Benfield System Revamp Experience at Yara Plant

Nitrogen + Syngas Conference
Barcelona, Spain
March 8, 2023

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Outline

- Background
- Performance Evaluation
- Summary of Modifications
- Post Performance

KPI, Houston

- A **boutique Consulting & Process Technology/Design-Engineering company**

- Based in **Houston and serving since 2005**

- **Specialized focus in Ammonia and Methanol plants upgrades & new projects (Gray, Blue & Green)**
  - **Project feasibility & Project development / execution support**
  - **Plant Engineering Studies for cost effective and practical solutions**

- Highly experienced Team in Houston *(including four ex-Licensor's personnel)*

- Completed over 150 upgrading Engg Studies/Projects globally

  (US, Canada, Trinidad, Saudi Arabia, India & Australia)

- **Provided "Owner's Engineers" services in several projects**

- **Many successful references including Six CO2 removal systems upgrades in Ammonia plants**

  (3 in aMDEA systems & 3 in Benfield Systems- US, Canada, Trinidad & Australia)

Background

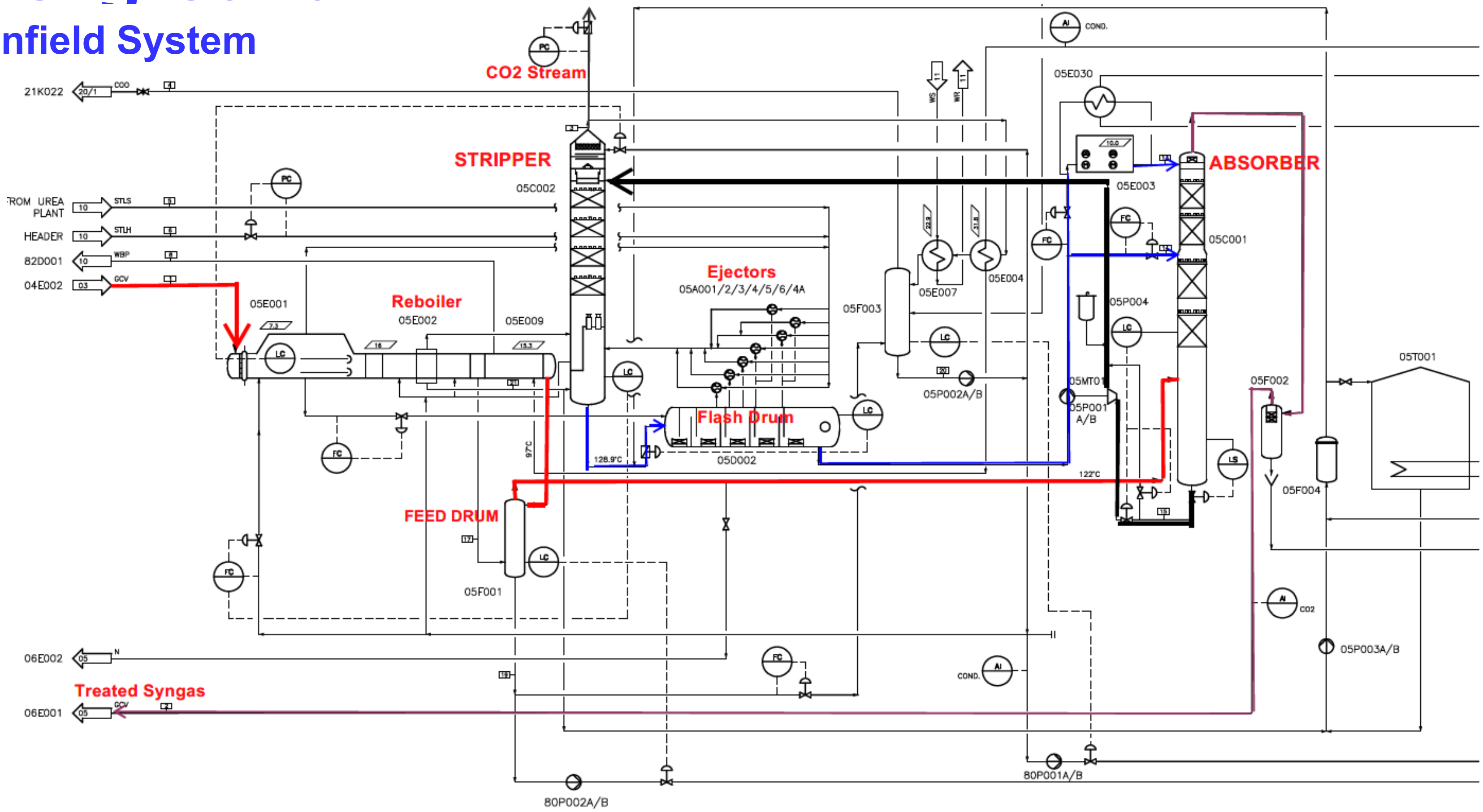
- Plant location & key upgrades
- Prior Benfield Upgrades
- Operating issues

