



Cost effective revamp of CO₂ removal systems in ammonia plants

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This paper presents cost effective revamp experience CO₂ removal Systems in three different Ammonia plants with an attractive payback of just few months. One of the plant uses MDEA:Pz system and the other two use Benfield systems.

The Ammonia plant # 1 with MDEA based CO₂ removal system was earlier revamped from its original name plate capacity of 600 stpd to ~1100 stpd using the original MEA trayed Absorber and Stripping Columns replaced with packing and new internals. The plant experienced excessive CO₂ slip (up to 3000 ppmv) at increased rates resulting in reduced plant efficiency. A review of the complete CO₂ removal system was carried out along with field measurements to identify the key bottlenecks. Following this, several cost effective and practical options were identified to reduce CO₂ slippage to a target value of less than 300 ppmv at the current capacity along with its maximum capacity of 1170 stpd and future capacity of 1250 stpd. A combination of new efficient packing and new distributors along with increase in circulation were not enough to meet this target due to mass transfer limitations. To support the performance targets, Absorber column was closely reviewed for increase in the packing height with different configurations. The studied options were jointly reviewed with the customer's operations, engineering as well as their construction group to select the most suitable practical option to satisfy well within the target performance with ~27% increase in the packing height. The selected option is currently in the implementation phase with all the hardware already ordered.

A similar issue of high CO₂ slip and corrosion in a two stage MDEA:Pz system in another Ammonia plant is currently being studied.

The other two Ammonia plants (#2 & 3) of ~2000 stpd capacity using Benfield-Act-1 CO₂ removal systems operated at ~108% of name plate capacity 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 the plant historical data, the system segment pressure drop increased from ~20 psi to ~30 psi in about three

months resulting in gradual increase in front end pressure with gradual reduction in Ammonia production and efficiency. This situation forced the operators to take a short plant shutdown every three months to clean up the exchanger which also resulted in additional loss of Ammonia production for nearly 10 hrs with reduced plant reliability. This problem continued despite replacement with new efficient Liquid distributors and demisters. Following this, KPI was also engaged to study & review the potential deficiencies and cost effective improvements to minimize or eliminate the carry over in the Benfield systems.

Following the review of all studied options with recommended modifications, KPI was advised to further carry out the engineering and supply of all the necessary hardware for both plants. They were successfully installed in 2009 in both Ammonia plants. They performed better than expected without any loss of Ammonia production or plant shut down until the next turnaround in 2013.

AMMONIA PLANT #1

MDEA BASED CO₂ REMOVAL SYSTEM

The existing single stage MDEA CO₂ removal system scheme is shown below in Fig.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 stpd to ~1100 stpd. The original Absorber and Stripper columns were used with trays replaced with packings and other internals. The current operating capacity is 1140 stpd to 1170 stpd depending on the seasonal variation. This plant was well stretched to its design limits and beyond.

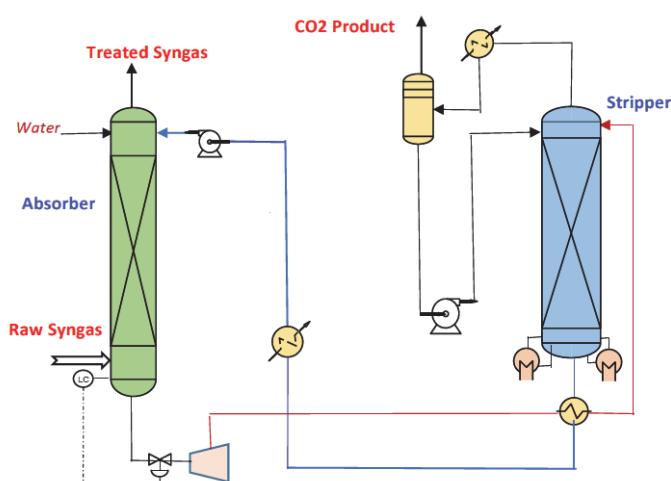


Fig. 1: MDEA:Pz CO₂ Removal Scheme

A holistic review of the reference CO₂ removal system was carried out by KPI to identify all the potential bottlenecks contributing to a shortfall in the performance. To support this, the following steps were taken:

- Gamma scan of the columns to determine any maldistribution
- Representative Operating data corresponding to max operating capacity
- Reconciliation of the operating data
- 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 & height
 - Adequacy/Limitations of Liquid distributor
 - Adequacy/Limitations of Feed Vapor distributor
 - Hydraulic adequacy/limitations of the Solvent circulation loop
 - Solvent and activator concentration for optimal performance

The Figures 2 to 5 below represent the base operating performance at 1140 stpd as modelled and reconciled with the actual operating performance. Gamma scan of Absorber indicates the liquid density variation profile in Fig. 2- with a variation between 8 to 15 units indicating mal-distribution. The Absorber operating at ~85% flood while Stripper has enough hydraulic capacity available as shown in Fig. 5. The Absorber temperature profile in Fig. 3 seems reasonable while CO₂ concentration profiles in Fig. 4 indicates ~2600 ppmv of CO₂ slip.

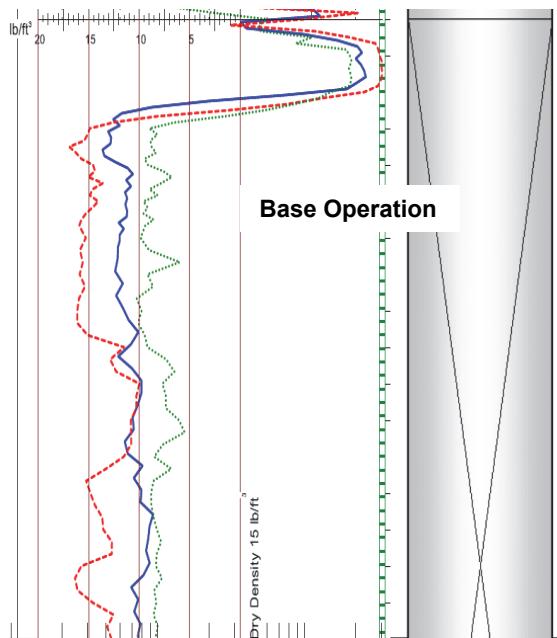


Fig. 2: Absorber Liquid Density Profile- measured

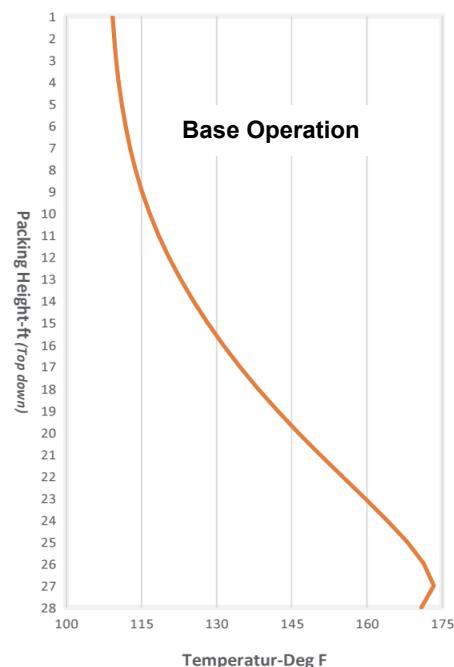


Fig. 3: Absorber Temperature Profile

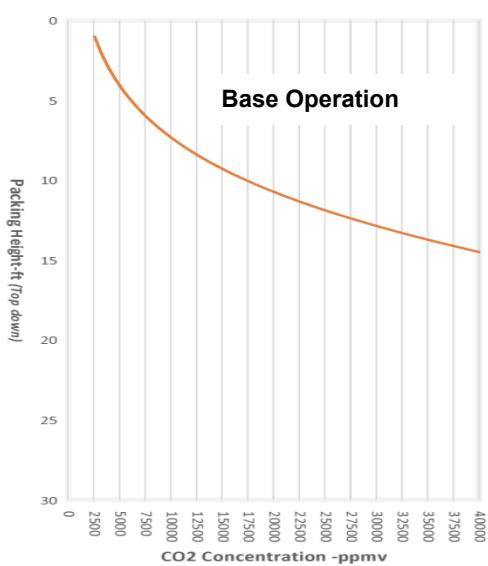


Fig. 4: Absorber Vapor CO₂ Concentration Profile

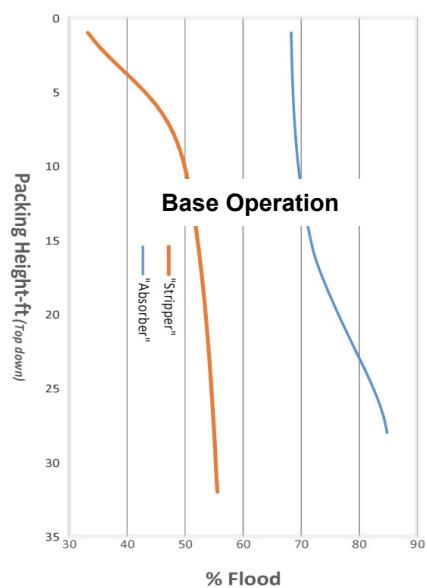


Fig. 5: % Flood- Absorber & Stripper

POTENTIAL CAUSES OF HIGH CO₂ SLIP

Based on the initial evaluation, Absorber column indicated the major limitations resulting in performance shortfall. The potential causes identified in the Absorber system were:

- ✓ Liquid mal-distribution determined through Gamma scan
- ✓ Undersized Liquid distributor in the Absorber leading to mal-distribution
- ✓ High momentum through vapor distributor in Absorber leading to mal-distribution

- ✓ Mass transfer limitations due to short packing height & incorrect loading
- ✓ Hydraulics & 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 CO₂ SLIP

In 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 vapor distributor
- ✓ Increase in Circulation rate
- ✓ Optimize 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 both the current & future operating cases. Most importantly, the new distributors were designed for installation and removal through the existing 17" manways to facilitate correct loading of packing.

