

Hydrocarbon Processing[®]

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Amine plant troubleshooting and optimization

Here is a practical operating guide
that uses control charting to maximize performance

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As part of a Federal Trade Commission mandated remedy to the merger of The Dow Chemical Company and the Union Carbide Corporation, INEOS plc was able to purchase both Dow's Ethanolamines and GAS/SPEC MDEA-based specialty amine businesses. This purchase became effective on February 12, 2001.

INEOS LLC was set up as the newly acquired company, which includes the GAS/SPEC Technology Group. All the key Ethanolamines and GAS/SPEC personnel were retained by INEOS LLC. All GAS/SPEC products, technology and know-how became the exclusive property of INEOS on a global basis.

Table 1. Heat and material balance data

	Dates
Contactora	
Feed gas flowrate, MMscfd	
Feed gas temperature, °F	
Feed gas pressure, psig	
Feed gas H ₂ S content, mol%	
Feed gas CO ₂ content, mol%	
Treated sales gas flowrate, MMscfd	
Treated sales gas temperature, °F	
Treated sales gas pressure, psig	
Treated sales gas H ₂ S content, ppm	
Treated sales gas CO ₂ content, mol%	
Differential pressure, psig	
Lean solvent flowrate, gpm	
Lean solvent temperature, °F	
Lean solution concentration, wt%	
Rich solvent temperature, °F	
Flash tank	
L.P. contractor solvent flowrate, gpm	
L.P. contractor solvent temperature, °F	
Bulk temperature, °F	
Bulk pressure, psig	
Lean/rich cross-exchanger	
Rich solvent in, °F	
Rich solvent out, °F	
Lean solvent in, °F	
Lean solvent out, °F	
Exchanger approach temperature, °F	
Regenerator	
Bottom temperature, °F	
Bottom pressure, psig	
Overhead temperature, °F	
Overhead pressure, psig	
Lean solution H ₂ S loading, mol/mol	
Lean solution CO ₂ loading, mol/mol	
Steam flowrate, lb/hr	
Steam pressure, psig	
Reboiler heat medium flowrate, gpm	
Reboiler heat medium density, lb/gal	
Reboiler heat medium specific heat, Btu/lb °F	
Direct-fired reboiler fuel feed rate, MMscfd	
Direct-fired reboiler efficiency, %	
Reflux section	
Reflux condenser inlet temperature, °F	
Reflux condenser outlet temperature, °F	
Reflux accumulator temperature, °F	
Reflux accumulator pressure, psig	
Reflux accumulator return to regenerator, gpm	
Acid gas temperature, °F	
Acid gas pressure, psig	
Barometric pressure, psia	

Table 2. Troubleshooting guide for "failure to meet specification"

- Acid gas concentrations in inlet gas have changed
- Feed gas temperatures have changed
 - >120°F for H₂S
 - <75°F for CO₂
- Lean amine solution is too hot
 - Fouled cross exchanger and/or lean amine cooler
 - Undersized cross exchanger and/or lean amine cooler
 - High ambient temperature
- Amine concentration too high or too low
 - Lack of equilibrium driving force (too high)
 - Inadequate moles of amine for moles of CO₂ and/or H₂S (too low)
- Inadequate lean loading
 - Poorly stripped solvent
 - Insufficient stripping steam in stripper
 - Low/high stripper pressure
 - Foaming in stripper
 - Contaminated solvent
 - Circulation rate below minimum turndown
 - Loss of trays or plugged packing
 - Other sulfur species causing high partial pressure
 - Leak in lean/rich cross exchanger
- Amine feed tray too low in absorber
 - Not enough stages for required removal
- Loss of contact trays/plugged packing in absorber
 - No stages for removal
 - Poor distribution/lack of contact between gas and amine
- Amine circulation rate too low
 - Not enough moles of amine for moles of CO₂ and/or H₂S
- Gas pressure has dropped
 - Driving force for removal reduced
- Contactor operating below minimum turndown
 - Poor hydraulics/loss of efficiency
- Maximum gas flow exceeded
 - Jet flooding/poor hydraulics/loss of efficiency
- Degraded solvent (heat stable salt buildup)
 - Less moles of active amine available for acid gas removal
 - Oxygen in feed gas
 - Thermal degradation
 - Carboxylic acids in feed gas
- Mechanical damage
 - Collapsed trays/broken packing
 - Plugged and/or broken distributors
 - Corrosion
- Contaminated/dirty solvent
 - Well treating chemicals
 - FeS
 - Corrosion products
- Foaming (see Table 3 for a more detailed outline)

► Amine losses

► Corrosion.

The first two categories, failure to meet specification and foaming, are normally immediate concerns requiring quick action. The other categories, amine losses and corrosion, are long term in their manifestation.

Failure to meet specification. Failure to meet the treated gas specifications can be the result of a single factor or several factors working in conjunction. These factors are outlined in Table 2. Generally, final identification of the cause(s) is a process of elimination. The cause(s) can be identified more quickly and corrected the sooner the possible contributing factors can be ruled out. The problem can sometimes be avoided altogether by monitoring key process parameters that could result in off-specification treated gas and responding appropri-

ately before they become a serious problem.

As suggested in Table 2, key process parameters that should be monitored and graphed are:

- Lean amine temperature and concentration
- Lean H₂S and/or CO₂ loading
- Amine circulation rate
- Stripper overhead temperature
- Absorber ΔP
- Inlet-gas flowrate
- Inlet-gas H₂S and/or CO₂ concentration
- Treated gas composition.

A prior knowledge of anticipated conditions, operating ranges and their effects on treated gas specifications are helpful in setting control points and appropriately reacting to changes as observed on control charts. A proactive approach to plant operations is always better than a reactive one.

