# Aspen Plus

*Aspen Plus Biodiesel Model*

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# Revision History

| Version | Description |
|---|---|
| V7.0 | First version |
| V7.3 | Revised model based on biodiesel databank with full speciation of biodiesel and kinetic model for transesterification. |

# Contents

# Introduction

This example is a model of a process for the alkali catalyzed production of biodiesel from vegetable oil. It is intended to:

- Provide an example of how to model the different areas of this process
- Supply a starting set of components and physical property parameters for modeling processes of this type

The model is not intended for equipment design or for specifying other engineering documents without further review by a process engineer with experience of biodiesel processes.

The model includes:

- A nominal set of chemical species and property parameters for this process
- Typical process areas including: transesterification, methanol recovery, water washing, FAME purification, catalyst removal, glycerol purification, feed stock recovery and the main streams connecting these units
- Reaction kinetics of transesterification
- Key process control specifications such as pure methanol flow rate, phosphoric acid flow rate, and specifications for distillation columns

This model is an extension of an earlier biodiesel model in Aspen Plus examples. The previous model used a single triolein to represent the vegetable oil and a single fatty acid methyl ester to represent biodiesel product. A 95% conversion of feedstock is assumed to model the transesterification reaction. The earlier model provided a useful description of the biodiesel production process and a preliminary comparison of process parameters and modifications for biodiesel production when the constituent components of vegetable oils are not available.

The current model takes advantage of the new biodiesel databank which offers physical properties of triglycerides, diglycerides and monoglycerides. This new model has a detailed kinetic model for transesterification and it can be used to compare plant performance for various feedstocks. Moreover, the quality of biodiesels from different feedstocks, as measured by properties such as density and kinematic viscosity, can be evaluated according to the predicted composition profile of methyl fatty acid esters. The distribution of various byproducts and products can be linked to cost data for calculating the material costs from various feedstocks.

# 1 Components

The following components represent the chemical species present in the process:

**Table 1. Components Used in the Biodiesel Model**

| ID | Type | Name | Formula |
|---|---|---|---|
| METHANOL | CONV | METHANOL | CH4O |
| OOO | CONV | TRIOLEIN | C57H104O6 |
| MMM | CONV | TRIMYRISTIN | C45H86O6 |
| PPP | CONV | TRIPALMITIN | C51H98O6 |
| PPS | CONV | TAG-PPS | C53H102O6-13 |
| PPO | CONV | TAG-POP | C53H100O6-5 |
| POS | CONV | TAG-POS | C55H104O6-3 |
| MMP | CONV | TAG-MMP | C47H90O6-10 |
| PPLI | CONV | TAG-PLIP | C53H98O6-5 |
| POO | CONV | TAG-POO | C55H102O6-6 |
| PLIO | CONV | TAG-PLIO | C55H100O6-7 |
| OOS | CONV | TAG-OOS | C57H106O6-4 |
| OOLI | CONV | TAG-OOLI | C57H102O6-5 |
| MPLI | CONV | TAG-MLIP | C51H94O6-3 |
| MM | CONV | 1,3-DIMYRISTIN | C31H60O5-1 |
| PP | CONV | 1,3-DIPALMITIN | C35H68O5-1 |
| OO | CONV | 1,3-DIOLEIN | C39H72O5-1 |
| PO | CONV | SN-1-PALMITO-3-OLEIN | C37H70O5-3 |
| PLI | CONV | SN-1-PALMITO-3-LINOLEIN | C37H68O5-3 |
| MP | CONV | SN-1-MYRISTO-3-PALMITIN | C33H64O5-7 |
| PS | CONV | SN-1-PALMITO-3-STEARIN | C37H72O5-7 |
| OS | CONV | SN-1-OLEO-3-STEARIN | C39H74O5-4 |
| LIO | CONV | SN-1-LINOLEO-3-OLEIN | C39H70O5-8 |
| MLI | CONV | SN-1-MYRISTO-3-LINOLEIN | C35H64O5-3 |
| 1-M | CONV | 1-MONOMYRISTIN | C17H34O4 |
| 1-P | CONV | 1-MONOPALMITIN | C19H38O4 |
| 1-S | CONV | 1-MONOSTEARIN | C21H42O4 |