New Feed Vapor Distributor

The existing feed vapor 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 & future operating cases. Most importantly, the new distributors were designed for installation and removal through the existing 17" manways.

Increase in Circulation & Hydraulics Adequacy

Increasing the solvent circulation rate was reviewed along with complete hydraulics evaluation of the lean circuit along with the lean MDEA pumps with a clear premise NOT to replace any of the existing pumps and its drivers. Interestingly, a marginal increase in circulation rate was possible with replacement of the existing impellers with 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- as covered under the new Packing.

New Efficient Packing

To improve the limitations of both mass transfer and hydraulics in the Absorber, new and efficient packings from two reputed suppliers were evaluated with an 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*) is shown in Fig. 6 and compared with the hydraulics of the existing packing- for both base and future capacities (*1140 stpd & 1250 stpd, respectively*). The hydraulic capacity of the Absorber indicates a substantial improvement with new efficient packing.

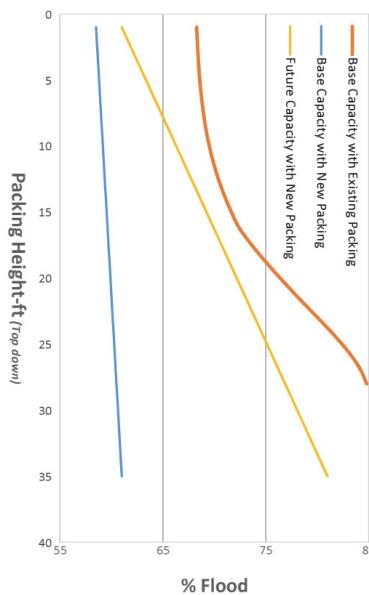


Fig. 6: % Flood- Absorber- New & Old Packing

New Packing Configurations

The latest and most efficient proven packings from two reputed suppliers were reviewed and modelled to evaluate their impact on CO₂ slip and hydraulics. A combination of split bed with two different packing sizes- with and without liquid re-distributors were also reviewed. Based on the detailed evaluation and modelled performance, it was decided to pursue with only one deeper bed for the most value- as further discussed below.

Incremental Packing Height & Practical Constraints

The existing packing height was determined to be a limiting factor to achieve the target CO₂ slip despite changes with the most efficient packing and the vapor-liquid distributors along with optimized solution concentration. Therefore, several options to maximize the packing bed height were closely investigated (Refer Table-1) with all the practical constraints for this old column.

