CERTIFICATION OF APPROVAL

Absorber Hydraulics Modification for Zero-Foaming of MDEA Solutions

by

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8677

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AJITPAL SINGH SEKHON

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Last but not least, the author would also like to express his appreciation to all his classmates for their assistance and support.

ABSTRACT

This thesis describes the research carried out to solve the foaming issues in Malaysia LNG Sdn. Bhd. with its Acid Gas Removal Units. The absorber column hydraulics and design is found to be not suitable for usage of MDEA solvents which gives a higher absorption capacity. A thorough study of absorber hydraulics and parametric study on foaming behavior is carried out. Modification for the hydraulics design is calculated and justified to avoid foaming. The report consist of four chapters that cover the introduction of the project, literature review of related topics, project methodology, Project Progresses and finally the conclusion.

The introduction part mainly discussed about the background of the study of foaming issue in the acid gas removal unit using MDEA solvent. Objectives and scope of the study is also defined here to specify the area of study.

Chapter 2 of the report describes more on the literature review of Hydraulic Limitations, Foaming Tendency, Foaming Stability, Column Hydraulics Design Consideration, Foaming Factor, and Acid Gas Absorber (Tray column) Internal Design.

The methodology and project work will be covered in the Chapter 3 of the report. In this part, the procedure identification of the study, and tool/software required is discussed. The methodology consists of work on reviewing design consideration for absorber column, study properties of MDEA solvents and foaming mechanics. The deliverable from this research is to propose design of absorber column with detailed calculation and modeling which is robust from MDEA solvent foaming.

Chapter 4 describes the Results and Discussion. Information from the Excel Modeling is made known here and communicated through tables and calculation basis.

Finally, the project conclusion is stated in the report together with the references used for research work on this project.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Acid gases (CO_2 & H_2S) are removed from Natural Gas using the Acid Gas Absorber Column (C2101) in Malaysia LNG DUA Sdn. Bhd (MLNG 2). Natural Gas feed is contacted by the Sulfinol-D solvent (physical solvent) in the tray column where the acid gases are absorbed by the solvent. To increase the absorption capacity of the acid gas, Ucarsol (chemical solvent) a MDEA based solvent is introduced. Foaming incidences and instabilities of the process performance occurs after absorber solvent change.

Foaming is a severe operational problem in acid gas absorption process using aqueous alkanolamine solutions. It occurs during plant start-up and operation in both absorber and regenerator.Based on plant experiences, foaming impacts integrity of plant operation, causing excessive loss of absorption solvents, premature flooding, reduction in plant throughput, off-specification of products, and high absorption solvent carryover to downstream plants. To date, the knowledge of foaming in this process is limited for oil and gas operations and even more limited for the application of CO_2 capture from industrial flue gas for the purpose of greenhouse gas emission reduction.

1.1.1 Foaming Symptoms and Effect in MLNG 2

Symptoms of Foaming

1. Pressure increase in absorber as gas holdup occurs due to ucarsol foam being at the trays disallowing the flow of gas.
2. Level drop in regenerator as less or no ucarsol is returning to it.
3. Sudden increase of absorber outlet flowrate exceeding its inlet flowrate as the gas holdup rushed out when it has adequate pressure.

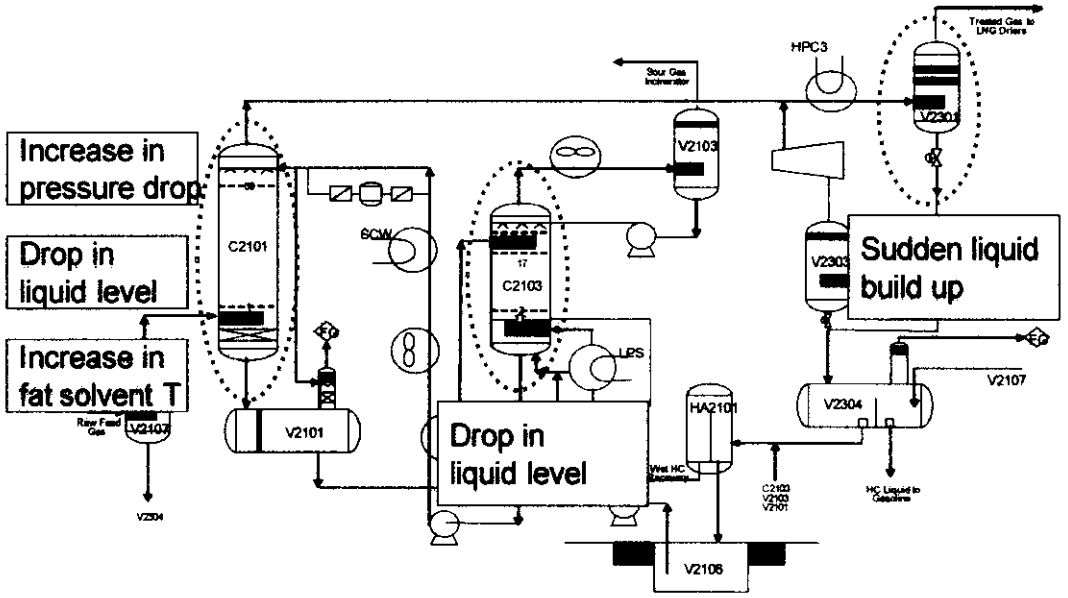

Figure 1.1 - Symtoms of Foaming

Effects

1. The absorption efficiency declines as adequate liquid-gas contact cannot be made.
2. Absorber outlet is polluted as ucarsol enters it. The liquid level of V2301 will increase and when HH alarm is triggered a trip will occur.

Operations Response

1. Inject antifoam.
2. Reduce production to reduce the feed rate into the absorber.
3. Liquid from V2301 is sent to the water separator. (Trip Function)

1.2 PROBLEM STATEMENT

The foaming incidences and instabilities in Acid Gas Removal Units (AGRU) of MLNG DUA Module 4 post solvent change out from Sulfinol-D to UCARSOL in October 2008 had caused a total of 10 trips and module slowdowns amounting to 7 BCe LNG losses.

The probable root cause of Module 4 instabilities are due to the combinations of:

1. Contamination of UCARSOL solvent with dissolved heavy hydrocarbon from the feedgas via the absorber
2. Incompatibility of polyglycol component in GT-10 antifoam with presence of Sulfolane in Ucarsol solvent
3. **Absorber column tray hydraulics limitation**

1.3 OBJECTIVE

Objectives of this project are:

1. Absorber design considerations in order to maintain a robust and efficient process.
2. Possible absorber hydraulics modifications to avoid foaming of MDEA solvents

Generally, this project will be divided into several steps which will be discussed further. In order to achieve the objectives, this project will be done according to time frame and planned schedule.

1.4 SCOPE OF STUDY

ASPECTS	SCOPE OF STUDY
Properties of MDEA Solvents	• Physical and chemical properties of MDEA solvents is characterized from solvent datasheets
Foaming Mechanics	• Study on foaming behavior and factors • Foaming Factor relation with tray hydraulics is determined
Design Consideration for Absorber Column	• Quantitative modeling of an efficient and robust absorber column towards foaming of MDEA based solvents

Table 1.1: Scope of study

These scopes of study are feasible because all the necessary equipments are available in the labs. Considering the time frame for this project, these above scopes of study is also feasible because each of the aspects tested will only consume at most 1 to 2 weeks to be completed with all the equipments and materials ready.

CHAPTER 2

LITERATURE REVIEW

2.1 HYDRAULIC LIMITATIONS

The hydraulics of the absorber column consists of the following;

- Tray spacing
- Weir height
- Downcomer height
- Valve type and number

Figure 2.1 - Absorber Tray Hydraulics

To avoid foaming, absorbers are design taking into consideration of a foaming factor which shows the foaming tendency. The lower the foaming factor value, the higher its foaming tendency and vice versa.

The foaming factor of Sulfinol-D is 0.8. Meanwhile Ucarsol has a lower foaming factor which is 0.73. Therefore, the tendency of Ucarsol to foam is higher. As Process DUA's AGRU absorber column is designed for the Sulfinol-D solvent, its hydraulics of the absorber is limited for the usage o the new solvent, Ucarsol.

The following weaknesses using Ucarsol a type of activated MDEA solvent are determined:

- Weir height too high
- Tray spacing too low

2.2 FOAMING TENDENCY

Foaming tendency is governed by the following properties:

- Surface Tension
- Elasticity of Film Layer
- Hydrocarbon Solubility
- Gelatinous Layer Formation
- Film Drainage
- Surface Viscosity

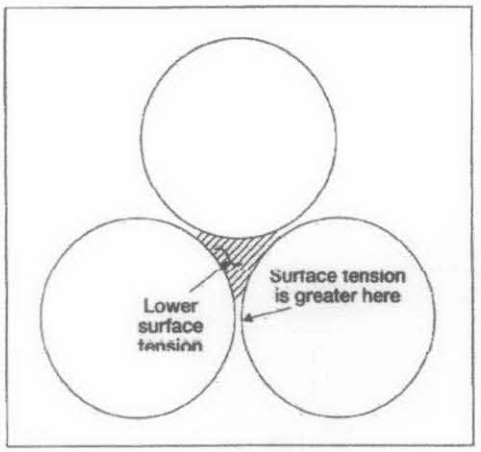

Figure 2.2 Foam Suface tension

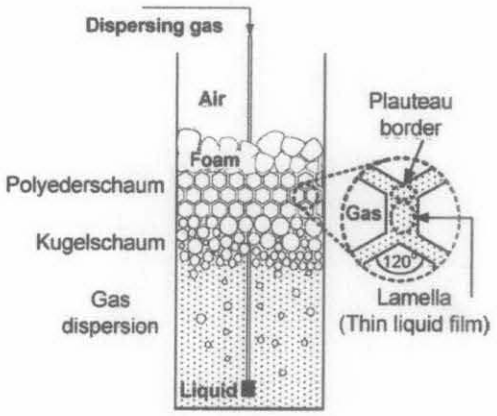

Figure 2.3: Foam characterization based on gas and liquid fraction criteria

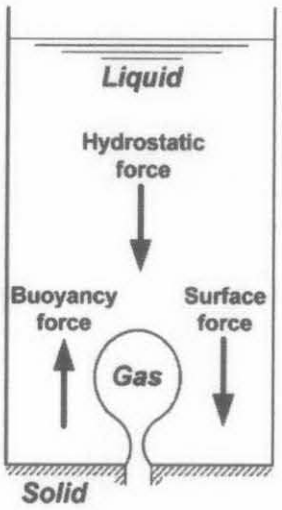

Figure 2.4: Three principal forces influencing bubble formation.

2.3 FOAMING STABILITY

Foam Stability. By nature, foams are subject to three main instabilities, i.e., thinning, coalescence, and rupture. Such instabilities lead to a decrease in their surface area and consequently surface free energy.14 It is an opposite characteristic to foam stability affected by surface elasticity, Marangoni effect, surface and bulk viscosity, repulsive Coulombic force, nd gravitational force. Surface elasticity (E) is an ability of surface to resist a thinning process due to a surface tension gradient. It is essentially a change in surface tension with respect to a change in surface area (A) as expressed below.

$$E = 2A(\mathrm{d}\,\gamma\,/\mathrm{d}A)$$

During gas dispersion, a surface tension gradient between a stretched and a nonstretched area of surfactant-adsorbed surfaces is created as the surface is exposed to rapid expansion and shrinkage. At this point, the surface elasticity is responsible for balancing this gradient by using viscous forces to induce the underlying liquid to flow from the stretched area to the nonstretched area as a result of self-contraction of surfaces. Consequently, the stretched area is thickened, and foam stability is enhanced. The phenomenon that the surface tension gradient causes a liquid flow in the lamella is referred to as **Marangoni effect**. Bulk viscosity and surface viscosity also play an important role in foam stability. The bulk viscosity is the liquid viscosity in a bulk liquid phase, while the surface viscosity is the liquid viscosity at the interface between gas bubble and liquid in the lamella. The surface viscosity is usually higher than the bulk viscosity, and is also increased accordingly to an increase in bulk viscosity. Generally, high bulk viscosity is favorable since it will slow down the drainage due to gravitational force. However, an increase in bulk viscosity can lead to a very high surface viscosity and eventually can destroy surface elasticity. This is because the surface films cannot be easily moved with only a small amount of external stress and becomes a solidlike at a high surface viscosity, which, in turn, decreases foam stability. In addition to the above-mentioned forces, other external forces also have an impact on the foam stability. The repulsive Coulombic forces typically slow down the gravity drainage, while the gravitational force does the opposite.

