Upgrading CO_2 removal systems

Simple modifications to three carbon dioxide removal systems raised their efficiencies with short payback periods

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Kinetics Process Improvements

Acid gas removal is an important step in petrochemical plants, refineries and syngas production. This article describes experience in cost effectively upgrading CO_2 removal systems in three ammonia plants with an attractive payback of just a few months. One of the plants uses a MDEA system and the other two use Benfield systems. A similar approach can be used in acid gas removal systems in petrochemicals plants and refineries.

MDEA based CO_2 removal system

The existing single stage MDEA CO_2 removal system scheme is shown in **Figure 1**. This conversion of an old MEA based system was implemented as a part of the overall ammonia plant capacity revamp from the original nameplate capacity of 600 t/d to about 1100 t/d. The original absorber and stripper columns were used, with trays replaced with packings and other internals. The current operating capacity is 1140 t/d to 1170 t/d, depending on seasonal variation. This plant was stretched to its design limits and beyond.

A holistic review of the reference CO_2 removal system was carried out by KPI to identify all the potential bottlenecks contributing to a shortfall in performance. To support this, the following steps were taken:

- Gamma scan of the columns to determine any maldistribution
- Representative operating data corresponding to maximum operating capacity
- Reconciliation of the operating data

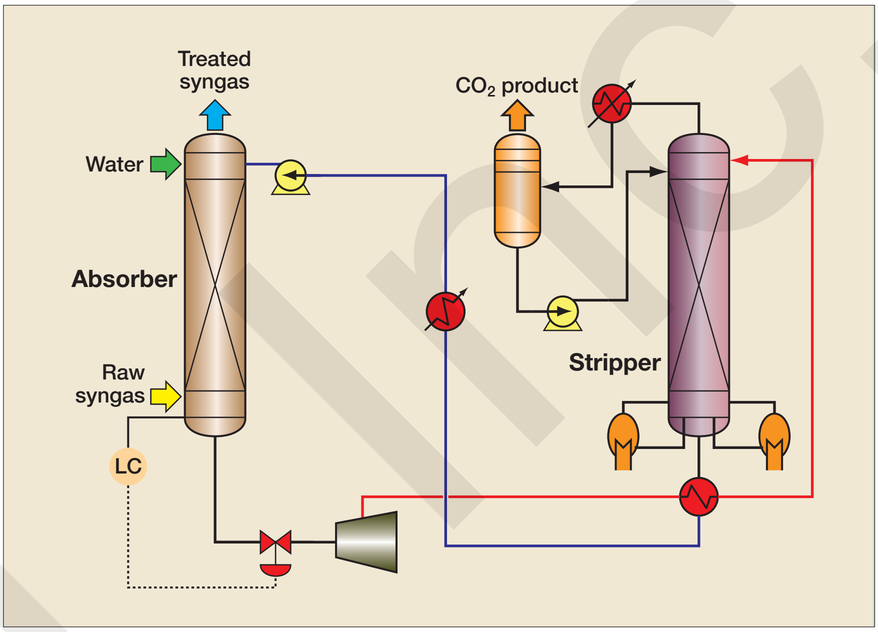

Figure 1 MDEA-piperazine CO_2 removal scheme

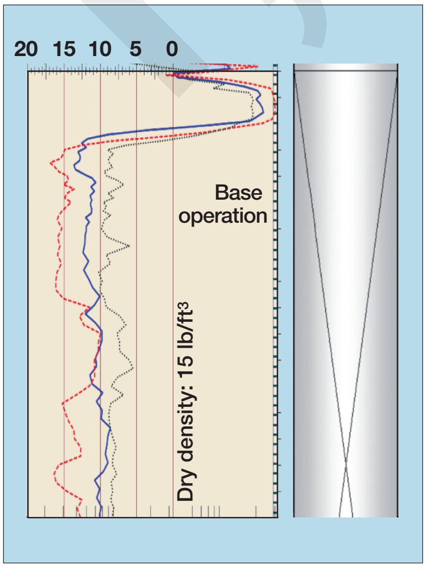

Figure 2 Absorber liquid density profile

- Simulation of the existing scheme to match the reconciled operating data
- Evaluation of potential bottlenecks at the current operating conditions:
  - Mass transfer limits of the existing packing type and height
  - Adequacy/limitations of liquid distributor
  - Adequacy/limitations of feed vapour distributor
  - Hydraulic adequacy/limitations of the solvent circulation loop
  - Solvent and activator concentration for optimal performance.