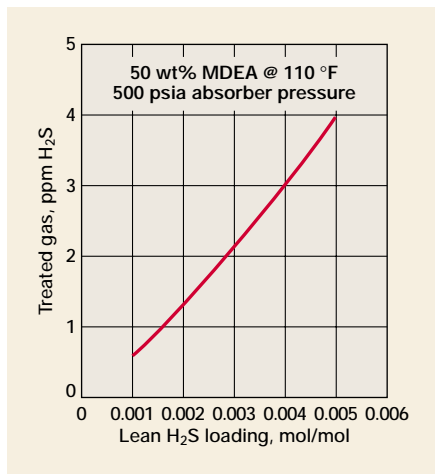


Fig. 2. H₂S in treated gas vs. lean amine loading.

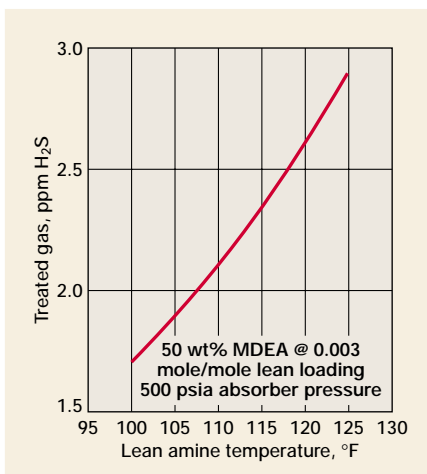


Fig. 3. H₂S in treated gas vs. lean amine temperature.

Example: A plant is designed to treat 15 MMscfd of gas at 500 psia, 100°F, and contains 3% CO₂ and 5% H₂S. The product has <4 ppm H₂S and 2% maximum CO₂. The plant operates with a 50 wt% MDEA solution circulating at 100 gpm. In this case, knowledge of trends that would be useful in setting up control charts and ranges might include but are not limited to:

- ▶ H₂S in treated gas vs. lean H₂S loading (Fig. 2)
- ▶ H₂S in treated gas vs. lean amine temp. (Fig. 3)
- ▶ Stripper overhead temp. vs. reflux ratio (Fig. 4)
- ▶ Lean H₂S loading vs. stripper reflux ratio (Fig. 5)
- ▶ Turnup and turndown characteristics at different circulation rates (Fig. 6).

Knowing directionally which way the plant will respond under different conditions allows operators to respond quickly and appropriately to upsets or changing conditions. Similar curves can easily be generated for different amines and process conditions.

Fig. 7 is an example of a run chart that has raw data for several of the critical parameters plotted versus time. These data show that the plant is performing adequately and meeting specifications until the H₂S goes off specification at 4 a.m. Without creating a run chart, an operator would not realize the plant was heading for trouble. When the sales gas finally went off spec, the operator would be in a “panic” situation. However, by plotting these data, it is obvious that the H₂S starts to creep up after 5 p.m. The run chart also shows that there is an increase in lean amine H₂S loading occurring at the same time. This is probably due to a stripper problem as indicated by a corresponding decrease in stripper reflux ratio.

Although run charts show raw data as a function of time, they still do not tell the operators *when* to start reacting. If sufficient data is collected, these run charts can easily be translated into control charts.

Control charting.

Step 1: run charts. The initial stage in developing a control chart has already been illustrated by plot-

ting specific raw data against time. The only difference when creating control charts is that these data should be plotted on the graph paper's top half instead of the entire page. As previously indicated, plotting raw data versus time is a “run chart.”

Once constructed (Fig. 8), the run chart should be examined for any trends, cycles or spikes. Trends or cycles may reflect recent changes to process operating conditions or repeatable events such as daytime heating cycles. Spikes may reflect bad data points, but they may also correspond to conditions that are quite far away from the “normal” set of operating conditions. The run chart is

intended to provide a feel for how the system is operating, but it does not provide any guidelines for when the data should be acted upon.

Step 2: range charts. This will help the operator and engineer determine whether the process is in control and whether further action can be taken with the raw data run chart. It is important to collect a *minimum* of 20 data points, and preferably 50 data points, before proceeding.

First, the range between individual data points is obtained by calculating the absolute difference between consecutive raw data points. This will result in a table of data with one less data point than the raw data. This is called moving range data or MR data. These are plotted in a second graph using the bottom half of the same chart paper where the run chart was plotted. The first moving range data point will correspond to the *second* time increment since there is no moving range data point available for the first time increment.

Once the MR data have been plotted, a center line and control limits must be added. The center line is the MR data average value. By definition, there is no lower control limit because this is a moving range chart. There is, however, an upper control limit. This value is calculated by multiplying the moving range average by 3.27. If the process is under control, 99.7% of all points measured will fall below the upper control limit (UCL_{mr}). This

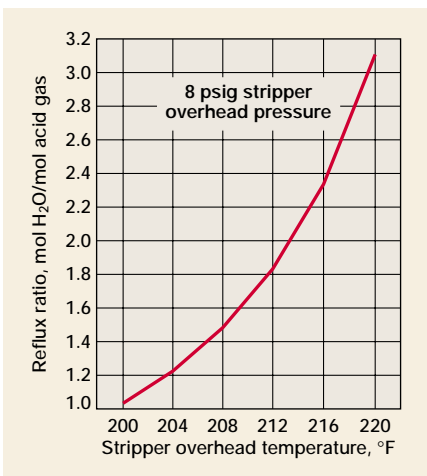


Fig. 4. Stripper overhead temperature vs. reflux ratio.

