Alternative Flow Schemes to Reduce Capital and Operating Costs of Amine Sweetening Units

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ABSTRACT

The design capability for gas-sweetening units has improved greatly. The selection of an efficient alternative flowsheet minimizes capital and operating costs.

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INTRODUCTION

Gas sweetening using amines is one of the oldest and most common process operations in the world. During the 1960's and early 1970's, technological interest in the process diminished greatly even though detailed knowledge of many facets of the process was quite limited. Due to the relatively cheap construction costs and an almost free energy supply at the well head, rule-of-thumb design techniques for gas sweetening units were usually all that were justified.

The energy and inflation problems of the 1970's has drastically affected amine sweetening technology. First, the increased price of natural gas, coupled with the declining production rates from the sweet gas fields, has made production of sour gas fields not only economically sound, but imperative if supplies are to remain near demand levels. Second, the energy and inflation problems are forcing operators to minimize equipment sizes and to consume as little gas as possible for sweetening, compressing and dehydrating operations in order to send more of the valuable product into the pipeline.

Conventional amine sweetening units, having a flow sheet similar to Figure 1, typically use on the order of 1000 to 10,000 BTU per lb of acid gas removed, a considerable investment of natural gas to supply pipeline grade product. This heat load can be decreased by heavily loading the rich amine from the absorber, but this approach greatly increases the corrosion potential of the rich amine solution, forcing the use of much more expensive corrosion resistant materials and, in turn, increasing capital and maintenance costs, and reducing the plant's operating lifetime.

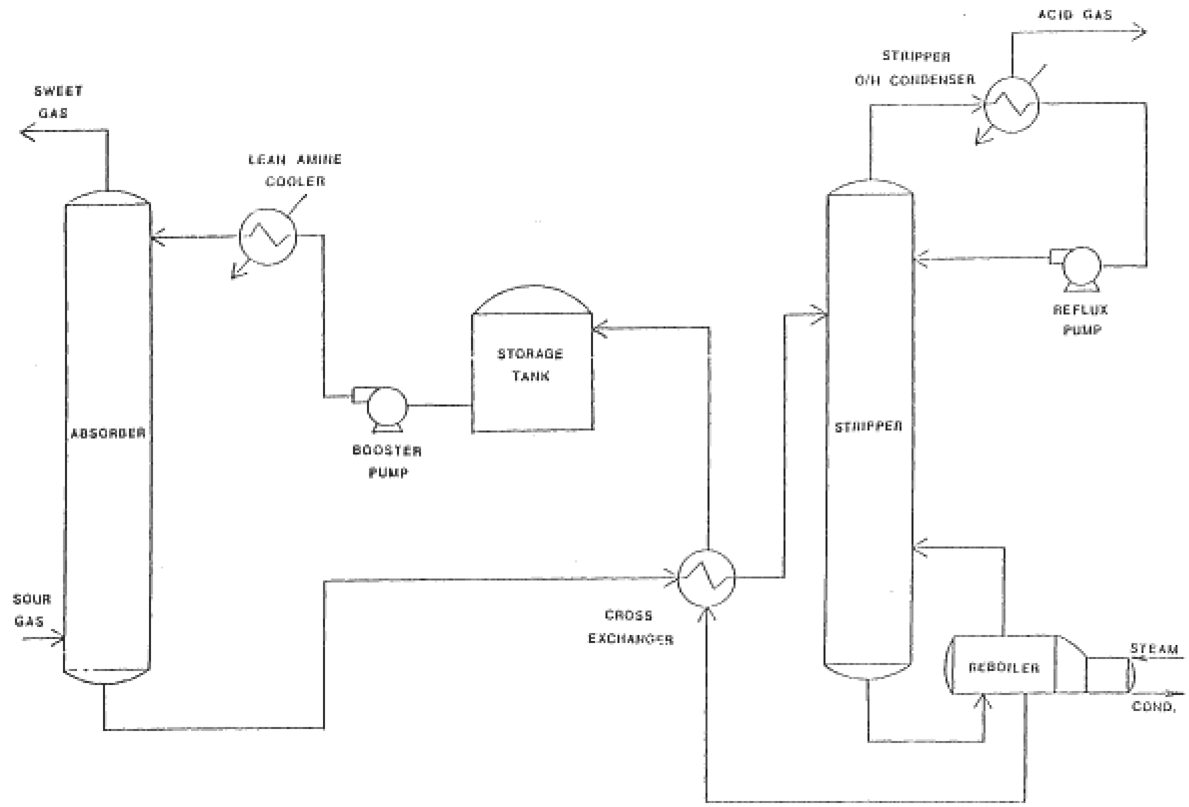

Figure 1. Process flow sheet for common sweetening plant.

