Hydraulic and Mechanical Study

of the

Amine Tower and Stripper Column Design

CO_2 Capture Facility

Kårstø, Norway

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0	12 NOV 08	Issued for comment	MJC	HS	ADB	BDR	WJE
Rev.	Date	Reason for Revision	By	Check	App	App	App

Bechtel Power Corporation	Job No. 25474	
	Document No. 25474 – 000 - 30R-M01G-00001	Rev. 0
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GASSNOVA	Project No. - Originator - Disc Code - Doc Type - Serial No. 10112936 –PB - P-TDO-0012	

Contents

Hydraulic and mechanical studies on CCC Plant column design

1.0 INTRODUCTION

This document describes the approach taken for the hydraulic and mechanical design of the CO2 Absorber towers and Stripper column in the CO2 Capture facility.

The sizing calculations, vessel datasheets and column internal datasheets are issued separately and previously to this report.

2.0 DISCUSSION

2.1 CO2 ABSORBER

The options for the absorber configuration were considered to be;

a. Single Tower

b. Two Towers

c. Single Rectangular Tower

The key considerations for selection were feasibility of design and construction, modularization (i.e. construction of complete or near-complete equipment off-site and transport as whole to site), process performance.

All 3 options were considered to be feasible for design and construction, but the single column would involve significant beam lengths up to the expected 17m column diameter. These beams would require substantial column height to be allocated to accommodating the lattice beam structures necessary to support the packing. The diameter would exceed 12m, which is the maximum preferred width for modularization.

The single rectangular tower could be constructed with some degree of modularization, but considerable construction works would be required on site. The packing and internals to be applied in the project are intended for performance in cylindrical columns. Some allowance for lesser performance in rectangular tower would need to be estimated and included.

The dual tower approach provides equipment for which the tower and its internals can be designed to commonly applied mechanical and hydraulic design codes and rules. The diameter is within the 12m preferred for largely complete off-site fabrication and transportation to site.

The CO2 Absorber towers are designed to the applicable design code for unfired pressure vessel (EN13445). The packing will be supported by lattice beam structures held on lugs or steps at the tower wall. The largest structure being to support the lower amine bed and consisting of 6 lattice beams constructed from ½" 304L Stainless Steel for each CO2 Absorber.

Tower internals for good contact between the amine and flue gas are selected from 3 general types;

a. trays

b. random packing

c. structured packing

Trays provide good contact over a wide operating range but the pressure drop is high and would require the blower to generate significant head and thus consume considerable power. This option was not seriously considered.

Random packing is cheap, provides good contact with a restricted operating range. Since the fall of the packing into position is random, at the relatively low liquid to gas flow rates in the absorber, there is a risk of non-uniform flow through the packing and consequent failure to achieve the desired CO2 absorption performance.

Structured packing, though more expensive than random packing, provides a much lower risk of non-uniform flow distribution. In addition gravity or trough distributors are specified for the liquid distribution across the packing beds. These ensure a uniform liquid distribution through the packing. The actual packing employed is selected with the vendor based on particular liquid and vapor loads in the tower.

Structured packing provides a low pressure drop and the internals (excluding tower inlet and outlet losses) have been confirmed by the vendor to not exceed the allowable pressure drop of 6 kPa.

The packing performance also requires uniform distribution of vapor flow to ensure localized flooding within the packing bed does not occur. At the flue gas inlet the vapor flow will not be uniform and this may result in uneven vapor distribution in the packed bed above the inlet. The vapor distribution is evaluated by Computational Fluid Dynamics (CFD), refer to Attachment 1. The vapor load is evaluated by means of the local peak velocity load F factor.

The CFD review of the CO2 Absorber design shows that with;

a. Feed ducting installed with an inside bend radius of 2m

b. No flue gas inlet distributor (open ducting inlet into the tower)

c. No vapor distributor tray below the packed bed

The vapor distribution in the packed bed is good. The local peak velocity load is less than F = 5 $Pa^{0.5}$ and the packing will perform as required. It is preferred to ensure the local peak velocity load F factor is less than 6 $Pa^{0.5}$ at which point local flooding can occur depending on the droplet size and liquid surface tension.

