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APPENDIX A

Test run Data

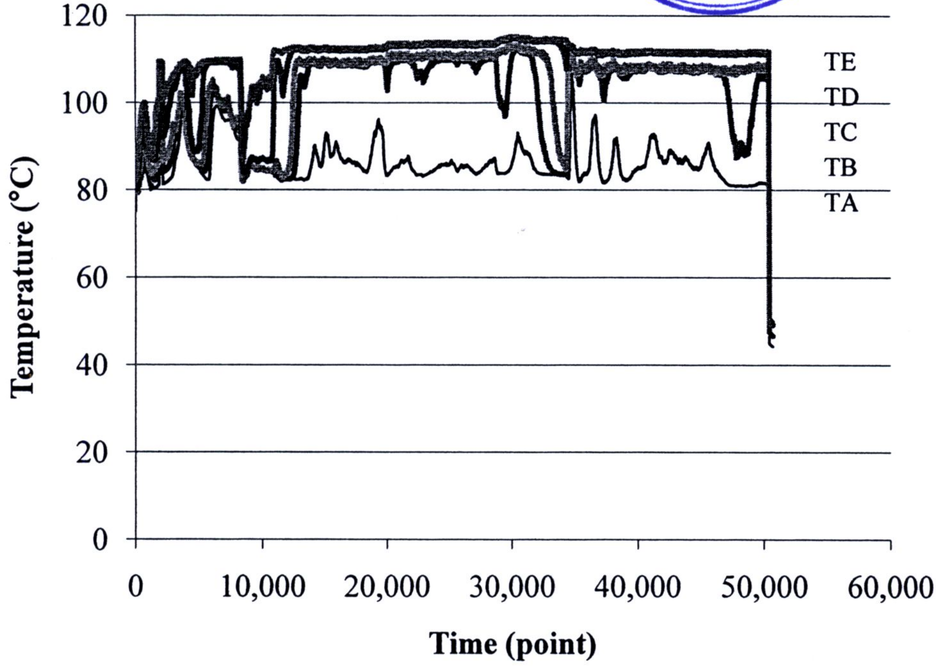

Figure A.1 Temperature profile of the column (TA-TE) from Test run data

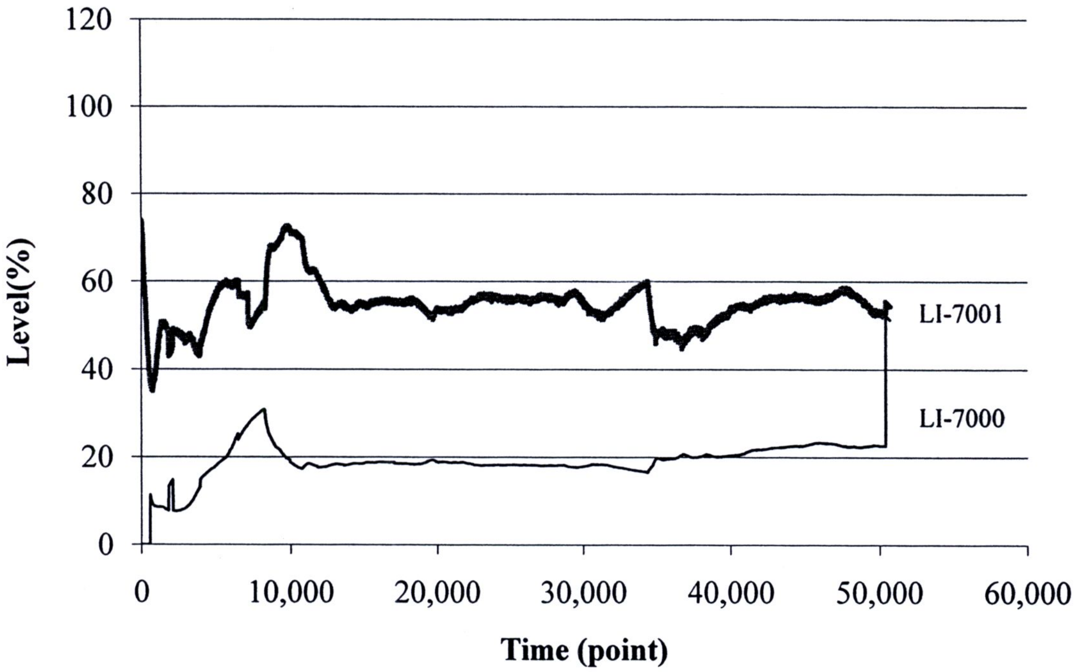

Figure A.2 Level of the reflux drum and distillate product drum from Test run data

APPENDIX B

Calculation of the number of theoretical stage

Calculation of the number of the theoretical stage

The number of the theoretical stages can be determined by the equation (2.4)

$$HETP = \frac{H}{N_t}$$

Where:	$HETP$	=	The height equivalent to theoretical plate
	H	=	The total packed height
	N_t	=	The number of theoretical stages

The total packed height (H) of the pilot distillation column can be calculated from the equation (B.1) below.

$$H = Height\ of\ each\ packed \times Number\ of\ packed \tag{B.1}$$

There are 5 sections of packing (A-E) along the column. The total height of each packing section is 0.4 m (8 packing packs).Therefore,

$$H = 0.4 \times 5 = 2\ m$$

The HETP can be determined from the relationship between HETP and the F-factor from Sulzer information.

