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Presentation Layout

1: Universiti Malaysia Pahang

- An overview

2: Introduction

- DWDC
- Oleochemical Industry
- Presentation scopes

3:Research Methodology

- Case study
- Model development
- Econ. & Env. assessment
- Hydraulic model
- Dynamic model

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- Model results
- Econ. & Env. Assessment
- Hydrodynamics
- Dynamic analysis

5: Concluding Remarks

- Summary
- Future works

UNIVERSITI MALAYSIA PAHANG

Corporate Video

UNIVERSITI MALAYSIA PAHANG

Faculty of Chemical & Natural Resources Engineering

- ❑ Program offered:-
  - ❑ Diploma in Chemical Engineering (Process Plant)
  - ❑ Bachelor of Chemical Engineering
  - ❑ Master in Chemical Engineering with Entrepreneurship
  - ❑ Master in Mining and Mineral Technology
  - ❑ Master in Process Plant Operation
  - ❑ Master by Research
  - ❑ Doctor of Philosophy (PhD)

- ❑ Research clusters
  - ❑ ProSES
  - ❑ Reaction
  - ❑ Advanced Material
  - ❑ Environment
  - ❑ BBEC
  - ❑ Separation
  - ❑ Heat and Mass Transfer

- ❑ Journal of Chemical Engineering and Industrial Biotechnology (JCEIB)

Introduction

❑ Distillation column are estimated to consume 40% of the total energy to operate plant.

❑ Researchers are motivated to develop and improve the efficiency of distillation processes through process:-

- **Intensification**
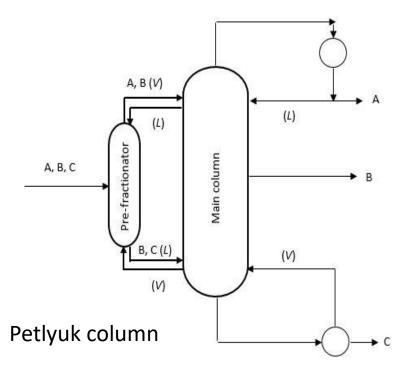- Heat integration
- Optimization
- Etc.

Introduction

❑ Areas of process intensification:-

1. Equipment - special designs that optimize critical parameters (e.g., heat transfer, mass transfer)

2. Methods – integration of multiple processing steps into a single unit operation i.e. Reactive distillation, Petyluk column & **Dividing wall distillation column (DWDC)**.
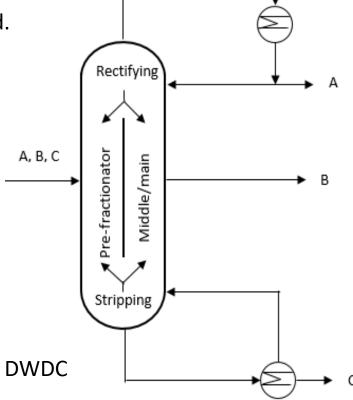
Introduction

Dividing Wall Distillation Column (DWDC)

❑ DWDC is intensified form of Petyluk column.

❑ Vertical wall in the middle part of the main distillation column.

❑ Split reflux and vapour flow to both sides of the wall.

❑ Prevent lateral mixing with fresh incoming feed.

Petlyuk column

DWDC

Introduction

Dividing Wall Distillation Column (DWDC)

❑ DWDC has been used for the past 18 years.

❑ Advantage for separating multicomponent mixtures with reduced cost and energy consumption.

❑ DWDCs are expected to become the standard in the chemical industry in the next decades because of promising cost and energy savings.

Introduction

Oleochemical Industry

- Malaysia is one of the key players in the oleochemical industry.
- Most oleochemical plant fractionation process used DC.
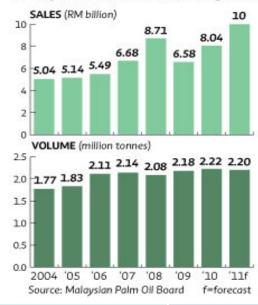- Offer huge opportunity for DWDC application.