Table- 1

Option#	Packing Height	CO ₂ Slip Target	Bed Configuration	Tower Modifications
Base	100%- Base	Way below target	Single	Wall Clips
1	112%	Below target	Single	Wall Clips
2	123%	Closer to target	Split bed	Wall Clips, complex supporting
3	127%	Meets target	Single bed	Wall clips & Ring

Based on a thorough review of all the options with the customer's Operations, Engineering along with its inspection history and their 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 the CO₂ removal is estimated using the new efficient packing, new efficient vapor and liquid distributors and an optimized solution concentration. The performance with new internals/packing with optimized 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. Two capacity cases compared are:

- ✓ Base capacity (1140 stpd)
- ✓ Future capacity (1250 stpd)

The additional packing height provides a significant reduction in CO₂ slip to achieve CO₂ slip well below 300 ppmv for the Base capacity and <500 ppmv for the future capacity as indicated in the Fig. 7.

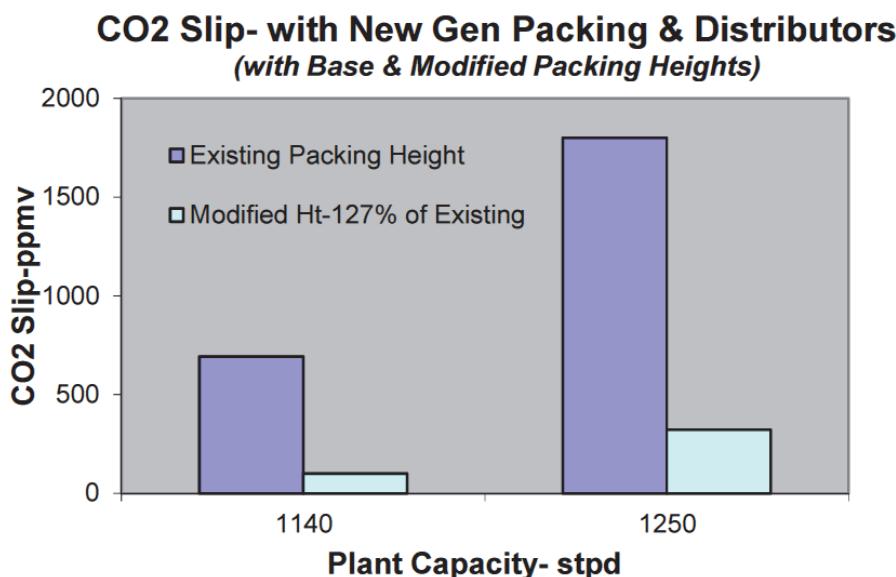
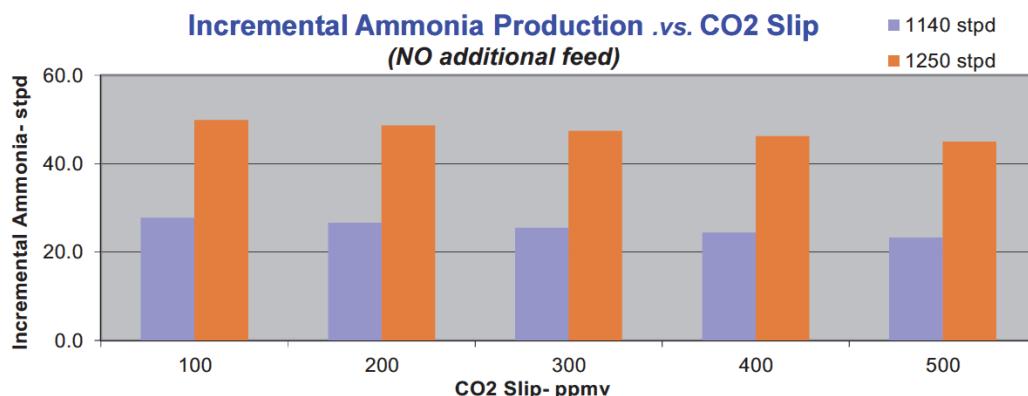


Fig. 7: Performance Estimate with modifications

Incremental Ammonia Production

Reducing CO₂ slip benefits Ammonia plant efficiency with a proportionate increase in Ammonia production for the same amount of feed gas as used with high CO₂ slip.

Incremental Ammonia production with improved performance of CO₂ removal system for the Base operating capacity (1140 stpd) and the future operating capacity (1250 stpd) are estimated and shown in Fig. 8. It indicates a capacity and efficiency improvement of ~2.4% for the Base case and ~3.6% for the Future case.