2.4 COLUMN HYDRAULICS DESIGN CONSIDERATION

Maximum tray hydraulic capacity can be limited by any one of three types of flooding:

(a) jet or entrainment flood,

(b) downcomer backup flood,

(c) downcomer choke flood.

The ability of a tray to operate at the lower end of the loading range is limited by

(d) weeping

(e) entrainment

that occurs even in the spray regime of operation as the liquid flow on the tray is decreased while maintaining a high vapor flow rate. The other low liquid rate limitation is vapor bypassing up downcomers as lowered liquid depths unseal the downcomers. In a perfectly balanced design, jet flood and choke flood will occur simultaneously and the column's diameter will be sized to be slightly more than adequate for the proposed loads; certainly pressure drop will not be high enough nor downcomer clearance tight enough to induce backup flood problems, nor will vapor bypass up downcomers.

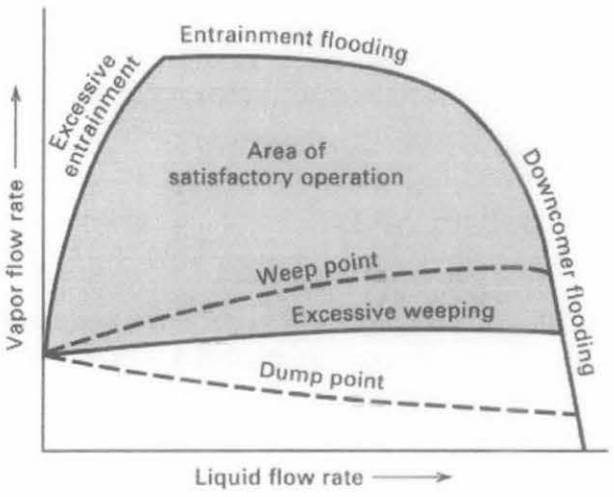

Figure 2.5: Tray Operating Diagram

2.4.1 Guidelines for Tray Column Design

System Derating Factor:

	Factor
Nonfoaming	1.0
Moderate foaming (e.g., absorbers, amine and glycol regenerators)	0.85
Heavy foaming (e.g., amine and glycol absorbers)	0.75

Based on compilation of Barnicki and Davis (1989)

Sieve Tray Design Guidelines

Tray Spacing:

Column Diameter, ft	<3	3–5	5–6	6–12	13–24
Tray Spacing, in.	6–12	18–24	24–30	30–36	35–48

Weir Height:

Should not exceed 15% of tray spacing
Froth regime: 1–4 in. (2 in. is normal)
Spray regime: >¼ in. (½ to ¾ in. is normal)

Downcomer Clearance:

Minimum: ½ in. less than weir height (¼–½ in. is normal)

Hole Diameter:

Typical: $\frac{1}{16}$–½ in.

Plate Thickness:

	Plate Thickness/Hole Diameter	
Hole Diameter, in.	Stainless Steel	Carbon Steel
$\frac{3}{16}$	0.43	1.0
¼	0.32	0.75
⅜	0.22	0.50
½	0.16	0.38

Weir Loading:

Typical: less than 96 gpm/ft

Pressure Drop:

Maximum, 1.5–3.0 in. of liquid for vacuum
8.0–10.0 in. of liquid for one atm or higher

System Derating Factor:

	Factor
Nonfoaming	1.0

Table 1-8 Typical Design Values of K_v for Sieve, Bubble-Cap, and Valve Plates			
	Kv – When Flow Parameter, Fv is:		
Plate Spacing, in.	0.01	0.1	1.0
6	0.15	0.14	0.065
9	0.18	0.17	0.070
12	0.22	0.20	0.079
18	0.30	0.25	0.095
24	0.39	0.33	0.13
36	0.50	0.42	0.15
Based on correlation of Fair (1963, 1987)			

Table 2.1: Guidelines for Tray Column Design

2.4.2 Multi Downcomer High Performance Trays

The high performance trays are based on multi downcomer principle which allows to accommodate high liquid loads.

Best tray for high liquid loadings

- Longest weir length per given column diameter
- Largest DC area per given column diameter
- Most uniform flow path length
- Most uniform vapor distribution
- Minimum inactive zones
- Maximum bubbling area

Highest capacity at large liquid loadings

- Lowest pressure drop at large liquid loadings
- Best mass transfer efficiency at large liquid loadings
- Lowest tower height per theoretical stage Tray spacing as low as 300 mm (11.8 in)

Can be equipped with different types tray deck

- Sieve holes

- Float valves
- Fixed valves

Mechanical features

- Multi-Downcomers located offset to the cross section centreline
- Multi-Downcomers supported by a central major beam and 360° tower support ring
- No need for downcomer bolting bars

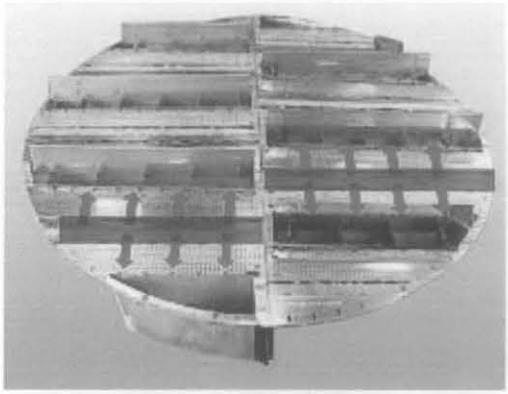

Figure 2.6: Multi Downcomer High Performance Tray

The picture below shows the Shell Hi-Fi Tray Box used in MLNG.

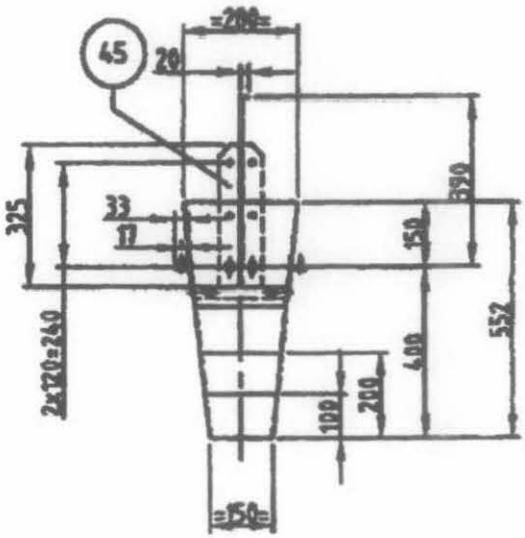

Figure 2.7: Shell Hi-Fi Tray Box

Flooding Vapor Velocity, u_{flood}:

$$u_{flood} = K\sqrt{\frac{\rho_L - \rho_V}{\rho_V}} \qquad \text{ft/s}$$

where the ρ's are the densities of the liquid, L, and vapor, v, and the K factor is

$$K = C_{sb}\left(\frac{\sigma}{20}\right)^{0.2}$$

where σ is the surface tension and C_{sb} is the capacity factor, which is a function of the flow parameter, F_{LV}:

$$F_{LV} = \frac{L}{V}\left(\frac{\rho_V}{\rho_L}\right)^{0.5}$$

where L and V are the mass flow rates of liquid and vapor, respectively.

By calculating F_{LV}, one can determine C_{sb} from the Fair correlation, figure below;

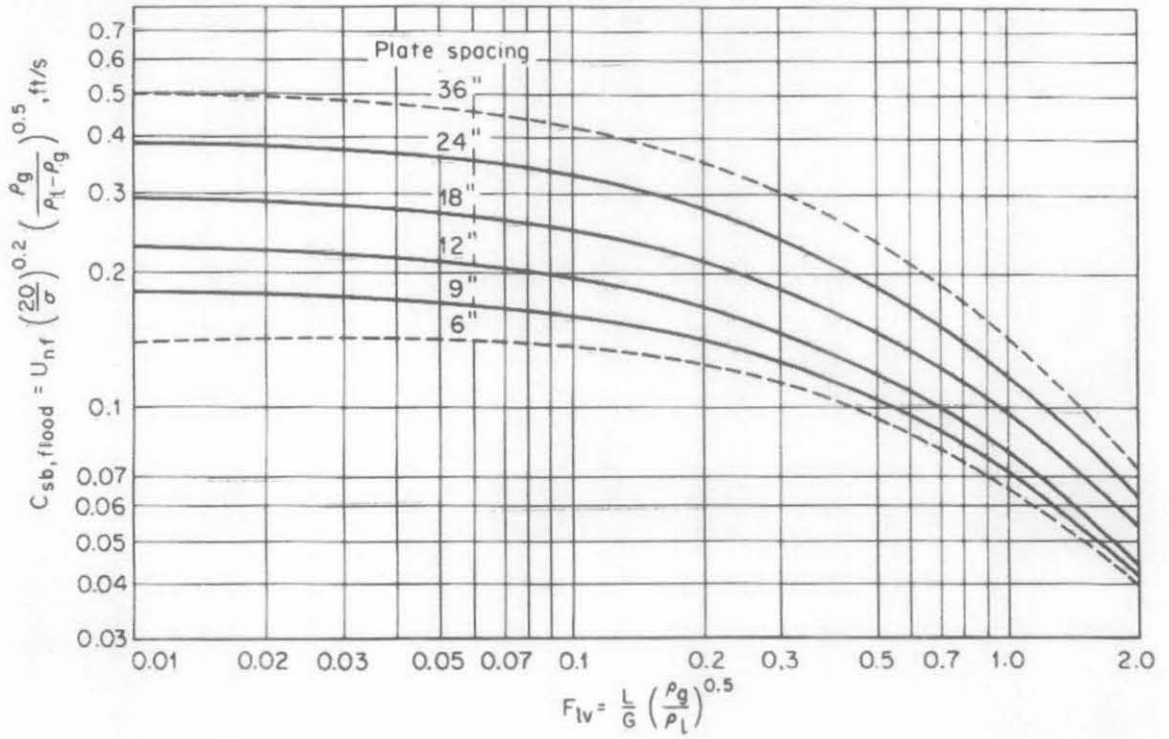

Figure 2.8: Capacity factor for flooding of trays

2.5 FOAMING FACTOR

To avoid foaming, absorbers are design taking into consideration of a foaming factor which shows the foaming tendency. The lower the foaming factor value, the higher its foaming tendency and vice versa.

Foaming factor can be incorporated in the K factor . These include a foaming factor, C_{FF}, and a tray area factor, C_{HA}:

$$K = C_{sb}\left(\frac{\sigma}{20}\right)^{0.2} C_{FF}C_{HA}$$

$C_{FF} = 1.0$ for non-foaming systems and $C_{FF} < 1.0$ for foaming systems.