| ID | Type | Name | Formula |
|---|---|---|---|
| 1-O | CONV | MONOOLEIN | C21H40O4 |
| 1-LI | CONV | 1-MONOLINOLEIN | C21H38O4-1 |
| METHYL-O | CONV | METHYL-OLEATE | C19H36O2 |
| METHYL-P | CONV | METHYL-PALMITATE | C17H34O2-N1 |
| METHYL-M | CONV | METHYL-MYRISTATE | C15H30O2-N1 |
| METHYL-S | CONV | METHYL-STEARATE | C19H38O2-N1 |
| METHY-LI | CONV | METHYL-LINOLEATE | C19H34O2 |
| GLYCEROL | CONV | GLYCEROL | C3H8O3 |
| NAOH | CONV | WATER | H2O |
| WATER | CONV | WATER | H2O |
| H3PO4 | CONV | WATER | H2O |
| NA3PO4 | CONV | WATER | H2O |

Vegetable oil is the mixture of triglycerides (TG) such as OOO, PPP and MMM, et al[1]. For this biodiesel model, we assume the feedstock is the palm oil whose composition profile is determined by Che Man[2]. Table 2 lists the glyceride composition of the refined, bleached and deodorized (RBD) palm oil.

## Table 2. Glyceride Composition of RBD Palm Oil[2]

| Glyceride | Glyceride Composition (%) |
|---|---|
| **Diglyceride** | **5.20** |
| **Triglyceride** | **94.80** |
| Triunsaturated | |
| OOO | 4.40 |
| OOLI | 0.58 |
| **Total** | **4.98** |
| Monosaturated | |
| PLIO | 9.68 |
| POO | 23.26 |
| OOS | 2.24 |
| **Total** | **35.18** |
| Disaturated | |
| MPLI | 2.20 |
| PPLI | 9.23 |
| PPO | 29.62 |
| POS | 4.90 |
| **Total** | **45.95** |
| Trisaturated | |
| MMM | 0.42 |
| MMP | 1.70 |
| PPP | 5.51 |
| PPS | 1.06 |
| **Total** | **8.69** |

The detailed fatty acid distribution in diglycerides is not given, so for convenience, we represent all the diglycerides in the feed with the PP molecule.

Diglycerides (DG) such as MM, OO, PLi, MP and monoglycerides (MG) including 1-M, 1-P, 1-S, 1-O, 1-Li are the intermediates of the transesterification reaction.

Methyl-Oleate, Methyl-Palmitate, Methyl-Myristate, Methyl-Stearate, and Methyl-Linoleate are the biodiesel products, with glycerol as a by-product.

Sodium hydroxide is used as the catalyst, and is removed by adding $H_3PO_4$ to precipitate $Na_3PO_4$. Because electrolyte chemistry is not modeled in detail, these electrolytes are modeled using physical property data for water, but with their correct molecular weights.

# 2 Process Description

The flowsheet is based upon information included in the paper of Zhang et al (2003)[3].

This biodiesel process model includes the following units:

### Table 3. General Unit Operations Used in the Bio-Diesel Process

| Unit | Purpose |
|---|---|
| Transesterification | React oil with alcohol in the presence of catalyst to yield biodiesel and glycerol |
| Methanol Recovery | Recover excess methanol |
| Water Washing | Separate fatty acid methyl ester (FAME) from glycerol and electrolytes |
| FAME Purification | Purify FAME and recover oil |
| Catalyst Removal | Remove excess catalyst |
| Glycerol Purification | Purify glycerol |

# 3 Physical Properties

The models used to calculate physical properties in Aspen Plus are grouped into methods named after the central model, for example Ideal, Redlich-Kwong-Soave, and NRTL (Non-Random Two Liquid). The property method used in this biodiesel model is Dortmund modified UNIFAC. This is suitable for preliminary work. NRTL would probably give more accurate results, but requires estimation of NRTL binary interaction parameters.