Type of separation unit	No. of production plant		
	Fatty acid	Fatty alcohol	Methyl ester
DC	9	3	3
DWDC	0	0	0

Number of Oleochemical Plants & Capacities: 2013 (tonne/year)

State	In Operation		Not In Operation		Under Planning		Total	
	No	Capacity	No	Capacity	No	Capacity	No	Capacity
Johore	6	608,900	0	0	0	0	6	608,900
Penang	3	791,325	0	0	0	0	3	791,325
Selangor	6	817,746	0	0	0	0	6	817,746
Other States	1	365,000	1	16,000	1	60,000	3	441,000
Malaysia	16	2,582,971	1	16,000	1	60,000	18	2,658,971

Source: MIDA/MPOB, 2014

Malaysia's oleochemical exports

SALES (RM billion)

5.04 5.14 5.49 6.68 8.71 6.58 8.04 10

VOLUME (million tonnes)

1.77 1.83 2.11 2.14 2.08 2.18 2.22 2.20

2004 '05 '06 '07 '08 '09 '10 '11f

Source: Malaysian Palm Oil Board   f=forecast

Introduction

Oleochemical Industry

Operability and controllability issues

Slow acceptance of DWDC

Lack of operational experience

Lack of a systematic design approach
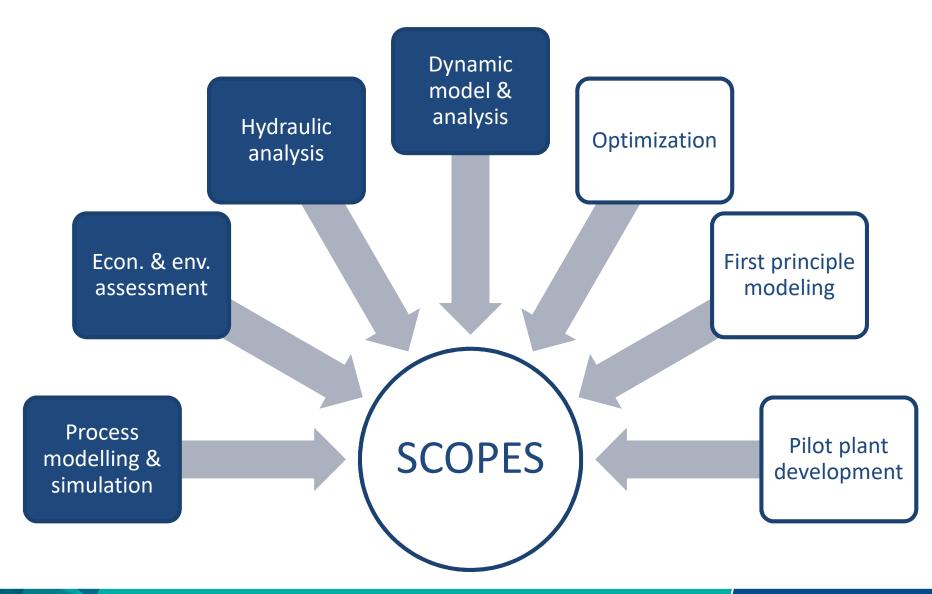
Presentation Scopes

- Case study : Oleochemical Fatty Acid Fractionation
- Model Development
- Econ. & Env. Assessment
- Hydraulic Model
- Dynamic Model

RESEARCH METHODOLOGY

Case Study

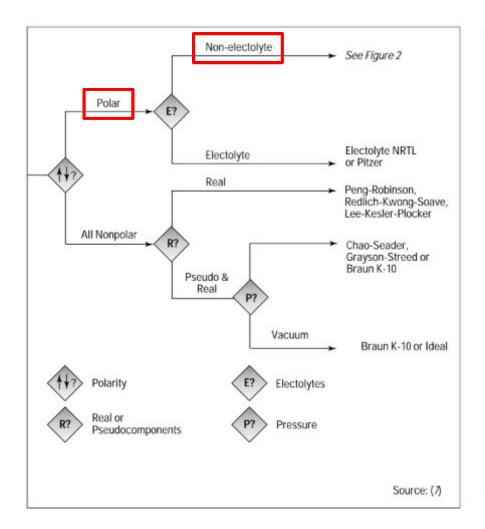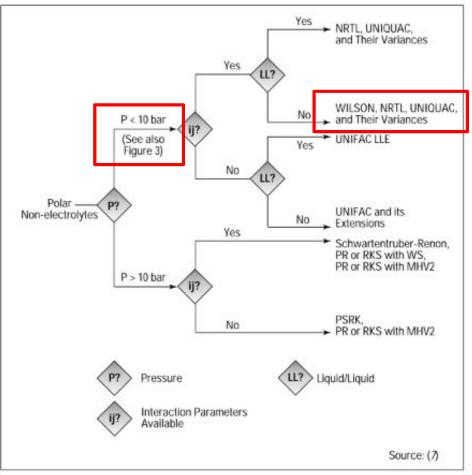## Oleochemical Fatty Acid (FAc) Fractionation

❏ FAc cuts; 99 wt% C6-C10 (PC), 99 wt% C12 (LC), 99 wt% C14 (MC), >99 wt % C16-C18 (HC)

❏ Data obtained from our industrial partner.