Designers of these units have accordingly begun to look increasingly at alternative flow sheets as well as different amines which can reduce the size of critical components and/or reduce the heat load of the plant without encountering loading and corrosion problems. In many cases, due to a combination of gas composition and pressure, a conventional plant cannot produce pipeline specification gas without resorting to unreasonable steam rates for amine regeneration or unusually low temperatures of the lean amine charged to the absorber. The most pressing example is the need to selectively remove a small amount of H_2S from a stream containing as much as 10 mole percent CO_2. The selection of an efficient and reliable alternative flow sheet has heretofore been something of an art rather than a science. While there are "cookbook" type methods to design plants based on the standard flow sheet, there is essentially no complete operating data in the literature for conventional or modified plants. This has forced designers to rely on intuition and limited data from previous plants.

This situation has changed since we have developed a process simulation program for gas sweetening plants using amines. The program is called TSWEET. It uses composition dependent acid gas K's based on equilibrium reaction constants and rigorous tray-by-tray distillation routines to simulate amine sweetening plants. The distillation routines are quite sophisticated, allowing heat to be added or rejected from any stage in either column, up to six feeds on each absorber, two feeds to each stripper, and up to six liquid side draws from each stripper. The program employs the flexible flow sheet concept and contains an adequate repertoire of unit operations to model an amine sweetening plant, including compressors, pumps, heat exchangers, flash drums, and distillation columns. The program can be used to explore alternative flow sheets and make intelligent decisions regarding the feasibility of an unorthodox flow sheet.

This paper will compare three alternative flow sheets to a "conventional" flow sheet under various conditions. In each case, the "base" case was selected from partial plant data contained in the literature. The program was used to simulate the base case and then to explore the alternatives to the actual plant. In this way, the advantages and disadvantages of each of the alternative flow sheets could be qualitatively evaluated. Two of the cases quoted used MEA and one of the cases employed DEA as the absorbant. The program will also simulate plants employing DGA and MDEA.

MULTIPLE ABSORBER FEED

This particular modification, shown in Figure 2, is used when the feed gas is high in acid gases. Under these conditions, if a conventional flow sheet is used, the absorber is very large, due to the necessity of handling large amounts of amine solution throughout the column. Absorption of acid gases is quite fast, taking place within the bottommost 3 or 4 trays in a 20 tray absorber, with the remainder of the trays used only for residual scrubbing to remove the last .01% of the H_2S down to the 3.6 ppm necessary to produce pipeline specification gas. Texas Gulf Sulfur's Worland Wyoming plant was simulated using TSWEET. A summary comparison of the program output to the data is shown in Table 1. An extensive set of operating data was published by Estep, McBride, and West (1). Although this plant is to some extent an alternative flow scheme in its own right, possessing two absorbers in parallel, each processing a different feed gas, we will examine only the high pressure absorber for the purposes of this discussion. The sour gas stream being charged to this unit consists of 26% acid gas, necessitating the massive flow rate of amine solution.