Further changes to the vapor distribution considered were;

a. Installing the flue gas ducting with an inside bend radius at NIL meters worsens the vapor distribution increasing the local peak velocity to F = 8 $Pa^{0.5}$. (refer to Attachment 1)

b. Including a flue gas inlet distributor will improve distribution significantly but such distributors are extremely large and costly. For the CO2 Absorber such a distributor will increase the total internals cost by 10%. The CFD study work to date suggests that such a distributor is unnecessary for a circular absorber tower.

c. A vapor distributor tray has been recommended by an internals vendor as an alternative for a distributor and can be provided within the hydraulic limit of 6 kPa pressure drop for all tower internals. That such a tray will improve the distribution (i.e. reduce the local peak velocity load F factor below 8 $Pa^{0.5}$) can be inferred from the CFD study for the stripper, where the draw-off tray in that tower improves the vapor distribution in the zone above.

2.2 STRIPPER

The stripper is a conventional distillation column and the diameter required for a single column was comfortably within the preferred maximum diameter of 12m for modularization. The Stripper column is designed to the applicable design code for unfired pressure vessel (EN13445).

Column internals for good stripping of the CO2 from the amine and flue gas are selected from 3 general types;

d. trays

e. random packing

f. structured packing

Trays provide good contact over a wide operating range but the pressure drop is relatively high. The LP steam pressure to the stripper reboiler is very low and so it is necessary to minimise the column operating pressure and internals pressure drop to obtain satisfactory performance. For the top reflux section the liquid reflux is low and trays are required. Since this section consists of only 3 trays the overall impact on the total column pressure drop is small.

Random packing is cheap, provides good contact with a restricted operating range. Since the fall of the packing into position is random there is a risk of non-uniform flow through the packing and consequent failure to achieve the desired amine stripping performance.

Structured packing, though more expensive than random packing, provides a much lower risk of non-uniform flow distribution. In addition gravity or trough distributors are specified for the liquid distribution across the packing beds. These ensure a uniform liquid distribution through the packing. The actual packing employed is selected with the vendor based on particular liquid and vapor loads in the column.

Structured packing provides a low pressure drop and the pressure drops have been confirmed by the vendor to be within those allowed by the process design.

The packing performance also requires uniform distribution of vapor flow to ensure localized flooding within the packing bed does not occur. Since the reboiler return flow enters from the column side, the flow at the bottom of the column will not be uniform and this may result in uneven vapor distribution in the packed bed above the inlet. The vapor distribution is evaluated by Computational Fluid Dynamics (CFD), refer to Attachment 1. The vapor load is evaluated by means of the local peak velocity load F factor.

The CFD review of the Stripper design shows that with 100% of the reboiler return vapor flow through a single 1220mm nozzle, the vapor distribution to the packed bed is very good (local peak velocity less than $F = 3\ Pa^{0.5}$) and the packing will perform as required. No inlet distributors are provided and the draw-off tray above the reboiler return acts to improve the vapor distribution.

The actual stripper design envisages 4 x 1220mm nozzle and so the vapor velocity into the stripper will be much reduced. The flow regime will be altered though the results in Attachment 1 show that the vapor distribution is mainly influenced by the collector tray below the packed bed which distributes the vapor by its pressure drop. It is expected that the flow distribution quality is better than with the simulated configuration.

3.0 CONCLUSION

3.1 CO2 ABSORBER

The selection of a circular tower allows the mechanical tower design to follow usual industry codes and methods. The diameter of 12m is within the preferred diameter for modularization for maximum off-site fabrication. The selection of structured packing provides good absorption performance within the allowable tower pressure drop. Liquid distribution to the packing is assured by trough distributors and the inlet ducting design produces a good vapor distribution to the packing without the need for a flue gas distributor.

3.2 STRIPPER

The selection of a circular column allows the mechanical column design to follow usual industry codes and mechanical methods. The diameter of 7m is within the preferred diameter for modularization for maximum off-site fabrication. Trays are selected for the reflux section to provide uniform liquid flow at the relatively low liquid flow. The impact on the column pressure drop is low due to the small number of trays (3 off). The selection of structured packing for the stripping section provides good stripping performance within the allowable column pressure drop. Liquid distribution to the packing is assured by trough distributors and vapor distribution to the packing is very good.

4.0 ATTACHMENT 1 – CFD STUDY REPORT

Attachment 1 contains 33 pages.

Although this attached report is from a single supplier of internal packing, the CCC design has been completed utilizing a generic approach to the internal packing design based on the receipt of this and another supplier's hydraulic, mechanical, and CFD analysis.