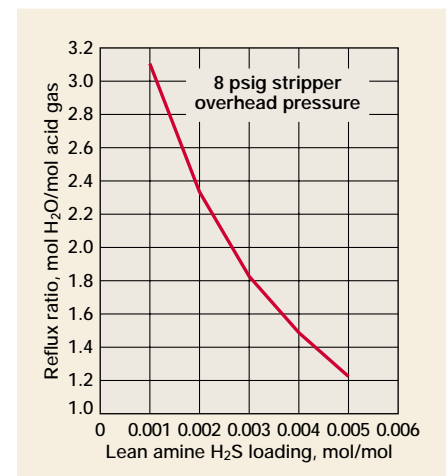


Fig. 5. Lean amine H₂S loading vs. stripper reflux ratio.

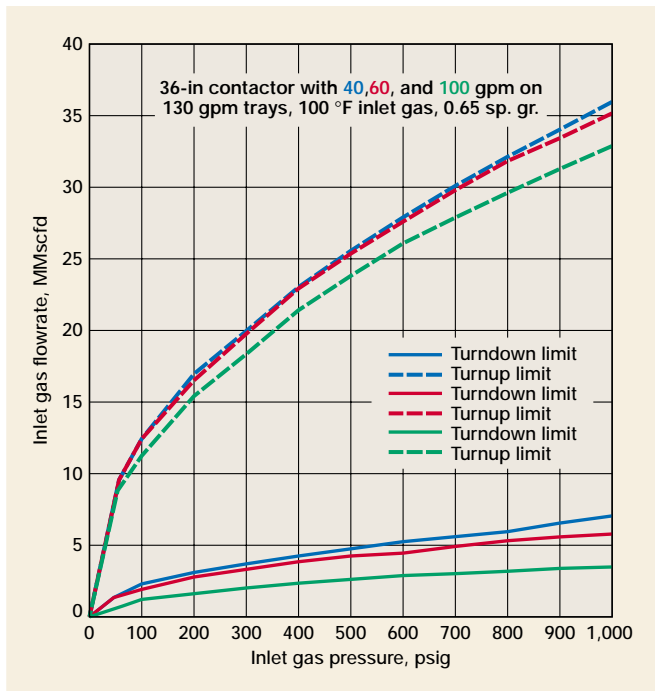


Fig. 6. Turnup/turndown vs. inlet pressure.

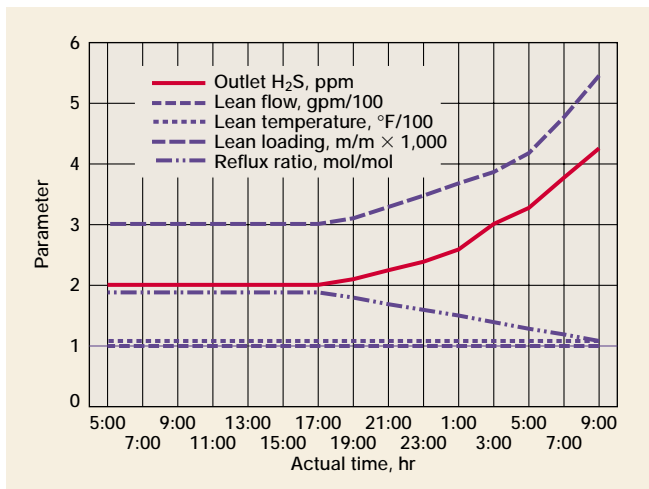


Fig. 7. Raw data run chart.

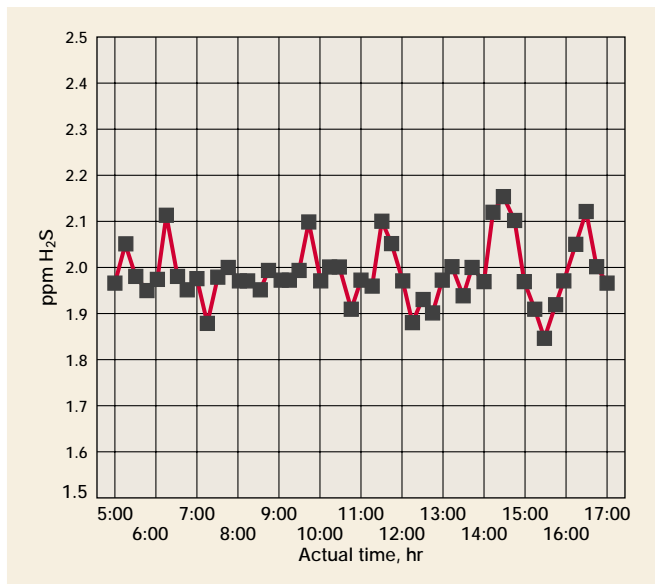


Fig. 8. Run chart.

graph is known as a moving range chart or MR-chart (Fig. 9).

MR-charts tell something about the process stability and are analyzed using two simple rules. The process is in control if all data points fall below UCLmr and the “Rules of Seven” are not violated. The Rules of Seven are that no seven consecutive points are above or below the center line, trending upward or trending downward.

If any data points lie above the UCLmr, the operator or engineer must check whether this point was properly measured or whether the measuring device was working properly. If measured properly, then the operator or engineer must determine the plant operating conditions during the sampling, if possible. If the plant operated better around the sampling time, then the operators and engineers must decide whether the plant should be operated at these conditions as a matter of course. If the plant operated poorly around the sample point then the plant should not be operated at this condition again. This avoids an out-of-control process.

Step 3: variables control chart. For this step, the MR-chart must be in control as previously defined. Fig. 9 shows that the MR-chart is indeed in control. There appears to be some cycling at the later times. This may be due to daytime heating interrupted by a rain shower, but the cycles do not violate the Rules of Seven.

