REFERENCES

Warren, J.D., Daniel. (2004). Product & Process Design Principles. New York: John Wiley and Sons, Inc.

Edgar, Himmelblau, Lasdon. (2001). Optimization of Chemiacal Processes. New York: McGraw-Hill.

Douglas. (1998). Conceptual Design of Chemical Processes. New York: McGraw-Hill.

Kamm, Gruber, Kamm (Eds.) (2006). Biorefineries – Industrial Processes and Products, Volume 1. Weinhem, Germany: Wiley-VCH.

Kamm, Gruber, Kamm (Eds.) (2006). Biorefineries – Industrial Processes and Products, Volume 2. Weinhem, Germany: Wiley-VCH.

Biegler, Grossmann, Westerberg. (1997). Systematic Methods of Chemical Process Design. New Jersey: Prentice Hall PTR.

Fogler. (2006). Elements of Chemical Reaction Engineering. Massachusetts: Prentice Hall PTR.

APPENDICES

Appendix A PROII Results File of Column T-103 and T-101

SIMULATION SCIENCES INC.	R	PAGE H-1
PROJECT Biodiesel	PRO/II VERSION 5.61	386/EM
PROBLEM Column	CALCULATION	Tran
	HISTORY	01/26/08

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UNIT 17, 'COLUMN-T103', 'Purify B100 Column'

TOTAL NUMBER OF ITERATIONS

CHEM METHOD 11

COLUMN SUMMARY

TRAY	TEMP DEG C	PRESSURE ATM	NET FLOW RATES LIQUID KG-MOL/HR	NET FLOW RATES VAPOR KG-MOL/HR	FEED	PRODUCT	HEATER DUTIES MM BTU/HR
1C	67.8	0.11	12.3			2.0L	-2.3827
2	234.9	0.11	34.3	14.2			
3	239.9	0.12	35.0	36.3			
4	242.7	0.12	33.3	37.0			
5	248.5	0.12	11.8	35.3		19.0L	
6	258.1	0.13	10.3	32.7			
7	264.4	0.13	11.5	31.3	24.5M		
8	271.1	0.13	11.7	7.9			
9	277.3	0.14	12.7	8.1			
10R	275.0	0.14		9.1		3.5L	0.5583

FEED AND PRODUCT STREAMS

TYPE	STREAM	PHASE	FROM TRAY	TO TRAY	LIQUID FRAC	FLOW RATES KG-MOL/HR	HEAT RATES MM BTU/HR
FEED	S31	MIXED		7	0.0634	24.52	6.3147
PROD	S29	LIQUID	1			1.99	0.0702
PROD	S32	LIQUID	5			19.00	3.4692
PROD	S30	LIQUID	10			3.52	0.9509

OVERALL MOLE BALANCE, (FEEDS - PRODUCTS) 3.9031E-15
OVERALL HEAT BALANCE, (H(IN) - H(OUT)) -8.9025E-08

REFLUX RATIOS

	-------- REFLUX RATIOS --------		
	MOLAR	WEIGHT	STD L VOL
REFLUX / FEED STREAM S31	0.4998	0.4259	0.4273
REFLUX / LIQUID DISTILLATE	6.1429	6.1429	6.1429

TRAY SIZING MECHANICAL DATA

SECTION	TRAY NUMBERS	TRAY PASSES	TRAY SPACING CM	SYSTEM FACTOR	TRAY TYPE	MIN DIAMETER CM
1	2 - 9	N/A	60.96	1.00	VALVE	38.10

TRAY SIZING RESULTS

TRAY	VAPOR L/S	LIQUID L/MIN	LIQUID L/S	VLOAD DIA, CM	-- DESIGN -- FF	NEXT SMALLER DIA, CM	NEXT SMALLER FF	NEXT LARGER DIA, CM	NEXT LARGER FF	NP
2	3674.	198.3	113.1	130.9	78.0	122.	90.5	137.	70.8	1
3	3663.	203.8	114.5	131.4	78.0	122.	91.2	137.	71.4	1
4	3432.	193.4	108.0	127.3	78.0	122.	85.4	137.	66.9	1
5	3157.	177.4	99.4	124.2	75.0	122.	78.0	137.	61.1	1
6	2971.	58.7	92.9	123.2	65.9	122.	67.3	137.	53.2	1

MECHANICAL RESTRICTION ON TRAY 6, FOR FF = 75.0, CALCD. DIA = 115.6
** WARNING ** MIXED PHASE FEED to tray 7. Carefully check the tray sizing results.