Figures 2-5 represent the base operating performance at 1140 t/d as modelled and reconciled with actual operating performance. A gamma scan of the absorber indicates the liquid density variation profile in **Figure 2**, with a variation between 8 and 15 units indicating maldistribution. The absorber is operating at about 85% flood while the stripper has enough hydraulic capacity available (see **Figure 5**). The absorber temperature profile in

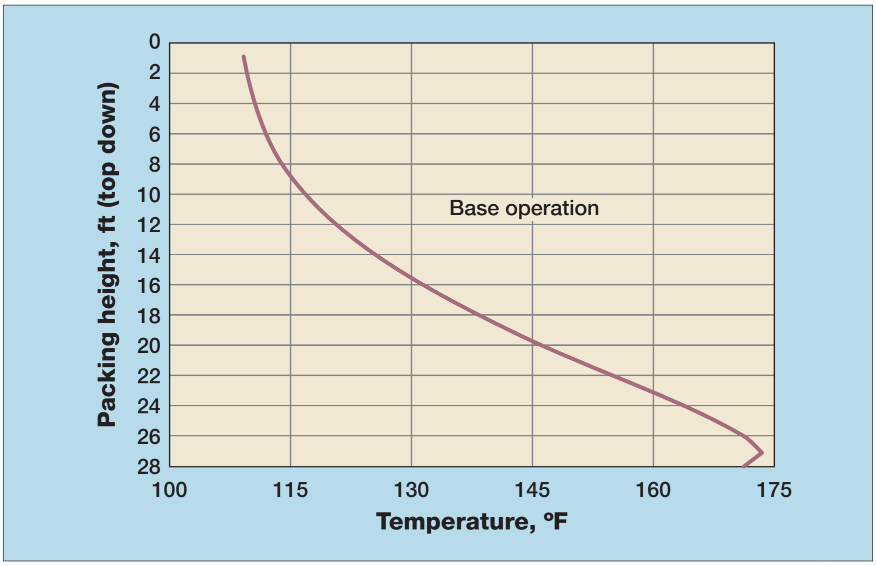

Figure 3 Absorber temperature profile

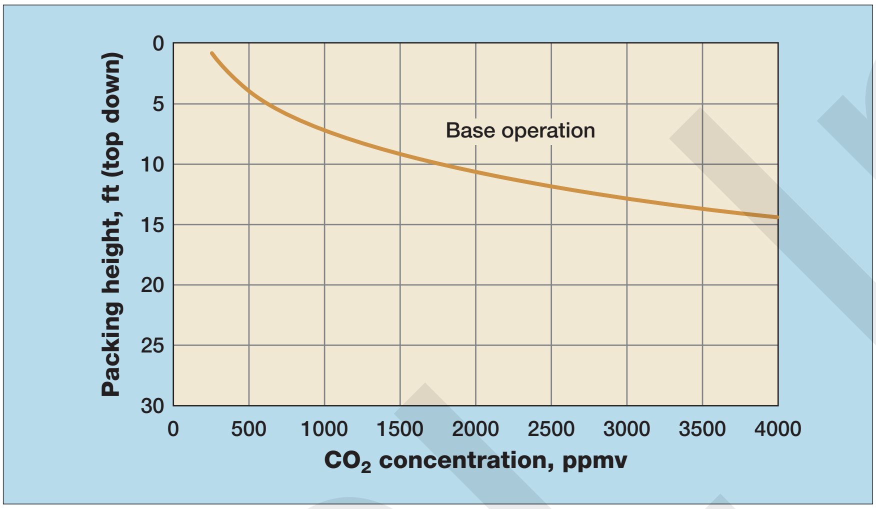

Figure 4 Absorber vapour CO_2 concentration profile

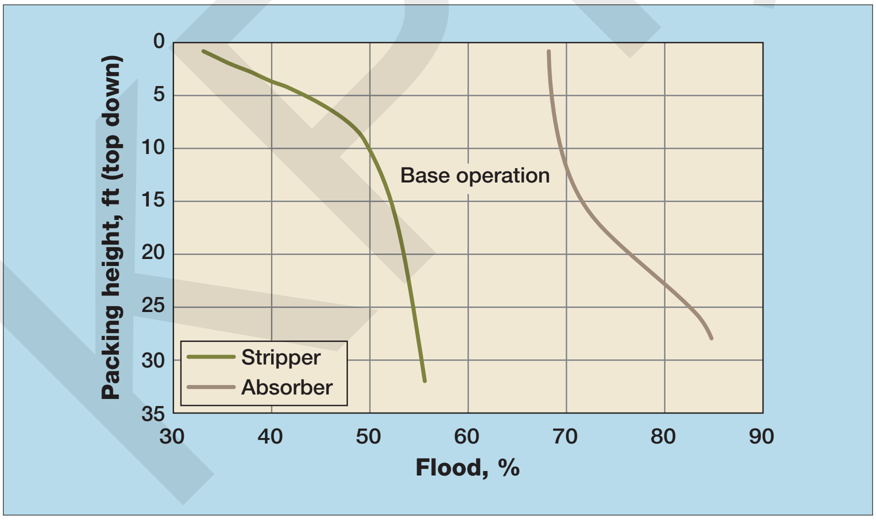

Figure 5 % flood: absorber and stripper

Figure 3 seems reasonable while the CO_2 concentration profile in **Figure 4** indicates about 2600 ppmv of CO_2 slip.

Potential causes of high CO_2 slip

Based on an initial evaluation, the absorber column indicated major limitations, resulting in a short-fall in performance. The potential causes identified in the absorber system were:

- Liquid maldistribution determined through gamma scan
- Under-sized liquid distributor in the absorber, leading to maldistribution
- High momentum through the vapour distributor in the absorber, leading to maldistribution
- Mass transfer limitations due to short packing height and incorrect loading
- Hydraulics and mass transfer limitations of the existing packing.

The stripper column did not indicate any hydraulic or mass transfer limitations or any performance issues.

Options to reduce CO_2 slip

As the next step, several options were evaluated with relevant inputs gathered from vendors. The following options were further simulated and reviewed for improved performance, including cost-benefit analysis:

- New efficient packing configurations with improved mass transfer and hydraulics