Errata/Comments on Attachment 1:

a. Pg 3 vapor density is at the inlet.

b. Both the towers and column were simulated without a vapor inlet device.

c. Small vertical dimension differences with the datasheet do not affect the study findings.

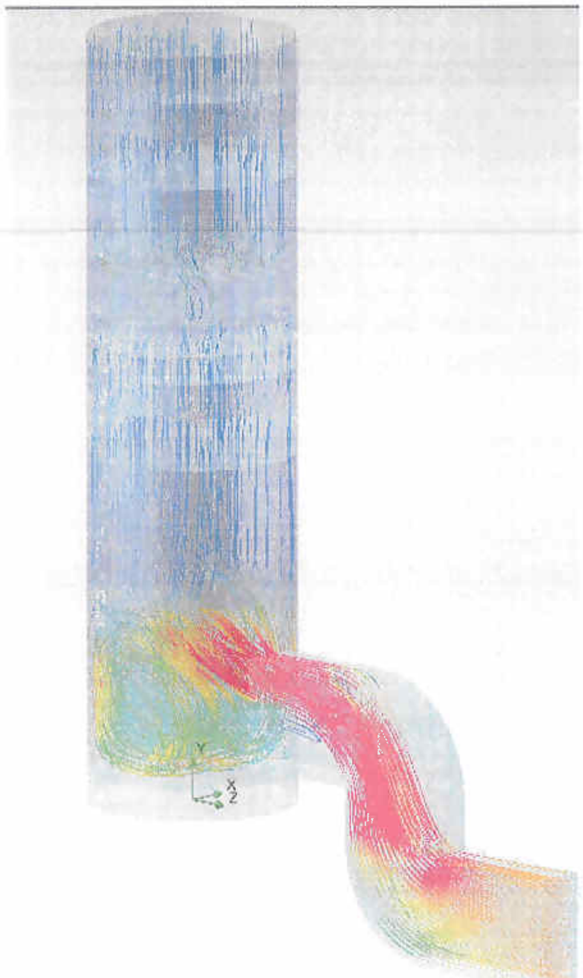
d. Pg 23 the vapor velocity will be 10m/s with 4 reboiler return nozzles.

SULZER

CFD-Report

Sulzer Chemtech

Numerical Analysis of vapor distribution of the CO2 KARSTO columns Absorber MV-101/MV-102 and Stripper MV 103



Project	Issued	Issued by
2134963 KARBEC	Nov 6th 2008	Ch. Bachmann
Karsto CO2 Project		

25474-000-30R-M01G-00001 Attachment 1
10112936-PB-P-TDO-0012 Attachment 1

Karsto FEED Study
Hydraulic and mechanical studies, Rev.0

CFD-Report

Content

1 General

1.1 Numerical Model and Geometry

The vapor flow through the column is simulated numerically using the fluid dynamics code COSMOS FLOWORKS. To model the turbulence behavior of the flow the standard k-ε-model is used.
The pressure drop over the packing bed is described by means of the resistance law $\Delta p = k\, H\, \rho\, v^2/2$, where k is dependent on the operating conditions and the type of the packing bed. The packing bed has been replaced by a porous media with the characteristics of the selected packing. To simplify the problem the vapor inlet flow rate is used to simulate the whole column without considering the absorption or stripping-rate. Liquid-Distributors, Trusses and support grids are not included in the model. As long such internals are placed parallel to the vapor flow there is no impact on the vapor distribution expected.

2 Simulation of Absorber columns MV 101 and MV 102

2.1 General conditions

Vapor flow at inlet nozzle	321 [m^3/s] uniformly distributed on both nozzle cross sections
Load case	100%
Vapor density ρ_G @ condition wash bed bottom	1.123 [kg/m^3]
Definition of F-factor	$\overline{w} \cdot \sqrt{\rho_G}$ [$Pa^{0.5}$]
Average column F-factor in packed section area after inlet	3.1 [$Pa^{0.5}$]
Pressure drop of packing bed 4 (bottom)	1210 [Pa]
Pressure drop of packing bed 3 (middle)	317 [Pa]
Pressure drop of packing bed 2 (Top)	609 [Pa]
Pressure drop of packing bed 1 (Top)	304 [Pa]
Pressure drop of Mist eliminator below collector tray	300 [Pa]