TRAY	VAPOR L/S	LIQUID L/MIN	LIQUID L/S	VLOAD DIA, CM	-- DESIGN -- FF	NEXT SMALLER DIA, CM	NEXT SMALLER FF	NEXT LARGER DIA, CM	NEXT LARGER FF	NP
7	2874.	62.8	85.5	118.5	65.6	107.	81.2	122.	62.0	1

MECHANICAL RESTRICTION ON TRAY 7, FOR FF = 75.0, CALCD. DIA = 110.9

TRAY	VAPOR L/S	LIQUID L/MIN	LIQUID L/S	VLOAD DIA, CM	-- DESIGN -- FF	NEXT SMALLER DIA, CM	NEXT SMALLER FF	NEXT LARGER DIA, CM	NEXT LARGER FF	NP
8	752.	63.8	22.7	68.7	54.7	61.	70.2	76.	44.2	1

MECHANICAL RESTRICTION ON TRAY 8, FOR FF = 70.0, CALCD. DIA = 61.1

TRAY	VAPOR L/S	LIQUID L/MIN	LIQUID L/S	VLOAD DIA, CM	-- DESIGN -- FF	NEXT SMALLER DIA, CM	NEXT SMALLER FF	NEXT LARGER DIA, CM	NEXT LARGER FF	NP
9	821.	69.4	25.3	69.6	58.8	61.	77.6	76.	48.8	1

MECHANICAL RESTRICTION ON TRAY 9, FOR FF = 75.0, CALCD. DIA = 62.0
** WARNING ** Design diameter includes mechanical restriction allowances.

UNIT 23, 'COLUMN-T101', 'Methanol Recovery'

TOTAL NUMBER OF ITERATIONS

CHEM METHOD 26

COLUMN SUMMARY

TRAY	TEMP DEG C	PRESSURE ATM	NET FLOW RATES LIQUID KG-MOL/HR	VAPOR	FEED	PRODUCT	HEATER DUTIES MM BTU/HR
1C	64.6	1.00	0.0			13.4L	-0.4632
2	107.3	0.21	0.0	13.4			
3	111.7	0.21	0.0	13.4			
4	112.0	0.22	25.9	13.4	37.9M		
5	112.6	0.22	26.1	1.4			
6R	180.0	0.23		1.5		24.5L	1.4127

FEED AND PRODUCT STREAMS

TYPE	STREAM	PHASE	FROM TRAY	TO TRAY	LIQUID FRAC	FLOW RATES KG-MOL/HR	HEAT RATES MM BTU/HR
FEED	S41	MIXED		4	0.6712	37.91	2.3747
PROD	S39	LIQUID	1			13.40	0.0684
PROD	S40	LIQUID	6			24.52	3.2558

OVERALL MOLE BALANCE, (FEEDS - PRODUCTS) -6.2450E-15
OVERALL HEAT BALANCE, (H(IN) - H(OUT)) -3.2492E-12

REFLUX RATIOS

	-------- REFLUX RATIOS -------- MOLAR	WEIGHT	STD L VOL
REFLUX / FEED STREAM S41	0.0010	0.0002	0.0002
REFLUX / LIQUID DISTILLATE	0.0028	0.0028	0.0028

TRAY SIZING MECHANICAL DATA

SECTION	TRAY NUMBERS	TRAY PASSES	TRAY SPACING CM	SYSTEM FACTOR	TRAY TYPE	MIN DIAMETER CM
1	2 - 5	N/A	60.96	1.00	VALVE	38.10

TRAY SIZING RESULTS

TRAY	VAPOR L/S	LIQUID L/MIN	VLOAD L/S	-- DESIGN -- DIA, CM	FF	NEXT SMALLER DIA, CM	FF	NEXT LARGER DIA, CM	FF	NP
2	546.8	0.0	8.497	54.9	46.8	46.	67.6	61.	38.0	1