- Increase in packing height, as noted later for different options
- New liquid distributor
- New feed vapour distributor
- Increase in circulation rate
- Optimise solution concentration.

New liquid distributor

The existing trough type V-notch liquid distributors were inadequate and considered less efficient for the service conditions. They were replaced with new efficient orifice deck distributors rated with sufficient design margin over the new service conditions for current and future operating cases. Most importantly, the new distributors were designed for installation and removal through the existing 17in manways to facilitate correct loading of packing.

New feed vapour distributor

The existing feed vapour distributor was also found to be inadequate, with a much higher momentum than recommended and also insufficient coverage of the cross section.

It was replaced with a T-type lateral distributor rated with sufficient design margin over the new service conditions for both the current and future operating cases. Most importantly, the new distributors were designed for installation and removal through the existing 17in manways.

Increase in circulation and hydraulics adequacy

Increasing the solvent circulation rate was reviewed along with a complete hydraulics evaluation of the lean circuit and the lean MDEA pumps, with a clear premise not to replace any of the existing pumps and drivers. Interestingly, a marginal increase in circulation rate was possible with replacement of the existing impellers at the maximum possible size, well within the maximum design rating of the existing drivers. Further, the impact of the higher circulation rate was also evaluated for both absorber and stripper columns with new packing type, size and different bed configurations.