Since the MR-chart is under control, the run chart can now be revised. By adding a central line as well as an upper and a lower control limit, this run chart can be translated into a variables control chart, also called an X-chart (Fig. 10). To calculate the central line, the raw data is averaged. The upper and lower control limits are then calculated in two steps.

First, the estimated standard deviation is calculated by dividing the moving range average value by 2.128. This standard deviation estimate is then multiplied by 3. The resulting product is added to and subtracted from the central line value to become the X-chart upper control limit (UCLx) and X-chart lower control limit (LCLx). Again, 99.7% of the data points will fall between these limits if the data is in control.

The Rules of Seven are then applied to the X-chart. Furthermore, the data points must fall between the two control limits to be considered in control. Fig. 10 satisfies all these criteria, so the data are in control. An example of what the overall X-MR control chart would look like for this data set is in Fig. 11.

Since these data represent stable plant operation, control limits and center lines will be used as new data is collected. This way the new data will be compared with a data set generated when the system was in control. As the operators and engineers advance to the next level of control charting, they will learn when it is appropriate to recalculate the center lines and control limits. This will not be discussed here.

Fig. 12 has some new data added to the X-chart. The H₂S outlet concentration gradually increases overnight. Incremental changes in the outlet H₂S concentration are such that no indication is given that the process is out of control. The variability between individual data points is not large enough nor continuous enough to trigger an out-of-control point or a trend on the extended MR-chart (Fig. 13).

Under normal operations, it is conceivable to have the operator not respond to this gradual change until the H₂S has nearly reached the treated pipeline specification of 4 ppm. At this point, the activity becomes a reactive exercise, not a proactive one. By using the control chart limits and the Rules of Seven, the operator would have responded within two hours of the H₂S going out of control. Fig. 14 shows the control chart sensitivity. After 17:45, there are seven consecutive data points above the center line. Also, there are seven data points trending upwards after 18:30. Either of these violations would trigger an operator response.

By recognizing a potential problem early enough, the operator has time to collect and review other data. The operator would look at all the run and control charts and check for positive or negative correlations. Fig. 15 shows a combined run chart of six critical operating parameters. There is a positive correlation between outlet H₂S content and differential pressure across the contactor. By a careful data review, the usual solution of increasing the reboiler temperature can be avoided. This is because the run chart data indicates the problem is in the system's front end and *not* the system's regeneration section. Increasing heat to the reboiler may appear to temporarily solve the problem by giving a leaner solution entering the contactor and, hence, a lower outlet H₂S content. But this will only delay proper response to the true problem—foaming in the contactor.

Even though this example is simplistic, it does point out the power of control charts combined with a little process know-how.

Step 4: implementing control charts. This methodology is not difficult to put into place. However, it takes a commitment by all members associated with a particular gas treating facility. The process can be implemented only with some graph paper, a pencil and a calculator. If fancy output is desired, there are various programs that will collect data and create elegant process control charts.

The key is to first have the people that are directly involved with the process decide which data are critical. Next, this same group of people will be given responsibility for constructing and maintaining the control charts. It does no good to have the data go into head office, have it manipulated by office professionals and sent back out. The time delay is too great and the person who sees immediate changes in the process is not at the plant and may not appreciate the significance of the change.

As more data is collected, it is most likely the facility will move away from X-MR charts and advance to Mbar-R charts and then to Xs charts. The major difference between these chart types is the amount of data the charts are based on, as well as how the data is manipulated. We will not go into these control charts. Their procedures are clearly outlined in other references.¹⁻⁶

We strongly recommend that personnel involved in the implementation and maintenance of control charts be given the proper tools to efficiently handle chart development. This can be through a team leader reading the appropriate background material and summarizing the critical issues during a couple of training sessions. Or it can be as simple as an operator doing some background reading and trying the charting.

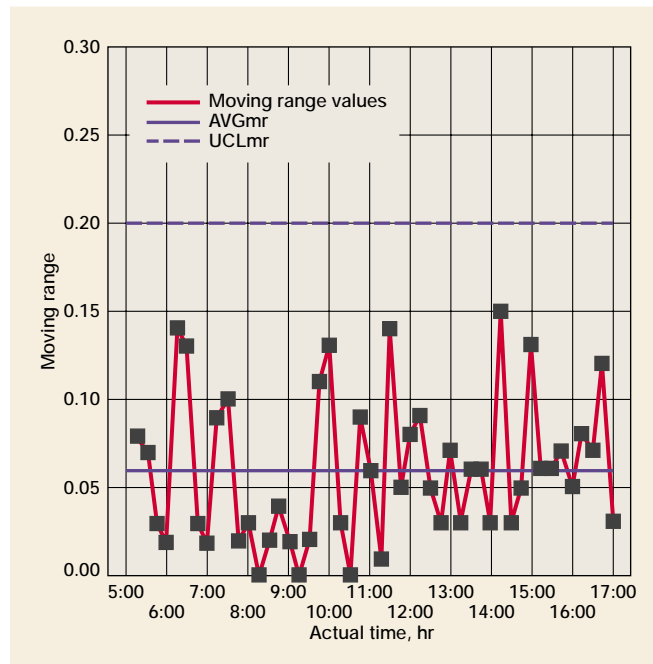


Fig. 9. Moving range control chart (MR-chart).