❏ Columns operated under vacuum 10 – 40 mbar.

❏ Columns temperature <270 C to avoid product degradation.

Component	Cuts	MW	T_{BP}, ^oC	Dipole moment, debye
(C6) Caproic acid, $C_6H_{12}O_2$		116.16	205.7	1.57092
(C8) Caprylic acid, $C_8H_{16}O_2$	Precut (PC)	144.21	239.7	1.69983
(C10) Capric acid, $C_{10}H_{20}O_2$		172.27	270.0	1.67884
(C12) Lauric acid, $C_{12}H_{24}O_2$	Light cut (LC)	200.32	298.7	1.63987
(C14) Myristic acid, $C_{14}H_{28}O_2$	Middle cut (MC)	228.38	326.2	1.67884
(C16) Palmitic acid, $C_{16}H_{32}O_2$		256.43	350.0	1.7388
(C18:1) Oleic acid, $C_{18}H_{34}O_2$	Heavy cut (HC)	280.45	354.9	1.21716
(C18:2) Linoleic acid, $C_{18}H_{32}O_2$		282.47	359.9	1.43901
(C18) Stearic acid, $C_{18}H_{36}O_2$		284.483	374.0	1.66985

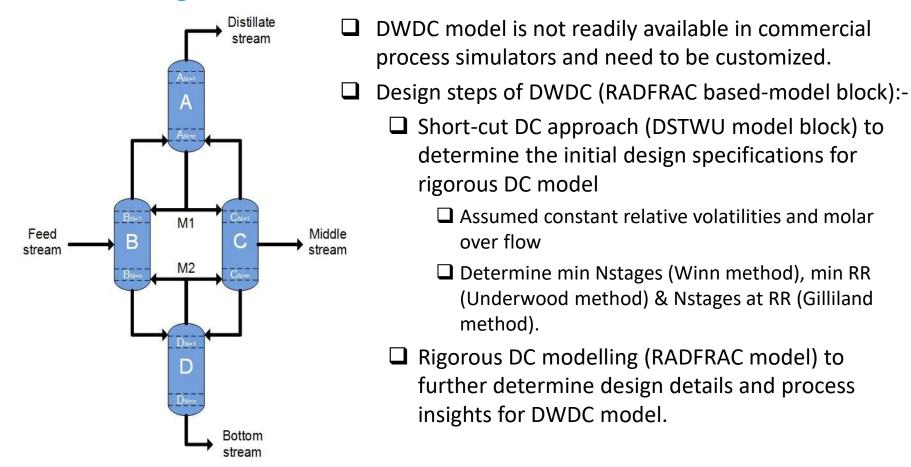# Model Development

Thermodynamic Model

Model Development

Thermodynamic Model

- Activity coefficient models i.e. NRTL, UNIQUAC, UNIFAC etc.

- In this work NRTL & UNIQUAC were compared with NIST data for C12 (Lauric acid) / C14 (Myristic acid) system.
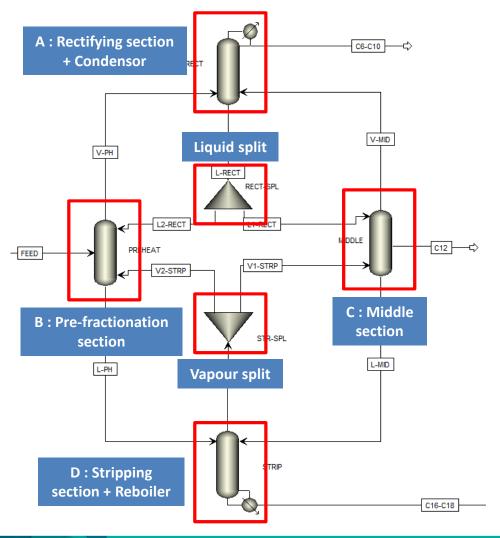
Model Development

DWDC Design

Distillate stream

Feed stream

M1

M2

Middle stream

Bottom stream

A : Rectifying section
B : Pre-fractionation section
C : Middle section
D : Stripping section

- ❑ DWDC model is not readily available in commercial process simulators and need to be customized.