Background

- Plant: Ammonia
- Location: Belle Plaines, Canada
- Original Capacity: 1500 mtpd (1992)
- Technology: TK/Uhde
- Expanded to: 2125 mtpd (1997 & 2009)
- CO_2 Removal: UOP Benfield *(Act 1-Single Stg Lo Heat)*

Background

Benfield System



Background

Prior Upgrades of Benfield System

- Larger efficient Packing in Absorber & Stripper
- Added two Ejectors and also increased direct LP steam injection to Stripper
- Increased Circulation rate
- Replaced with Chevron trays in top section of Stripper
- Upgraded overhead CW condenser and Reflux drum of the Stripper
- Increased Benfield & Activator concentrations

Background

Operating Issues *(before 2022 Revamp)*

- Current operation stretched to its limits
- High DP excursions in Absorber resulting in potential flooding
- High CO_2 slip (2500 to ~4000 ppmv) resulting in
  - Higher inerts in Synloop & lost Ammonia production
- Excess use of higher-pressure LP steam resulting in;
  - Extra firing in Aux boiler
  - Venting the excess LP steam in Urea Plant
  - Higher CW consumption
  - Higher than required Demin temp resulting in poor efficiency of deaerator with more venting

Background

Operating Issues *(before 2022 Revamp)*

- **Higher Feed Temp coupled with higher rates resulting in**
  - **High loading in Feed Separator & system water balance**
- **Flash Drum inadequacy likely resulting in inefficient Ejector performance**

  [Flash drum & Ejector mechanical integrity with occasional cracks dictated its EOL]
- **Reboiler heat transfer limitations**

  [Reboiler Tubes mechanical integrity issues with reduced tube thickness]
- **Benfield Carry over from Stripper top bed**

Study Evaluation Scope/Approach

➢ **Phase-1: Study to identify, quantify and justify the upgrades**

- Yara defined Scope of Study
  - **Evaluate all possible options to reduce CO_2 slip**
  - Minimize or eliminate the injection of higher pressure LP steam
  - **Redesign Flash drum** for the current operation within the space constraints
  - **Redesign of Ejectors** of Flash drum to
    - Optimize its performance using only LP motive steam
  - **Redesign Reboiler to**
    - Optimize stripping performance
    - Reduce temperature of Demin stream to deaerator
    - And, possibly reduce process gas temperature going to the Absorber
  - **Redesign Feed Separator**
  - **Evaluate**
    - **Overall hydraulics of the Absorber and Stripper internals**
- Budgetary Cost Estimates of new/modified items
- Cost: Benefit Analysis
- Recommendations for upgrades with justification

[KPI Scope]
~ 11 weeks

Project Scope/Approach

- ➢ **Phase 2: Prepare Process Design Package of Selected Upgrades** **[KPI Scope] ~ 8 weeks**
- ➢ **Phase 3+: Detail Engg, Procurement & Construction** **[Phase 3+: By Others]**

Evaluation Approach

- Plant and design data review & reconciliation
- Set up the Base simulation and calculation models to match plant data
- Review the adequacy of all major items
- Preliminary sizing of the new/modified items
- Prepare Inquiries for budgetary quotes
- Cost: Benefit Analysis
- Review & Recommendations

Key Findings

- Base Simulation vs Plant Data
- Absorber
- Stripper
- Flash Drum
- Ejectors
- Reboiler
- Feed Separator
- Power Recovery Turbine
- Reduction in CO2 slip options