C_{HA} is based upon the ratio of the vapor hole area A_h to the tray active area, A_a. The vapor hole area, A_h, is the area open to vapor flow, for example, it is the total area of the holes on a sieve tray. The active tray area is the total tray area less the area of the downcomers leading down from the tray above and down to the tray below:

$$C_{HA} = 1.0 \qquad \text{for } A_h/A_a \geq 0.10$$

$$C_{HA} = 5(A_h/A_a) + 0.5 \qquad \text{for } 0.06 \geq A_h/A_a \leq 0.10$$

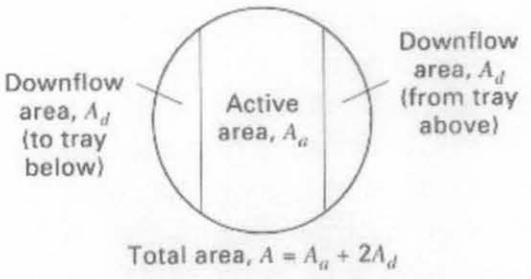

Figure 2.9: Downcomer Area

2.6 ACID GAS ABSORBER (TRAY COLUMN) INTERNAL DESIGN

The following figures show the internals of the current absorber in MLNG 2;

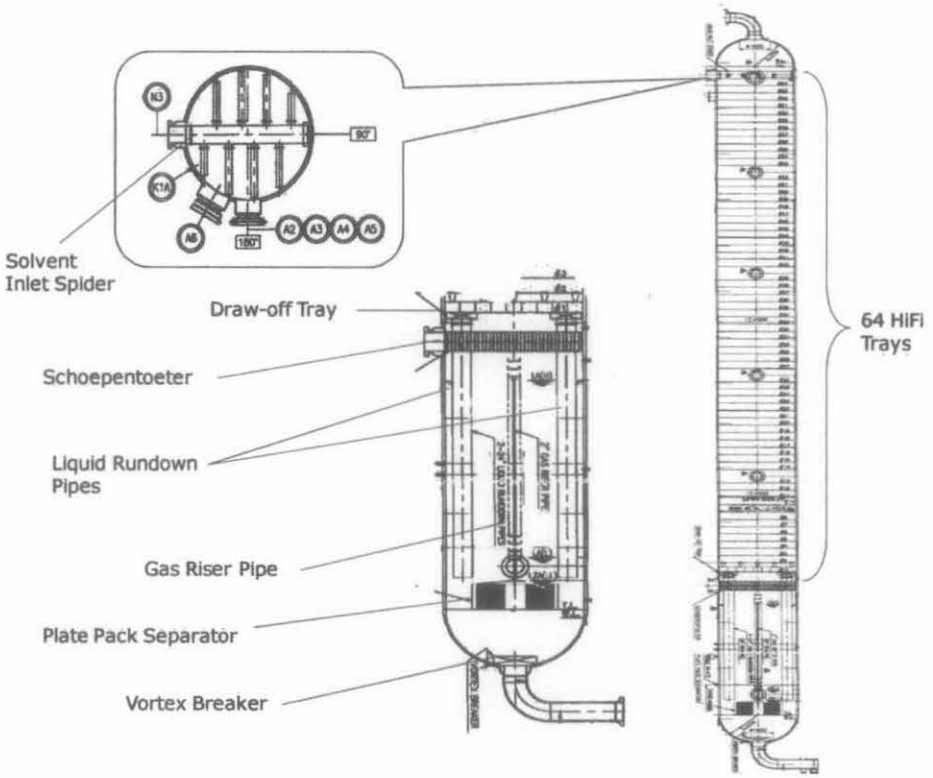

Figure 2.10: Collum bottom internals

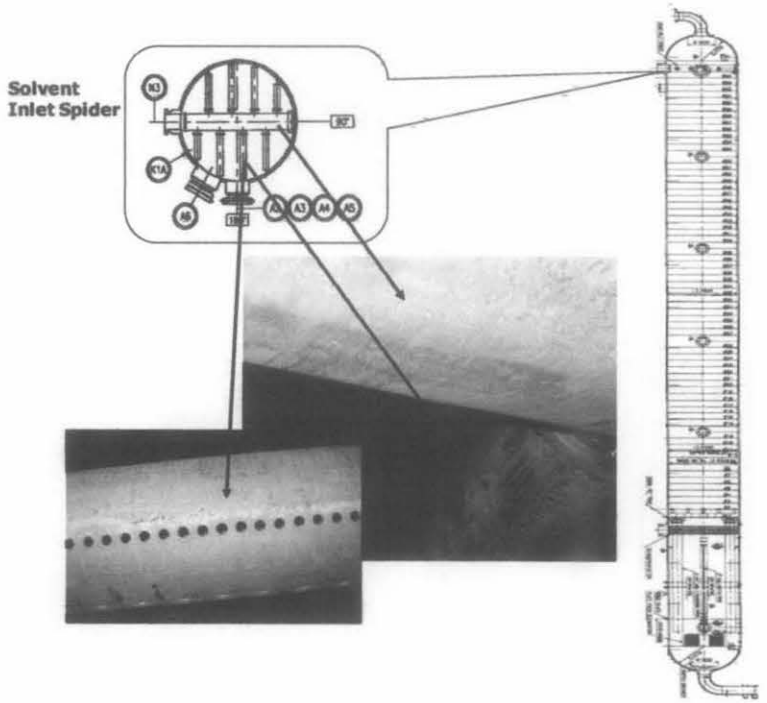

Figure 2.11: Solvent inlet

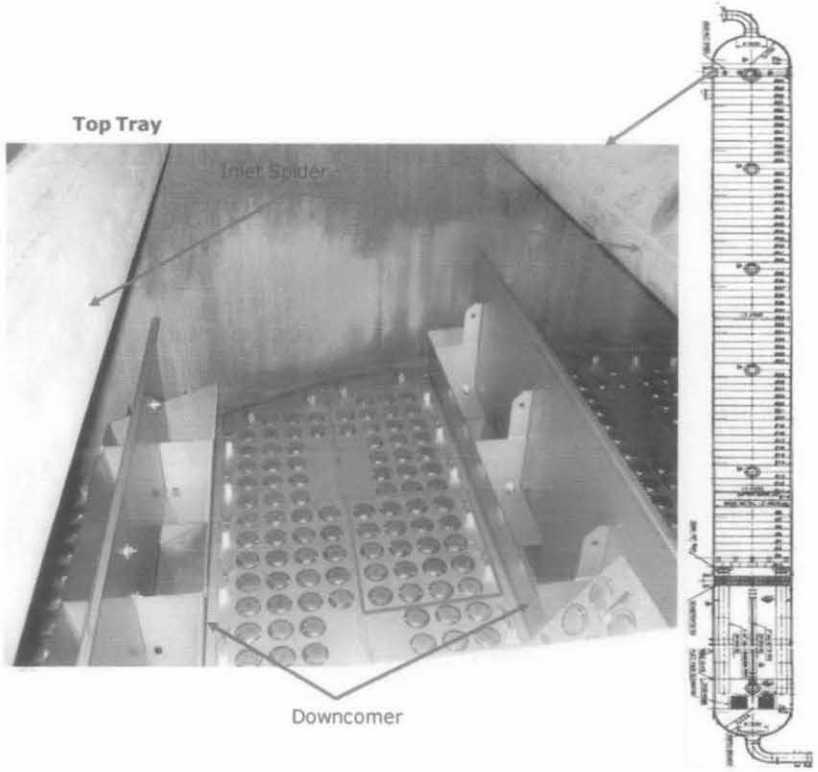

Figure 2.12: Top Tray

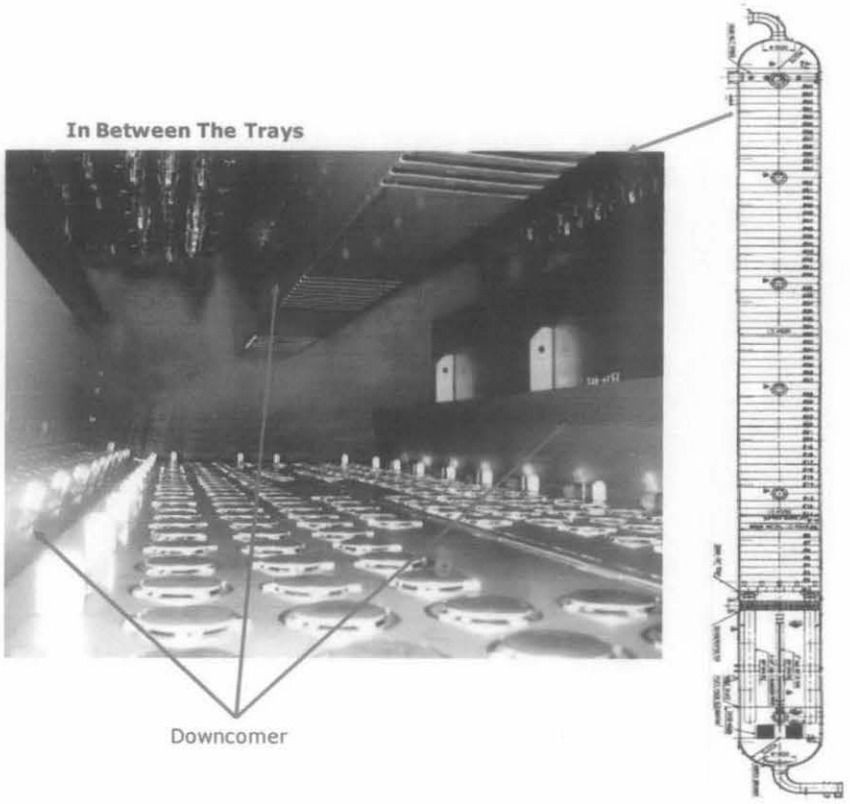

Figure 2.13: Downcomer

The Trays and "Caps"