- ❑ Design steps of DWDC (RADFRAC based-model block):-

  - ❑ Short-cut DC approach (DSTWU model block) to determine the initial design specifications for rigorous DC model

    - ❑ Assumed constant relative volatilities and molar over flow

    - ❑ Determine min Nstages (Winn method), min RR (Underwood method) & Nstages at RR (Gilliland method).

  - ❑ Rigorous DC modelling (RADFRAC model) to further determine design details and process insights for DWDC model.

Model Development
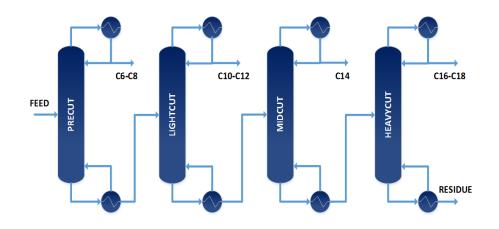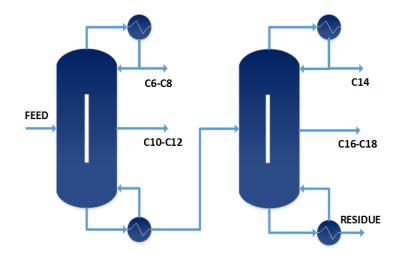
DWDC Flowsheet

- 1 DWDC = 4 RADFRAC blocks (represent 4 internal sections) + 1 condenser + 1 reboiler + 1 liquid split + 1 vapor split
- Create complex interactions thus increased column complexity and computational effort.
- DOF is reduced to 2 (Section A & D).
- Model converge is low and require a lot of parameter tweaking and tuning.
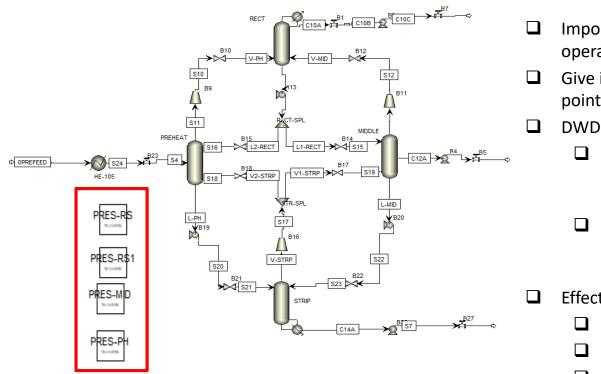
Econ. & Environ. Assessment

- 1 DWDC = 4 towers.
- DC = 4 towers + 4 reboilers + 4 condensors
- DWDC = (4 towers) x 2 + 2 reboilers + 2 condensors
- BEM type shell and tube exchangers for condensors.
- Kettle type for reboiler
- MOC is stainless steel
- Capital cost = Tower + Packing + Reboiler + Condensor
- Operating cost = Cooling water + HP steam
- Environmental analysis using Carbon Tracking tools in Aspen Plus.
  - CO2 emission factor data source is US-EPA-Rule-E9-5711
  - Fuel source is natural gas.

Hydraulic Model

Transfer block

- ❑ Important for design purposes and prevent operational and control problems.
- ❑ Give insights on the effect pressure drops, flood points, vapour and liquid flows.
- ❑ DWDC model extension:-
  - ❑ Packing rating option with updated pressure drop profile using built-in vendor correlations.
  - ❑ Transfer block to prevent negative pressure & pressure consistency for different run.
- ❑ Effect of packing type to cost:-
  - ❑ HETP: 0.1 m - 0.7 m.
  - ❑ Packing type: 125Y & 250Y
  - ❑ Cost were calculated using:-

$$C_{packing} = \left[\left(\frac{A_{packing}}{2} \right) \cdot T_{packing} \cdot \rho_{moc} \cdot C_{moc}) \gamma_{mc} \right] V_{vessel}$$

$$TPC^n = C_{packing}^n \cdot V^n$$
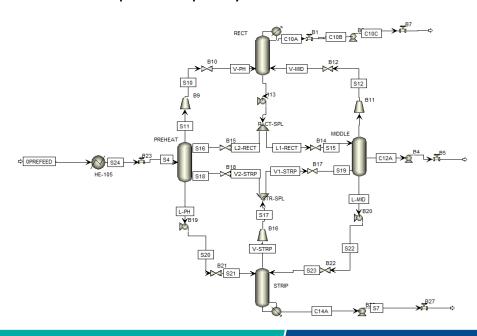
$$TPC_{DWC} = \sum_n TPC^n$$

Dynamic Model

- Relative gain array (RGA) and singular value analysis (SVA) to determine the best 3X3 control configuration.