New efficient packing

To improve the limitations of both mass transfer and hydraulics in the absorber, new and efficient packings from two suppliers were evaluated with extensive in-house modelling for their quantitative impact on performance. The improved hydraulics with the selected new efficient packing with increased packing height (127% of the existing height) is shown in **Figure 6** and compared with the hydraulics of the existing packing for both base and future capacities (1140 t/d and 1250 t/d, respectively). The hydraulic capacity of the absorber indicates a substantial improvement with the new efficient packing.

New packing configurations

The latest and most efficient proven packings from two suppliers were reviewed and modelled to evaluate their impact on CO_2 slip and hydraulics. A combination of split bed with two different packing sizes – with and without liquid redistributors – was also reviewed. Based on the detailed evaluation and modelled performance, it was decided to go ahead with only one deeper bed for the most value.

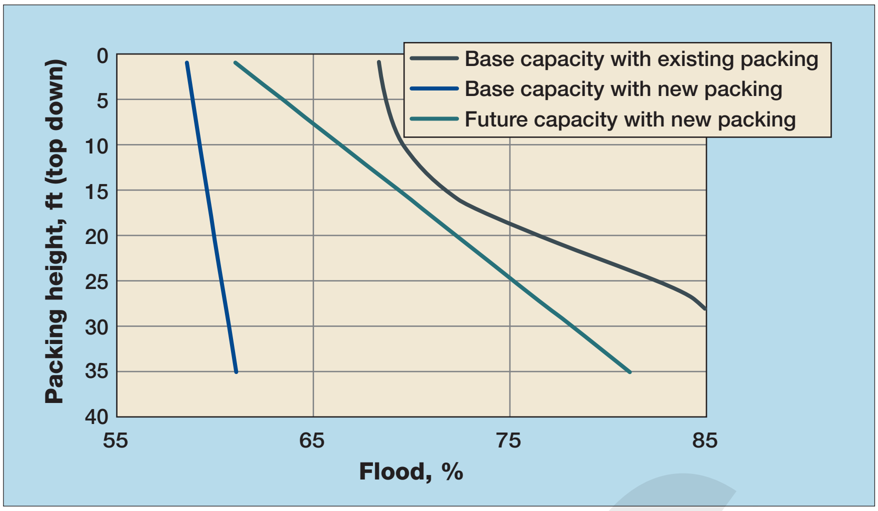

Figure 6 % flood: absorber with new and old packing

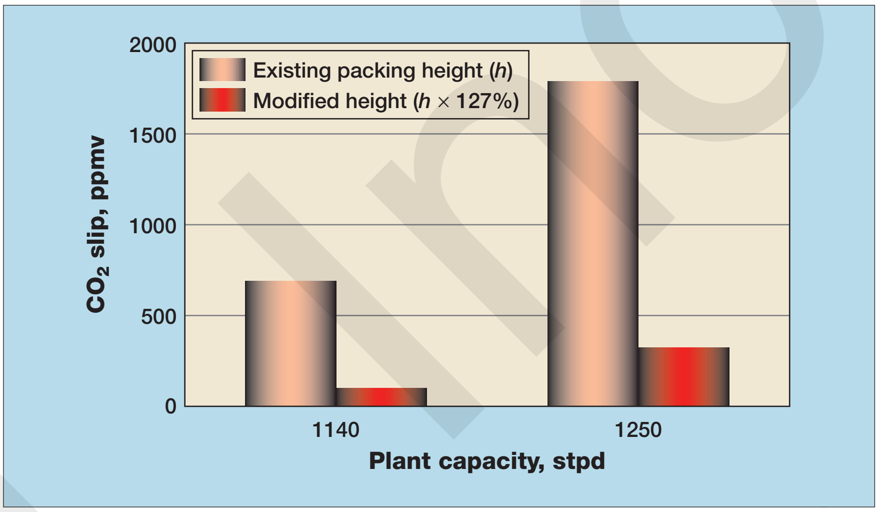

Figure 7 Performance estimation with modifications

Incremental packing height and practical constraints

The existing packing height was determined to be a limiting factor to achieve the target CO_2 slip despite changes with the most efficient packing and the vapour-liquid distributors along with optimised solution concentration. Therefore, several options to maximise the packing bed height were investigated (see **Table 1**) with all the practical constraints for this old column.