MECHANICAL RESTRICTION ON TRAY 2, FOR FF = 70.0, CALCD. DIA = 39.7

3	534.7	0.0	8.304	54.4	46.5	46.	65.8	61.	37.0	1

MECHANICAL RESTRICTION ON TRAY 3, FOR FF = 70.0, CALCD. DIA = 39.2

** WARNING ** MIXED PHASE FEED to tray 4. Carefully check the tray sizing results.

4	541.2	119.6	8.290	61.9	37.0	61.	38.2	76.	24.2	1

MECHANICAL RESTRICTION ON TRAY 4, FOR FF = 70.0, CALCD. DIA = 46.6

5	69.2	120.2	1.198	42.6	17.9	38.	22.9	46.	15.6	1

MECHANICAL RESTRICTION ON TRAY 5, FOR FF = 70.0, CALCD. DIA = 27.3

** WARNING ** Design diameter includes mechanical restriction allowances.

Appendix B Specific Heat Analysis for T-103 and T-101

I. Distillation column T103

By analyzing the condenser and reboiler heat duty in the distillation column the various sources of heat necessary for the column can be understood.

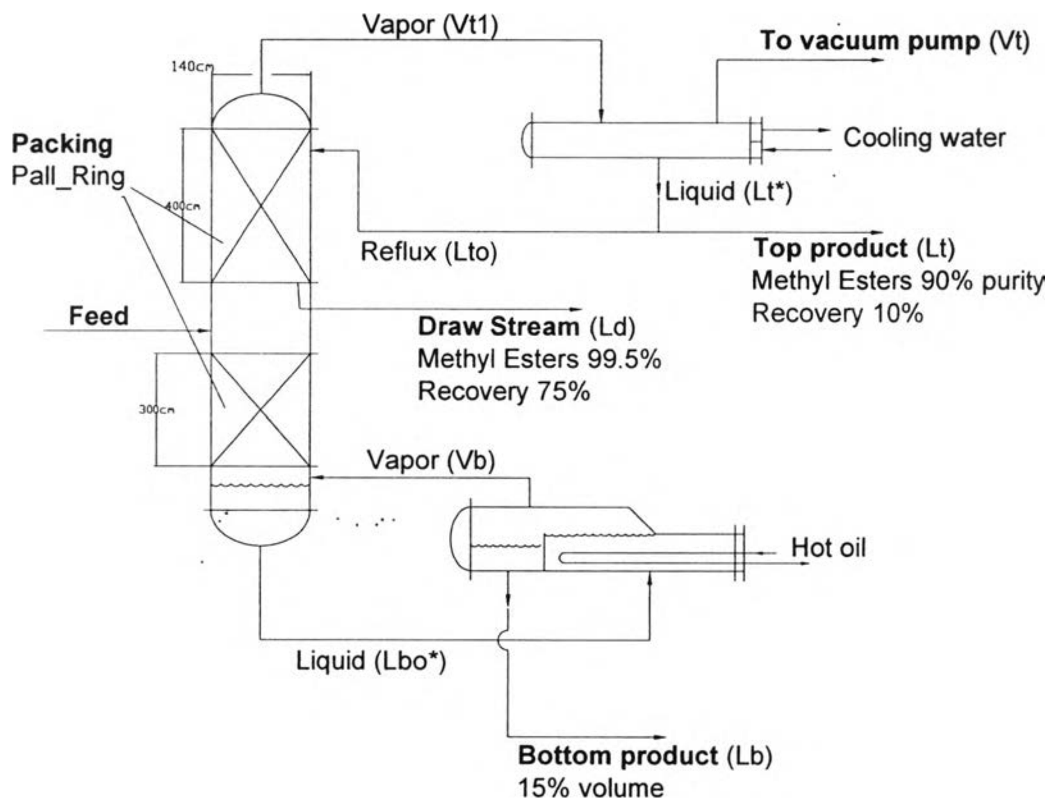

Figure B1 Material-balance diagram for continuous vacuum column T-103

i. For Condenser (Partial Condenser)

Reflux ratio: L_{to}/L_t

Mass balance:

$V_{t1} = V_t + L_{to} + L_t$

Heat condensation of condenser:

$Qc = (L_{to} + L_t)*\Delta H_{vap}$

where: $\Delta H_{vap} = \Sigma \Delta Hi_{vap}*xi$

ΔHi_{vap}: Heat of vaporization of component (i) in stream V_{tl} at condenser conditions, collected from the ICAS report. (In this case, ΔHi_{vap} = 0.19MMBTU/kmol.hr.)

xi: fraction mol of component (i) in stream V_{tl}, collected from the PRO/II report.

ii. For Reboiler

Mass balance:

$L_{bo}^* = L_b + V_b$

Heat supply of reboiler:

$Qb = Q_c + Q_j$

where: Q_c: Heat duty of Condenser.

Q_j: heat duty for T-101 (from Table 4.18 we have Q_j = 1.383 M*KJ/hr.)

Reflux ratio:

$V_b = Qb/\Delta H_{vap}$

$\Delta H_{vap} = \Sigma \Delta Hi_{vap} * xi$

ΔHi_{vap}: Heat of vaporization of component (i) in stream V_{tl} at Reboiler conditions, collected from the ICAS report. (In this case, ΔHi_{vap} = 0.50MMBTU/Kmol.hr.)

Xi: fraction mol of component (i) in stream L_{bo}^*.

$R = V_b/L_b$

L_b: product flow, collected from the PRO/II report.

Then, the heat duty for each section as a function of reflux ratio of the column can be calculated (Table B1).

Table B1 Relationship between reflux ratios, heat added or removed of condenser, reboiler-T103

Relationship between reflux ratios-T103				
Reflux Ratio (L/D) Condenser	4	6	8	10
Heat condensation MMBTU/hr	1.69	2.37	3.04	3.72

Heat vaporization MMBTU/hr	0.00	0.54	1.21	1.89
Reflux Ratio Reboiler	0.00	2.28	5.16	8.03

II. Distillation column T101

By analyzing condenser and reboiler heat duty in distillation column T-101, the value of the required heats for the column can be derived.