Performance review of Major Items

Plant data vs Simulation

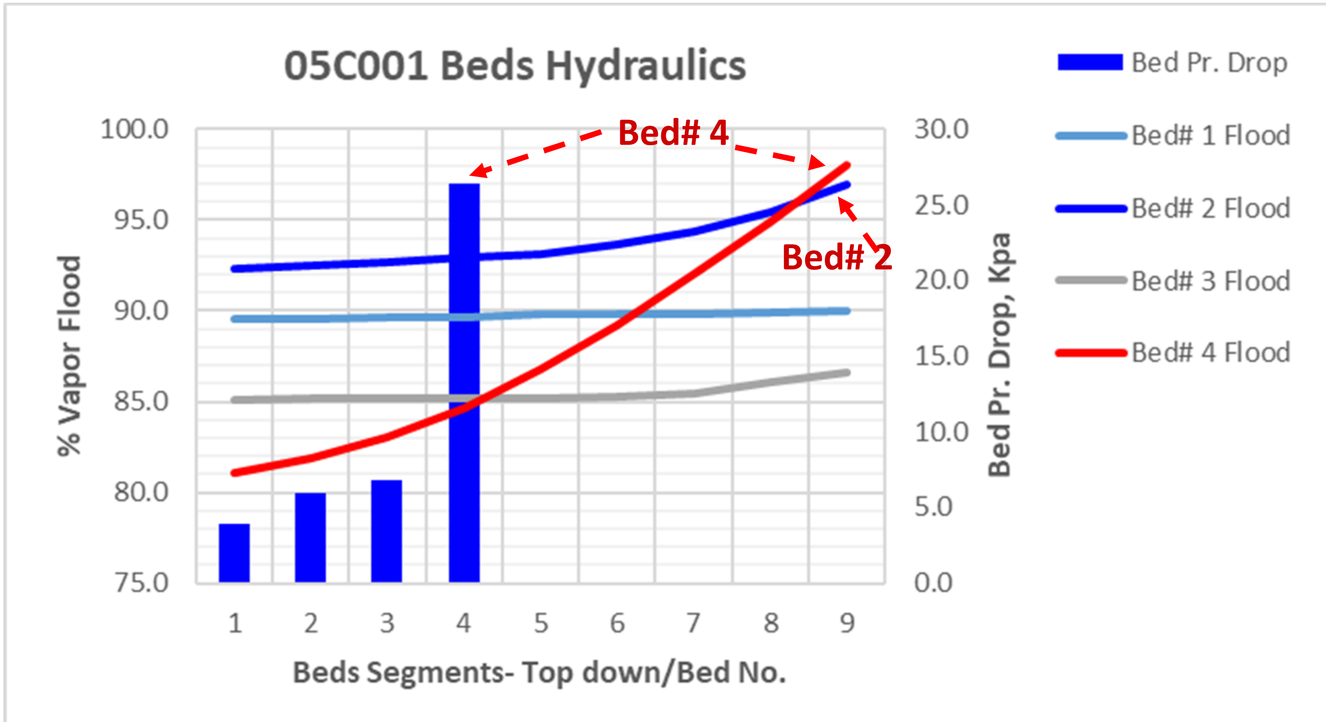
Parameters	Plant Data	Simulated
Feed Temp- deg C	119.3	119.3
Cold Solvent Temp- deg C	81.9	81.9
Warm Solvent Temp- deg C	118.4	118.4
Least Flash Pressure- KPA (A)	143	143
Total Circulation Rate, m3h	1734	1734
Solvent Flow to top bed-m3/h	287	287
Solvent Flow to 3rd bed-m3/h	1447	1447
K_2CO_3 Concentration, %wt	33.9	33.9
Activator Concentration, %wt	0.76	0.76
Fc- Stripper Bottoms	NA	0.461
Fc-Flash Drum	0.368	0.361
Fc- Absorber Bottoms	NA	0.789
Rebiler Duty, MW	NA	19.8
CO_2 Slippage, ppmv	4000	4110
Stripper Bottom Temp, Deg C	127.3	127.4
Absorber Bottoms Temp (1)	128.8	120.7
Stripper Top Pressure, Kpa-A	180	180
Absorber Top Pressure, Kpa-A	3175	3175
ΔP- 05C001	52	43.1 (2)
ΔP- 05C002	22.8	14.3 (2)
% Flood- 05C001	NA	Refer Profile
% Flood- 05C002	NA	Refer Profile
Steam Flow to Ejectors, Kg/h (391 Kpa-A. 162 C)	47670	47670

Notes: (1) The temperature difference is perhaps due to excessive carry over in the Vapor Feed from 05F001; (2) The calculated ΔP only for the Packed beds while Plant data ΔP is higher as it also includes pressure drop of trays, exit, inlet and across the ditributors

Performance review of Major Items

Hydraulics of Absorber beds

- **The Beds# 2 & 4:**
  - ✓Incipient flooding
  - ✓Estimated flood > 97%

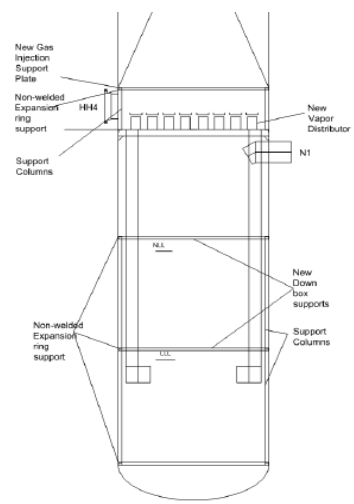


Performance review of Major Items

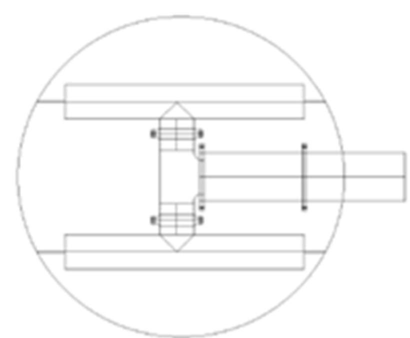
Inlet Vapor distributor in Absorber

- The inlet vapor flow was evaluated with high degree of mal-distribution due to
  - A very high velocity &
  - A close proximity to the bottom bed
- An inlet vapor distributor was highly recommended.
- The challenge was- how to install without any existing support brackets or ring
- Two options were worked out
  - Welded &
  - Non-Welded