- RGA and SVA analysis were performed in Aspen Plus.

- Model extension to Aspen Dynamics (Pressure driven)
    - Extended flowsheet to include additional block i.e. valve, pumps, compressors
    - Additional dynamic input specifications i.e. reflux drum, sump
    - Packing rating
    - Pressure check to ensure pressure consistency

- Control tuning based on ZN PID controllers.

- Performance analysis:-
    - Disturbances rejection: ±5% in feed flowrate
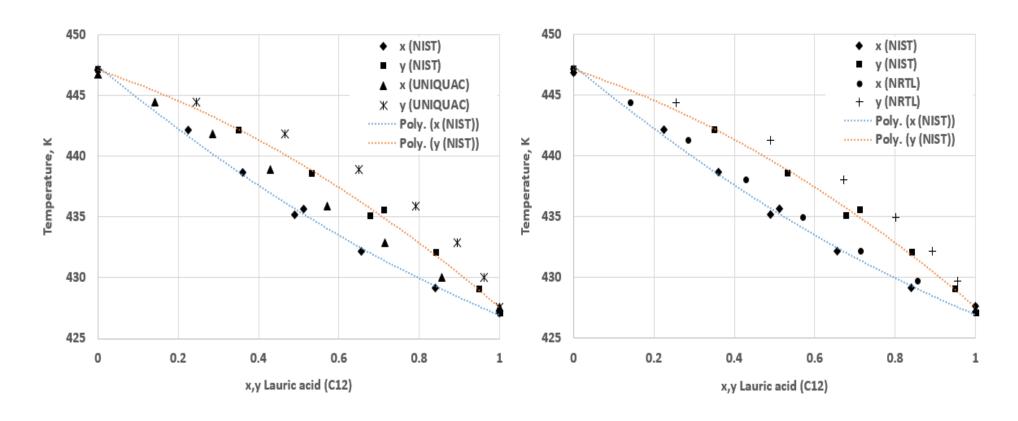   - Set point tracking: ±5% variation in product purity

- Modelling Results

- Econ. & Env. Assessment

- Hydraulic Performance

- Dynamic Analysis

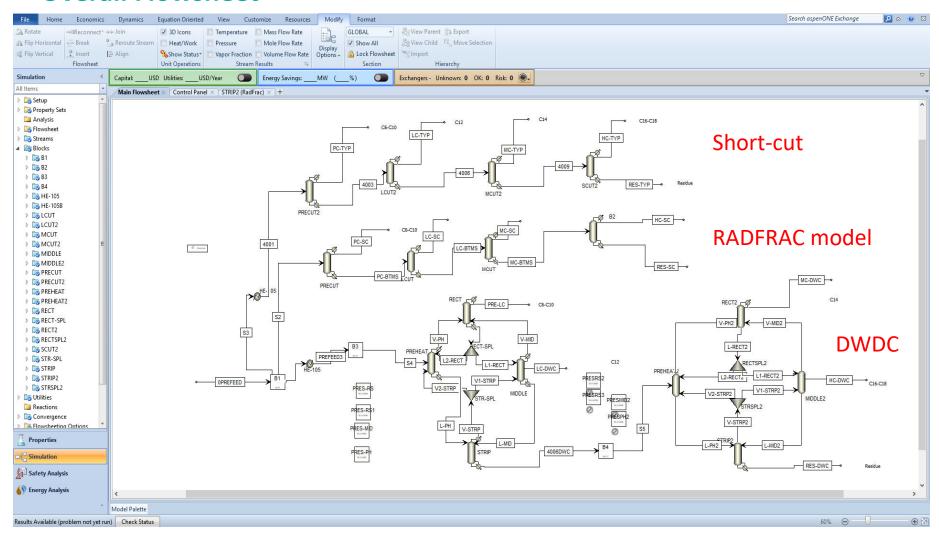# RESULTS & DISCUSSIONS

Modelling Results

Txy diagram for C12/C14 between NIST data and UNIQUAC predictions (left plot), and between NIST data and NRTL predictions (right plot). The dotted line is the polynomial curve for the NIST data. **NRTL was chosen as the thermodynamic model.**