However, the Dortmund modified UNIFAC model requires the UFGRPD parameter. This parameter stores the functional group information which contains UNIFAC group numbers and the number of occurrences of each group. For those components missing the UFGRPD parameters, the Property Estimation tool in Aspen Plus, when enabled, can automatically calculate UFGRPD according to their molecular structures. Analogously, when the UNIFAC model or Lyngby modified UNIFAC model is used, UFGRP and UFGRPL parameters are required, respectively.

So for convenience, we select **Estimate all missing parameters** in Estimation options in this model.

Thermophysical property model parameters of tri-, di-, and mono-glycerides are currently available in the new biodiesel databank.

# 4 Reactions

A kinetic reaction model named PALM-OIL has been created for use in REACTOR. In addition, catalyst removal is modeled with a fixed conversion reaction in NEUTR. (See Chapters 5 and 6 for more info on these blocks.)

## A. Transesterification Kinetics: PALM-OIL

1. Kinetic OOO + Methanol --> Methyl-O + OO
2. Kinetic OO + Methyl-O --> OOO + Methanol
3. Kinetic OO + Methanol --> Methyl-O + 1-O
4. Kinetic Methyl-O + 1-O --> OO + Methanol
5. Kinetic 1-O + Methanol --> Glycerol + Methyl-O
6. Kinetic Glycerol + Methyl-O --> Methanol + 1-O

7. Kinetic MMM + Methanol --> Methyl-M + MM
8. Kinetic Methyl-M + MM --> MMM + Methanol
9. Kinetic MM + Methanol --> Methyl-M + 1-M
10. Kinetic Methyl-M + 1-M --> MM + Methanol
11. Kinetic 1-M + Methanol --> Glycerol + Methyl-M
12. Kinetic Glycerol + Methyl-M --> Methanol + 1-M

13. Kinetic PPP + Methanol --> Methyl-P + PP
14. Kinetic Methyl-P + PP --> PPP + Methanol
15. Kinetic PP + Methanol --> Methyl-P + 1-P
16. Kinetic Methyl-P + 1-P --> Methanol + PP
17. Kinetic 1-P + Methanol --> Glycerol + Methyl-P
18. Kinetic Glycerol + Methyl-P --> Methanol + 1-P

19. Kinetic PPS + Methanol --> Methyl-S + PP

20. Kinetic Methyl-S + PP --> PPS + Methanol
21. Kinetic PPS + Methanol --> Methyl-P + PS
22. Kinetic Methyl-P + PS --> PPS + Methanol
23. Kinetic PS + Methanol --> Methyl-P + 1-S
24. Kinetic Methyl-P + 1-S --> Methanol + PS
25. Kinetic 1-S + Methanol --> Glycerol + Methyl-S
26. Kinetic Glycerol + Methyl-S --> Methanol + 1-S
27. Kinetic PS + Methanol --> Methyl-S + 1-P
28. Kinetic Methyl-S + 1-P --> Methanol + PS

29. Kinetic PPO + Methanol --> Methyl-O + PP
30. Kinetic Methyl-O + PP --> PPO + Methanol
31. Kinetic PPO + Methanol --> Methyl-P + PO
32. Kinetic Methyl-P + PO --> PPO + Methanol
33. Kinetic PO + Methanol --> Methyl-P + 1-O
34. Kinetic Methyl-P + 1-O --> Methanol + PO
35. Kinetic PO + Methanol --> Methyl-O + 1-P
36. Kinetic Methyl-O + 1-P --> PO + Methanol

37. Kinetic MMP + Methanol --> Methyl-P + MM
38. Kinetic MM + Methyl-P --> Methanol + MMP
39. Kinetic MMP + Methanol --> Methyl-M + MP
40. Kinetic MP + Methyl-M --> Methanol + MMP
41. Kinetic MP + Methanol --> Methyl-P + 1-M
42. Kinetic Methyl-P + 1-M --> MP + Methanol
43. Kinetic MP + Methanol --> Methyl-M + 1-P
44. Kinetic Methyl-M + 1-P --> MP + Methanol