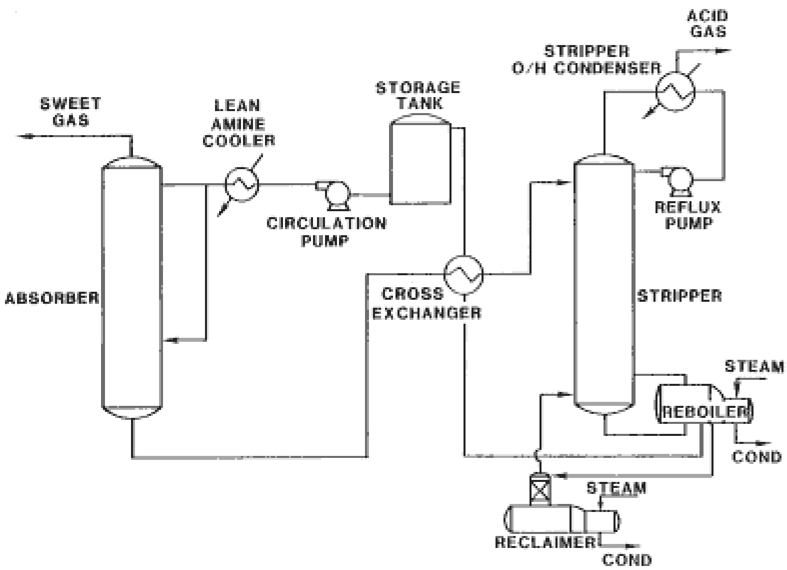

Figure 2. Process flow sheet for multiple feed absorber.

Table 1. Comparison of Worland data to TSWEET results.

	Worland	TSWEET
High Pressure Gas		
H2S, gr/100 SCF	.25	.180
CO2, ppm	nil	.696
Low Pressure Gas		
H2S, gr/100 SCF	.5	.519
Amine Solution		
Rich H2S, gr/gal	2455	2512
Lean H2S, gr/gal	89	98.5
Rich CO2, gr/gal	428	455.3
Lean CO2, gr/gal	132	182.9
Circ rate, gpm	1460	1460
Steam lb/gal	1.12	1.12

The full flow rate of amine is not needed in the upper section of the absorber since very little absorption occurs there. The lean amine stream can therefore be split, with most of the amine charged near the bottom of the column where a large flow rate can pick up the massive amounts of acid gas in the first few stages. Obviously, this section of the absorber would have to be of its present large size to handle the flow rates. The top section of the column, however, could be considerably smaller, scrubbing the nearly sweet gas with a flow rate of amine that may be an order of magnitude lower than the total amine flow rate.

COLUMN INTERNAL CONDITIONS STAGE DUTY TEMP VAPOR LIQU

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Figure 3 shows the flow rate and composition profiles for a multiple charge absorber scrubbing the same gas feed as for the Worland plant. As can be seen, the bottoms flow rates are essentially identical. Using a simple sizing correlation from Perry's, the required size of the absorber bottom section is 9.25 ft. which is the same as the actual plant. However, for two feed points the top of the absorber would have to be only 6.5 ft. This reduction in size can result in significant capital savings since this tower must handle high pressures and corrosive materials. If the column is trayed rather than packed, an additional saving is realized by using smaller diameter trays. The primary disadvantage of this flow sheet can be seen from Figure 3. Due to the fact that there is not as much amine entering the top section of the column, acid gas removal from the gas is not quite as complete as for a single feed. At first glance this seems unreasonable since the amine loading does not change appreciably in this section of the column. Examination of the temperature profile in the column explains the difference in results. In the single feed absorber, the large flow rate of amine solution in the upper section of the column cools the gas stream to the point that the top tray is operating at essentially the lean amine temperature. In the multiple feed absorber, the amine in the top section does not cool the partially sweetened gas as much and, as a result, the top stage is operating at a slightly higher temperature. At this temperature, equilibrium is markedly affected. Another point which is frequently overlooked is that since more heat is carried out of the absorber by the overhead gas, less heat is available to heat up the bottoms, which as a result, are somewhat cooler. This means that a somewhat higher equilibrium loading is possible. This fact can be used to the designer's advantage if low inlet gas pressure or high inlet gas temperature blocks rich amine loading.

MULTIPLE SERIES ABSORBERS

This flow sheet is an outgrowth of the first alternative. There is no reason for the two sections of the absorber to be contained in the same vessel. If the designer does not desire to add the amine from the top section to the lean amine charged to the bottom, the sections can be separated into two columns, as shown in Figure 4. This configuration also gives additional flexibility to the design due to the accessibility of the semisweet gas stream. This stream can be cooled and/or compressed to enhance acid gas recovery in the "upper" absorber section. Cooling the gas is a simple and direct method of getting around the disadvantage of increased acid gas residuals in the previous example. If the gas is also compressed between the absorbers, residuals can be reduced tremendously compared to a plant with a conventional flow sheet operating at the lower pressure. In many cases, the feed stream cannot be compressed due to corrosion restraints in the compressor while the semisweet stream is clean enough to avoid this difficulty.