Modelling Results

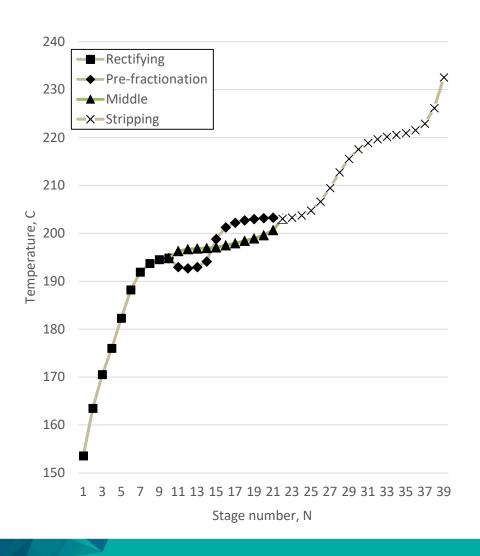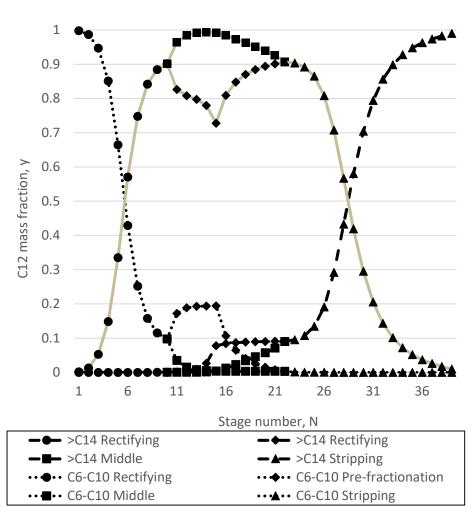## Overall Flowsheet

Short-cut

RADFRAC model

DWDC

Modelling Results

Results Summary

	DC				DWDC	
	PC	LC	MC	HC	DWC 1	DWC 2
Reflux ratio	3.45	1.48	2.16	0.1	12.7	4.5
Stages	29	27	24	9	10 (A) 11 (B) 11 (C) 18 (D)	11 (A) 11 (B) 11 (C) 6 (D)
Feed stage	10	7	9	5	5 (at B)	5 (at B)
Pressure [mbar]	40	40	15	10	40	15
Reboiler duty [kW]	556.4	1186.5	402	252.6	1332.2	746.7
Condenser duty [kW]	354.39	1147.6	461.9	235.2	1091.4	804.8
Distillate temp. [°C]	153.5	197.1	194.9	211.9	153.5	194.8
Bottom temp. [°C]	207.7	232.6	221.6	227.3	232.6	238.1
Diameter [m]	1.44	2.15	1.63	1.33	1.72 (A) 1.38 (B) 1.34 (C) 2.00 (D)	1.88 (A) 1.36 (B) 1.34 (C) 1.91 (D)

Modelling Results

Temperature & Composition Profile
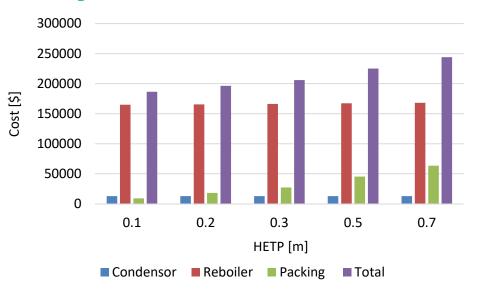
Econ. & Environ. Assessment
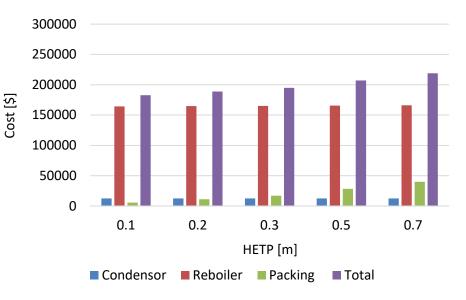
	DC	DWDC	Difference (k$)	Difference (%)
Total bare module cost				
- Column towers [k$]	649.7	731.2	-81.5	**-12.5**
- Condensers [k$]	341.6	284.2	57.4	**16.8**
- Reboilers [k$]	1,312	1,216	96.0	**7.3**
- Total [k$]	2,303.3	2,231.4	71.9	**3.1**
Operating cost				
- Cooling [k$/yr]	14.8	12.7	2.1	**16.9**
- Heating [k$/yr]	257.6	233.9	23.7	**10.2**
- Total [k$]	272.5	246.6	25.9	**10.5**
Environmental analysis				
- Total CO_2 emission [kg/hr]	773.04	701.7	-	**10.2**