45. Kinetic PPLI + Methanol --> Methy-LI + PP
46. Kinetic Methy-LI + PP --> PPLI + Methanol
47. Kinetic PPLI + Methanol --> Methyl-P + PLI
48. Kinetic Methyl-P + PLI --> PPLI + Methanol
49. Kinetic PLI + Methanol --> Methy-LI + 1-P
50. Kinetic Methy-LI + 1-P --> PLI + Methanol
51. Kinetic PLI + Methanol --> Methyl-P + 1-LI
52. Kinetic Methyl-P + 1-LI --> PLI + Methanol

53. Kinetic 1-LI + Methanol --> Glycerol + Methy-LI
54. Kinetic Glycerol + Methy-LI --> Methanol + 1-LI

55. Kinetic POO + Methanol --> Methyl-O + PO
56. Kinetic Methyl-O + PO --> POO + Methanol
57. Kinetic POO + Methanol --> Methyl-P + OO
58. Kinetic Methyl-P + OO --> POO + Methanol

59. Kinetic POS + Methanol --> Methyl-S + PO
60. Kinetic Methyl-S + PO --> Methanol + POS
61. Kinetic POS + Methanol --> Methyl-P + OS
62. Kinetic Methyl-P + OS --> Methanol + POS
63. Kinetic POS + Methanol --> Methyl-O + PS
64. Kinetic Methyl-O + PS --> Methanol + POS

65. Kinetic PLIO + Methanol --> Methyl-O + PLI
66. Kinetic Methyl-O + PLI --> Methanol + PLIO
67. Kinetic PLIO + Methanol --> Methyl-P + LIO
68. Kinetic Methyl-P + LIO --> Methanol + PLIO
69. Kinetic PLIO + Methanol --> Methy-LI + PO
70. Kinetic Methy-LI + PO --> Methanol + PLIO
71. Kinetic LIO+ Methanol --> Methyl-O + 1-LI
72. Kinetic Methyl-O + 1-LI --> LIO + Methanol
73. Kinetic LIO+ Methanol --> Methy-LI + 1-O
74. Kinetic Methy-LI + 1-O --> LIO + Methanol

75. Kinetic OOS + Methanol --> Methyl-S + OO
76. Kinetic Methyl-S + OO --> OOS + Methanol
77. Kinetic OOS + Methanol --> Methyl-O + OS
78. Kinetic Methyl-O + OS --> OOS + Methanol
79. Kinetic OS + Methanol --> Methyl-O + 1-S
80. Kinetic Methyl-O + 1-S --> Methanol + OS
81. Kinetic OS + Methanol --> Methyl-S + 1-O
82. Kinetic Methyl-S + 1-O --> Methanol + OS

83. Kinetic OOLI + Methanol --> Methy-LI + OO

84. Kinetic Methy-LI + OO --> OOLI + Methanol
85. Kinetic OOLI + Methanol --> Methyl-O + LIO
86. Kinetic Methyl-O + LIO --> OOLI + Methanol

87. Kinetic MPLI + Methanol --> Methy-LI + MP
88. Kinetic Methy-LI + MP --> MPLI + Methanol
89. Kinetic MPLI + Methanol --> Methyl-M + PLI
90. Kinetic Methyl-M + PLI --> MPLI + Methanol
91. Kinetic MPLI + Methanol --> Methyl-P + MLI
92. Kinetic Methyl-P + MLI --> MPLI + Methanol
93. Kinetic MLI + Methanol --> Methyl-M + 1-LI
94. Kinetic Methyl-M + 1-LI --> MLI + Methanol
95. Kinetic MLI + Methanol --> Methy-LI + 1-M
96. Kinetic Methy-LI + 1-M --> MLI + Methanol

## B. Catalyst Removal

3 NaOH + $H_3PO_4$ --> $Na_3PO_4$ + 3 Water 100% conversion of NaOH

The power expressions are used for the rate-controlled transesterification reactions:

$$r = k\left(\frac{T}{T_o}\right)^n \exp\left(-\frac{E}{RT}\right)\prod_{i=1}^{N} C_i^{ai}\left(\frac{1}{T}-\frac{1}{T_o}\right) \quad (1)$$

Where:

$r$ = Rate of reaction;

$k$ = Pre-exponential factor;

$T$ = Absolute temperature;

$T_o$ = Reference temperature;

$n$ = Temperature exponent;

$E$ = Activation energy;

$R$ = Universal gas constant;

$N$ = Number of components in the reaction;

$C_i$ = Concentration of component $i$;

$a_i$ = The stoichiometric coefficient of component $i$ in the reaction equation.

