OPTIMISING GAS TREATMENT

Pedro Ott and Ralph H. Weiland, Optimized Gas Treating, Inc., USA, explore the efficiency and drawbacks of a split-flow configuration in alkanolamine-based acid gas removal processes.

Using alkanolamines to removal acid gases is 1930s vintage technology, nearly a century old. Still in wide use today, it is applied primarily to pipeline gas conditioning and treating refinery sour gases. The basic process (Figure 1) centres on a closed, solvent-circulation loop where the acid feed gas contacts lean solvent in an absorber column chemically removes hydrogen sulfide (H_2S), carbon dioxide (CO_2) and other acid species according to their concentrations, solubilities, and reactivity. The rich solvent is regenerated by applying heat to a reboiler at the base of the stripping column where chemical reactions reverse and the acid gas desorbs from loaded (rich) solvent.

System energy demands and solvent flow requirements quickly rise as the acid gas content in the feed gas increases. Over the years, this basic process has been improved, implementing new and better performance solvents and blends that maximise acid gas removal while reducing energy requirements.

As the energy and solvent circulation requirements grow from processing larger feedstocks with higher acid gas content, designers, and technologists have devised modifications to the basic process to reduce energy consumption. One of these process scheme variations has been described by Mohebbi and Moshfeghian.[1] There, a split-flow process configuration (Figure 2) is outlined for sour gas sweetening applications. It showed 39% reboiler duty savings with a split configuration (897 m^3/h total circulation, 390 m^3/h lean, 507 m^3/h semi-lean, 54.5 MW reboiler duty) vs a conventional scheme (790 m^3/h, 90 MW), respectively.

Conceptually, the split-flow configuration takes a large flow of partially regenerated (semi-lean) solvent from the stripping column and introduces it toward the absorber's midpoint. The semi-lean loop is intended to absorb the bulk of the acid gas within the absorber's lower section, with the smaller lean flow now requiring much less duty to regenerate it to the solvent loading required to meet the treated gas specification. However, there are numerous potential drawbacks to split-flow processing.

Before proceeding, it is worth making a critical, qualitative comparison between single-recycle and split-flow processing.

One of the most pressing concerns in any gas treating facility is acidic corrosion. The general rule-of-thumb is not to allow rich solvent loading to exceed 0.4 – 0.45 (moles CO_2 per mole of total amine). Lean amine loading is set by the treated gas CO_2 specification on the assumption that these will be in close equilibrium at the top of the absorber. In LNG production, treating to <50 ppmv CO_2 is generally required and this sets the lean solvent loading at roughly 0.02 or better. This sets 0.38 – 0.43 as the maximum net[2] CO_2 loading. In a single-recycle process, this is the maximum net loading of the entire solvent stream. In a split-flow process, however, only the lean portion of the solvent has such a high net loading value; the semi-lean portion has a much lower value because it is not regenerated to nearly the same extent. Solvent capacity depends on solvent flow rate and amine strength, as well as net loading:

$$Capacity = (Amine\ Strength)(Solvent\ Flow\ Rate)(Maximum\ Net\ Loading)$$

In a split-flow process, capacity can be increased by using higher strength amine, but the resulting higher boiling points and consequent amine degradation rates make that approach ill-advised (if it is even possible at all). Solvent flow rate can be increased; however, the objective is to reduce reboiler heat duty whereas higher solvent flow rate tends to increase it (Table 1). The remaining option is to permit higher net loadings by relaxing the limit on solvent rich-loading limit. This will necessitate mitigating corrosion issues, perhaps by cladding portions of the process equipment exposed to hot, highly-loaded solvent and by using upgraded metallurgy piping in some areas.

Even if split-flow processing can provide substantially reduced energy consumption, potential savings must recognise the following drawbacks and additional costs:

- Larger capital cost for installing additional equipment such as semi-lean/rich anime exchanger, semi-lean cooler, semi-lean pump.
- Increased capital cost for installing a taller absorber to achieve adequate mass transfer. This also results in the additional cost for loading additional packing and additional internals for the semi-lean draw, and possibly column diameter transitions to optimise tower diameters.
- Greater operating costs resulting from possible amine flow. This also results in increased column diameter.
- Higher lean and semi-lean solvent acid gas loadings and, depending on solvent circulation rate, rich