Hydraulic Performance

Operating cost for Mellapak 125Y

Operating cost for Mellapak 250Y

Packing type	HETP of DWC1					HETP of DWC2				
	0.1	0.2	0.3	0.5	0.7	0.1	0.2	0.3	0.5	0.7
125Y	A	A	A	A	A	A	A	A	B	B
250Y	A	A	A	A	B	A	B	B	C	C

Effect of packing type and HETP to column reboiler convergence. "A" indicate that the column reboiler fully converged. "B" indicate warning in which the minimum temperature approach of 5 °C were violated. "C" indicate error in which the reboiler temperature cross with the utility temperature.
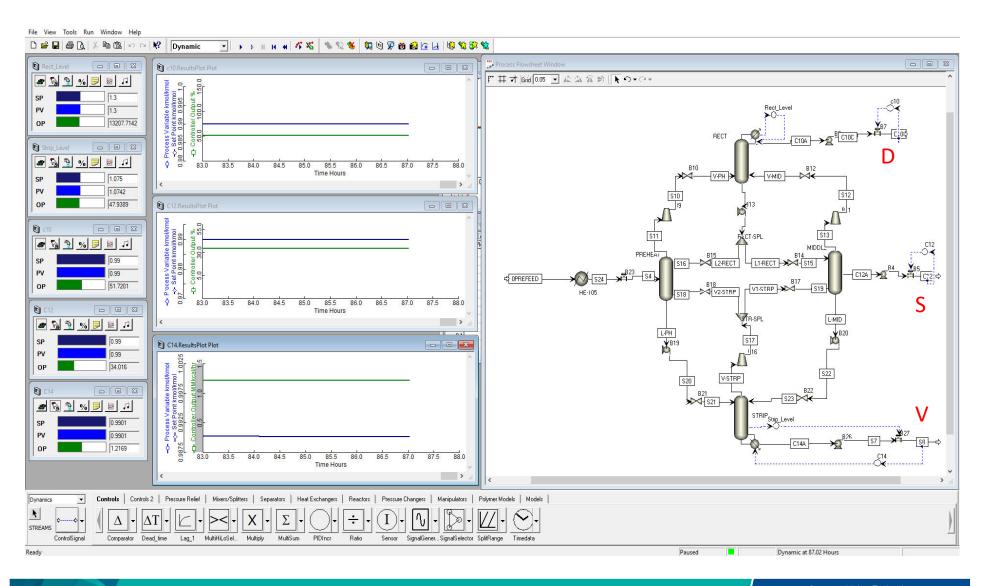
Dynamic Analysis

RGA results

Controlled variables	Manipulated variables		
	L	S	V
x_{C10}	-3.3070	4.3080	-0.0010
x_{C12}	4.2978	-3.4826	0.1848
x_{C14}	0.0092	0.1746	0.8162
	L	S	B
x_{C10}	-3.0273	4.0208	0.0065
x_{C12}	0.6892	-0.4059	0.7166
x_{C14}	3.3381	-2.6149	0.2768
	D	**S**	**V**
x_{C10}	**0.9916**	-0.0949	0.1033
x_{C12}	-0.1153	**1.1151**	0.0002
x_{C14}	0.1237	-0.0202	**0.8965**
	D	S	B
x_{C10}	-13.2389	-3.4140	17.6529
x_{C12}	0.7780	-0.2493	0.4713
x_{C14}	13.4609	4.6632	-17.1242