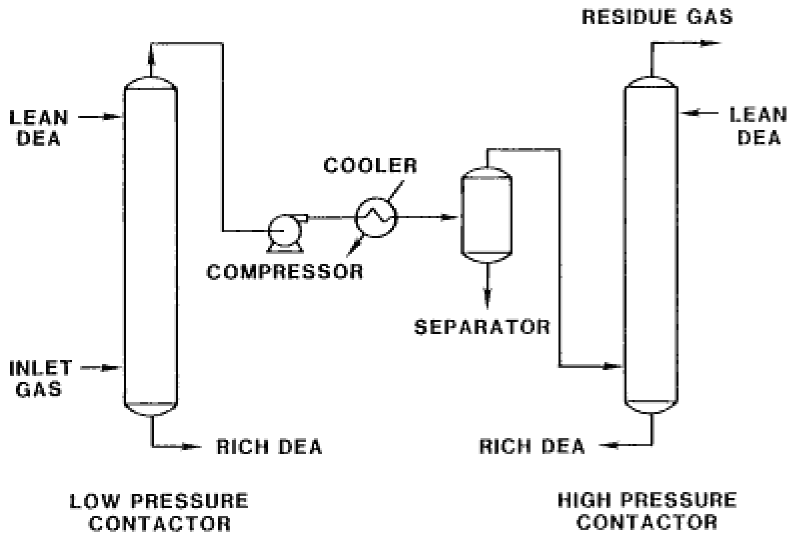

Figure 4. Process flow

A specific example of this type plant has been documented in a paper by Donnelly and Henderson (2). The inlet gas stream contained over 8.5% acid gas at a pressure of only 21 psig. This low pressure makes it impossible to produce specification gas in a conventional plant with any reasonable steam rate in the stripper. The approach used in this case was to absorb as much acid gas as possible at the low inlet pressure, leaving approximately 1% acid gas in place. This stream was low enough in acid gas to eliminate the exotic materials requirement in the compressor. The plant performance cannot be compared to a "conventional" flow sheet since, without compression of the sour gas feed, specification gas could not be produced. The "conventional" low pressure plant which came closest to producing equivalent gas required over double the reboiler duty, half again the amine circulation rate, and a much larger trim cooler to reduce the lean amine temperature from 115 degrees F to 100 degrees F.

SPLIT FLOW AMINE PLANTS

While the previous two flow schemes split the lean amine stream, they are not the scheme which is generally thought of as split flow. A typical split flow plant is shown in Figure 5. Instead of stripping the entire amine stream to the lean concentration, part of the amine is taken from the stripper as a side stream, cooled, and pumped into the lower section of the absorber. Thus, the amine in the side draw is not completely stripped and has a higher residual acid gas loading. However, since it is contacted with the incoming sour gas, it can still pick up the majority of the acid gas in the lower section of the absorber. As a result of the side draw, the amine flow rate in the bottom of the stripper is much lower and a given amount of steam can strip the amine much harder than in a conventional stripper. The split flow configuration is most advantageous in cases where the lean amine must be very clean to produce specification gas. When using the split flow option, either the rich amine loading or the overall circulation rate must usually be increased slightly since the semi-lean amine has a higher residual acid gas loading than for a conventional flow plant. In many cases, a split flow configuration can drastically reduce the required steam stripping rate.