In equation (1), the concentration basis is Molarity, the factor $n$ is zero, and $k$ and $E$ are given in Table 4. The kinetic parameters for reactions 1-96 in Table 4 are derived from the work of Narvaez et al. (2007)[4]. The effect of concentration of catalyst on the transesterification was studied in the paper[4], but the given kinetics didn't include the concentration of catalyst. So we made some conversions to add the concentration of catalyst (sodium hydroxide) into Narvaez's kinetics.

**Table 4. Parameters $k$ and $E$ in Equation (1)**

| Reaction Type | Reaction No. | $k$ ($T_o$ =323.15K) | $E$ (kcal/mol) |
|---|---|---|---|
| $TG \rightarrow DG$ | 1,7,13 | 0.02311 | 13.5 |
| | 19,29,37,45,57,59,61,63,65,67, 69,75,83,87,89,91 | 0.00770 | |
| | 21,31,39,47,55,77,85 | 0.01541 | |
| $DG \rightarrow TG$ | 2,8,14,20,22,30,32,38,40,46, 48,56,58,60,62,64,66,68,70,76, 78,84,86,88,90,92 | 0.001867 | 10.3 |
| $DG \rightarrow MG$ | 3,9,15 | 0.10659 | 17.4 |
| | 23,27,33,35,41,43,49,51,71,73, 79,81,93,95 | 0.05330 | |
| $MG \rightarrow DG$ | 4,10,16,24,28,34,36,42,44,50, 52,72,74,80,82,94,96 | 0.002217 | 16.2 |
| $MG \rightarrow FAME$ | 5,11,17,25,53 | 0.05754 | 6.2 |
| $FAME \rightarrow MG$ | 6,12,18,26,54 | 0.000267 | 11.9 |

Note that Narvaez et al. (2007) just proposed the transesterification kinetics of palm oil instead of the individual triglycerides that make up the oil. So, in this work, we assume the kinetics of all the constituent triglycerides are the same as that for the triglyceride mixture, palm oil. For example, both reaction 1 and reaction 7 are steps to producing diglycerides (DG) from triglycerides (TG), so the rate constants of these two reactions are treated as equal. Another assumption is that we have considered all possible reactions for TGs and DGs. Using component PPS as the example:

PPS will take part in the following parallel reactions:

19. PPS + Methanol --> Methyl-S + PP

21. PPS + Methanol --> Methyl-P + PS

And the rate constant of Reaction 21 is regarded as twice that of Reaction 19 because there are two P fragments with PPS.

# 5 Simulation Approaches

***Unit Operations*** - Major unit operations in this model have been represented by Aspen Plus blocks as shown in Table 5.

### Table 5. Aspen Plus Unit Operation Blocks Used in the Biodiesel Model

| Unit Operation | Aspen Plus "Block" | Comments / Specifications |
|---|---|---|
| Transesterification | RCSTR | Rigorous simulation with kinetics reactions. |
| Methanol Recovery | RadFrac | Rigorous multi-stage distillation model.<br>7 theoretical stages. |
| Water Washing | Liquid-Liquid Extractor | Rigorous multi-stage liquid-liquid extractor model.<br>6 theoretical stages |
| FAME Purification | RadFrac | Rigorous multi-stage distillation model.<br>6 theoretical stages. |
| Catalyst Removal | RStoic<br><br>Sep | Simplified simulation with stoichiometric reactions<br>Simplified simulation for solid removal |
| Glycerol Purification | RadFrac | Rigorous multi-stage distillation model.<br>6 theoretical stages. |

***Streams*** - Streams represent the material and energy flows in and out of the process. Streams can be of three types: Material, Heat, and Work. Feeds to the biodiesel model are oil, methanol, sodium hydroxide, water and acid.