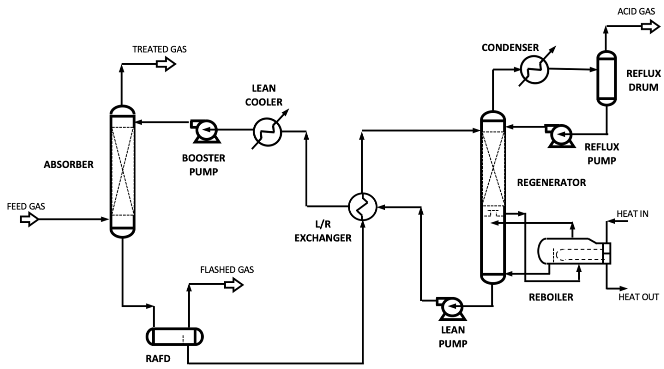

Figure 1. Conventional amine flowsheet.

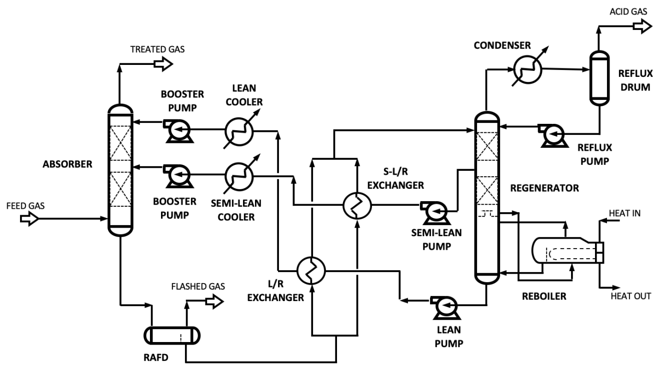

Figure 2. Split-flow amine flowsheet.

Table 1. Overall circulation (1X, 1.25X, 1.50X)

	Circulation 1X						Circulation 1.25X						Circulation 1.5X					
Duty ratio Btu/gallon	900	1100	1250	1400	1550	1700	900	1100	1250	1400	1550	1700	900	1100	1250	1400	1550	1700
Reboiler duty (million Btu/h)	49.122	49.071	49.919	50.49	52.153	53.171	52.384	52.251	52.282	52.221	52.734	52.913	53.903	54.706	54.584	54.668	55.089	55.278
Absorber outlet (CO_2 ppmy)	2	2	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.9	1.8	1.9	1.9	1.9
Absorber semi-lean draw faction	0.21	0.34	0.4	0.45	0.48	0.51	0.324	0.436	0.495	0.540	0.576	0.606	0.42	0.513	0.56	0.6	0.63	0.656
Absorber rich loading	0.4564	0.4591	0.4564	0.4559	0.4542	0.4535	0.4088	0.4135	0.4143	0.4121	0.4101	0.4079	0.3892	0.3925	0.3897	0.3906	0.3877	0.3874
Absorber lean loading	0.0075	0.0057	0.0047	0.0040	0.0025	0.0032	0.0098	0.0074	0.0063	0.0054	0.0047	0.0042	0.0108	0.0082	0.0068	0.0060	0.0052	0.0047
Absorber semi-lean loading	0.0696	0.0566	0.0431	0.0387	0.0333	0.0312	0.1664	0.1387	0.1256	0.1125	0.1027	0.0949	0.2189	0.1904	0.1709	0.1628	0.1507	0.1442
Semi-lean % CO_2 removal	98.269	98.143	98.350	98.361	98.457		98.326	98.225	98.248	98.416	98.540	98.656	98.194	98.179	98.391	98.370	98.555	98.592
Lean % CO_2 removal	1.721	1.848	1.641	1.630	1.534	1.495	1.665	1.765	1.742	1.574	1.450	1.335	1.797	1.182	1.600	1.621	1.436	1.398

solvent could also reach high enough acid gas loading to exceed the maximum limits for metallurgical integrity.

- Controls become more complex to balance duty on lean/rich and semi-lean/rich exchangers to maintain rich amine temperature fed to the regenerator.

- Requires tight flow control in the semi-lean loop to achieve minimum reboiler duty, excessive semi-lean draw starves lean amine flow to the absorber top, which results in sudden increases on absorber outlet acid gas content. By contrast, insufficient semi-lean draw results in higher reboiler energy demand above the targeted minimum.

Energy savings must be balanced against design and operational constraints. A detailed techno-economic analysis with favourable NPV and payout years outcomes will then determine in which cases (if any) the split-flow configuration should be considered.

Case study

Using example results from ProTreat® simulation, the performance of a conventional, single-recycle loop is compared to the split-flow configuration based on the following treating premises:

- 500 million ft^3/d feed gas at 760 psig, 100˚F; feed gas contains 2 mol% CO_2 (typical feedstock).