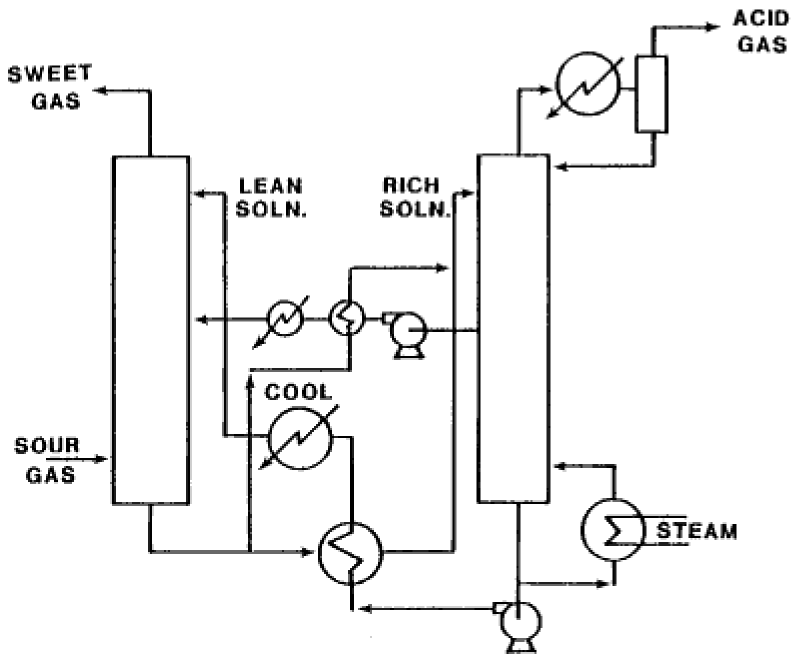

Figure 5. Flow sheet for split flow plant.

The base plant for this case was also discussed by Estep, McBride, and West. This plant was located in Okotoks, Alberta and processed sour natural gas as well as a gas stream which had been used to sweeten sour condensate. Since the natural gas was used to sweeten the sour condensate, the sulfur content of the sweet gas had to be much lower than pipeline spec. Therefore, the owners of the plant elected to use the split flow scheme to produce sweet gas containing on the order or .01 gr/100 SCF. As can be seen from Table 2, the program results matched the Okotoks data quite well.

Table 2. Comparison of Okotoks data to TSWEET results.

	Okotoks	TSWEET
High Pressure Gas		
H2S, gr/100 SCF	.01	.05
Amine Solution		
Lean H2S, gr/gal	19.9	15.7
Lean CO2, gr/gal	176	112.7
Semi-lean H2S, gr/gal	338	313.4
Semi-lean CO2, gr/gal	--	270.6
Circ rate, gpm	2000	2000
Steam lb/gal	0.9	0.9

The .01 gr/100 SCF specification is far beyond the abilities of the standard flow sheet as can be seen from Table 3, which shows the performance of both a standard and a split flow plant using the same circulation rate. The split flow plant produced much cleaner gas for each lb of steam consumed, but at the expense of a more complicated plant. There is an extra cross exchanger, trim cooler, and pump train in addition to the controls. This flow sheet should be considered in cases where the designer expects to have trouble adequately stripping the lean amine to make spec, either because the H_2S to CO_2 ratio is high, the spec is tight, or the stripper overhead pressure is low.

Table 3. Comparison of split and conventional flow plants.

	Split Sweet Gas		Conv. Sweet Gas	
Steam lb/gal	H2S gr/100 SCF	CO2 gr/100 SCF	H2S gr/100 SCF	CO2 gr/100 SCF
0.75	0.059	0.025	--	--
0.80	0.052	0.022	0.38	0.27
0.90	0.042	0.017	0.26	0.18
1.0	0.036	0.013	0.16	0.14

SUMMARY AND CONCLUSIONS

Three alternative flow schemes for gas sweetening plants have been presented with each possessing some advantages and disadvantages. The multiple feed absorber is desirable to greatly reduce the amine flow rate to the top of the absorber. A precontactor would have the potential of significantly reducing the diameter of the entire absorber.

Multiple absorbers are very useful for sweetening low pressure gas streams which must be compressed to higher pressures. Considerably lower circulation and steam rates as well as a cheaper compressor can be realized. The primarv disadvantage is that a second absorber is required.

A split flow plant is desirable to sweeten gas streams with a high H_2S/CO_2 ratio, with a low H_2S specification in the sweet gas and for a low stripper pressure. Significant reductions in equipment sizes and steam requirements can also be realized for this configuration. However, additional equipment consisting of a cross exchanger, trim cooler, pump and controls are necessary.

The amine sweetening process simulation program, TSWEET, can be used to find the best plant configuration and operating conditions with a minimum of time and effort. The program has been shown to match the performance of several plants using various flow schemes.

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