***Design-Specs, Calculator Blocks*** - The simulation includes a Design Spec and a Calculator Block as shown in Tables 6 & 7:

### Table 6. Design Specs Used in the Biodiesel Model

| Spec Name | Spec (Target) | Manipulated Variable |
|---|---|---|
| MEOHCONC | Mass fraction of methanol in reactor outlet is 0.092 | Methanol feed stream flow rate |

## Table 7. Flowsheet Calculators Used in the Biodiesel Model

| Name | Purpose |
|---|---|
| PO3FLOW | $H_3PO_4$ feed flow is determined according to excess sodium hydroxide. |

# 6 Simulation Results

The Aspen Plus simulation flowsheet is shown in Figure 1.

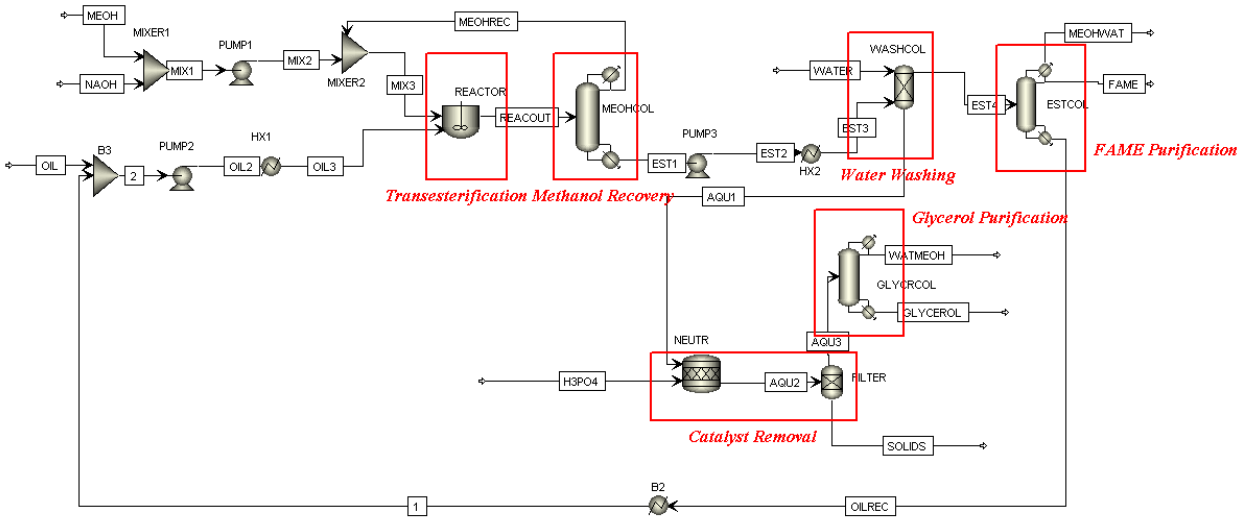


***Figure 1. Biodiesel Flowsheet in Aspen Plus***

Key simulation results are presented in Table 8.

## Table 8. Key Simulation Results

| | | |
|---|---|---|
| Plant capacity (pure FAME) | 9.23 | MM kg/yr |
| Oil feed | 1050 | kg/hr |
| Methanol feed | 127.094 | kg/hr |
| Catalyst feed | 50 | kg/hr |
| $H_3PO_4$ feed | 40.8 | kg/hr |
| Water feed for washing | 50 | kg/hr |
| Transesterification reactor biodiesel composition | 0.758 | Mass fraction |
| Transesterification reactor oil conversion | 0.983 | 1 h |
| Product FAME purity | 0.997 | Mass fraction |
| Product Glycerol purity | 1 | Mass fraction |

The oil feed is the sum of the constituent triglycerides while the FAME production is the sum of all the methyl esters.

Table 9 compares the composition profile of biodiesel product calculated with the current model and with the previous model based on the same chemical feeds and flowsheet. The properties for biodiesel obtained in both simulations are analyzed to evaluate the quality specification required by ASTM (American Society for Testing and Materials)[5] and EN (European Norms) standards[6].