- Lean loading as needed to achieve less than 50 ppmv CO_2 (99.7% CO_2 removal or higher).

- Rich solvent loading allowed leaving the absorber is 0.45 maximum due to corrosion and equipment material selection considerations.

- Solvent circulation rate fixed to 20 980 lbmol/h (CO_2 free), strength 45 wt% MDEA blended with activator.

- Lean/rich exchanger approach of 20˚F to maximise regenerator rich amine feed preheat.

- 40 ft beds of 2 in. random packing for both absorber and regenerator columns.

- Reboiler duty is adjusted to meet these process parameters.

Additionally, for the split-flow configuration, there are further considerations:

- Overall solvent circulation rate (lean + semi-lean) fixed to 1.0X, 1.25X, and 1.5X the 20 980 lbmol/h base solvent circulation rate set for the single recycle loop.

- Regenerator semi-lean solvent draw is maximised to meet a 1.8 ppmv CO_2 specification adopted for the single recycle loop case.

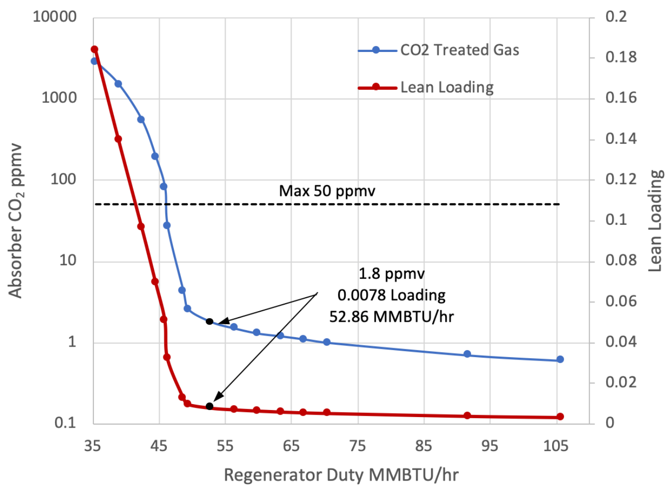

Figure 3. Effect of reboiler duty on treating.

Table 2. Single recycle loop configuration (base case). Key variables include:	
Absorber CO_2 outlet ppmv	**1.8**
CO_2 removed (%)	99.99
CO_2 removed (%) at absorber mid-section	99.17
Lean loading (mol/mol)	0.0078
Rich loading (mol/mol)	0.445
Solvent circulation (lbmol/h)	20 980
Regenerator feed temperate (˚F)	220.8
Regenerator reboiler duty (million Btu/h)	52.86
Absorber/regenerator bed height (ft)	40

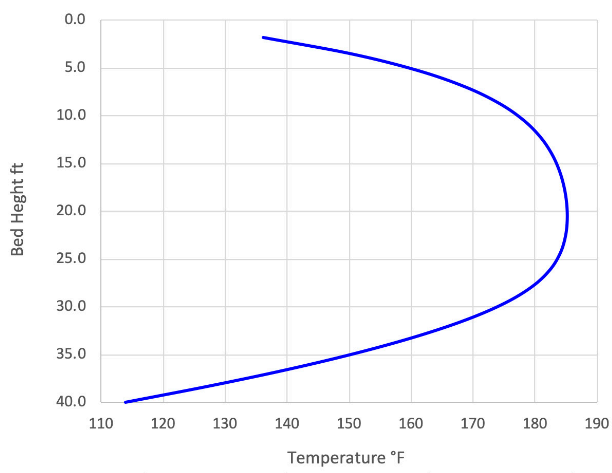

Figure 4. Absorber temperature profile.

- Absorber and regenerator bed heights are increased to 80 ft to maximise mass transfer as allowed by CO_2 solvent equilibrium.

- Optimum split for the rich amine stream feeding lean/rich and semi-lean/rich exchangers to maximise heat recovery for achieving maximum regenerator feed preheating.

Single recycle loop results

Figure 3 shows absorber outlet CO_2 content and solvent lean loading for ProTreat simulations at constant 21 980 lbmol/h circulation with varying reboiler duty. The regenerator requires about 46 million Btu/h reboiler duty to meet the maximum 50 ppmv CO_2 at the absorber outlet. Note however that this is a very sensitive operating condition – the regenerator temperature profile is collapsed indicating insufficient solvent regeneration. Lean loading is extremely sensitive to reboiler duty and only a small duty reduction will cause the lean loading to increase precipitously. This quickly raises the absorber CO_2 content beyond the intended CO_2 target specified. For better and more stable unit control, the regenerator is purposely driven at higher duty (52.86 million Btu/h) which achieves a much lower but stable 1.8 ppmv CO_2 at the absorber outlet. Key operating variables are summarised in Table 2.