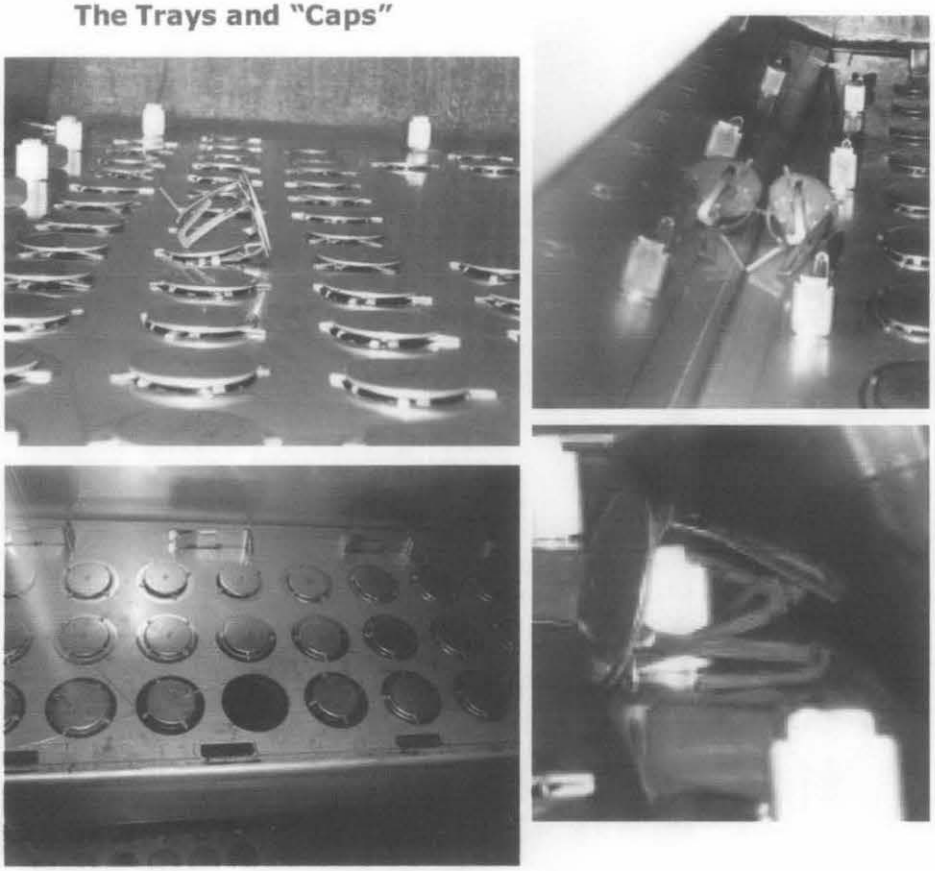

Figure 2.14: Tray valve caps

The Bottom Part

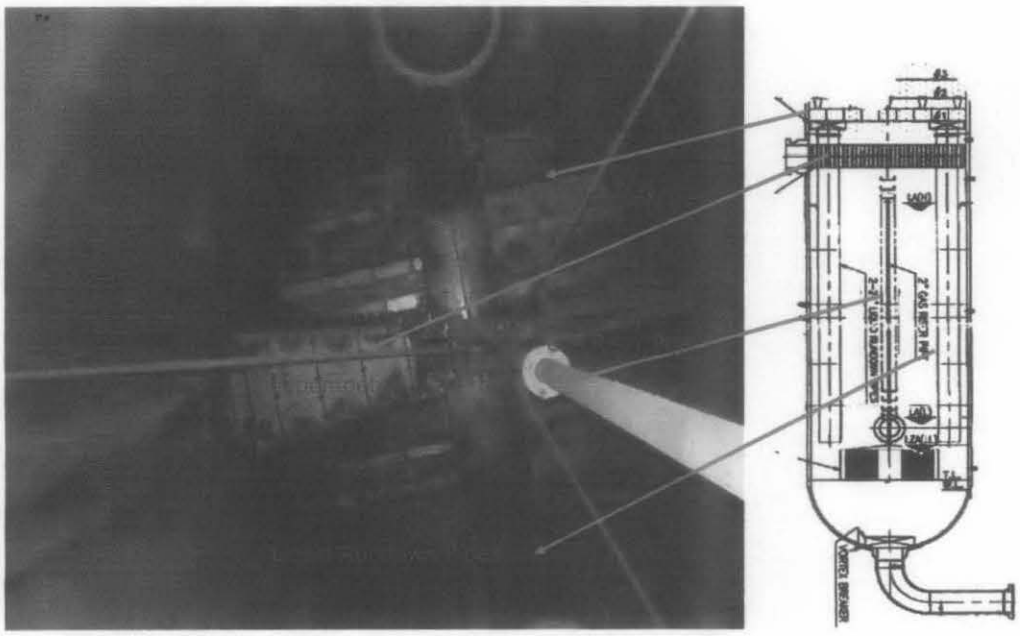

Figure 2.15: Column bottom view

Types of tray valves

Floating valve trays are typically used in basic applications where higher turndown ratios are required. Due to their ability to control vapor flow, they provide a higher sustained efficiency over a wider operating range than sieve trays.

Smaller valves provide more capacity than larger ones due to reduced pressure drop and entrainment rate.

Figure 2.16: BDH Trays

Figure 2.17: Round Valve Trays

Figure 2.18: Snap-in Valve Trays

Figure 2.19: Cages Valve Trays

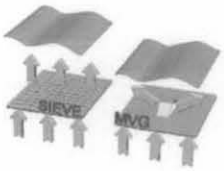

Figure 2.20: Fixed Valves

2.7 GAS ABSORPTION SOLVENT

2.7.1 Physical solvent – Sulfinol (DIPA)

Absorption in a physical solvent relies on the solubility of CO2 in the solvent rather than a chemical reaction with the solvent.

MLNG Sulfinol-D process is a regenerative absorption process for the removal of H2S, CO2, COS, CS2, mercaptans and organic sulphides and disulphides from gases. Aromatics, such as Benzene, Toluene and Xylene will be absorbed as well.

Sulfinol is a mixed solvent, consisting of di-isopropanolamine (DIPA), sulfolane (tetra hydrothiophene-dioxide) and water.

Chemistry of the Process

The acid gases react with DIPA according to the reactions, supplemented by the physical solubilities of the gases in the sulfolane, as shown below.

The overall reaction equations, in which R denotes the isopropanol group (CH3-CHOH-CH2), can be represented as follows:

- H_2S-ABSORPTION

$$H_2S + R_2NH = HS^- - R_2NH_2^+$$

- CO_2-ABSORPTION

$$CO_2 - 2R_2NH = R_2NCOO^- - R_2NH_2^+$$

carbamate ate

$$CO_2 - H_2O - R_2NH = HCO_3^- + R_2NH_2^+$$

carbonate

- COS-ABSORPTION

$$COS - 2R_2NH = R_2NCOS^- - R_2NH_2^+$$

thiocarbamate

The equilibrium of reactions shifts to the right hand side of the equations, removal of the impurities from the gas, at low temperature and high pressures.

At high temperatures and low pressures, as applied in the regenerator, the equilibrium is shifted to the left hand side of the reaction, resulting in the removal of the acid gases from the solvent.

2.7.2 Chemical solvent – Ucarsol (MDEA)

With chemical solvents, the absorption primarily depends on chemical reactions between the solvent and CO2. Post capture, heat is required to release the CO2 and regenerate the solvent.

UCARSOL AP 814 is used in a regenerative absorption process for the removal of H_2S, CO_2, and organic sulfur compounds from gases. UCARSOL AP 814 is an aqueous MDEA-based solvent, which contains a proprietary amine mixture for accelerated and efficient removal of the above compounds.

a. H_2S-absorption

$$H_2S + R_2NCH_3 = HS + R_2NH + CH_3$$

The presently designed MLNG Dua Module 5 amine system when operating with UCARSOL AP 814 has the capability to reduce the CO_2 and H_2S content of the natural gas feed from greater than 6.5 mol% CO_2 and 300 ppm mol H_2S to less than 50 ppm mol CO_2 and 3.3 ppm mol H_2S maximum, respectively, in the treated natural gas. The flash gas ex V-2101, going to LP fuel, will meet the present maximum of 200 ppm mol H_2S.

b. CO_2-absorption

1. $$CO_2 + H_2O = H_2CO_3$$

2. $$H_2CO_3 + R_2NCH_3 = HCO_3 + R_2NH + CH_3$$

The equilibrium of the above reactions shifts to the righthand side of the equations (removal of the impurities from the gas) at low temperature and high pressures. At high temperatures and low pressures (as applied in the regenerator) the equilibrium is shifted to the left hand side of the reaction, resulting in the removal of the acid gases from the solvent.

2.8 FOAMING ROOT CAUSE ANALYSIS

The flowchart below describes the root cause analysis for foaming incidents in MLNG. The hydraulics incompatibility is seen to be the most likely cause of this problem. As ineffective antifoam injection could also be a cause, consultation has been done with MLNG Technical Department that a higher chance of the foaming is due to the hydraulics.

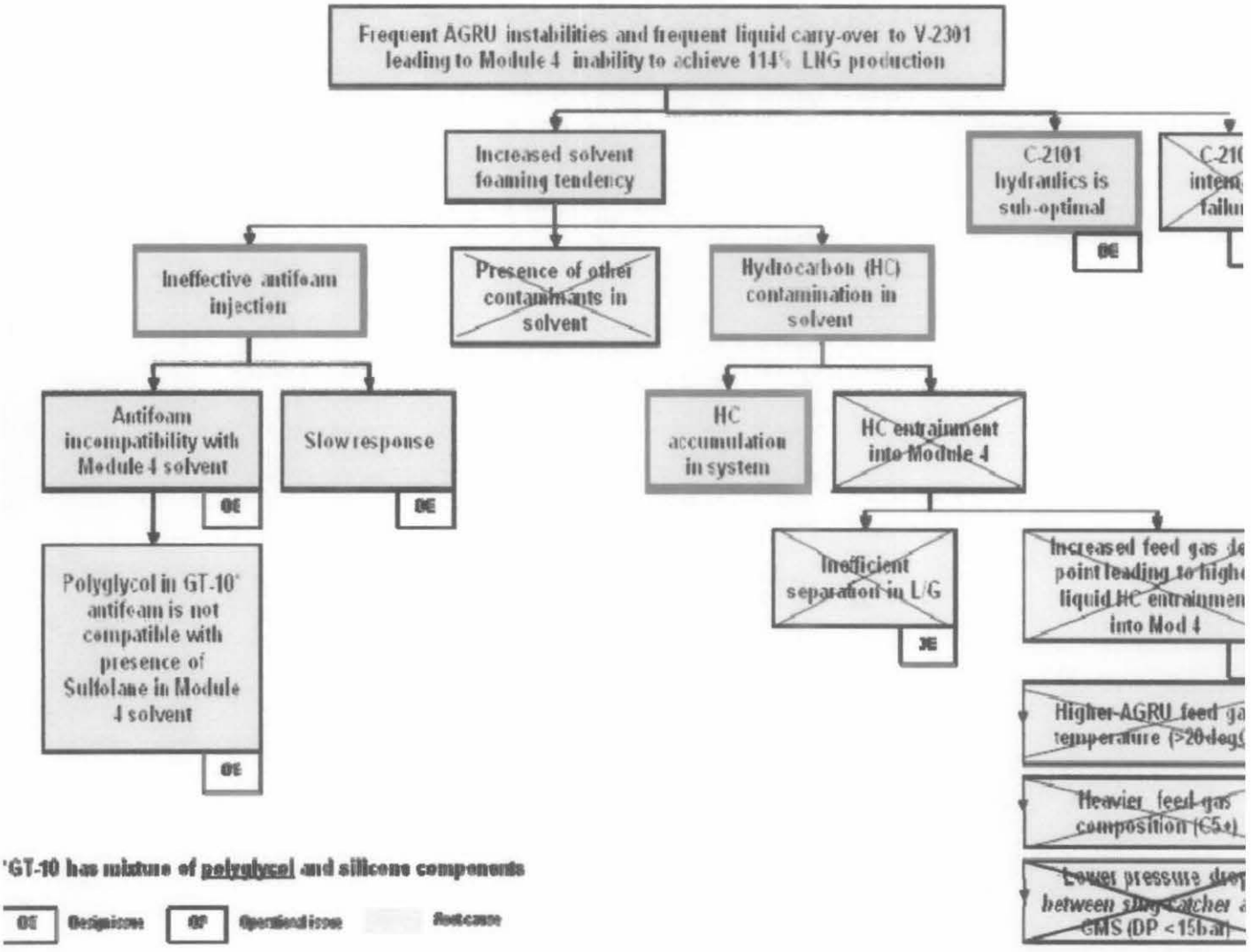

Figure 2.21: Root cause analysis

CHAPTER 3

METHODOLOGY / PROJECT WORK

3.1 PROCEDURE IDENTIFICATION

Generally, this project involves 5 main phases, which are shown below:

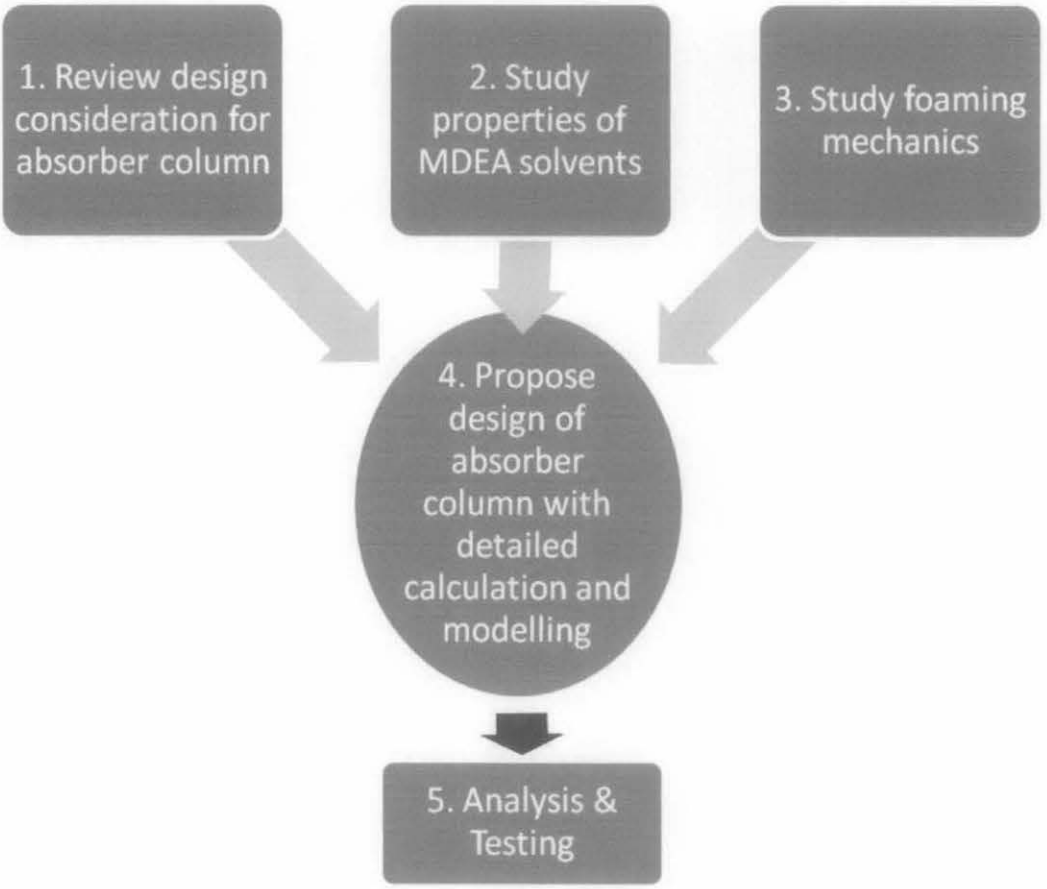

Figure 3.1: Methodology

Tray Column Design Procedure

A trial and error approach is necessary in plate design; starting with a rough plate layout, checking key performance factors and revising the design, as necessary, until a satisfactory design is achieved. The following design procedure is carried out;

1. The maximum and minimum vapour and liquid flowrates is calculated for the required turndown ratio.
2. The system physical properties is collected and/or estimated.
3. A trial plate spacing is selected. (Previous column design tray spacing)
4. The column diameter is estimated based on the flooding considerations.
5. A trial plate layout is made; downcomer area, active area, hole area, hole size, weir height.
6. Weeping rate is checked, if unsatisfactory step 5 is repeated.
7. Plate pressure drop is check, if too high step 5 is repeated.
8. Downcomer backup is checked, it too high step 5 and 3 is repeated.
9. Plate layout details are decided; calming zones, unperforated areas.
10. The percentage flooding is recalculated based on the chosen column diameter.
11. Entrainment is checked, if too high step 4 is repeated.
12. Step 3 to 12 are repeated to find optimum design values of the weir height and tray spacing to avoid foaming.

3.2 TOOLS REQUIRED

- **UCARSOL properties datasheet**
- **MLNG 2 Absorber current design datasheet**
- **Excel Spreadsheet**

3.2.1 GANTT CHART

For this project, the workloads are divided equally between FYP1 and FYP 2. The project activities and the key milestones for FYP 2 are as in Gantt Chart next page. For FYP 1, the project activities are more to research and data collection base to create a good project ground. After research stage, the calculation and modeling work is done in FYP 2.

No.	Detail/ Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14	15	16	17	18	19	20
1	Excel Spreadsheet Modeling of Column Hydraulics	●	●	●							Mid-Semester											
2	Analysis of results from model				●																	
3	Submission of Progress Report I				●																	
8	Analysis of proposed design								●													
13	Submission of Progress Report 2 (Draft Final Report)												●									
14	Poster Exhibition / Pre EDX													●								
15	Submission of Dissertation (soft bound)															●						
16	Final Oral Presentation																			●	●	
17	Submission of Project Dissertation (Hard Bound)																					●

Table 3.1: Gantt chart

CHAPTER 4

RESULTS AND DISCUSSIONS

The following calculation of the Excel spreadsheet modeling for the column design is done to determine optimum weir and downcomer height as well as tray spacing. Following the visit to MLNG for data gathering these values are to be obtained for the design data of the absorber column. Certain information is not allowed to be included here due to proprietary information agreement.

The table below shows the data acquired from the design book of MLNG Dua Acid Gas Absorber for the modeling purposes.

Operating Data	TOP	BOTTOM	OR TOP AND BOTTOM
TOWER INSIDE DIAMETER (mm)			4300
TRAY SPACE (mm)			500
TOTAL TRAYS			55
Internal Conditions at Tray Number			
VAPOUR TO TRAY			
RATE (kg/hr)	113.55	133.24	
DENSITY (kg/m^3)	39.52	47.38	
PRESSURE (bar)	50.3	51.15	
TEMPERATURE (°C)	44	71.9	
LIQUID FROM TRAY			
RATE (kg/hr)	315.35	333.25	
MASS DENSITY (kg/m^3)	1043.2	1079.1	
TEMPERATURE (°C)	44	71.9	
Technical/Mechanical Data			
Type of tray			Valve Tray (HiFi)
Tray thickness (mm)			2
Number of Calm. Sect. per tray			10
Width a top of weir (mm)			360
Weir height (mm)			150
Baffle height (mm)			330
Downcomer height (mm)			275
Required net free area (%)			9
Type of valve			Shell Snap-in
Number of valves per tray			1040

Table 4.1: Operating & Specification Data

Basis of Calculations in EXCEL Spreadsheet Model

The following shows the calculation steps used as functions in the EXCEL spreadsheet created to provide numerical relationship understanding between the parameters involved in the tray column design and possible modification to reduce foaming.

Physical properties

Top stage:

Molecular weight = 18.40

Liquid mass flow rate, L_W = 315.35 kg/s

Vapour mass flow rate, V_W = 113.55 kg/s

Vapour rate, V = $\frac{113.55 \, x \, 3600}{18.40}$

= 22206.52 kmol/h

Pressure = 50.3 bar ga

Temperature = 44 °C

Vapour Density, ρ_V = 39.52 kg/m^3

Liquid Density, ρ_L = 1043.2 kg/m^3

Surface Tension = 47 dyne/cm

= 47 x 0.001

= 4.7×10^{-2} N/m

Bottom stage:

Molecular weight = 20.08

Liquid mass flow rate, L_W = 333.25 kg/s

Vapour mass flow rate, V_W = 133.24 kg/s

Vapour rate, V = $\frac{133.24 \, x \, 3600}{20.08}$

= 23887.65 kmol/h

Pressure = 51.15 bar ga

Temperature = 71.9 °C

Vapour Density, ρ_V = 47.38 kg/m^3

Liquid Density, ρ_L = 1079.1 kg/m^3

Surface Tension = 42 dyne/cm

= 42 x 0.001

= 4.2 x 10^{-2} N/m

Column Diameter

The liquid-vapour flow factor F_{LV} formula is given by:

$$F_{LV} = \frac{L_W}{V_W}\sqrt{\frac{\rho_V}{\rho_L}}$$

Where

L_W = liquid mass flow-rate, kg/s

V_W = vapour mass flow-rate, kg/s

To calculate the column diameter,

Top stage:

$$F_{LV}\ \text{top} = \frac{315.35}{113.55}\sqrt{\frac{39.52}{1043.2}}$$

$$= 0.52$$

$$F_{LV}\ \text{bottom} = \frac{333.25}{133.24}\sqrt{\frac{47.38}{1079.1}}$$

$$= 0.54$$

Appropriate Tray Spacing from Excel Modelling iteration is found to be 0.6m

The K factor formula is given by:

$$K = C_{sb}\left(\frac{\sigma}{20}\right)^{0.2} C_{FF}C_{HA}$$

Where;

σ = surface tension

C_{sb} = capacity factor (refer Figure 2.8)

C_{FF} = foaming factor

C_{HA} is based upon the ratio of the vapor hole area A_h to the tray active area, A_a.

$$C_{HA} = 1.0 \qquad \text{for } A_h/A_a \geq 0.10$$

$$C_{HA} = 5(A_h/A_a) + 0.5 \qquad \text{for } 0.06 \geq A_h/A_a \leq 0.10$$

From iterations of the Excel Absorber Modeling Spreadsheet; Tray Spacing = 0.6m

Hence, $C_{sb} = 0.4$

From the MLNG Dua Absorber Design Book; Tray calming section area = 38%

Hence, $C_{HA} = 1.0$

From Ucarsol Properties Sheet; Foaming Factor $C_{FF} = 0.73$

$$\text{Top } K_1 = 0.4\left(\frac{0.047}{20}\right)^{0.2}(0.73)(0.1)$$

$$= 0.087$$

$$\text{Bottom } K_1 = 0.4\left(\frac{0.042}{20}\right)^{0.2}(0.73)(0.1)$$

$$= 0.085$$

Correction for surface tensions

The Corrected K factor formula is given by:

$$\text{Corrected } K_1 = \left(\frac{\sigma}{0.02}\right)^{0.2} 0.087$$

$$\text{Top Corrected } K_1 = \left(\frac{0.047}{0.02}\right)^{0.2} 0.087$$

$$= 0.1032$$

$$\text{Bottom Corected } K_1 = \left(\frac{0.042}{0.02}\right)^{0.2} 0.085$$

$$= 0.0985$$

Flooding velocity

The Flooding Velocity formula is given by:

$$u_f = K_1\sqrt{\frac{\rho_L - \rho_V}{\rho_V}}$$

Where

u_f = flooding vapour velocity, m/s, based on the net column cross-sectional area A_n

K_1 = a constant known as the K factor, previously calculated

Top u_f = $0.1032\sqrt{\frac{1043.2 - 39.52}{39.52}}$

= 0.52 m/s

Bottom u_f = $0.0985\sqrt{\frac{1079.1 - 47.38}{47.38}}$

= 0.46 m/s

Designing for 85% flooding at maximum flow rate:

Top $\perp_v$ = 0.52x 0.85

= 0.442 m/s

Bottom $\perp_v$ = 0.46 x 0.85

= 0.391 m/s

Maximum volumetric flow rate, V_v:

$$\text{Top} = \frac{(22206.52)(18.40)}{(39.52)(3600)}$$

$$= 2.872\ m^3/s$$

$$\text{Bottom} = \frac{(23887.65)(20.08)}{(47.38)(3600)}$$

$$= 2.812\ m^3/s$$

Net area required

The net area required formula is given by:

$$\text{Net Area Required} = \frac{Vv}{Corrected, uf}$$

$$\text{Top} = \frac{2.87}{0.442}$$

$$= 6.50\ m^2$$

$$\text{Bottom} = \frac{2.81}{0.391}$$

$$= 7.18\ m^2$$

Downcomer area as 38% of total (from design book)

Column cross-sectional area

$$\text{Column cross sectional area} = \frac{Net\_Area}{1 - Downcomer\_Area}$$

$$\text{Top} = \frac{6.5}{0.62}$$

$$= 10.48\ m^2$$

$$\text{Bottom} = \frac{7.18}{0.62}$$

$$= 11.59\ m^2$$

Column diameter:

$$\text{Top} = \sqrt{\frac{(10.48)(4)}{\pi}}$$

$$= 3.65\ m$$

$$\text{Bottom} = \sqrt{\frac{(11.59)(4)}{\pi}}$$

$$= 3.84\ m$$

Using the same diameter above and below feed, reducing the perforated are for plates above the feed.

Provisional Plate Design

Column diameter, D_C	=	4.4 m
Column area, A_C	=	15.21 m^2
Downcomer area, A_d	=	0.38 x 15.21
	=	5.78 m^2
Net area, A_n	=	15.21 – 5.78
	=	9.43m^2
Active area, A_a	=	15.21 – (2 x 5.78)
	=	3.65 m^2
Hole area, A_h take 11% A_a	=	0.40 m^2
Weir length, l_W	=	1.2 x 4.4
	=	3.56 m
Taking weir height, h_w	=	170 mm
Hole diameter	=	25 mm
Plate thickness	=	2 mm

Weeping check

Maximum liquid rate	=	333.3 kg/s
Minimum liquid rate at 70% turn-down		
	=	0.7 x 333.3
	=	233.3 kg/s

For a segmental downcomer, the liquid crest over the weir can be written as:

$$h_{OW} = 750\left[\frac{L_W}{\rho_L l_W}\right]^{2/3}$$

Where

l_W = weir length, m.

h_{OW} = weir crest, mm liquid.