Based on a thorough review of all the options with the owner's operations and engineering groups, together with the inspection history and construction group, it was decided to pursue the maximum height option #3 with some hot work within the absorber column.

Estimated performance improvements

The new performance of CO_2 removal is estimated using the

Options to maximise packing bed height

Option#	Packing height	CO_2 slip target	Bed configuration	Tower modifications
Base	100% of base	Way below target	Single	Wall clips
1	112%	Below target	Single	Wall clips
2	123%	Closer to target	Split bed	Wall clips, complex supports
3	127%	Meets target	Single bed	Wall clips and ring

Table 1

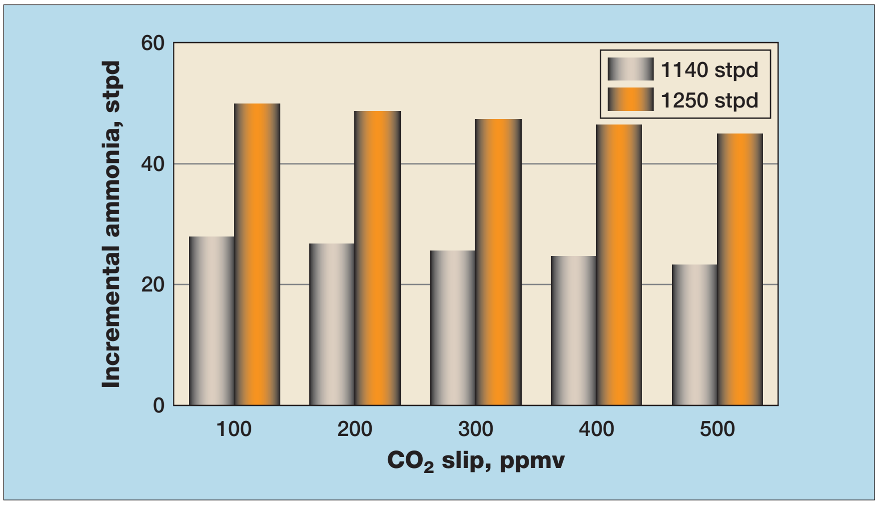

Figure 8 Incremental ammonia production with reduced CO_2 slip

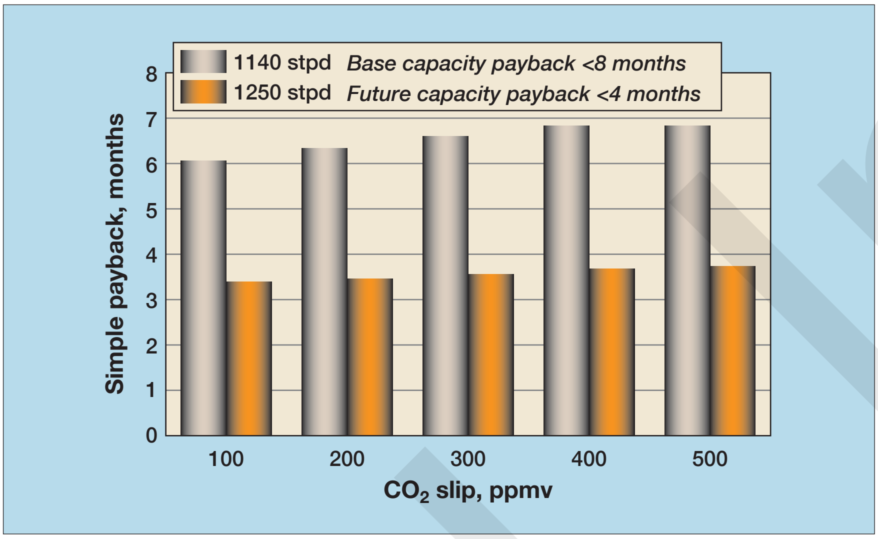

Figure 9 Estimated payback of modifications

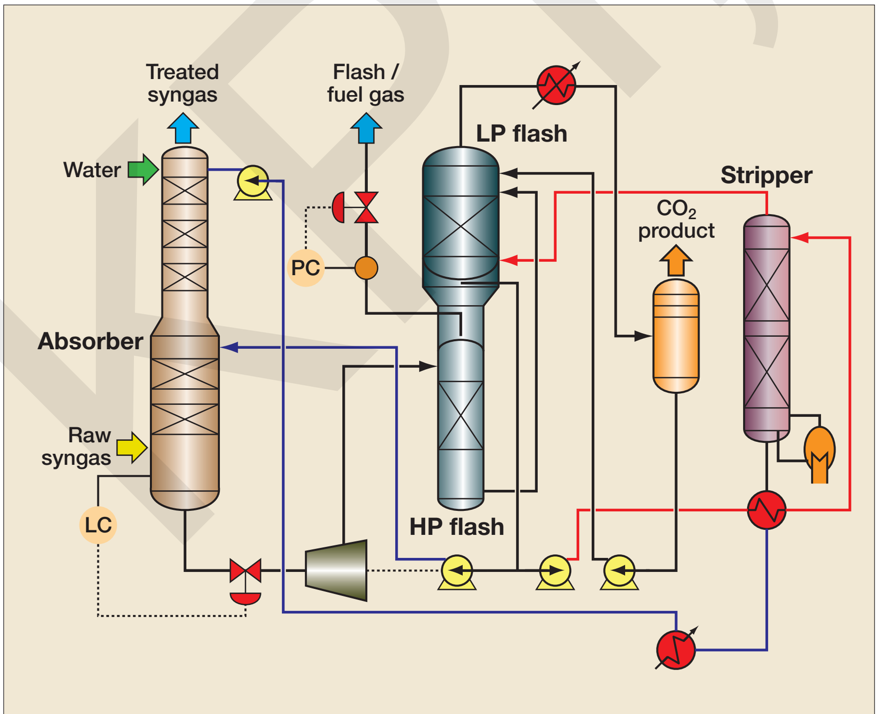

Figure 10 MDEA-piperazine scheme: two stage

new efficient packing, new efficient vapour and liquid distributors and an optimised solution concentration. The performance with new internals/packing with optimised solvent is further compared for two capacity cases using the modified packing height (127% of the existing packing height) in the existing absorber to provide the most value with the least cost. The two capacity cases compared are:
- Base capacity (1140 t/d)
- Future capacity (1250 t/d).

The additional packing height provides a significant reduction in CO_2 slip to achieve a figure well below 300 ppmv for the base capacity and <500 ppmv for future capacity (see **Figure 7**).

Incremental ammonia production
Reducing CO_2 slip benefits ammonia plant efficiency with a proportionate increase in production for the same amount of feed gas used with high CO_2 slip.

Incremental ammonia production with improved performance of the CO_2 removal system for the base operating capacity (1140 t/d) and the future operating capacity (1250 t/d) are estimated and shown in **Figure 8**. This indicates a capacity and efficiency improvement of about 2.4% for the base case and about 3.6% for the future case.

Economics of CO_2 removal system upgrade
Based on the modifications being carried out and the expected performance improvements, the payback period for the base case is estimated to be less than eight months and the payback for the future capacity case would be less than four months (see **Figure 9**). The basis of this estimate is the incremental ammonia production relative to the base case ammonia production corresponding to a high CO_2 slip for the two capacity cases and median netback on ammonia.

Additional CO_2 removal schemes under review
Another MDEA based two stage CO_2 removal system is under review for high CO_2 slip and corrosion related issues (see **Figure 10**).