Non-Welded Option



Welded



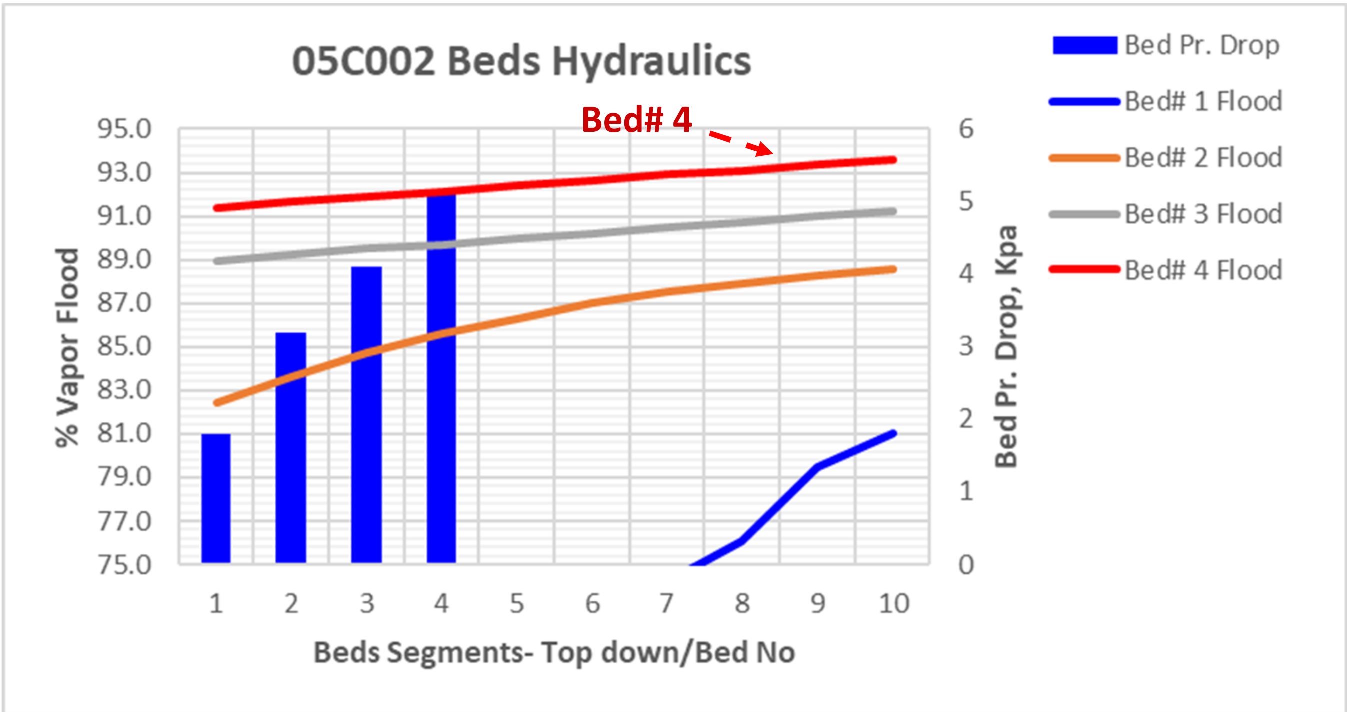
Performance review of Major Items

Hydraulics of Stripper beds

➢ **The Beds# 3 & 4:**

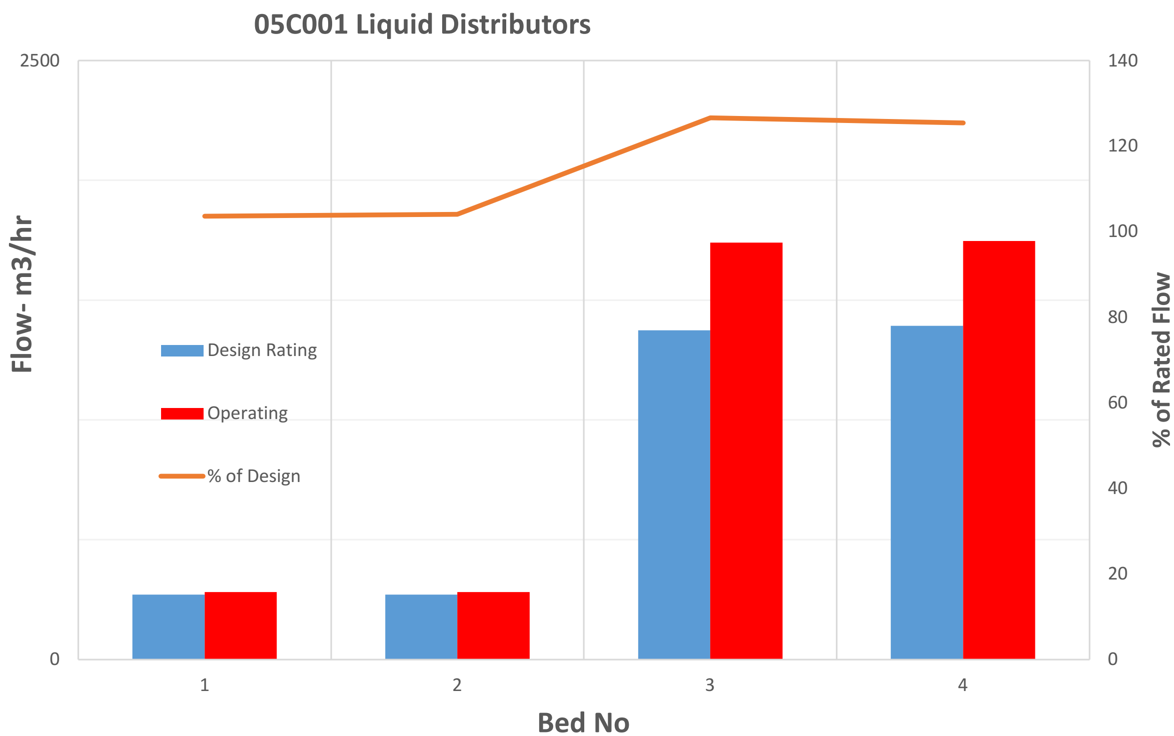
✓Incipient flooding

✓Estimated flood ~ 91% & 94%



Performance review of Major Items

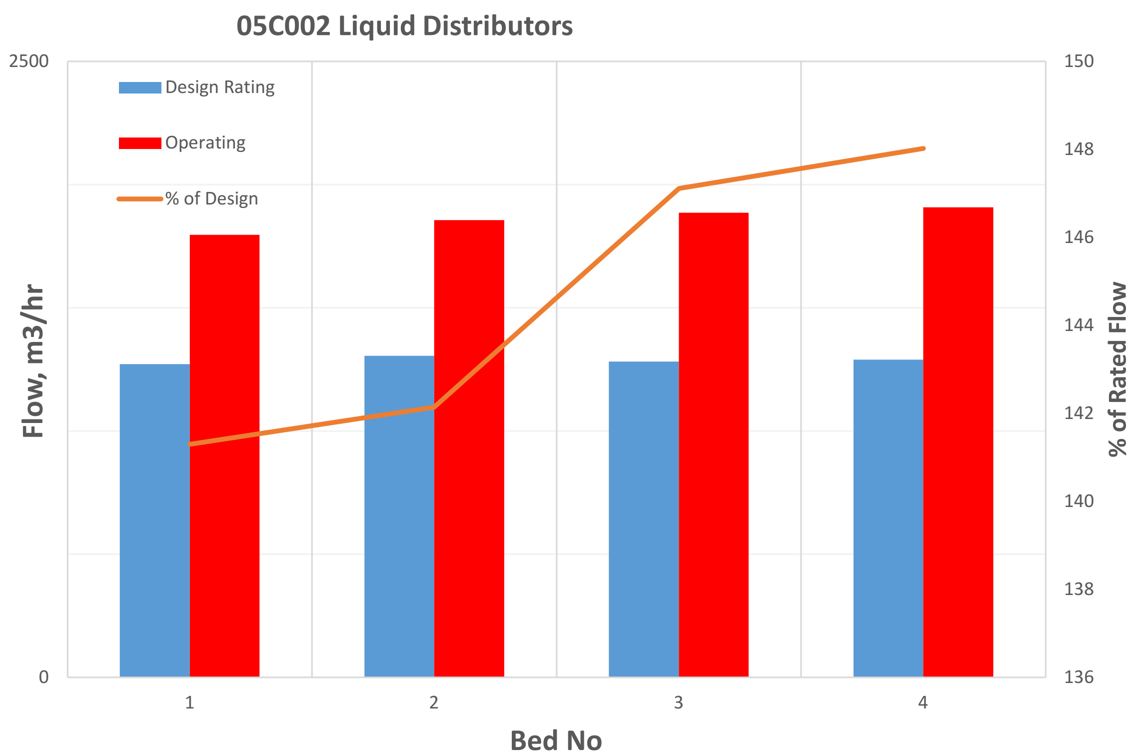
Liquid distributors in Absorber



Liquid distributors operating way above their max ratings

Performance review of Major Items

Liquid distributors in Stripper



Liquid distributors operating way above their max ratings

Performance review of Major Items

Packed beds

- **To improve bed hydraulics and to reduce the CO_2 slippage,** KPI **extensively investigated & evaluated many different combinations of packings for the Absorber and the Stripper columns**

- This included the **most efficient offerings of four different suppliers including the random and various structured packings**

- **As a part of evaluation of different packings, we used the base simulation model with only the changes made in the packing types and sizes for both the columns without changes to any other parameters**. We reviewed and compared the relative performance changes in bed hydraulics along with overall CO_2 slippage