## Table 9. FAME Distribution in the Product

| | Current Model | Old Model | EN14214 | ASTM D6751 |
|---|---|---|---|---|
| Methyl-O (wt%) | 37.82 | 99.7 | | |
| Methyl-P (wt%) | 49.34 | - | | |
| Methyl-M (wt%) | 2.15 | - | | |
| Methyl-S (wt%) | 2.82 | - | | |
| Methyl-Li (wt%) | 7.57 | - | | |
| FAME (wt%) | 99.7 | 99.7 | >96.5 | |
| Monoglycerides (wt%) | 0.27 | - | <0.80 | |
| Diglycerides (wt%) | Trace | - | <0.20 | |
| Triglycerides (wt%) | Trace | 0.3 | <0.20 | |
| Density at 15°C, kg/m3 | 889.19 | 874.7142 | 860-900 | |
| Viscosity at 40°C, mm2/s | 3.85 | 4.54 | 3.50-5.00 | 1.90-6.00 |

From the Table 9, the constituent FAMEs obtained in the two simulations are very different. So are the qualities of the biodiesel products. The new model offers the capability to model biodiesel product quality quantitatively.

Table 10 presents the composition profile of the recycled oil in both simulations.

## Table 10. Composition of Recycled Oil

| | Current Model | Old Model |
|---|---|---|
| **Monoglycerides (wt%)** | **35.3** | **-** |
| 1-M | 0.27 | - |
| 1-P | 12.76 | - |
| 1-S | 1.25 | - |
| 1-O | 17.55 | - |
| 1-LI | 3.46 | - |
| **Diglycerides (wt%)** | **13.7** | **-** |
| MM | 0.06 | - |
| PP | 3.28 | - |
| OO | 2.03 | - |
| PO | 5.48 | - |
| PLI | 1.09 | - |
| MP | 0.30 | - |
| PS | 0.36 | - |
| OS | 0.36 | - |
| LIO | 0.64 | - |

| | Current Model | Old Model |
|---|---|---|
| MLI | 0.07 | - |
| **Triglycerides (wt%)** | **45.6** | **94.6** |
| OOO | 2.29 | 94.6 |
| MMM | 0.18 | - |
| PPP | 3.30 | - |
| PPS | 0.61 | - |
| PPO | 14.85 | - |
| POS | 2.34 | - |
| MMP | 0.74 | - |
| PPLI | 4.37 | - |
| POO | 11.60 | - |
| PLIO | 2.85 | - |
| OOS | 1.06 | - |
| OOLI | 0.46 | - |
| MPLI | 0.98 | - |
| **FAMEs (wt%)** | **5.4** | **5.4** |
| **Total Flow (kg/h)** | **38.36** | **54.91** |

Figures 2 and 3 compare the temperature profiles in the glycerol purification column and FAME purification column, respectively.