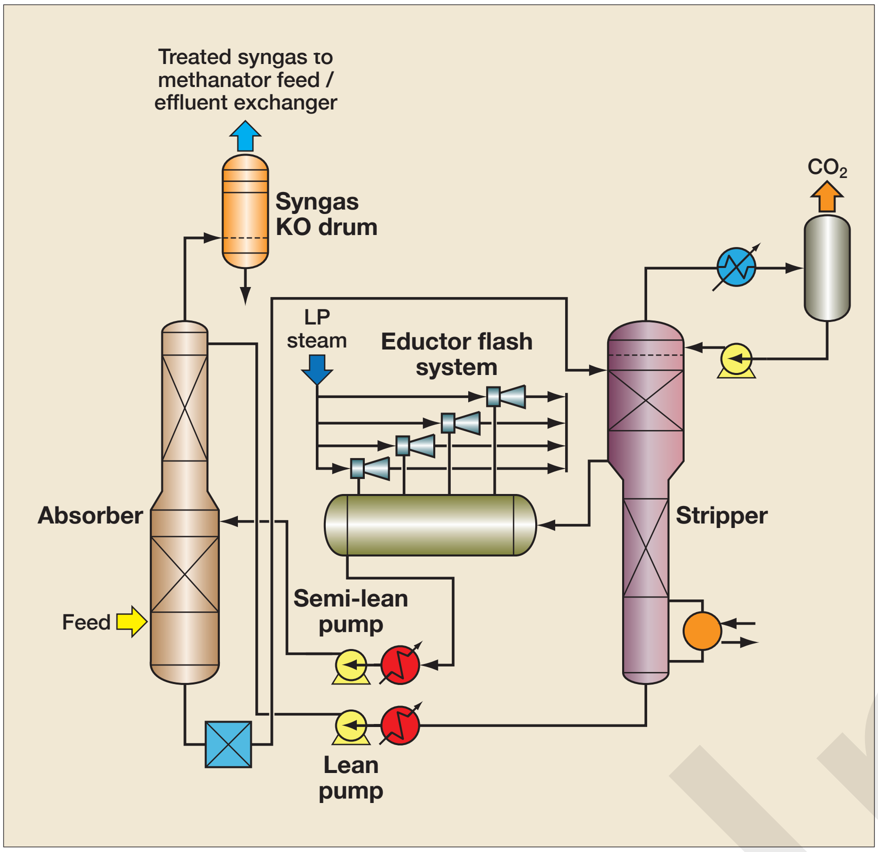

Figure 11 Benfield process schematic for ammonia plants 2 and 3

Benfield CO_2 removal system

The existing Benfield process scheme for CO_2 removal in ammonia plants 2 and 3 is shown in **Figure 11.** Both plants operated at about 108% of their name plate capacity of about 2000 t/d and consistently experienced a significant carry-over from the absorber, resulting in pressure drop build-up across the downstream methanator feed/effluent exchanger. Based on plant historical data, the system segment pressure drop increased from 20 psi to 30 psi in about three months, resulting in a gradual reduction in ammonia production and in the plants' efficiencies. This situation forced the operators to undertake a short plant shutdown every three months to clean up the exchanger, which also resulted in additional loss of ammonia production for nearly 10 hours with reduced plant reliability. This problem continued despite replacement with new efficient liquid distributors and demisters in both the absorbers and syngas knockout drums.

Following replacement with new liquid distributors and demisters with only marginal improvement in carry-over, KPI was engaged to study and review the potential deficiencies and recommend suitable cost effective improvements to minimise or eliminate the carry-over.

The following potential causes of carry-over were identified:

Reducing CO_2 slip benefits ammonia plant efficiency with a proportionate increase in production for the same amount of feed gas used with high CO_2 slip

- A significant fraction of smaller droplets (<10 microns) in the carry-over: recently replaced separation devices were considered inadequate to efficiently capture the smaller droplets.
- Insufficient vapour disengagement space in the absorbers and syngas knockout drums could lead to channelling with inefficient vapour-liquid separation.
- Make-up water quality with carry-over of any undissolved solids could eventually deposit in the downstream methanator feed/effluent exchangers.
- Excessive foaming could potentially result in carry-over.
- Lower velocities with carry-over coupled with higher localised temperature in the downstream methanator feed/effluent exchanger could promote fouling rates.