Table 3. Troubleshooting guide for foaming

Symptoms

- Fluctuating absorber or stripper ΔP
- Amine carryover from absorber, stripper or flash tank
- Swinging liquid levels in any vessel
- Decrease in H₂S removal with increase in CO₂ removal
- Off-specification treated gas
- Positive results from foam test
- Poorly stripped solvent

Causes

- Hydrocarbons + organic acids => amine soaps
 - Poor inlet gas separation
 - Lean amine temperature too low
- Well-treating fluids and corrosion inhibitors
 - Inadequate inlet gas separation
- Oil, inhibitors and welding fluxes
 - Improperly cleaned equipment
- Suspended solids* (FeS, carbon fines, colloidal iron oxide)
 - Poor inlet gas separation
 - Inadequate solution filtration
- Raw cotton filters
 - Improper selection of filter material
- Makeup water
 - Corrosion inhibitors from steam condensate system
 - Bacteria

Prevention—maintaining a clean system is the key!

- Maintain lean amine temperature 10°F above inlet gas temperature to minimize hydrocarbon condensation
- Adequate inlet gas separation to minimize liquid hydrocarbons, iron sulfide/suspended particles and well-treating chemicals from entering the amine system
- Proper cleanout of new equipment prior to startup
- Adequate carbon and mechanical filtration
- Foam test with proposed makeup or initial fill water
- Proper mechanical filter material selection
- Temporary use of antifoams
 - Either silicone, polyglycol or high molecular-weight alcohols
 - Antifoam usage in most cases should be considered a temporary treatment while the root cause(s) is identified and corrected

*Suspended solids do not cause foaming, but rather stabilize the foam.

Benefits of using control charts will soon be seen in the daily operation of a facility as well as during optimization activities.

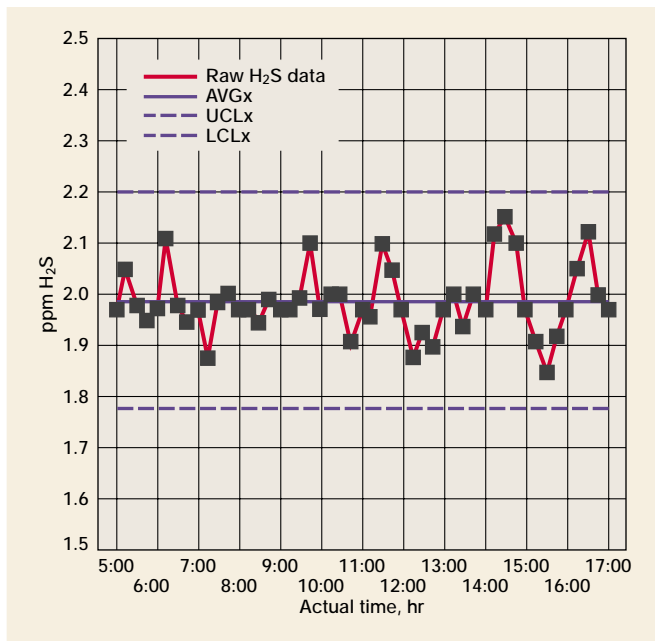


Fig. 10. Variables control chart (X-chart).

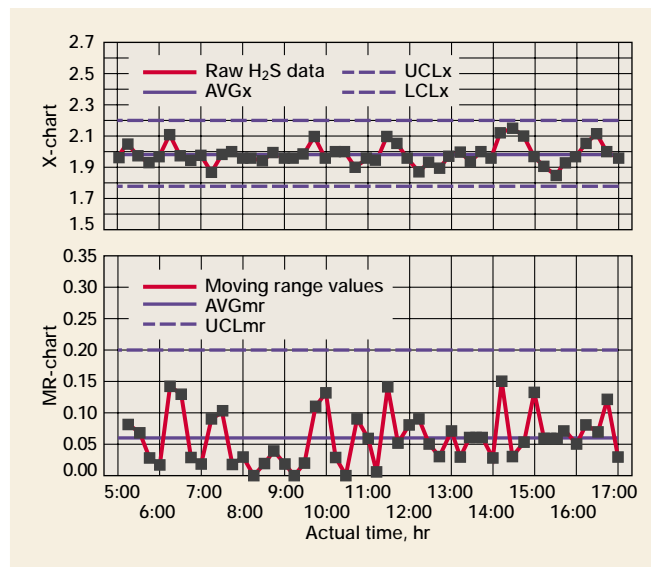


Fig. 11. Control charts for variables data.

Table 4. Troubleshooting guide for losses

Mechanical

Both gas/liquid & liquid/liquid applications:

- ANY permanent, unwanted or unscheduled physical removal of solvent from the plant
 - Leaks at pipe flange/gasket connections
 - Pressure gauge/sample line purges
 - Unrinsed cartridge filter elements
 - Amine sump contamination/disposal
 - Heat exchanger leaks

- Pump seal flushes or leaks
- Frequent filter changes
- Unrinsed carbon bed
- Excessive daily sample volumes

Entrainment

Gas/liquid applications only:

- Unwanted or uncontrolled liquid in gas dispersions (mists/sprays) formed
 - Tower diameter too small for gas flow
 - Trays at or above flooding
 - Amine distributors undersized or plugged
 - Damaged knock-out vessels
- Unwanted or uncontrolled gas in liquid dispersions (foams) formed
 - Refer to Table 3

- Tower pressure below design
- Trays damaged or plugged
- Damaged or missing mist eliminator pads

Liquid/liquid applications only:

- Unwanted or uncontrolled liquid in liquid dispersions (emulsions) formed
 - Fluid velocity greater than 15 gpm/ft²
 - Amine distributor orifice velocity > 170 ft/min
 - Hydrocarbon superficial velocity > 130 ft/hr
 - H.C. disperser orifice velocity > 1.25 ft/sec

- Packing material not steel or ceramic construction
- Amine superficial velocity > 60 ft/hr
- Damaged tower internals

Solubility

Liquid/liquid applications only:

- Amine concentrations greater than 40 wt%
- Low system pressures

- High system temperatures
- MEA > DEA > MDEA

Vaporization

Both gas/liquid & liquid/liquid applications:

- High amine concentrations
- Low system pressures

- High system temperatures
- MEA > DGA > DIPA > MDEA > DEA

Degradation

Both gas/liquid & liquid/liquid applications:

- Chemical degradation
 - Reaction with carbon dioxide (MEA & DEA only)
 - Reaction with oxygen (all amines)
- Thermal decomposition
 - Skin temperatures greater than 350 °F
- Heat stable salt formation
 - Inlet gas contaminants
 - Oxygen degradation
 - Thermal degradation byproducts

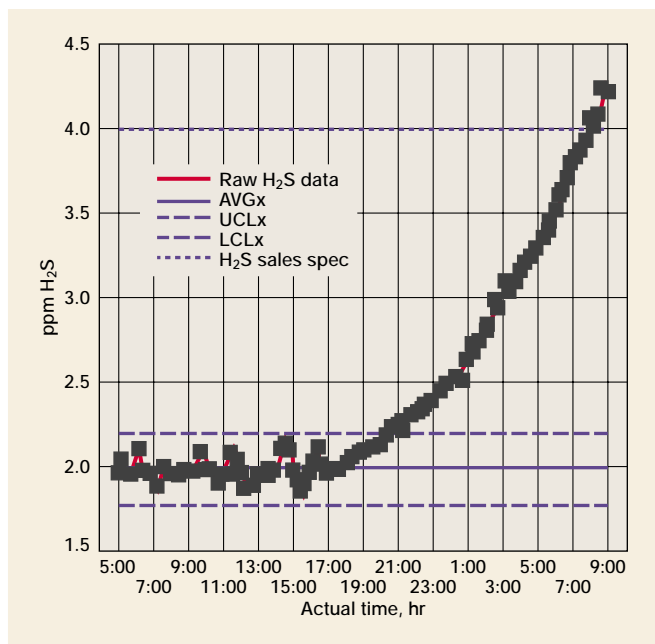


Fig. 12. Extended X-chart with new data.

Foaming. Table 3 lists some common symptoms of foaming along with likely causes. Foaming is the most common cause of upsets in an amine plant, usually resulting in excessive amine losses, off-specification treated gas and a reduction in treating capacity. All of these affect operating costs and revenue. Monitoring key parameters such as absorber or stripper pressure drop, vessel liquid levels and treated gas outlet composition can alert the operators to potential foaming problems.

Fig. 14 shows the use of a combination of run charts to alert the operator to a foaming problem by monitoring absorber ΔP as well as outlet H_2S content. Again, not only is it important to monitor key process parameters, but to understand what they are indicating so appropriate corrective or preventative action can be taken.

Operating philosophy when dealing with foaming should be to address the root cause as opposed to continually treating symptoms. Using antifoams for temporary relief is acceptable. But for long-term, more reliable operation, identifying and correcting the root cause(s) should be the norm.

Amine losses. Every amine plant can expect to have some amine losses associated with its operation. Acceptable losses vary with different applications. However, excessive amine losses can have a negative economic impact on total plant operating cost, and it is important to understand how losses can occur and the appropriate corrective action to take. Losses usually fall into five major categories: mechanical, entrainment, solubility, vaporization and degradation. Listed in Table 4 is a troubleshooting guide for amine losses based on Stewart and Lannings' method.⁷

Corrosion. This can result in unscheduled downtime, loss of production, reduction in equipment life and even injury or death. Corrosion in alkanolamine gas

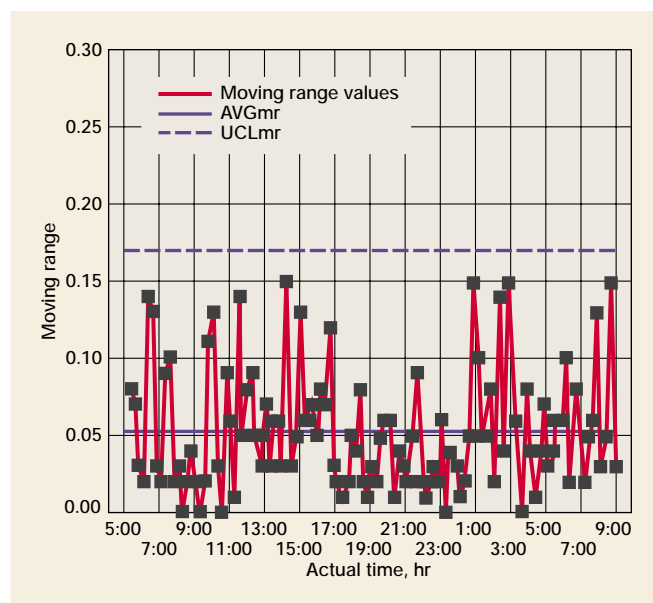


Fig. 13. Moving range control chart (MR-chart).

treating plants can, however, be controlled and minimized with proper plant design and operating parameters. The key is to minimize acid-gas flashing and to understand other contributing factors that can enhance corrosivity of amine solutions. Like the three previous categories, monitoring and an understanding of key process parameters can help minimize corrosion in amine units. Listed in Table 5 is a troubleshooting guide for corrosion based on a method from DuPart, Bacon and Edwards.⁸

OPTIMIZATION

It is almost imperative that amine plant operations be optimized to the maximum. It is no longer acceptable to operate plants with huge safety margins on circulation rate and energy input. Plants are required to function closer to the edge of the operating envelope. This new operating discipline can only be achieved with an understanding of the operating envelope and penalties associated with huge safety margins.