SVA results
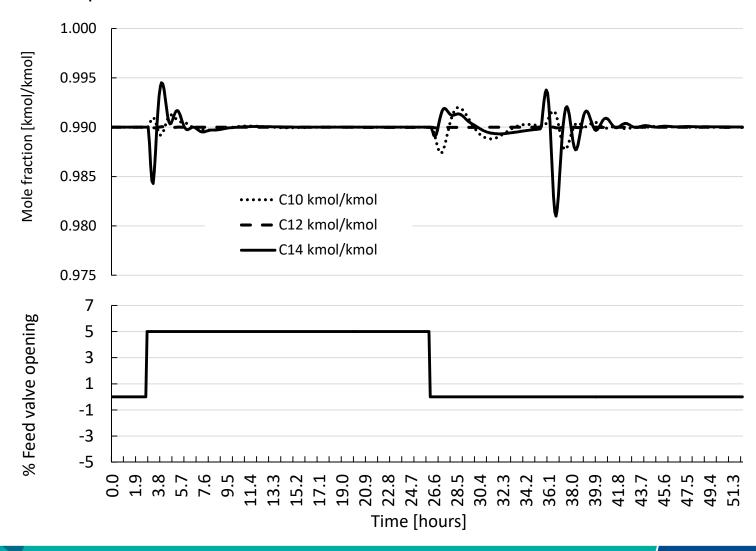
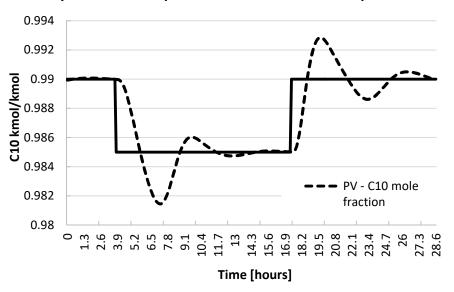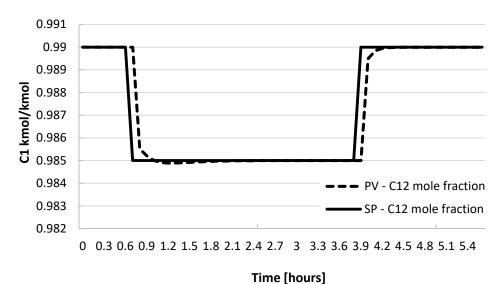| Pairing	Controlled variables	Manipulated variables [a]	CN
1	$x_{C10}, x_{C12}, x_{C14}$	LDS	2765.00
2	$x_{C10}, x_{C12}, x_{C14}$	LSV	147.84
3	$x_{C10}, x_{C12}, x_{C14}$	LSB	222.00
4	$x_{C10}, x_{C12}, x_{C14}$	LDV	139.46
5	$x_{C10}, x_{C12}, x_{C14}$	LDB	18.81
6	$x_{C10}, x_{C12}, x_{C14}$	LVB	1004.33
7	**$x_{C10}, x_{C12}, x_{C14}$**	**DSV**	**3.83**
8	$x_{C10}, x_{C12}, x_{C14}$	DSB	33.03
9	$x_{C10}, x_{C12}, x_{C14}$	DVB	4.22

Dynamic Analysis

Dynamic Analysis

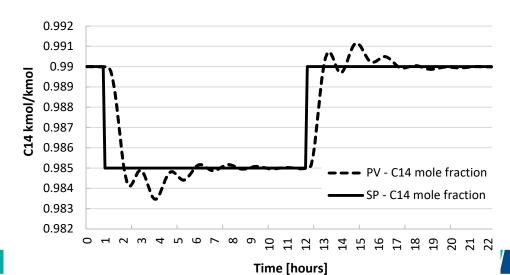Dynamic response of ±5% variations in feed flowrate

Dynamic Analysis

Dynamic response of ±5% in set point

Concluding Remarks

❑ A DWDC model was successfully developed in Aspen Plus.

❑ Economic and environmental assessment shows that DWDC saves >3% total capital cost, >10% total operating cost and reduce >10% carbon emission

❑ Pressure and hydraulic analysis were successfully implemented.

❑ Dynamic model were successfully modelled in Aspen Dynamic.

❑ DSV control configuration was selected and perform well for disturbance and set point change.

Concluding Remarks

❑ Current & Future works:-

- Heat integrated DWDC (Norul Malakiah, PhD)

- Pilot plant controllability and operability study (On-going)

- Reactive/Extractive DWDC (Latest interest)

- Advanced process control

- Offline and online optimization

- Process fault detection and diagnosis

THANK YOU

Acknowledgement

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- POPSIG IChemE

- Monash University Malaysia

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