Findings and recommendations

Based on an adequacy check and further analysis of the absorber overhead system, the following recommendations were made based on the findings:

- The vapour-liquid disengagement space in the syngas knockout drum was found to be inadequate. This was considered to be a significant cause of uneven flow distribution and channelling, resulting in poor separation efficiency and potential carry-over.
- The existing slotted pipe feed distributor was recommended to be replaced with an even flow distributor to overcome this limitation.
- Recently replaced demister pads in the absorbers and syngas knockout drums of both plants were also found to be inadequate to efficiently capture the smaller liquid droplets, potentially resulting in carry-over.
- It was recommended that the demister pads be replaced with a new design using a combination of co-knit polymer with metal.
- Syngas velocities in the shell side of the feed/effluent exchangers were initially concerning but no modification was warranted as the intent was to simply minimise or eliminate carry-over as opposed to pushing the carry-over through higher exchanger velocities into the downstream catalyst beds. Therefore, no change in the downstream exchanger was recommended.
- A phase 2 recommendation was made for an *in situ* spray system for the syngas knockout drums, should the recommended modifications

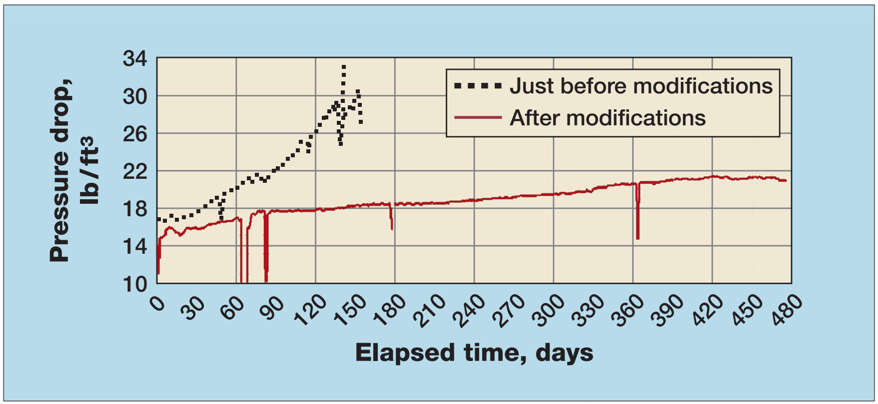

Figure 12 ΔP trend before and after modifications

in phase 1 not yield the expected performance.

Modifications

Based on the above findings and recommendations, the following modifications were engineered and supplied through KPI for both plants:

- Special co-knit polymer demisters for the absorbers and syngas knock-out drums in both ammonia plants
- Even flow distributors engineered to be supported within the existing vessels without any hot work on the vessel shell.

Performance improvements

A performance chart of the ΔP trend over more than 450 days, before and after the modifications, clearly indicates a fairly steady pressure drop (see **Figure 12**). No plant shutdown or any loss of ammonia production was experienced for the next four years before a turnaround for the lingering carry-over problem in both ammonia plants. The simple modifications were successful and were carried out within a day.

Further, the phase 2 recommendation to include a spray system was not required during this period.

Economics of a CO_2 removal system upgrade

The modifications implemented were very simple and engineered and supplied within a month. They were installed quickly within a day shift by the operator. Based on a reclaim of production lost following the modifications, the real payback time was less than three months.

Conclusions

High CO_2 slippage is a common problem in ammonia plants as well as acid gas removal systems in petrochemical plants and refineries. It mainly occurs when plant capacities are stretched with the following common limiting factors:

- Limited mass transfer due to:
  - Inadequate vapour/liquid distribution
  - Inefficient packing
  - Packing height limitations
- Heat transfer limitations due to:
  - Cooling
  - Reboiling
- Insufficient circulation due to limiting pump capacities:
- Non-optimal solution concentration.

KPI implemented simple and cost effective solutions with a MDEA-piperazine based system in an ammonia plant with a payback period of four to eight months.

Carry-over in a Benfield CO_2 removal system is experienced in several plants. Plant operators have adopted different measures to mitigate this problem. KPI successfully implemented simple and cost effective systems in two large ammonia plants with a payback of less than three months.

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