Figures 4 – 6 show respective profiles for absorber temperature, percent CO_2 recovery and CO_2 actual vs equilibrium partial pressure.

The absorber temperature bulge is at the column mid-way point, the bottom half (20 ft) absorbs 98.5% of the CO_2 fed while the top 20 ft serves as polishing section absorbing the remaining 1.49% for 1.8 ppmv CO_2 content at the absorber outlet.

The regenerator temperature profile shows a well regenerated system with most of the stripping occurring within the top 15 ft and the remaining 25 ft achieving low loadings 0.013 at the bottom of the column and 0.0078 at the reboiler outlet.

The absorber operates under a mass transfer limited regime so a taller bed would further lower the treated gas CO_2 content, helping to further reduce either solvent circulation or reboiler duty; however, in such a case, the rich loading leaving the absorber increases beyond the recommended 0.45 max limit for carbon steel metallurgy.

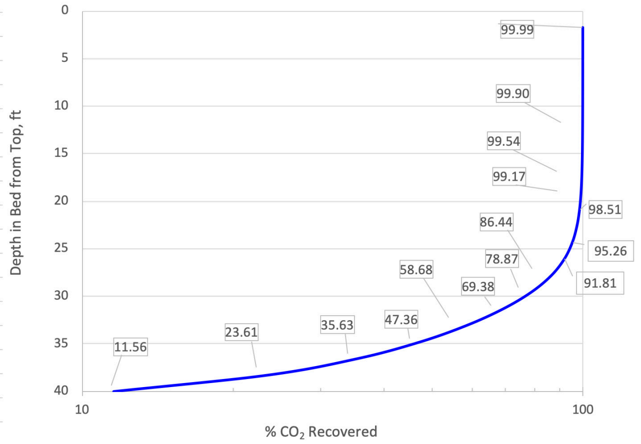

Figure 5. CO_2 recovered vs depth into bed.

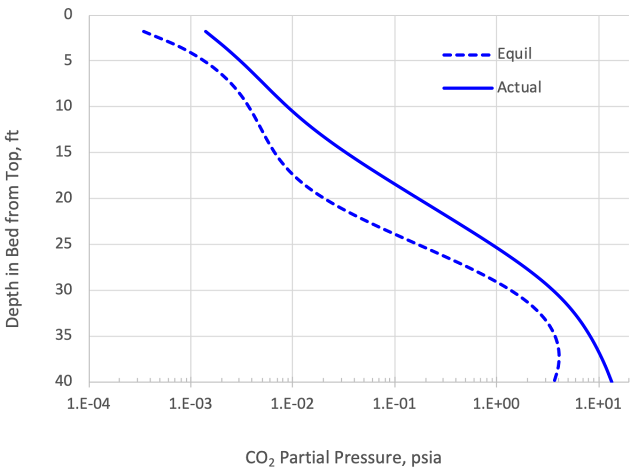

Figure 6. CO_2 partial pressure profile.

Table 3. Split-flow configuration results with taller beds – key variables

Simulation run	Case A	Case B	Case C
Overall circulation	1.5X base	1.5 X base	1.0X base
Regenerator semi-lean draw fraction	0.585	0.632	0.525
Absorber CO_2 outlet (ppmv)	0.1	1.8	1.7
CO_2 removed (% overall)	99.999	99.991	99.992
CO_2 removed semi-lean section	91.031	76.92	57.73
CO_2 removed lean section	8.97	23.07	42.26
Lean solvent loading	0.0036	0.0031	0.0029
Semi-lean solvent loading	0.272	0.324	0.323
Rich loading	0.449	0.491	0.597
Regenerator reboiler duty (million Btu/h)	52.25	46.71	40.33
Reboiler energy savings vs base case (%)	1.13	13.16	23.70

Split flow with semi-lean loop results

With split configurations, key performance variables are difficult to analyse to get an optimum unit design with pre-specified packed tower heights because the semi-lean draw rate simultaneously affects all variables considered, which makes it difficult to isolate the effect of any particular variable. The procedure to optimise this process and to successfully converge the simulation model is as follows:

1. Modify the single recycle model to include in the simulation the regenerator semi-lean draw stream, semi-lean/rich solvent exchanger, semi-lean solvent cooler and pumps, to configure the split flow scheme. Start with column semi-lean regenerator draw and absorber injection located at column mid-section, splitting 50% rich amine between the lean/rich and semi-lean/rich exchangers for regenerator feed preheating. Set the reboiler regenerator energy requirements as a duty/flow ratio specification so the duty is scaled proportionally as the semi-lean stream draw varies.