Performance review of Major Items

Packed bed evaluation for Absorber

Type# 1

Bed 1 (Top):	IMTP® 60 random packing
Bed 2:	Top half: IMTP® 60 random packing Bottom Half: IMTP® 70 random packing
Bed 3:	IMTP® 60 random packing
Bed 4:	Top half: IMTP® 70 random packing Bottom half: PROFLUX® severe service grid

Type# 2

Bed#1 (Top):	MellapakCC™
Bed#2:	MellapakCC™
Bed#3	No Change
Bed#4	No Change

Type# 3

Bed#1 (Top):	RMP N 200X
Bed#2:	RMP N 200X
Bed#3	RMP N 200X
Bed#4	RMP N 125X

Type# 4

Bed#1 (Top):	SuperBlend 2-Pac # 5060
Bed#2:	SuperBlend 2-Pac # 70
Bed#3	SuperBlend 2-Pac # 6070
Bed#4	SuperBlend 2-Pac # 6070

Performance review of Major Items

Packed bed evaluation for Stripper`

Type# 1

Bed 1 (Top):	IMTP® 60 random packing
Bed 2:	IMTP® 70 random packing
Bed 3:	IMTP® 70 random packing
Bed 4:	PROFLUX® severe service grid

Type# 2

Bed#1 (Top):	RMP N 200X
Bed#2:	RMP N 200X
Bed#3	RMP N 200X
Bed#4	RMP N 125X

Type# 3

Bed#1 (Top):	MellapakCC™
Bed#2:	MellapakCC™
Bed#3	Mellapak™ 125X
Bed#4	Mellapak™ 125X

Type# 4

Bed#1 (Top):	SuperBlend 2-Pac # 6070
Bed#2:	SuperBlend 2-Pac # 6070
Bed#3	SuperBlend 2-Pac # 6070
Bed#4	SuperBlend 2-Pac # 6070

Performance review of Major Items

Packed beds

i. The new recommended 4th Random packing combinations of different suppliers were able to provide significant improvement in the hydraulics but at the expense of CO_2 slippage.

ii. Various types of Structure packings were also evaluated. They were not considered viable for the prevailing high liquid loadings without a commercial reference

iii. The hydraulic improvement at the expense of CO_2 slippage was not a viable option. Based on this outcome, NO changes in the existing packing were recommended

Performance review of Major Items
Flash Drum

a. The existing Flash drum was evaluated inadequate for the Base operating rate with a limiting vapor disengagement space and also the liquid residence time.

b. The limited vapor disengagement space was also affecting the ejector performance.

c. The new Flash drum was re-sized with five compartments *(same as existing)* to minimize the existing piping modifications.

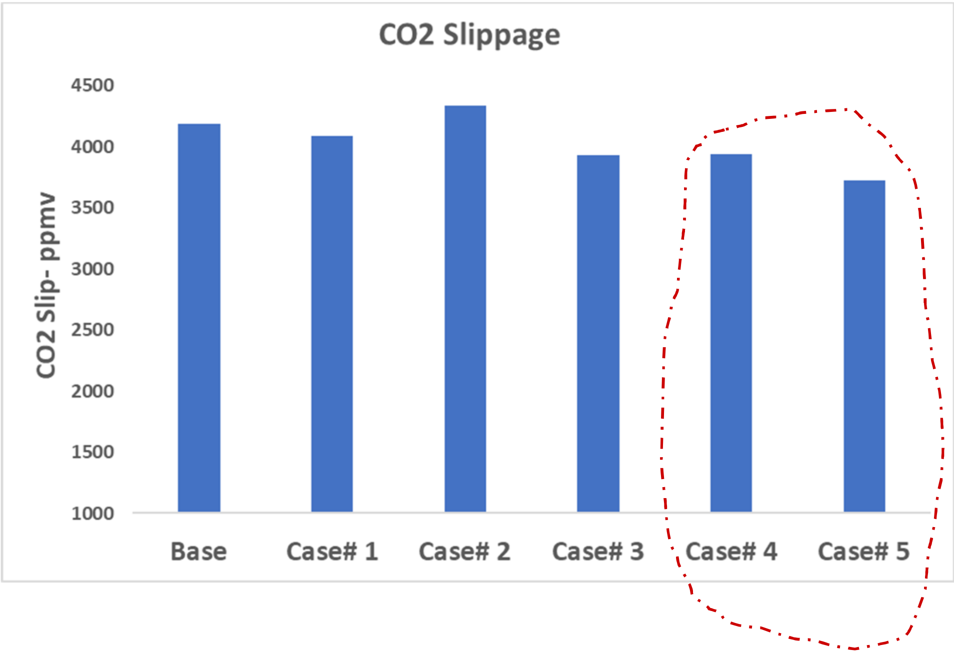
d. The new larger size fitted well within the specified site space constraints.