Fig. 8: Incremental Ammonia Production with reduced CO₂ slip

Economics of CO₂ Removal System Upgrade

Based on the modifications being carried out and the expected performance improvements, the **payback period for the base capacity (1140 stpd) is estimated to be less than 8 months and the payback for the future capacity (1250 stpd) to be less than 4 months-** as shown in Fig. 9. The basis of this estimate is the incremental Ammonia production relative to the base Ammonia production corresponding to high CO₂ slip for the two capacity cases and median netback on Ammonia.

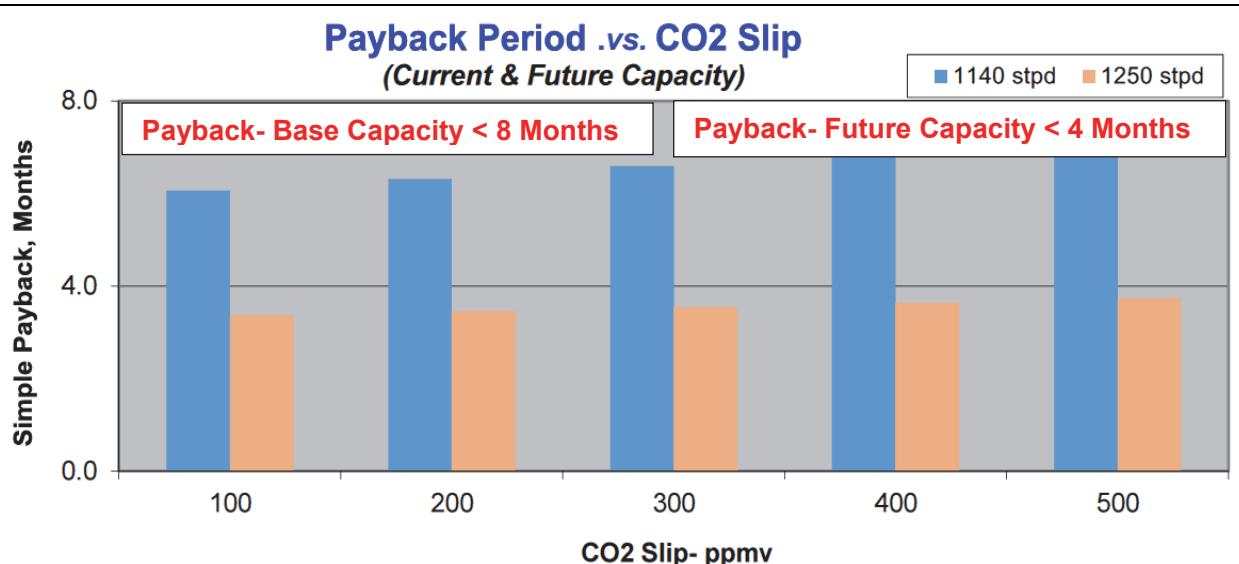


Fig. 9: Payback estimate of modifications

Additional CO₂ Removal Schemes under Review

Another MDEA based two-stage CO₂ removal system is under review for high CO₂ slip and corrosion related issues- as shown in Fig.10. Depending on its outcome, it will be summarized in the near future.