L_W = liquid flow-rate, kg/s.

Maximum h_{OW} = $750\left[\frac{333.3}{(1079.1)(3.56)}\right]^{2/3}$

= 147 mm liquid

Minimum h_{OW} = $750\left[\frac{233.3}{(1079.1)(3.56)}\right]^{2/3}$

= 116 mm liquid

At minimum rate = $h_W + h_{OW}$

= 170 + 116

= 286 mm

From Figure 11.30 (1, p. 571)

$K_2 = 30.7$

The minimum design vapour velocity is given by:

$$\breve{u}_h = \frac{[K_2 - 0.90(25.4 - d_h)]}{(\rho_V)^{1/2}}$$

Where

$\breve{u}_h$ = minimum vapour velocity through the holes (based on the hole area), m/s

d_h = hole diameter, mm.

K_2 = a constant, dependent on the depth of clear liquid on the plate, obtained from Figure 11.30 (1, p. 571)

$$u_h(\min) = \frac{30 - 0.9(25.4 - 25)}{(47.38)^{1/2}}$$

$= 4.31$ m/s

$$\text{Actual minimum vapour velocity} = \frac{\min imum\ vapour\ rate}{A_h}$$

$$= \frac{(0.7)(2.81)}{0.40}$$

$= 4.90$ m/s

So, minimum operating rate will be above weep point.

Although the actual minimum velocity is not very significantly above the weep point, with the use of Shell HiFi Trays (Multidowncomer Trays) will improve this condition.

Plate pressure drop

Maximum vapour velocity through holes = $\frac{2.81\,m^3/s}{0.40\,m^2}$

= 7.00 m/s

Plate thickness/hole diameter = 2 mm/40mm = 0.05

Hole area/Perforated area ≈ Hole area/Active area = 0.08

C_0 = 0.88 [2, p. 573]

Pressure drop through dry plate

$$= 51\left(\frac{7.00 m/s}{0.88}\right)^2\left(\frac{47.38\,kg/m^3}{1079.1\,kg/m^3}\right)$$

= 142 mm

Residual head = $\frac{12.5 \times 10^3}{1079.1\,kg/m^3}$

= 12 mm

Total plate pressure drop

= 142 mm + (170 mm + 147 mm) + 12 mm

= 470 mm

Downcomer Liquid Back-up

Downcomer pressure loss

Take h_{ap} = h_W - 10

= 160 mm

Area under apron

$$A_{ap} = h_{ap} \; x \; l_W$$

A_{ap} = $3.56 \times 190 \times 10^{-3}$

= $0.57 \; m^2$

Pressure drop in downcomer

$$h_{dc} = 166\left[\frac{L_{wd}}{\rho_{l A_m}}\right]^2$$

Where

L_{wd} = liquid flow rate in downcomer, kg/s

A_m = either the downcomer area A_d or the clearance area under the downcomer A_{ap}; whichever is small, m^2

h_{dc} = $166\left[\frac{333.3}{(1079.1)(0.68)}\right]^2$

= 49 mm

The downcomer back-up is given by:

$$h_b = (h_W + h_{OW}) + h_t + h_{dc}$$

Where

h_b = downcomer back-up, measured from plate surface, mm.

h_{dc} = head loss in the downcomer, mm.

h_b = (170 + 147) + 470+ 49

= 836 mm

Entrainment check

Superficial vapour velocity = $\frac{2.81\,m^3/s}{9.43\,m^2}$

= 0.298m/s

Flooding at superficial vapour velocity = $\frac{0.298\,m/s}{0.461\,m/s}$

= 65%

This value is below the assumed value of 85%. Therefore, the calculations are acceptable.

Fractional entrainment = 0.025 [1, p. 524]

Since the value is well below 0.1, the effect of entrainment on plate efficiency is small [1, p. 524].

Checking Residence Time

$$t_r = \frac{A_d h_{bc} \rho_L}{L_{wd}}$$

Where

t_r = residence time, s

h_{bc} = clear liquid back-up, m

$$t_r = \frac{(5.78)(836)(1079.1)}{333.3}$$

= 15.64 s

Perforated Area

From Figure 11.32 (1, p. 573), at l_w/D_c = 1.05/1.3

= 0.81

θ_c = 108^o

Angle subtended at plate edge by unperforated strip = 180-108

= 72^o

Mean length, unperforated edge strips = (4.4x 0.05)π(72/180)

= 5.47 m

Area of unperforated edge strips = 0.05 x 5.47

= 0.27 m^2

Mean length of calming zone = (4.4 - 0.1) x Sin(108/2 x π/2)

= 3.48 m

Area of calming zone = 2 x 3.48 x 0.1

= 0.7 m^2

Total area for perforations, A_p = 3.65-0.27-0.7

= 2.68 m^2

A_h/A_p = 0.29/2.68

= 0.11

From Figure 11.33 (1, p. 574)

l_p/d_h = 2.4

Number of Holes

Area of one hole = $[\pi \times (25/1000)^2]/4$

= 0.004911 m^2

Number of holes = $\frac{0.40}{0.0004911}$

= 818

The following is the tabulated designed data computed using the Excel Spreadsheet Model using the basis of calculation shown on the previous pages. Trial and error approach is done to acquire the desired design values.

Flow rates and physical properties

	Top (at Tray 1)	Bottom (at Tray 52)
Maximum vapour flow rate, V_w (kg/s)	113.55	133.24
Maximum liquid flow rate, L_w (kg/s)	315.35	333.25
Vapour density, r_V (kg/m^3)	39.52	47.38
Liquid density, r_L (kg/m^3)	1043.20	1079.10
Surface tension, s (N/m)	0.0470	0.0420

Table 4.2: Flow rates and physical properties

Column diameter

	Top (at Tray 1)	Bottom (at Tray 52)
Liquid-vapour flow factor, F_{LV}	0.54	0.52
Plate spacing (m)	0.550	0.550
K_1	0.087	0.085
Corrected K_1	0.103	0.099
Flooding velocity, u_f (m/s)	0.520	0.461
Flooding at maximum flow rate (%)	85.00	85.00
Corrected u_f (m/s)	0.442	0.391
Maximum vapour flow rate, V_v (m^3/s)	2.87	2.81
Net area required (m^2)	6.50	7.18
Downcomer area (% of total)	38	38
Minimum column cross-sectional area (m^2)	10.48	11.59
Minimum column diameter (m)	3.65	3.84
Selected column diameter, D_c (m)	4.40	4.40

Table 4.3: Column diameter

Provisional plate design

Column diameter, D_c (m)	4.40
Column area, A_c (m^2)	15.21
Downcomer area, A_d (m^2)	5.78
Net area, A_n (m^2)	9.43
Active area, A_a (m^2)	3.65
Hole area, A_h (=8% of A_a) (m^2)	0.29
Weir length, l_w (m)	3.56
Weir height, h_w (mm)	200
Hole diameter, d_h (mm)	40.00
Plate thickness (mm)	2.00

Table 4.4: Provisional plate design

Weeping check

Maximum liquid flow rate, L_w (kg/s)	333.3
Turn-down (%)	70
Minimum liquid flow rate (kg/s)	233.3
Maximum weir crest, h_{ow} (mm)	147
Minimum weir crest, h_{ow} (mm)	116
$h_w + h_{ow}$ at minimum liquid flow rate (mm)	316
K_2	30.0
Minimum vapour velocity through holes, u_h (m/s)	6.27
Actual minimum vapour velocity (m/s)	6.74

Table 4.5: Weeping check

Plate pressure drop

Maximum vapour velocity through holes, u_h (m/s)	9.63
C_0	0.88
Pressure drop through dry plate, h_d (mm)	268
Residual head, h_r (mm)	12
Total pressure drop, h_t (mm)	627
Total pressure drop, h_t (Pa)	6632

Table 4.6: Plate pressure drop

Downcomer liquid back-up

Clearance height under downcomer, h_{ap} (mm)	195
Area under apron, A_{ap} (m^2)	0.69
Pressure drop in downcomer, h_{dc} (mm)	33
Back-up in downcomer, h_b (mm)	1006
Plate spacing + Weir height	0.75
h_b/(Plate spacing + Weir height)	1.34
Residence time, t_r (s)	18.83

Table 4.7: Downcomer liquid back-up

Entrainment check

Superficial vapour velocity, u_n (m/s)	0.298
Flooding (%)	65

Table 4.8: Entrainment check

Perforated area

q_c (°)	109
Angle subtended at plate edge by unperforated strip (°)	71
Mean length of unperforated edge strips (m)	5.39
Area of unperforated edge strips (m^2)	0.27
Mean length of calming zone (m)	3.50
Area of calming zone (m^2)	0.70
Total area of perforations, A_p (m^2)	2.68
A_h/A_p	0.11
l_p/d_h	2.40
Pitch length, l_p (mm D)	12.0

Table 4.9: Perforated area

Number of holes

Area of one hole (m^2)	0.0012571
No. of holes	232

Table 4.10: Number of holes

The following design modifications are proposed to avoid foaming by taking into consideration of the lower foaming factor of Ucarsol;

1. Tray spacing: +15%
2. Weir height: +15%
3. Downcomer height: -10%
4. No. of tray holes: -10%
5. Hole Diameter: -30%
6. Hole Area: +3%

Design calculation redone with above changes are proven to be feasible in avoiding other tray operating failures; weeping; entrainment; flooding.

Valve Cap Type; the current snap-in calve cap is also proposed to be changed to round type for its higher strength to avoid cap displacement due to higher pressure drop in the new design.

Figure 4.1: Snap-in Valve cap (Current type)

Figure 4.2 Round Valve cap (Proposed)

Modification Justifications

Figure 4.3 - Absorber Tray Hydraulics

Tray Spacing

The increased tray spacing of +15% will create a higher pressure drop between trays in the absorber column. This will prevent the formation of the bubbles, breaking it before it turns creates froth.

Weir height

The increase in weir height is done to compensate for the lower numbers of trays. Having increased tray spacing in the same column requires the total number of tray in the column to be reduced for maintaining the same height. Hence, this loss is countered by increasing the liquid gas contact by adding the weir height.

Downcomer height

To accommodate the higher liquid flow through the down comer due to increased weir height, the downcomer height is reduced. This is done to avoid jet flooding. Moreover, it provides a better flow of froth incase of foaming thus disrupting the foam as it flows downwards.

No. of tray holes, Hole Diameter, & Hole Area

During the modeling of the absorber column design modification, weeping is noted to happen with the increased liquid volume over the tray as the weir height is increased. Therefore, a slight modifications on total hole numbers, hole diameter and area is done to reduce weeping tendency.

By comparing this modification with the literature review done, the proposed design is seen to be feasible to avoid foaming. As suggested in literature review, the foaming factor is incorporated into the design and is foreseen using the vapour flooding flowrate. This is how the modification done is proved to ensure success in a robust absorber performance avoiding severe foaming problems being encountered in MLNG currently.

Economics consideration of proposed tray change

Tray hydraulics change cost is estimated to be at RM 1 million including a module downtime of about 30 days. However, foaming has caused a much severe lost in production (approximately RM 500 million) and also equipment damage (heat exchanger tubes) which had lead to downtime. Hence it is a more economical approach to consider the tray change to avoid grater losses in the long term.

MLNG Dua Debottlenecking (MDD) production target

The MLNG DUA Debottlenecking (MDD) Project is a plant change project carried out for the purpose of increasing each train's production capacity from 100% (Design) to 121.4 %(Post MDD). Therefore, the total production capacity of DUA is targeted to increase from 7.8 mtpa to 9 mtpa Post MDD.