Flash Drum had a mechanical integrity issues with occasional cracks on internals

Performance review of Major Items`

CO2 slip sensitivity

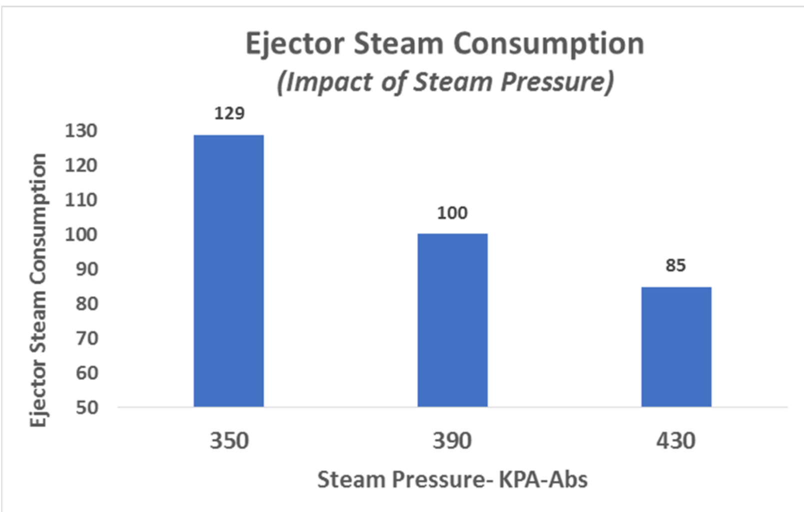
Case# 1: Higher Circulation (~1.5% more than Base)
Case# 2: Lower Feed Temp (~10 °C lower than Base)
Case# 3: Lower Solvent Temp (~10°C lower than Base)
Case# 4: Higher Reboil Duty (105% of Base)
Case# 5: Lower F/Drum Press (~5 Kpa lower than Base)

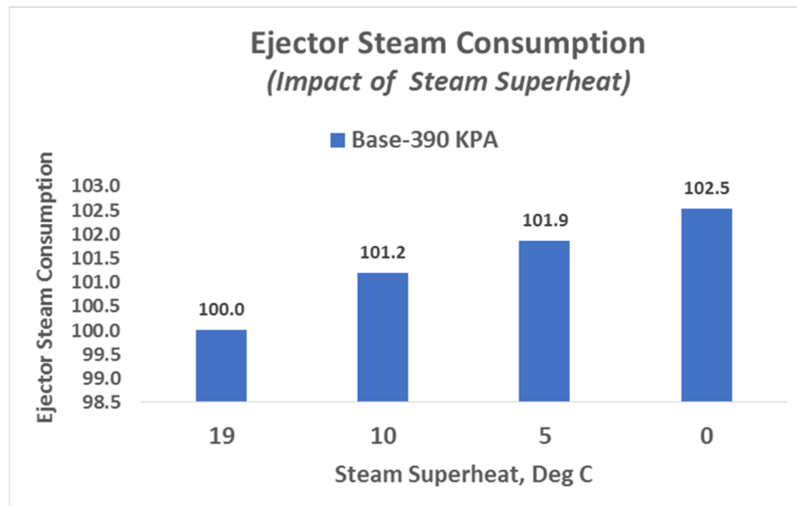


Performance review of Major Items

Ejectors

- Ejectors were inefficient & were using higher-pressure LP steam with mechanical integrity issues
- It was preferred to use LP steam of Urea plant to avoid venting it
- The existing 7 ejectors were recommended to be replaced with only five with a slightly lower drum pressure in the last compartment





Performance review of Major Items

Reboiler

- A slightly higher Reboil duty helps in lowering CO_2 slippage.
- The new replacement reboiler is designed for ~ 110% of duty within the existing hydraulics and space constraints
- The available net liquid head for the Reboiler is quite limited at the current operating load. This limitation can result in liquid overflow in the bottoms Chimney tray of the Stripper affecting the performance with a higher CO_2 slippage.
- Therefore, the new replacement Reboiler for a larger heat transfer area will have a very limited option to increase its size by extending in tube length only to the extent of a viable space availability

Performance review of Major Items

Feed & two other Separators

- All three existing Separators *(Feed, CO2 & Treated Syngas)* were reviewed for their adequacy
- **The Feed Separator was found to be very inadequate while two other Separators were found adequate at the current operating loads**
- The existing Feed Separator recommended for upgrading to minimize excessive carryover which contributes to mal-distribution and the water balance in the system affecting the performance of the Absorber

Performance review of Major Items

Power Recovery Turbine

- The upgrade was reviewed for additional power recovery of 225 KWh
- The existing unit already maxed out on its impeller size
- So any further improvement will require a new larger model
- **Based on a broad cost: benefit review, it was decided not to currently pursue**