To successfully optimize an amine unit and maintain an optimum process, a good baseline data set and an understanding of, and commitment to, optimized target conditions is required. If one or the other is missing, the optimization will be haphazard or will not occur. Again, continuous gathering of plant data, graphical representation and an understanding of the cause-and-effect relationship between different process parameters is a key aspect of successful plant optimization.

Optimization of a plant entails the correct balance between capacity, energy and corrosion. Ideally, acid gas in the treated-gas stream should be slightly less than the maximum specified limit, heat input to the reboiler should be at a minimum and corrosion should be within tolerable and accepted limits.

An important, but frequently overlooked, aspect of plant optimization is to get everybody involved in the process. Teamwork and "buy-in" are very important and

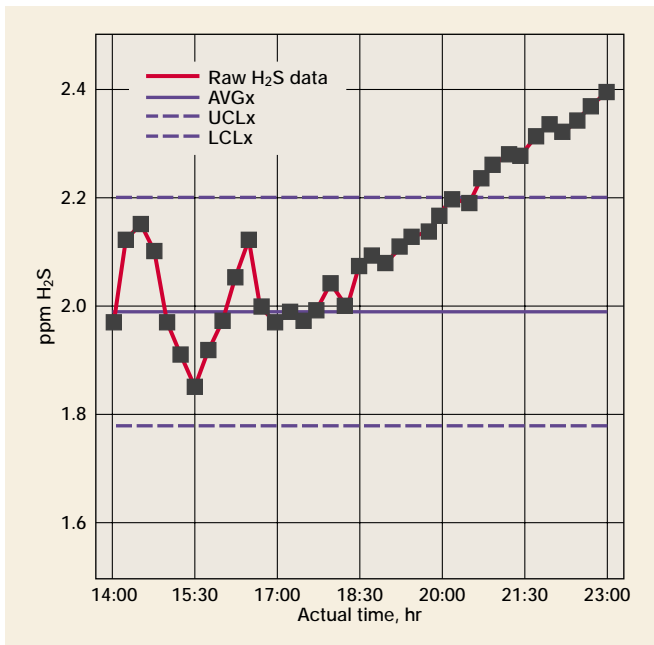


Fig. 14. Detailed look at extended X-chart.

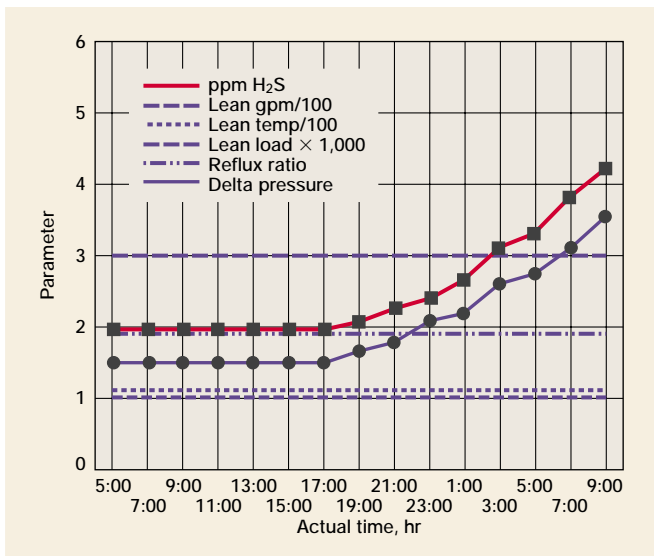


Fig. 15. Combined run charts.

will contribute to short- and long-term success. The steps necessary in this concept are:

1. Gather and examine baseline data set.
2. Generate the appropriate control charts.
3. Identify potential areas for improvement.
4. Set target process parameters.
5. Adjust target process parameters.
6. Monitor changes in process as result of adjustments.
7. Determine leading edge process parameters.
8. Update the control charts.
9. Calculate cost savings and communicate to everyone.

Example: A plant originally designed for 50 MMscfd is only treating 30 MMscfd due to declining flows from the field. Design and baseline data is in Table 6.

Potential areas for improvement in this case include:

- Reducing circulation rate
- Increasing amine concentration
- Lowering stripper reflux ratio
- Reducing overall reboiler duty.

Table 5. Troubleshooting guide for corrosion

Types of corrosion

- General corrosion
 - Uniform material deterioration
- Galvanic corrosion
 - Dissimilar metallurgy coupled together in the presence of an electrolyte
- Crevice corrosion
 - Concentration cells are allowed to form in stagnant areas of the system
- Pitting corrosion
 - Stagnant areas with high halide ion content accelerate this condition
- Intergranular corrosion
 - Most often found in stainless steels in heat affected zones
- Selective leaching corrosion
 - Removal of one element from a metallic alloy
- Erosion corrosion
 - High flowrates and turbulence can accelerate attack on a metal
 - Aggravated by the presence of solid particles or entrained gas bubbles
- Stress corrosion cracking
 - Simultaneous presence of tensile stress and corrosive media
 - Presence of chloride ion can induce this phenomenon
- Hydrogen damage corrosion
 - Mechanical damage caused by the presence of, or the interaction of the metal with, hydrogen

Symptoms

- | | |
|---|------------------------------------|
| High solution metals (Fe, Cr, Ni, etc.) content | Vessel failure |
| Wall thinning using ultrasonic monitoring | High rates on coupons or probes |
| Physical leaks | Positive solution corrosivity test |