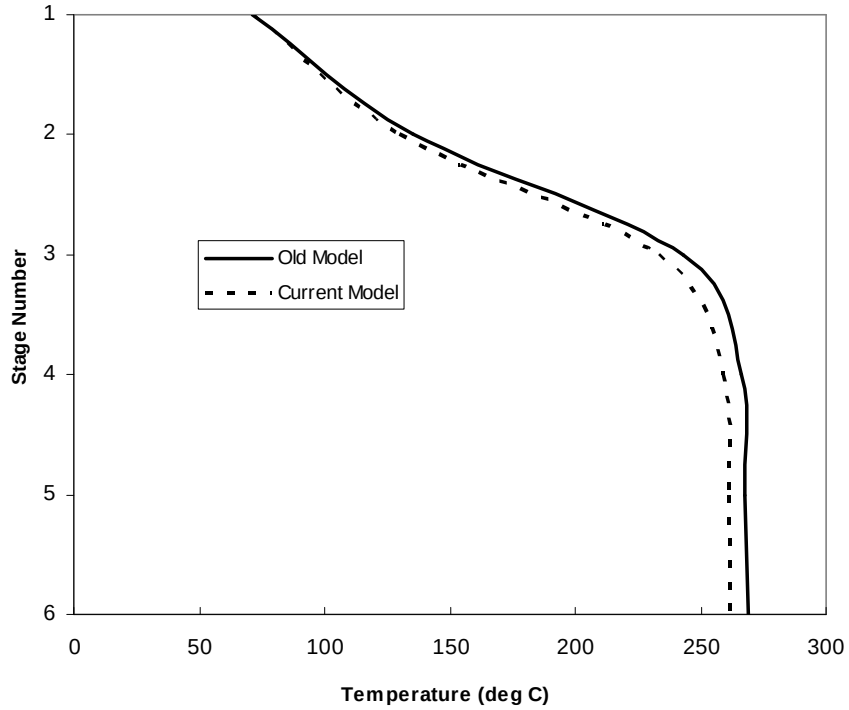


***Figure 2. Glycerol Purification Temperature Profile for the Old Model and Current Model***

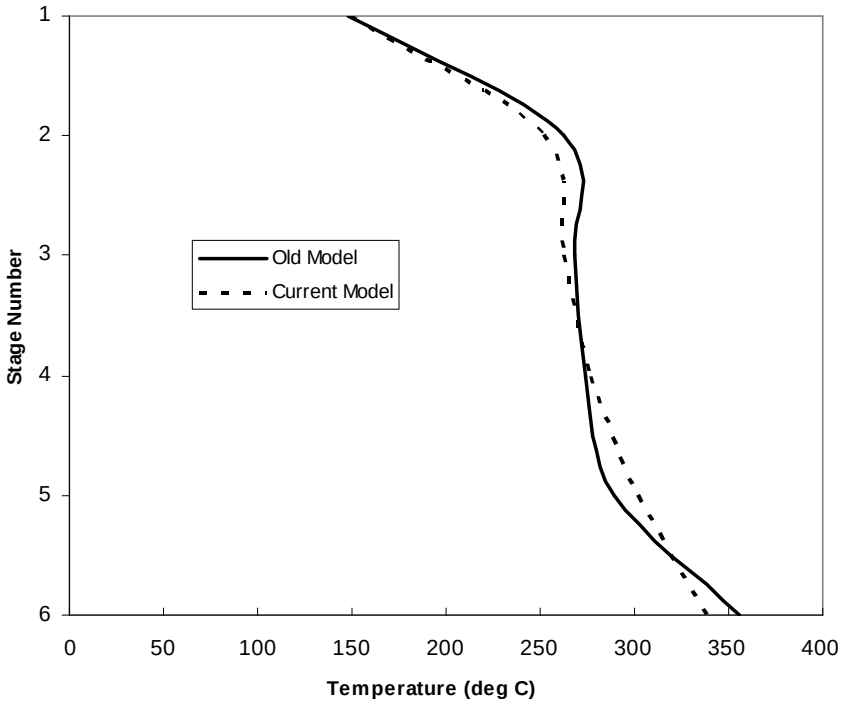


***Figure 3. FAME Purification Temperature Profile for the Old Model and Current Model***

# 7 Conclusions

The biodiesel model provides a useful description of the process, especially introducing the kinetics of transesterification into the process. The model can be used as a guide for understanding the process and the economics in change of biodiesel feedstock, and also as a starting point for more sophisticated models for plant design and specifying process equipment.

# References

[1] Y.H. Hui, "Handbook of Food Science, Technology, and Engineering", *Marcel Dekker*, 9.6-9.10, 2005.

[2] Y.B. Che Man, T. Haryati, H.M. Ghazali, B.A. Asbi, "Composition and Thermal Profile of Crude Palm Oil and Its Products", *Journal of American Oil Chemical Society*, 76:237-242, 1999.

[3] Y. Zhang, M.A. Dube, D.D. McLean, M. Kates, "Biodiesel Production from Waste Cooking Oil: 1. Process Design and Technological Assessment", *Bioresource Techchnology*, 89:1-16, 2003.

[4] P.C. Narvaez, S.M. Rincon, F.J. Sanchez, "Kinetics of Palm Oil Methanolysis", *Journal of American Oil Chemical Society*, 84:971-977, 2007.

[5] http://en.wikipedia.org/wiki/ASTM_D6751

[6] http://en.wikipedia.org/wiki/EN_14214#cite_ref-0