Summary of Key Modifications

Summary of Modifications/Replacements

	Before Revamp	After Revamp	Remark
1	Underrated Liquid Distributors in Absorber	All four Liquid distributors repalced with new efficient ones	
2	Mal-distribution of Inlet vapors to Absorber	Even Flow inlet Vapor distributor installed	Welded option used
3	Incipient Flooding in Absorber beds	None	
4	Underrated Liquid Distributors in Stripper	All four Liquid distributors repalced with new efficient ones	
5	Flash drum inadequate & resulting in inefficient Ejector operation (& mechnical integrity issues)	Replaced with new larger one	Existing: 3.81 m x 12.7 m New: 4.3m x 15.7m
6	Inefficient Ejectors using higher pressure steam (& mechnical integrity issues)	Replaced existing 7 with new 5	
7	Reboiler slightly undersized (& mechanical Integrity issues)	Replaced with a new one	
8	Feed Separator- Inadequate leading to carry over	Currently not done	Planned later
9	Power Recovery Turbine maxed out & bypassed	Currently not Economical	Planned later

Changes in Absorber

- Inlet Vapor Distributor (York Even-flow vane type)
- Orifice Deck Distributor- Bed 1
- Orifice Deck Distributor- Bed 2
- Orifice Deck Distributor- Bed 3
- Orifice Deck Distributor- Bed 4
- Demister above Bed 1

Installation of Inlet Vapor Distributor in Absorber

New Tower Attachments at Nozzle N1

General Comments:

12" Elbow at nozzle N1 was cut 200mm from shell. New tower attachments were welded in place to support the new inlet device, new York Evenflow Vane Inlet device was installed as per scope. Center beam supporting Bed 1 packing was oriented 90 degrees different than on drawings.

Bed#2 Liquid Distributor in Absorber

EXISTING

As-found Orifice Deck Distributor

General Comments:

Existing orifice deck distributor was found intact, and was removed. Distributor was heavily fatigued and pieces could be broken by hand.

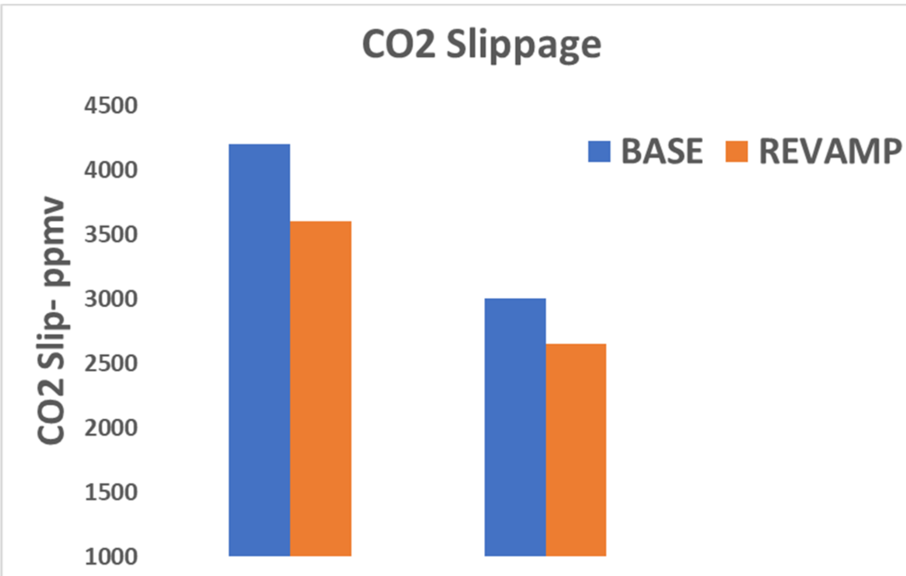
NEW

New Orifice Deck Distributor

Changes in Stripper

- Orifice Deck Distributor- Bed 1
- Orifice Deck Distributor- Bed 2
- Orifice Deck Distributor- Bed 3
- Orifice Deck Distributor- Bed 4
- Demister above valve trays
- Chevron mist Eliminators above Bed#1
- 3 Flexitray Valve trays above Bed#1

Expected CO2 Slip after Recommended Mods



Performance Post Revamp

	Before Revamp	After Revamp	Remark
1	CO2 Slip (2500 to 4000 ppmv)	Reduced by ~1500 ppmv (better than expected 600 ppmv)	50% contribution to incremental Ammonia production
2	High DP Excursions in Absorber with Unstable opeartion	No more DP excursions with a very stable opeeration since August 2022	
3	LP Steam venting in Urea plant	Enabled full use of LP steam & no more venting in Urea plant	
4	Additional Aux boiler firing (HP to higher pressure LPS let down for ejectors)	Much reduced HP steam Aux boiler firing & GHG reduction	
5	Maximum Ammonia Productio 2127 mtpd	Record Ammonia production of 2149 mtpd	50% contribution to incremental Ammonia for reduced CO2 slip
6	Urea Production	Urea Production increased due to more CO2 recovery	~90% of incremental Urea production for higher CO2 recovery
7	Overall Energy Consumption	Lower despite a marginal increase in LPS flow to Ejectors (~3.5% more)	

Thank You

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