Process considerations

- Rich acid gas loading too high due to low amine concentrations or under-circulation of amine
 - There is potential for corrosion at total acid gas loadings greater than:
 - 0.35 mols acid gas/mol MEA
 - 0.40 mols acid gas/mol DEA
 - 0.45 mols acid gas/mol MDEA
- Residual lean amine acid loadings too high due to insufficient stripping.
 - Lean side acid gas flashing can occur if lean loadings exceed:
 - 0.15 mols acid gas/mol MEA
 - 0.07 mols acid gas/mol DEA
 - 0.01 mols acid gas/mol MDEA
- Poor quality makeup water adds contaminants to amine system that enhance corrosion
 - Water quality to amine plants should not exceed:
 - 100 ppm for total dissolved solids
 - 50 ppm for total hardness as calcium ion
 - 2 ppm for chloride ion
 - 3 ppm for sodium ion
 - 3 ppm for potassium ion
 - 10 ppm for dissolved iron
- Presence of heat stable salts will enhance corrosion
- Incorrect amine chosen for the intended use
- Improper metallurgy in all or part of the system
- Solution flow velocities exceeding 3 ft/sec. in carbon steel and 8 ft/sec. in stainless steel
- Large step changes, either increases or decreases, in piping internal diameters
- Short radius elbows
- Flange gasket material protruding into pipe flow area causing a restriction or turbulence
- High suction pressure drop across pumps
- Insufficient available net pump suction head
- Control valves improperly located
- Inadequate mechanical and/or carbon filtration
- Non-stress relieved or insufficiently stress relieved hardware being used
- Inlet gas knock-out underdesigned, allowing contaminants to enter amine solution
- Suction side leaks and no pad gas on tanks, sumps, etc., thereby allowing oxygen into the system
- Bulk solution temperatures exceeding 260°F

Table 6. Data for optimization example

	Design	Baseline	Optimized
Inlet gas flow, MMscfd	50	30	30
Inlet gas pressure, psia	1,000	850	850
Inlet gas temperature, °F	100	100	100
Inlet H ₂ S, mol%	7.0	7.0	7.0
Inlet CO ₂ , mol%	3.0	3.0	3.0
CO ₂ specification, mol%	2.0 max	2.0 max	2.0 max
CO ₂ in treated gas, mol%	1.47	1.13	1.51
H ₂ S specification, ppm	<4	<4	<4
H ₂ S in treated gas, ppm	2.40	0.54	2.90
MDEA, wt%	50.0	40.0	50.0
Amine circulation, gpm	440	350	264
Lean H ₂ S loading, mol/mol	0.005	0.002	0.005
Rich H ₂ S loading, mol/mol	0.409	0.385	0.409
Lean CO ₂ loading, mol/mol	0.005	0.002	0.005
Rich CO ₂ loading, mol/mol	0.101	0.110	0.098
Lean amine temperature, °F	110	110	110
Rich amine temperature, °F	150	141	149
Rich amine entering stripper, °F	217	217	226
Stripper overhead temperature, °F	206	213	206
Stripper reflux ratio, mol/mol	1.20	2.00	1.20
Stripper bottoms temperature, °F	247	245	247
Stripper bottoms pressure, psig	10.0	10.0	10.0
Inlet temperature to LA cooler, °F	178	167	168
Reboiler duty, MMBtu/h	24.93	20.94	13.83
Cross-exchanger duty, MMBtu/h	13.06	11.99	8.91
Lean amine cooler duty, MMBtu/h	12.71	8.83	6.55
Acid gas condenser duty, MMBtu/h	10.54	11.09	6.29

Typically, a reduction in circulation rate and heat input to the reboiler are the obvious areas for improvement. However, some plants have been optimized by increasing circulation rate to minimize rich acid-gas loadings and corrosion associated with acid-gas flashing in the rich amine.

Optimization is not limited to adjustment of process parameters. Optimization could include installation of an online, lean-amine-loading analyzer, reconfiguration or installation of mechanical and carbon filtration and using a different amine.

The sequence that should be followed when trying to reduce circulation rate and plant energy input is to first reduce circulation rate while maintaining heat input into the reboiler. This will reduce the sensible heat load in the stripper and result in a higher stripper reflux rate with about the same or lower lean acid-gas loadings. This will keep treated gas at current levels. Process parameters to watch when reducing circulation rate include rich amine temperature, treated-gas temperature, rich amine loadings and treated gas H₂S and/or CO₂ composition. Depending on the amine used, there are guidelines for maximum rich loadings and rich amine temperatures (Table 5). The plant should not be allowed to go off specification. Treated-gas temperature increases will result in a higher load on downstream dehydration equipment. After the optimum circulation rate has been determined, heat to the reboiler can be reduced while closely monitoring treated H₂S and/or CO₂ in conjunction with lean amine loadings to make sure they do not exceed specifications and maximum recommended guidelines as outlined in Table 5.

Optimum reboiler heat input is established when the maximum lean loading is exceeded or the treated outlet composition is bumping the specification.

Target values for this example are 264 gpm and 14.96 MMBtu/h heat input to the reboiler. These two target

values were determined by using this four-step process:

1. Ratio the current gas rate to design gas rates.
2. Multiply this gas ratio with design circulation to get the target lean-solvent circulation rate.
3. Ratio this target circulation rate to the design circulation rate.
4. Multiply the solvent circulation ratio by the design reboiler duty to get the target reboiler duty.

The final optimized operating variables are in Table 6.

A review of optimized process parameters compared to the baseline conditions shows several immediate savings and benefits:

- Reduced amine pumping requirements resulting in lower power or steam consumption depending on the type of pump
- Reduced air and/or water requirements for the lean amine cooler and acid gas condenser
- Increased CO₂ slip resulting in a higher concentration of H₂S to downstream sulfur recovery equipment
- Reboiler energy savings of \$74,655/yr, based on a 350-day operating year and \$1.25/MMBtu.

When a systematic approach is taken to amine plant optimization, the results are usually immediate and sustainable money savers.

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