall Europe Limited
023 9230 3303 phone
023 9230 2509 fax
fuelsandchemicals@pall.com email

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