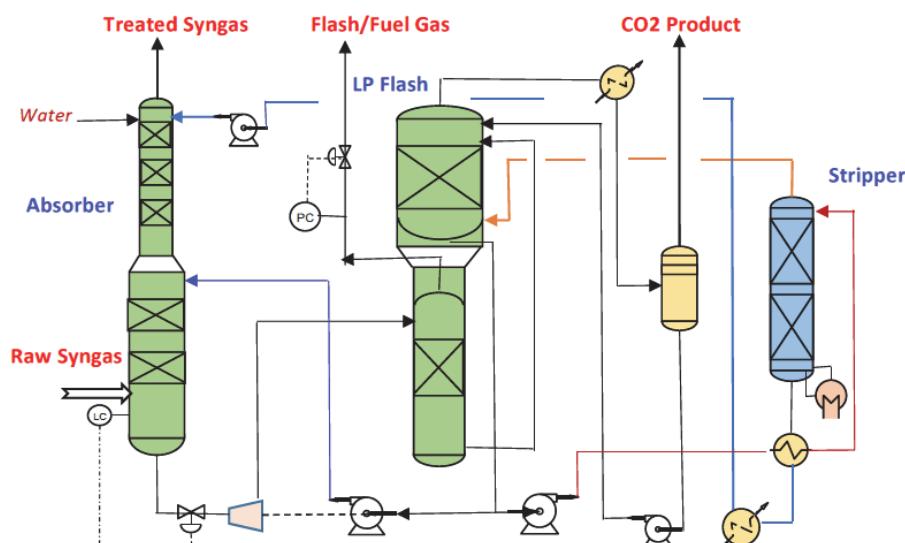


Fig. 10: MDEA:Pz Scheme- two stage

CO₂ SYSTEM UPGRADE OF AMMONIA PLANTS # 2 & 3 BENFIELD- ACT-1 BASED CO₂ REMOVAL SYSTEM

The existing Benfield process scheme for CO₂ removal in Ammonia plants #2 & 3 is shown in Fig. 11. Both Ammonia plants operated at ~108% of name plate capacity of ~2000 stpd 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 the plant historical data, the system segment pressure drop increased from ~20 psi to ~30 psi in about three months resulting in gradual reduction in Ammonia production and plants efficiencies. This situation forced the operators to take a short plant shutdown every three months to clean up the exchanger which also resulted in additional loss of Ammonia production for nearly 10 hrs with reduced plant reliability. This problem continued despite replacement with new efficient Liquid distributors and demisters in both Absorbers and Syngas KO drums.

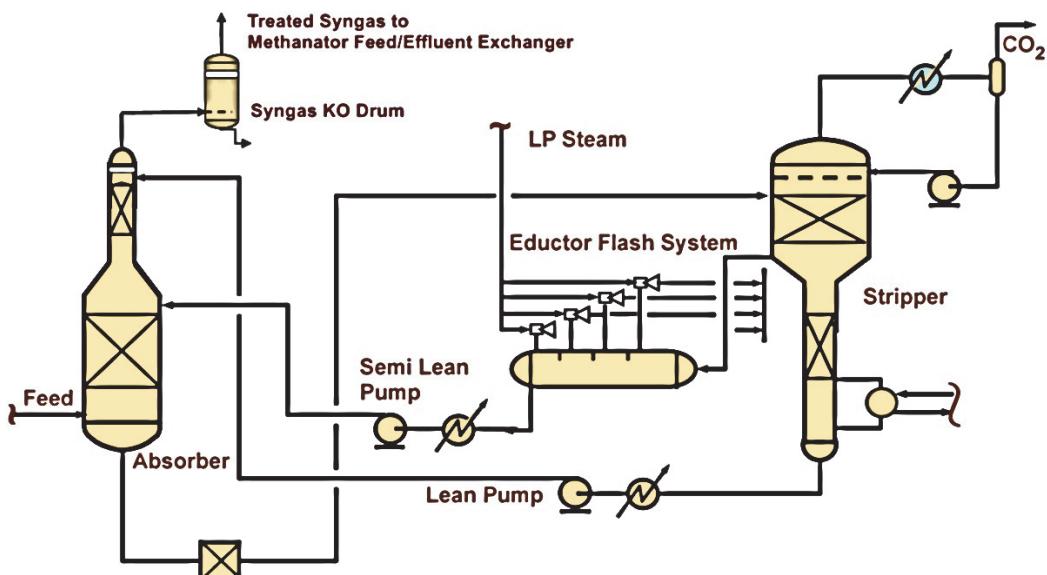


Fig. 11: Benfield Process Schematic for Ammonia plants# 2& 3

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

Following potential causes of carry-over were identified:

- Significant fraction of smaller droplets (< 10 microns) in the carry over. Recently replaced separation devices considered inadequate to efficiently capture the smaller droplets below 10 microns
- Insufficient vapor disengagement space in Absorbers and the Syngas KO drums leading to channelling with inefficient vapor-liquid separation
- Make up water quality with carry-over of any un-dissolved solids- eventually depositing in the downstream Methanator Feed- Effluent Exchangers
- Excessive foaming could potentially result in carry over
- Lower velocities with carry over coupled with higher localized temperature in the downstream Methanator Feed/Effluent Exchanger could promote the fouling rates