2. Select desired acid gas treating specification.

3. Select desired overall solvent circulation.

4. Maximise column bed heights as allowed by equilibrium pinch constraints.

5. Increase the regenerator semi-lean draw fraction until meeting the absorber target acid gas specification.

6. Adjust the rich amine split fed to the lean/rich and semi-lean/rich exchangers for achieving maximum regenerator rich solvent temperature.

7. Repeat steps 5 and 6 to minimise reboiler duty needed while obtaining a balanced performance for absorber treated acid gas outlet, rich amine loading, semi-lean draw ratio and maximum rich amine preheat.

8. Move absorber semi-lean injection and regenerator semi-lean draw locations and repeat steps 5 and 6 as required to arrive to the optimum design.

Table 1 summarises the system performance when including the semi-lean loop for the split-flow configuration at 1.0, 1.25, and 1.5 times the overall solvent circulation with same 40 ft columns bed heights and exchangers heat recovery approach temperatures used for the simple recycle loop case

These tables show that higher semi-lean draw rates and higher overall solvent circulation hardly reduce the reboiler duty at all, the best case achieves a marginal 7% energy reduction (from 52.85 to 49.12 million Btu/h) for a maximum 0.21 semi-lean draw ratio fraction at 1.0X overall circulation case. In all cases evaluated, increasing the semi-lean draw fraction above the maximum possible for meeting the absorber CO_2 specification, results in higher rich amine loading beyond 0.45 limit and much larger reboiler duties exceeding the 52.86 million Btu/h base case. Further evaluation of regenerator semi-lean stream draw location and absorber semi-lean stream injection at various column heights above and below the column middle did not show any significant advantage for reboiler energy reduction.

Increasing absorber and regenerator bed height achieves lower absorber outlet CO_2 content which allows for larger regeneration semi-lean draw fraction. Taller beds, while beneficial, may reach pinch conditions where additional bed height does not achieve any additional absorption/stripping, limiting the maximum CO_2 removal effectiveness.

Table 3 summarises the split configuration performance equipped with taller (80 ft) packed beds for both absorber and regenerator columns; evaluated at two solvent overall circulation rates 1.0 and 1.5X, respectively.

Case A shows that 0.45 maximum rich amine load constrains the 0.585 maximum feasible semi-lean draw ratio without gain in reboiler duty savings, despite the fact that the CO_2 in the treated gas is much lower than the targeted 1.8 ppmv. Case B has a larger semi-lean draw rate while Case C has a lower overall solvent circulation rate. These cases have noticeable reboiler energy savings but at the expense of much larger rich loadings, exceeding the maximum 0.45 limit. They also shift the absorber CO_2 recovery profile, showing a substantially lower CO_2 recovery in the absorber's semi-lean section.

Figures 7 and 8 show respectively profiles of absorber temperature, percent CO_2 recovery and actual vs equilibrium CO_2 partial pressure; Figure 9 shows the regenerator temperature profile, all for Case A.

The absorber temperature profile shifts when injecting semi-lean stream quenching the temperature rise associated with heat release by the CO_2 reaction. The maximum temperature obtained is smaller and the temperature bulge location moves further down the column into the semi-lean section. The CO_2 removal is not completely depleted within the semi-lean section, thus the

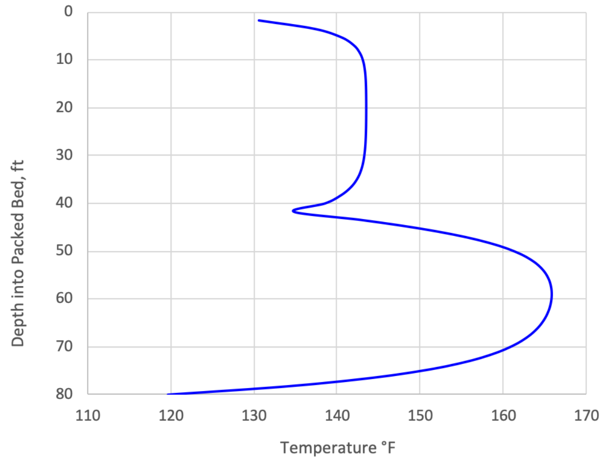

Figure 7. Absorber temperature profile.