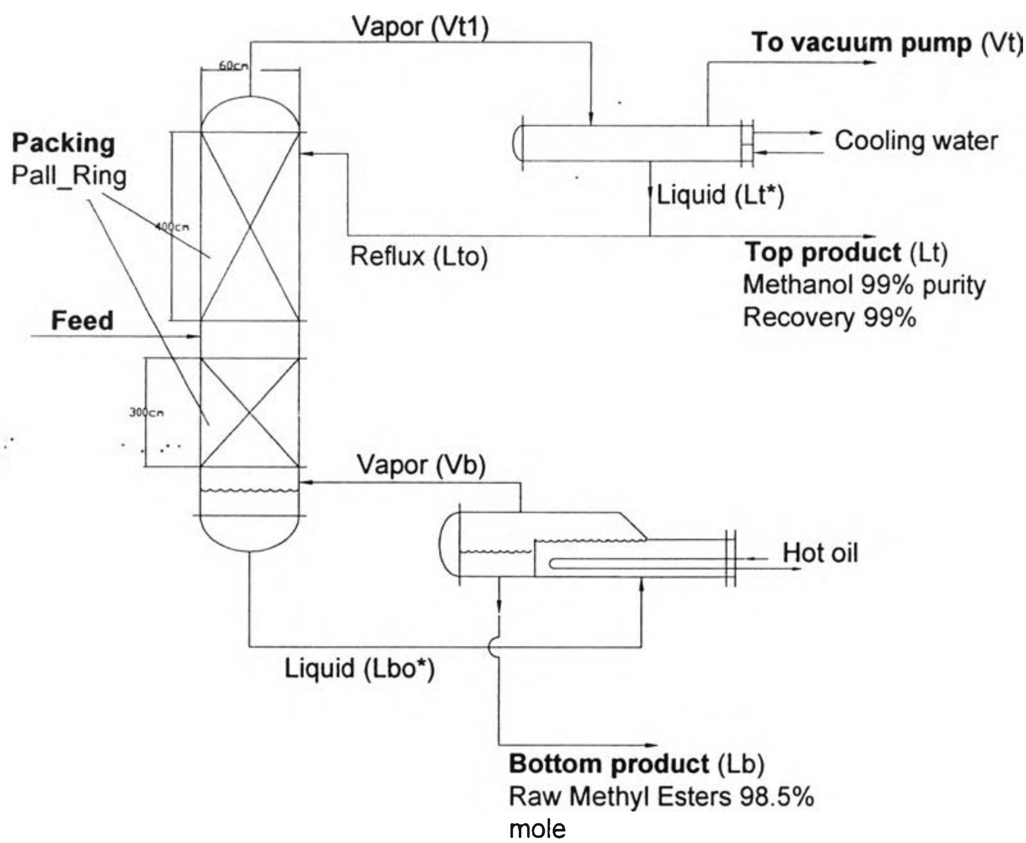

Figure 4.14 Material-balance diagram for continuous vacuum column T-101.

i. For Condenser (Partial Condenser)

Reflux ratio: L_{to}/L_t

Mass balance:

$V_{t1} = V_t + L_{to} + L_t$

Heat condensation of condenser:

$Qc = (L_{to} + L_t)*\Delta H_{vap}$

where: $\Delta H_{vap} = \Sigma \Delta Hi_{vap}*xi$

ΔHi_{vap}: Heat of vaporization of component (i) in stream V_{t1} at condenser conditions, collected from the ICAS report. (In this case, ΔHi_{vap} = 0.035MMBTU/Kmol.hr.)

xi: mole fraction of component (i) in stream V_{t1}, collected from the PRO/II report.

ii. For Reboiler

Mass balance:

$L_{bo}* = L_b + V_b$

Heat duty of reboiler:

$Qb = Q_c + Q_j$

where: Q_c: Heat duty of Condenser.

Q_j: heat duty for T-101 (From Table 4.16 we have Q_j = 3.351 M*kJ/hr).

Reflux ratio:

$V_b = Qb/\Delta H_{vap}$

$\Delta H_{vap} = \Sigma \Delta Hi_{vap}*xi$

ΔHi_{vap}: Heat of vaporization of component (i) in stream V_{t1} at Reboiler conditions, collected from the ICAS report. (In this case, ΔHi_{vap} = 1.01MMBTU/kmol.hr).

xi: fraction mol of component (i) in stream L_{bo}*.

$R = V_b/L_b$

L_b: product flow, collected from the PRO/II report.

Then, the heat duty for each section as a function of reflux ratio of column can be calculated (Table B2).

Table B2 Relationship between reflux ratios, heat added or removed of condenser, reboiler-T101

Relationship between reflux ratios-T101				
Reflux Ratio (L/D) Condenser	0	2	4	6
Heat condensation MMBTU/hr	0.46	1.39	2.32	3.25
Heat vaporization MMBTU/hr	1.41	2.34	3.27	4.20
Reflux Ratio Reboiler	0.06	0.10	0.13	0.17

Appendix C Optimization of the Operating Temperature for Distillation Column T-103

Because the limit of operation temperature is below 285°C, the optimum operating temperature must be chosen.

An increase of temperature makes the recovery increase but it also increases the cost of the energy supply for the column (Table C.1).

Table C.1 Optimization of the operating temperature for distillation column T-103 from alternative design 1

Optimize Operating Temperature of Distillation Clumn T-103								
Option	Temp (^{0}C)	Recovery	Heat Add Qh MMBTU/hr	Heat Remove(Qc) MMBTU/hr	Column Dia.(cm)	Cost for Energy (Baht)	Cost of Product (Baht)	Benefit (Baht)
1	265	75%	0.22	-1.90	128	104.87	184800	184695
2	270	81%	0.40	-2.11	130	190.67	199584	199393
3	275	85%	0.55	-2.38	133	262.17	209440	209178
4	280	87%	0.80	-2.54	134	381.33	214368	213987

where

Temp, recovery, heat, column diameter: collected from the PRO/II result

Cost for energy = Qh*Ph, Ph=500 baht*hr/MMBTU

Cost of product = F*Recovery*Price

F: flowrate of product = 7700 liters/hr

Price = 34 baht/liter of product

By varying the temperature at the bottom of distillation column T103 (Table C.1), we can see that the optimum temperature is 280°C. But for safety reasons, a temperature of 275°C was chosen.

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