From the theory, F-factor can be determined by the multiplication of the superficial vapor velocity (W_G) and the vapor density (ρ_G) following in equation (B.2)

$$F\text{-}factor = W_G \times \sqrt{\rho_G} \tag{B.2}$$

The vapor density (ρ_G) of this system is the density of Benzene – Toluene mixture in the vapor phase which obtains from the Aspen Plus simulation. The value of the vapor density (ρ_G) is 3.039 kg/m^3.

The superficial vapor velocity (W_G) is calculated from equation (B.3) below.

$$W_G = \frac{\text{Boilup rate}}{\text{Cross sectional area of column}} \tag{B.3}$$

The boilup rate is obtained from the result of Aspen Plus simulation and its value is 8.71kg/hr. The volumetric flow rate of the boilup rate is calculated as shown in section below.

$$\text{Boilup rate} = 8.71\frac{kg}{hr} \times \frac{1}{3.039}\frac{m^3}{kg} \times \frac{1}{3,600}\frac{hr}{s}$$

$$\text{Boilup rate} = 8.144 \times 10^{-4} \frac{m^3}{s}$$

The cross sectional area of the column can be determined from the diameter of the column (0.078 m) below.

$$\text{Cross sectional area} = \pi \times \frac{D^2}{4}$$

$$\text{Cross sectional area} = \pi \times \frac{0.078^2}{4} = 4.778 \times 10^{-3} m^2$$

From equation (B.3) :

$$W_G = \frac{8.144 \times 10^{-4} \frac{m^3}{s}}{4.778 \times 10^{-3} m^2}$$

$$W_G = 0.17 \frac{m}{s}$$

From equation (B.2), the value of F-factor is calculated following equation below

$$F\text{-}factor = 0.17 \times \sqrt{3.039}$$

$$F\text{-}factor = 0.296$$

From the relationship between HETP and F-factor, when the F-factor value is 0.296 the HETP is 0.04 m that means the height of packing is 0.04 m per each stage.

The number of the theoretical stages can be calculated by plugging the value of HETP and the total packed height (H) into equation (2.4) as following below.

$$N_T = \frac{H}{HETP}$$

$$N_T = \frac{2}{0.04}$$

$$N_T = 50 \text{ stages}$$

APPENDIX C

Dynamic Responses

Results from Aspen Plus simulation

C.1Dynamic responses when the operating conditions are changed

Table C.1 shows the results of the energy consumption of the heater and the mass fraction of Benzene in the overhead stream from the Aspen Plus simulation program. The results are shown into 2 steps which are changing the feed location from packing C to D and increasing the reflux rate from 6.465 to 6.982 kg/hr.

Table C.1 Temperature profile along the column (A-E) of pilot distillation column

Parameters	Base case	Step 1*	Step 2**
Heat duty (kW)	1.04	1.04	1.11
Xbz	0.964	0.964	0.964

* Feed location changes from packing C to D

** Reflux rate changes from 6.465 to 6.982 kg/hr

C.2 Calculation of the maximum purity of Benzene in the overhead stream

The maximum purity of Benzene in the overhead stream can be calculated from equation below.

$$\text{Feed of benzene} = \text{Totalflow} \times \text{massfraction of Benzene}$$

$$= 1.724 \frac{kg}{hr} \times 0.503$$

$$= 0.868 \frac{kg}{hr}$$

$$\text{Distillate rate} = 0.9 \ \frac{kg}{hr}$$

$$\therefore \text{maximum Benzen in the overhead stream} = \frac{0.868}{0.9} = 0.964$$

APPENDIX D

Task for the start-up operation

Task for scenario 1 (Distillate > Reflux > Bottom)

For shut-down operation

```
Task Start runs at 0.1
//Shutdown
wait 0.1;
ramp(Blocks("T-7000").TmedReb,20,1.3);
wait 0.1;
ramp(streams("OVHD").FmR,0,0.001);
ramp(Blocks("T-7000").Reflux.FmR,0,0.001);
wait 0.1;
ramp(streams("FEED").FmR,0,0.5);
wait 0.1;
ramp(streams("BOTT").FmR,2.8,0.1);
wait for Blocks("T-7000").SumpLevel <= 0.335;
ramp(streams("BOTT").FmR,0,0.5);
//wait 0.1;
//ramp(streams("FEED").FmR,1.724,2);
```