Findings & Recommendations

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

- The vapor-liquid disengagement space in Syngas KO 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- as shown in Fig. 12.
- The recently replaced new demister pads in Absorbers and Syngas KO drums of both plants were also found to be inadequate to efficiently capture the smaller liquid droplets potentially resulting in carryover.
- It was recommended to be replaced with a new special design using a combination of co-knit polymer with metal- as shown in Fig.13.
- Relatively velocities the Syngas in the shell side of Feed/Effluent exchangers were initially concerning but no modification was warranted as the intent was to simply minimize or eliminate the 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-II recommendation was made for an in-situ spray system for Syngas KO drums, should the above recommended modifications of the initial phase did not yield the expected performance.



Fig. 12: Special demister with co-knit polymer



Fig. 13: Even Flow Distributor

Modifications

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

- Special Co-knit polymer demisters for Absorbers & Syngas KO drums for both Ammonia plants
- Even flow distributors- they were engineered to be supported within the existing vessels without any hot work on the vessel shell

Performance Improvements

The performance chart of Fig.14- measured as ΔP trend of more than 450 days of performance- before and after the modifications clearly indicates a fairly steady pressure drop. **No plant shut down or any loss of Ammonia production was experienced for the next four years before the turnaround for this lingering carry over problem in both Ammonia plants. The simple modifications were very successful and were carried out within a day only.**

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

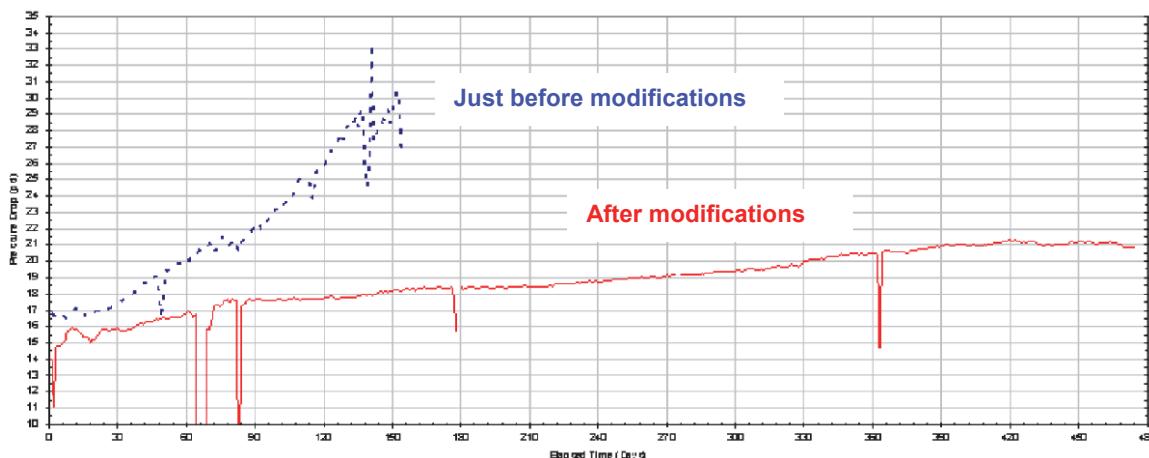


Fig. 14: ΔP trend- before & after the modifications

Economics of CO₂ Removal System Upgrade

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

CONCLUSIONS

Conclusions are summarized as follows:

- I. High CO₂ slippage is a common problem experienced in several Ammonia plants. It is mostly the case when the plant capacities are stretched with the following common limiting factors:
 - Limiting mass transfer due to
 - Inadequate vapor/liquid distribution
 - Not so efficient packing
 - Packing height or stage limitations
 - Heat transfer limits
 - Cooling
 - Reboiling
 - Insufficient circulation due to limiting pump capacities
 - Un-optimal solution concentration
KPI is glad to share their approach and experience with the implementation of simple and cost effective solutions for MDEA: Pz based system in an Ammonia plant with payback period between 4 to 8 months
- II. Carry over in Benfield CO₂ removal system is experienced in several Ammonia plants. Plant operators have adopted several different measures to mitigate this problem. KPI is glad to share their experience of successfully implementing very simple and cost effective systems in two large Ammonia plants with a payback of less than 3 months.

"Simplicity is the ultimate sophistication." – Leonardo da Vinci