Moreover it is also vital to avoid decrease of production due to higher Acid Gas content in future feed gas. Ucarsol is introduced here to be used as the Acid Gas Removal Unit solvent replacing the current solvent, Sulfinol. Ucarsol is favoured as it has a significant higher absorption capacity of the acid gas compared to Sulfinol. This is to ensure that the Post MDD production capacity can be achieved. Again it is seen here, that to achieve this target the tray change is seen to be vital for the efficient usage of Ucarsol an MDEA solvent.

CHAPTER 5

CONCLUSION

The Excel model gives an understanding on the tray hydraulics numerical relationship and is a quantitative approach to estimate the appropriate designs specification for the column internals (weir height, downcomer height, tray spacing and other possible parameters). From this modeling the vapor flooding point is the key reference point to predict foaming occurrence.

From the above results, it can be concluded that the hydraulics modification proposed (increase of tray spacing & weir height, decrease of downcomer height and number of tray holes) to avoid MDEA solvent (Ucarsol) foaming, is proven to be feasible as well to avoid other tray operating failures; weeping; entrainment; flooding.

Further investments are mandatory in order to make Ucarsol and/or other alternative solvent robust for higher production capacity.

RECOMMENDATION

Due to time constrain the study of this project was done on a conceptual model only. In future, this same study could be done on an experimental model where the tray column hydraulics can be tested for its performance. The experimental model can then further quantify and verify the difference obtained here.

In addition, different type of acid gas absorption solvent can also be tested with for its compatibility. A solvent with a higher foaming factor would be preferred for use with the current MLNG Dua's Absorber. It is recommended that the tray hydraulics compatibility check is done before the solvent change as foaming risks may cost expensive downtime and further damage equipments

As heavy hydrocarbon can also be a cause for foaming to occur, it will be benefiting to install an activated carbon filter to remove the heavies dissolved in the solvent to avoid froth formation.

Moreover, antifoam dosage and component has to be regularly be revised for changes in the gas feed do that it does not induce any adverse effect.

Regular change of Ucarsol solvent can also assist in foaming prevention. This is as used and contaminated Ucarsol (dissolved hydrocarbon) are prone to foam.

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APPENDIX 1

The following pages show the physical properties of Ucarsol (MDEA Solvent)

UCARSOL™ AP 814 Solvent
For CO_2 Removal

Introduction

UCARSOL™ AP 814 solvent is one of The Dow Chemical Company's series of advanced-performance gas treating solvents. Specifically designed for carbon dioxide (CO_2) removal in natural and synthesis gas processing, UCARSOL AP Solvent 814 is effective in both sweet and sour gas streams.

Low heats of reaction, combined with the ability to remove both CO_2 and H_2S, allow the gas processor to conform to current environmental regulations concerning sulfur emissions, while meeting product gas BTU specifications. UCARSOL AP Solvent 814 is particularly useful for processing feed gas with high amounts of carbon dioxide. It performs well in cryogenic applications with low CO_2 product gas specifications.

Special Features

UCARSOL AP 814 solvent offer these important advantages versus generic gas treating solutions.

- Significant energy savings through reduced reboiler duty, decreased pumping requirements because of lower solvent circulation, and elimination of the need for solvent reclaiming.
- Reduced solvent losses because of low foaming tendency and lower solvent vapor pressure.
- Increased acid gas processing ability with existing facilities.
- Local technical support and complete solvent services available to assure ongoing trouble-free operation.
- Noncorrosive at 50 wt% use concentration.
- Supported by The Dow Chemical Company, the global leader in providing gas treating processors with specialized technology and services.

Corrosion Effects

The results of various heat transfer and laboratory corrosion tests on stainless steel and mild steels and actual field experience in numerous operating units indicate that solutions of UCARSOL AP 814 solvent, maintained properly and used as specified, exhibit virtually no corrosion! See "Storage and Handling" (page 6) for effects on other materials.

Gas Treating Services

Dow is the worldwide leader in providing gas treating processors with specialized technology and services. To aid in both plant design and operation, UCARSOL solvents are supported by advanced computer capabilities, state-of-the-art laboratory, field test equipment, analytical procedures, and an ongoing optimization program. The services Dow provides encompass preliminary assessments, start-up services, continual monitoring, and follow-up services. Included in this total support program are training for your people in the field, regular sample testing, and performance evaluation. To ensure complete customer protection and satisfaction, Dow is there every step of the way—before, during, and after installation.

Computer Capabilities

With information drawn from the actual operating conditions of over 350 plants, Dow has the largest formulated solvents database in the industry. Dow's sophisticated computer programs provide a powerful tool for process analysis and design, including tray-by-tray calculations. Hydraulic evaluations can be made of existing trayed or packed towers to ensure that conversion to UCARSOL solvents will be trouble-free.

Field representatives have laptop computers that can be taken into a customer's plant, making it possible to predict the performance of UCARSOL solvents under actual plant conditions. In addition to its use as an in-field preliminary design tool, the laptop computer is extremely valuable after conversion to make any adjustments necessary to optimize the process.

Laboratory and Field Testing

Dow's Analytical Services Laboratory performs regular service analyses of customer solvents to ensure good performance of the amine unit, as well as specialized analyses to assist in trouble-free operation. Among the routine analyses performed are ion chromatography, atomic absorption, and solution alkalinity. Specialized analyses include gas chromatography/mass spectroscopy, FTIR (Fourier Transform Infra Red), ICP (Inductively Coupled Plasma Spectroscopy), NMR (Nuclear Magnetic Resonance Spectroscopy), and x-ray fluorescence. Analyses are normally completed and reported to the customer within a few days. Dow's written report usually includes a technical service interpretation of the analytical results and their impact on the customer's operation.

Sample Kits

Dow offers a unique sample kit. Completely self-contained, the kit provides everything necessary—from containers to labels—to obtain lean amine samples, seal them, and safely ship them for routine analysis.

Other Services

Dow's engineering expertise is also available to provide information on process and equipment requirements, and Dow's corrosion group can assist in field inspections or set up corrosion-monitoring programs for customers. Also, Dow trains customer personnel prior to and during conversion and works with them to ensure optimum performance.

Physical Properties

UCARSOL AP 814 solvent can be used as aqueous solutions in various concentrations; however, a 50% aqueous solution has been found to offer the optimum performance. Physical property data for pure and 50% aqueous solutions of UCARSOL AP 814 solvent have been developed and are presented on the following pages.

Additional information on UCARSOL AP 814 solvent, its properties and advantages, is available on request. To explore more specifically what UCARSOL AP 814 solvent can do for your existing or proposed gas treating unit, contact Dow at the numbers listed on the back of this brochure.

Table 1 • Physical Properties of UCARSOL AP 814 Solvent

	Value
Average Weight per Gallon at 20°C, lb	8.73
Average Weight per Liter at 20°C, kg	1.05
D lb per Gallon/D at 20°C	0.00644
D kg per Liter/D at 20°C	0.00077
Coefficient of Thermal Expansion Per °C (est)	
at 20°C	0.00073
at 55°C	0.00078
Boiling Point, °C (°F)	
at 760 mm Hg	125.9 (258.6)
at 50 mm Hg	60.1 (141.1)
at 10 mm Hg	32.0 (89.7)
Pour Point, °C (°F)	-48 (-54.4)
pH at ambient conditions	11.2
Specific Gravity, 20°/20°C	1.0448
Solubility	
in Water at 20°C, weight percent	100
of Water in at 20°C, weight percent	100
Flash Point, °C (°F)	
Pensky-Martens Closed Cup, ASTM D93,	102 (215)
Cleveland Open Cup, ASTM D92	132 (270)

Table 2 • Physical Properties of 50 Percent by Weight Aqueous UCARSOL AP 814 Solvent

	Value
Boiling Point, °C (°F)	
at 760 mm Hg	103.6 (218.6)
at 50 mm Hg	41.3 (106.3)
at 10 mm Hg	14.6 (58.3)
Freezing Point, °C (°F)†	4.2 (39.5)
pH at ambient conditions	11.2
Specific Gravity, 20/20°C	1.04352
Solubility	
in Water at 20°C, weight percent	100
of Water in at 20°C, weight percent	100

†Slurry formation (two-phase freeze separation) may begin at 4°C (40°F). This slurry is pumpable down to -11°C (12°F) in most cases.