For start-up operation

```
wait 0.1;
ramp(streams("FEED").FmR,1.724,0.5);
wait for Blocks("T-7000").SumpLevel >= 0.45;
ramp(streams("FEED").FmR,0,0.001);
wait 0.1;
ramp(Blocks("T-7000").TmedReb,115,1);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,10.344,0.1);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,0,0.001);
ramp(streams("FEED").FmR,1.724,0.5);
wait 0.1;
ramp(streams("OVHD").FmR,0.9,0.5);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,6.465,0.5);
wait 0.1;
ramp(streams("BOTT").FmR,0.824,0.5);
ramp(Blocks("T-7000").TmedReb,120,0.5);
End
```

Task for scenario 2 (Distillate > Bottom > Reflux)
For shut-down operation

```
Task Start runs at 0.1
//Shutdown
wait 0.1;
ramp(Blocks("T-7000").TmedReb,20,1.3);
wait 0.1;
ramp(streams("OVHD").FmR,0,0.001);
ramp(Blocks("T-7000").Reflux.FmR,0,0.001);
wait 0.1;
ramp(streams("FEED").FmR,0,0.5);
wait 0.1;
ramp(streams("BOTT").FmR,2.8,0.1);
wait for Blocks("T-7000").SumpLevel <= 0.335;
ramp(streams("BOTT").FmR,0,0.5);
//wait 0.1;
//ramp(streams("FEED").FmR,1.724,2);
```

For start-up operation

```
wait 0.1;
ramp(streams("FEED").FmR,1.724,0.5);
wait for Blocks("T-7000").SumpLevel >= 0.45;
ramp(streams("FEED").FmR,0,0.001);
wait 0.1;
ramp(Blocks("T-7000").TmedReb,115,1);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,10.344,0.1);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,0,0.001);
ramp(streams("FEED").FmR,1.724,0.5);
wait 0.1;
ramp(streams("OVHD").FmR,0.9,0.5);
wait 0.1;
ramp(streams("BOTT").FmR,0.824,0.5);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,6.465,0.5);
ramp(Blocks("T-7000").TmedReb,120,0.5);
End
```

Task for scenario 3 (Bottom > Distillate > Reflux)

For shut-down operation

```
Task Start runs at 0.1
//Shutdown
wait 0.1;
ramp(Blocks("T-7000").TmedReb,20,1.3);
wait 0.1;
ramp(streams("OVHD").FmR,0,0.001);
ramp(Blocks("T-7000").Reflux.FmR,0,0.001);
wait 0.1;
ramp(streams("FEED").FmR,0,0.5);
wait 0.1;
ramp(streams("BOTT").FmR,2.8,0.1);
wait for Blocks("T-7000").SumpLevel <= 0.335;
ramp(streams("BOTT").FmR,0,0.5);
//wait 0.1;
//ramp(streams("FEED").FmR,1.724,2);
```

For start-up operation

```
wait 0.1;
ramp(streams("FEED").FmR,1.724,0.5);
wait for Blocks("T-7000").SumpLevel >= 0.45;
ramp(streams("FEED").FmR,0,0.001);
wait 0.1;
ramp(Blocks("T-7000").TmedReb,115,1);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,10.344,0.1);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,0,0.001);
ramp(streams("FEED").FmR,1.724,0.5);
wait 0.1;
ramp(streams("BOTT").FmR,0.824,0.5);
wait 0.1;
ramp(streams("OVHD").FmR,0.9,0.5);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,6.465,0.5);
ramp(Blocks("T-7000").TmedReb,120,0.5);
End
```

Task for scenario 4 (Bottom > Reflux > Distillate)

For shut-down operation

```
Task Start runs at 0.1
//Shutdown
wait 0.1;
ramp(Blocks("T-7000").TmedReb,20,1.3);
wait 0.1;
ramp(streams("OVHD").FmR,0,0.001);
ramp(Blocks("T-7000").Reflux.FmR,0,0.001);
wait 0.1;
ramp(streams("FEED").FmR,0,0.5);
wait 0.1;
ramp(streams("BOTT").FmR,2.8,0.1);
wait for Blocks("T-7000").SumpLevel <= 0.335;
ramp(streams("BOTT").FmR,0,0.5);
//wait 0.1;
//ramp(streams("FEED").FmR,1.724,2);
```