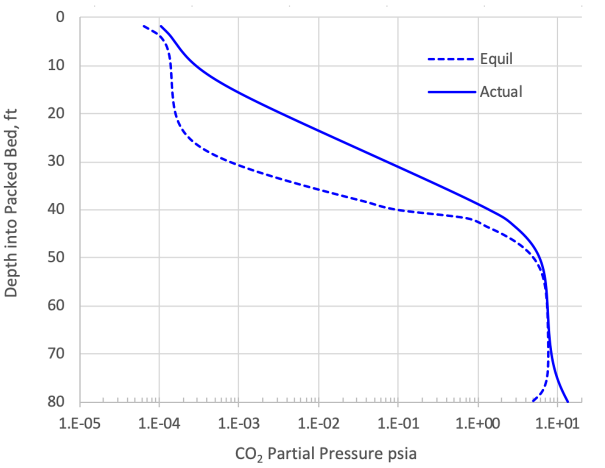

Figure 8. CO_2 partial pressure profile.

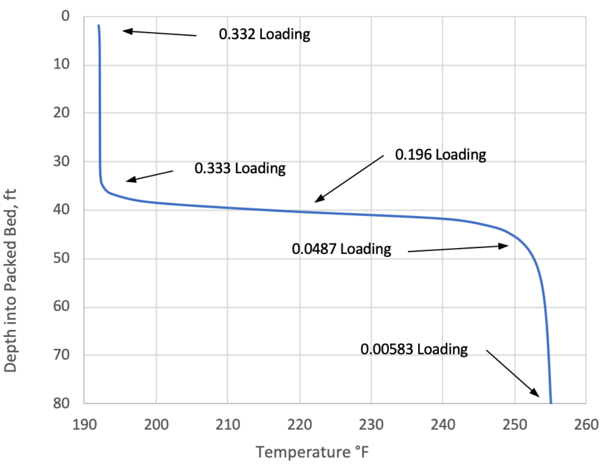

Figure 9. Regenerator temperature profile.

remaining CO_2 travels up the absorber and continues to react with lean solvent, forming a smaller second bulge in the absorber lean section.

Percentage CO_2 removal also degrades; the absorber bottom half achieves only 93.03% compared to 99.17% with conventional single recycle loop configuration. This percentage removal quickly degrades as the semi-lean fraction draw increases or the overall solvent circulation decreases.

Plotting the absorber equilibrium vs actual CO_2 partial pressure shows that there is a 10 ft section in equilibrium for the semi-lean zone not performing any CO_2 removal. This explains the shift in absorber CO_2 removal between the lean and semi-lean sections.

Regenerator temperature and solvent loading profile also shift accordingly to the semi-lean draw rate. CO_2 stripping occurs towards the regenerator bottom and is accompanied by a big loading jump at the reboiler. Semi-lean solvent loading also increases as the semi-lean draw fraction goes up.

Take away conclusions

The single recycle loop classic configuration is the most efficient design applicable for most design cases since acid gas is contacted throughout the whole column with a well regenerated solvent. The system could have stable operating controls to cope with variability changes. The case study shows that for a typical LNG feed pretreatment, the reboiler energy benefits are none-to-marginal at best for the additional equipment and metallurgical considerations.

Split-flow configuration could be an advantage in certain cases. A large reboiler energy reduction can be achieved with larger semi-lean solvent draw rates, but at the expense of:

1. Rich amine loadings exceeding maximum threshold limit. However, if the economics warrants the use of stainless-steel metallurgy for rich amine piping and cladding in the upper section of the regenerator, substantially reduced reboiler energy consumption can result. This is a trade-off between operating and capital costs.

2. Lower CO_2 percentage recovery along the absorber column.

3. CO_2 absorption becomes highly-dependent on semi-lean draw fraction setpoint control, which causes wide variations in the purified gas CO_2 content.

4. Additional equipment for the semi-lean loop circuit. An economic analysis will inform the choice between the single-loop, classic case and the split-flow configurations. **LNG**

References

1. MOHEBBI, V., and MOSHFEGHIAN, M., 'Method Calculates Lean, Semi-Lean Streams in Split Flow Sweetening', *Oil & Gas Journal*, (23 July 2007).
2. Net loading is the increase in loading between the top and bottom of the absorber. It is a measure of solvent capacity.