Figure 1 • Density of Aqueous UCARSOL AP 814 Solvent Solutions

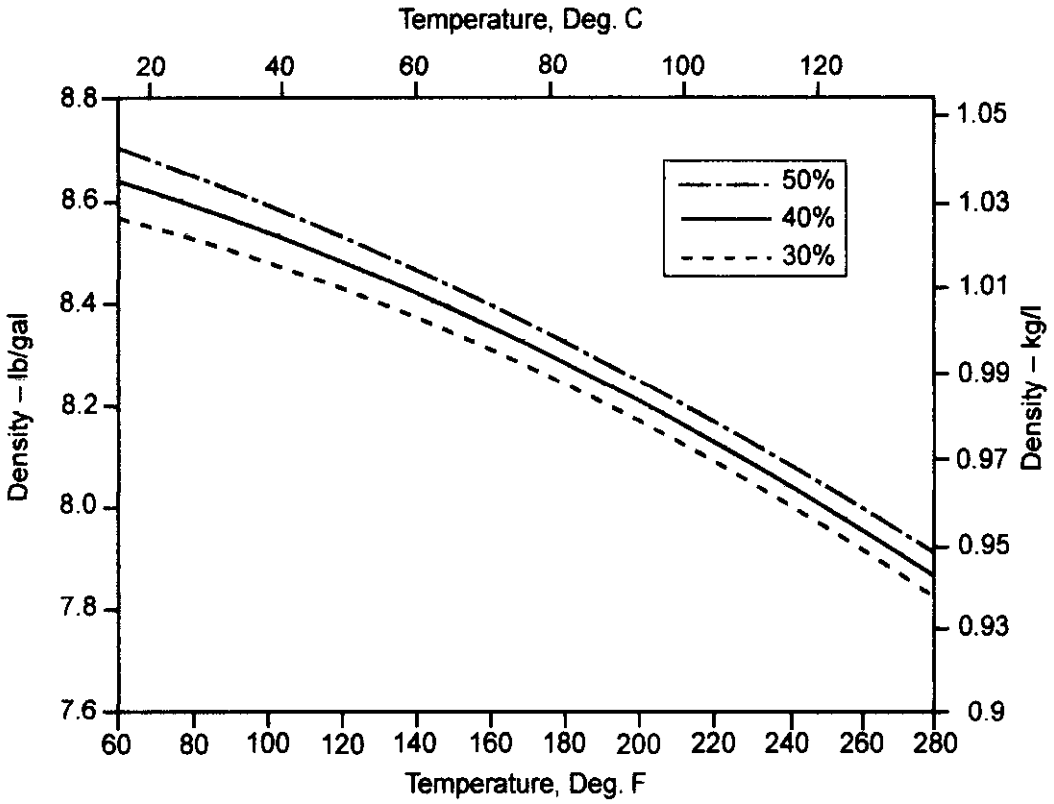


Figure 2 • Viscosity of Aqueous UCARSOL AP 814 Solvent Solutions

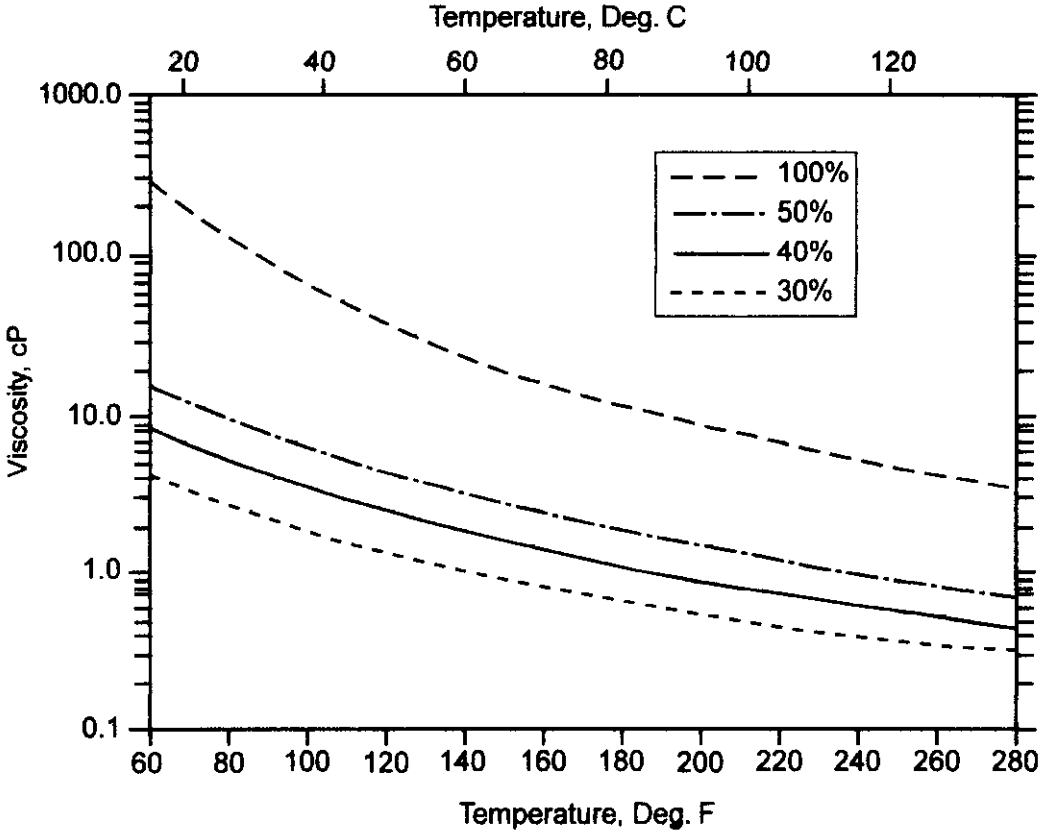


Figure 3 • Specific Heat of Aqueous UCARSOL AP 814 Solvent Solutions

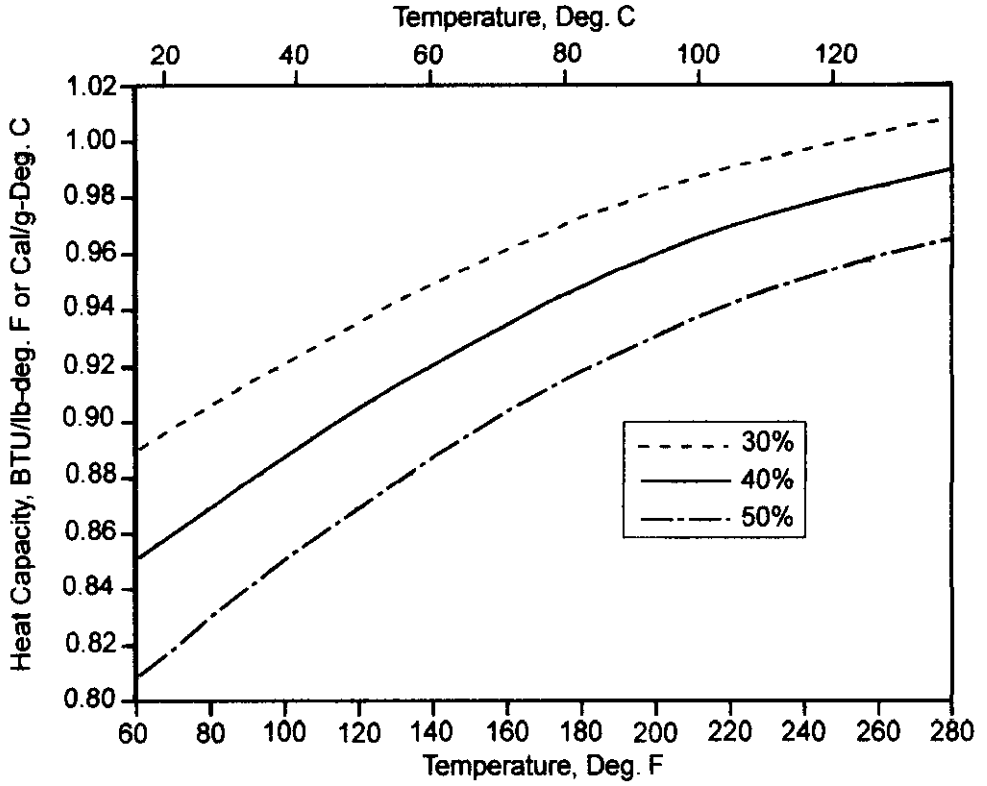


Figure 4 • Thermal Conductivity of Aqueous UCARSOL AP 814 Solvent Solutions

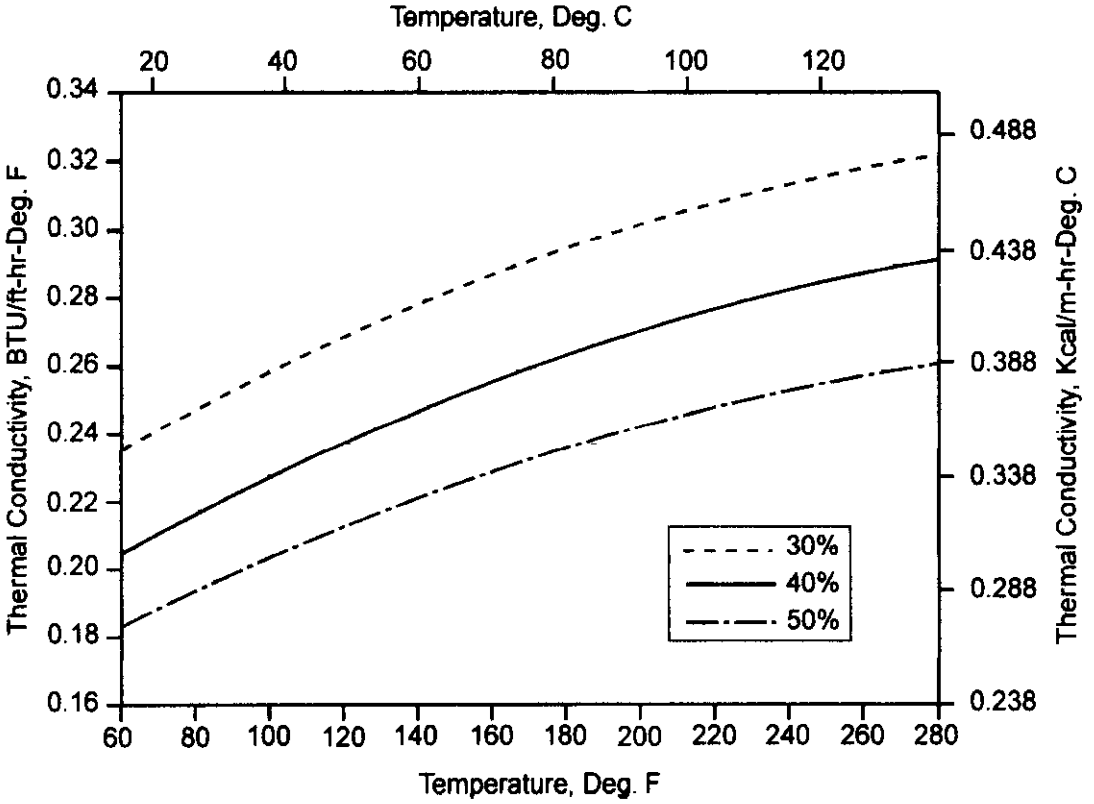
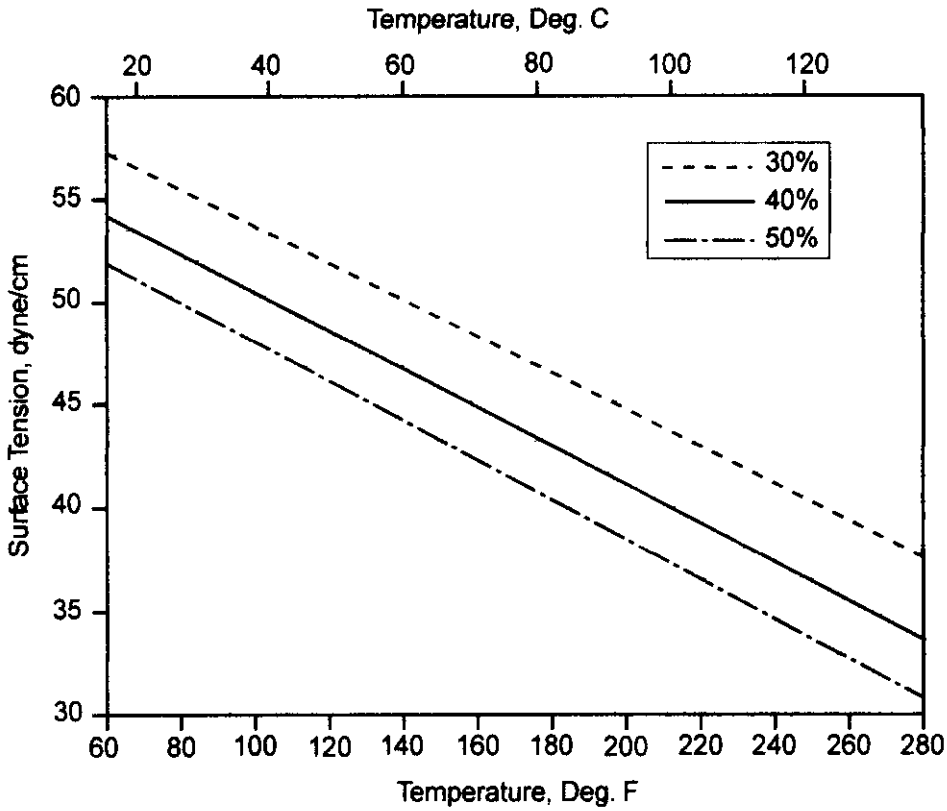


Figure 5 • Surface Tension of Aqueous UCARSOL AP 814 Solvent Solutions



Storage and Handling

UCARSOL AP 814 solvent is usually stored and handled in carbon steel equipment. It is also compatible with stainless steel. **Zinc or galvanized steel and copper and its alloys should not be used.**

This product becomes viscous at outside winter temperatures and has a pour point of -48°C (-54.4°F). Therefore, storage inside a warm building or in a heated, insulated tank may be desirable. A centrifugal pump is suitable for transfer service, assuming the temperature of the product is sufficiently above its pour point. A rotary or gear pump is suggested for lower temperature transfers.

Piping should be of adequate size to handle the maximum viscosity expected to be encountered. Valves, piping, etc., are usually of steel construction. Type 304 stainless steel, spiral wound GRAFOIL™ gaskets for flanges and GRAFOIL packing for valves is recommended.

Aqueous solutions of UCARSOL AP 814 solvent can be handled in steel equipment. They should **not** be handled or stored in contact with aluminum, zinc, or galvanized iron, or copper and its alloys.

Product Safety

When considering the use of any Dow products in a particular application, you should review Dow's latest Material Safety Data Sheets and ensure that the use you intend can be accomplished safely. For Material Safety Data Sheets and other product safety information, contact Dow at the numbers listed on the back of this brochure. Before handling any other products mentioned in the text, you should obtain available product safety information and take necessary steps to ensure safety of use.

No chemical should be used as or in a food, drug, medical device or cosmetic, or in a product or process in which it may contact a food, drug, medical device or cosmetic until the user has determined the suitability and legality of the use. Since government regulations and use conditions are subject to change, it is the user's responsibility to determine that this information is appropriate and suitable under current, applicable laws and regulations.

Dow requests that the customer read, understand, and comply with the information contained in this publication and the current Material Safety Data Sheet(s). The customer should furnish the information in this publication to its employees, contractors and customers, or any other users of the product(s), and request that they do the same.

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