For start-up operation

```
wait 0.1;
ramp(streams("FEED").FmR,1.724,0.5);
wait for Blocks("T-7000").SumpLevel >= 0.45;
ramp(streams("FEED").FmR,0,0.001);
wait 0.1;
ramp(Blocks("T-7000").TmedReb,115,1);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,10.344,0.1);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,0,0.001);
ramp(streams("FEED").FmR,1.724,0.5);
wait 0.1;
ramp(streams("BOTT").FmR,0.824,0.5);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,6.465,0.5);
wait 0.1;
ramp(streams("OVHD").FmR,0.9,0.5);
ramp(Blocks("T-7000").TmedReb,120,0.5);
End
```

Task for scenario 5 (Reflux > Distillate > Bottom)

For shut-down operation

```
Task Start runs at 0.1
//Shutdown
wait 0.1;
ramp(Blocks("T-7000").TmedReb,20,1.3);
wait 0.1;
ramp(streams("OVHD").FmR,0,0.001);
ramp(Blocks("T-7000").Reflux.FmR,0,0.001);
wait 0.1;
ramp(streams("FEED").FmR,0,0.5);
wait 0.1;
ramp(streams("BOTT").FmR,2.8,0.1);
wait for Blocks("T-7000").SumpLevel <= 0.335;
ramp(streams("BOTT").FmR,0,0.5);
//wait 0.1;
//ramp(streams("FEED").FmR,1.724,2);
```

For start-up operation

```
wait 0.1;
ramp(streams("FEED").FmR,1.724,0.5);
wait for Blocks("T-7000").SumpLevel >= 0.45;
ramp(streams("FEED").FmR,0,0.001);
wait 0.1;
ramp(Blocks("T-7000").TmedReb,115,1);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,10.344,0.1);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,0,0.001);
ramp(streams("FEED").FmR,1.724,0.5);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,6.465,0.5);
wait 0.1;
ramp(streams("OVHD").FmR,0.9,0.5);
wait 0.1;
ramp(streams("BOTT").FmR,0.824,0.5);
ramp(Blocks("T-7000").TmedReb,120,0.5);
End
```

Task for scenario 6 (Reflux > Bottom > Distillate)

For shut-down operation

```
Task Start runs at 0.1
//Shutdown
wait 0.1;
ramp(Blocks("T-7000").TmedReb,20,1.3);
wait 0.1;
ramp(streams("OVHD").FmR,0,0.001);
ramp(Blocks("T-7000").Reflux.FmR,0,0.001);
wait 0.1;
ramp(streams("FEED").FmR,0,0.5);
wait 0.1;
ramp(streams("BOTT").FmR,2.8,0.1);
wait for Blocks("T-7000").SumpLevel <= 0.335;
ramp(streams("BOTT").FmR,0,0.5);
//wait 0.1;
//ramp(streams("FEED").FmR,1.724,2);
```

For start-up operation

```
wait 0.1;
ramp(streams("FEED").FmR,1.724,0.5);
wait for Blocks("T-7000").SumpLevel >= 0.45;
ramp(streams("FEED").FmR,0,0.001);
wait 0.1;
ramp(Blocks("T-7000").TmedReb,115,1);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,10.344,0.1);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,0,0.001);
ramp(streams("FEED").FmR,1.724,0.5);
wait 0.1;
ramp(Blocks("T-7000").Reflux.FmR,6.465,0.5);
wait 0.1;
ramp(streams("BOTT").FmR,0.824,0.5);
wait 0.1;
ramp(streams("OVHD").FmR,0.9,0.5);
ramp(Blocks("T-7000").TmedReb,120,0.5);
End
```

CURRICULUM VITAE

NAME	Mr. Suthipong Laikitmongkol
DATE OF BIRTH	1 July 1987
EDUCATIONAL RECORD	
HIGH SCHOOL	High School Graduation Taweethapisek School, 2004
BACHELOR'S DEGREE	Bachelor of Engineering (Chemical Engineering) Kasetsart University, 2008
MASTER'S DEGREE	Master of Engineering (Chemical Engineering) King Mongkut's University of Technology Thonburi, 2010

King Mongkut's University of Technology Thonburi
Agreement on Intellectual Property Rights Transfer for Postgraduate Students

Date 25 April 2011

Name Suthipong Middle Name -
Surname/Family Name Laikitmongkol
Student Number 52403817 who is a student of King's Mongkut's University of Technology Thonburi (KMUTT) in ○ Graduate Diploma ☑ Master Degree
○ Doctoral Degree
Program Chemical Engineering Practice School Field of Study Chemical Engineering
Faculty/School Engineering
Home Address 544 Soi Taksin 11 Road Taksin
Tambon Banglumpulang District Clongsan Province Bangkok
Postal Code 10600 Country Thailand

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Student

Signature...Transferee
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Associate Dean for Academic Affairs (Acting for Dean)

Signature...Witness
(Assoc.Prof.Dr. Anawat Sungpet)

Signature...Witness
(Assoc. Prof. Dr. Thongchai Srinophakun)