รายงานการวิจัยฉบับสมบูรณ์

การออกแบบเครื่องปฏิกรณ์แบบต่อเนื่องสองขั้นตอนเพื่อผลิตเมทิลเอสเทอร์จากน้ำมันปาล์มดิบชนิดหีบรวมชนิดกรดสูง

คณะวิศวกรรมศาสตร์ มหาวิทยาลัยสงขลานครินทร์
วิทยาเขตหาดใหญ่

หัวหน้าโครงการวิจัย รศ.กำพล ประทีปชัยกูร

งานวิจัยนี้ได้รับทุนอุดหนุนการวิจัย
จากเงินงบประมาณแผ่นดิน ประจำปีงบประมาณ 2554

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Topic: Design of Two-Stage Continuous Reactor for Producing Methyl Ester from High Free Fatty Acid Mixed Crude Palm Oil

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ABSTRACT

Generally, high quality of biodiesel in high productivity is required under the low cost investment. Therefore, the continuous stirred tank reactors (CSTR) are preferred in the investment because it is easy to fabricate and to control the product quality from liquid-liquid reaction under the low cost investment. The principle of kinetics, unit operation of chemical engineering and heat transfer are used to design CSTR for producing biodiesel from mixed crude palm oil (MCPO) via the two-stage process (esterification followed by transesterification). After finishing the design, the designed system was verified by simulating with The ASPEN PLUS Simulation Engine (chemical commercial program). Finally, the system was fabricated and operated. The results indicated that the efficiency of the two-stage continuous process in full system was lower than the design around 10 %. FFA could be reduced from 16-18 wt% to less than 1 wt% under the optimization of 23.04 v% of methanol, 2.07 v% of sulfuric acid, 2.22 min of retention time, and 793 rpm of stirrer speed (40 L/hr of oily solution yield and 15 L/hr of waste solution yield). The concentration of biodiesel at 95.70 wt% having yield around 43 L/hr and of glycerin around 12 L/hr was obtained under the test operated condition of 24 v% of methanol and 1 %wt/v of potassium hydroxide under 4 min of retention time of and 793 rpm of stirrer speed. After purification, it was found that 75.06% of biodiesel based on initial MCPO (84.44% of biodiesel based on acidified MCPO) was obtained.

Keywords: Biodiesel, Continuous reactor, CPO, Methyl ester, Mixed crude palm oil, The two-stage process

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NOMENCLATURES

A	The initial regent
A_d	The surface area of decanter (m^2)
A_i	Area of inner surface of reactor (m)
A_o	Area of outer surface of reactor (m)
A_m	Logarithmic mean area (m^2)
A_s	Surface area (m^2)
ASTM	American standard test method
[A]	The molar concentration of reagent A
[AL]	The concentration of alcohol (mol/L)
a	The coefficient of reagent A, The reaction order of reagent A and FFA
a_1	The experiment determined constant
B	The initial reagent
[B]	The molar concentration of reagent B
b	The coefficient of reagent B, The reaction order of reagent B and alcohol
C	The product
C_A, C_{A0}	The concentration of reagent A (mol/L)
C_{AL}	The concentration of alcohol (mol/L)
C_B, C_{B0}	The concentration of reagent B (mol/L)
C_C, C_{C0}	The concentration of product C (mol/L)
C_D, C_{D0}	The concentration of product D (mol/L)
C_{DG}	The concentration of diglyceride (mol/L)
C_E	The concentration of ester (mol/L)
C_{FFA}	The concentration of free fatty acid (mol/L)
C_{GL}	The concentration of glycerol (mol/L)
C_{MG}	The concentration of monoglyceride (mol/L)
C_p	Specific heat at constant pressure, KJ/kg· °C or KJ/kg·K
C_{TG}	The concentration of triglyceride (mol/L)
C_{WT}	The concentration of water (mol/L)
CSTR, CSTRs	Continuous stirred tank reactors
[C]	The molar concentration of product C

NOMENCLATURES (Cont')

c	The coefficient of product C, The reaction order of product C and ester
D	The product
D_a	Diameter of turbine impeller (cm)
D_{am}	The diameter of impeller (m)
D_d	Diameter of turbine impeller disc (cm)
D_h	Diameter of hole on separate plate (cm)
D_i	The inside diameter of reactor (m)
D_o	The outside diameter of reactor (m)
D_r	Diameter of reactor or tube (m)
D_s	Diameter of separate tank plate (cm)
D_t, D_{tm}	The diameter of reactor or tank (cm, m)
DG	Diglyceride
[D]	The molar concentration of product D
[DG]	The concentration of diglyceride (mol/L)
d	The coefficient of product D, The reaction order of product D and water
E_s	Space between turbine and bottom tank (cm)
EN	European test method
[E]	The concentration of ester (mol/L)
e	The thickness of turbine (cm)
F_A, F_B, F_C, F_D	The molar flow rate
F_{A0}, F_{B0}, F_{C0}, F_{D0}	The initial molar flow rate
F_{A1}	The molar flow rate (mol/min)
FFA	Free fatty acid
[FFA]	The concentration of free fatty acid (mol/L)
f	The thickness of axle (cm)
G	Space between baffle and wall (cm)
GL	Glycerol
[GL]	The concentration of glycerol (mol/L)
g	The thickness of axle ring (cm)
H_n	Reactor height (m)

NOMENCLATURES (Cont')

H_t, H_{tm}	The height of reactor or tank (cm, m)
HOR', HOR"	Alcohol
H_2O	Water
H_2SO_4	Sulfuric acid
$h_{horizontal, n tube}$	The average heat transfer coefficient for vertical tier of *N* horizontal tube (W/m·°C)
$h_{horizontal, 1 tube}$	The average heat transfer coefficient for vertical tier of 1 horizontal tube (W/m·°C)
h_i, h_2	The convection heat transfer coefficients inside (W/m^2·°C)
h_o, h_1	The convection heat transfer coefficients outside (W/m^2·°C)
J	Baffle width (cm)
KOH	Potassium hydroxide
k	Thermal conductivity, W/m· °C
k_a, k_1	The rate coefficient of the forward reaction
k_{-a}, k_2	The rate coefficient of the reverse reaction
k_m	Thermal conductivity of reactor material or tube wall (W/m^2·°C)
k_y	The amount of independent variables
L	Blade length (cm)
L_d	The length of decanter (m)
Lj	The length of jacket (m)
L_t	The thickness of reactor wall (m)
MCPO	Mixed crude palm oil
ME	Methyl ester or biodiesel
MeOH	Methanol
MG	Monoglyceride
[MG]	The concentration of monoglyceride (mol/L)
$\dot{m}$	Mass flow rate (kg/s)
N, N_s	The speed of stirrer (rpm, rps)
N	The number of horizontal tube vertical tier (tube)
N_{min}	The minimum number of distillatory plate

NOMENCLATURES (Cont')

N_{RE}	Reynolds number
NaOH	Sodium hydroxide
Nu	Nusselt number
n	The number of fin
P'_A	Vapor pressure of components A (N/m^2)
P'_B	Vapor pressure of components B (N/m^2)
PBR	Packed bed reactor
PFR	Plug-flow tubular reactor
Pr	Prandtl number
Q	The mixing flow rate (m^3/hr)
$\dot{Q}$	Rate of heat transfer of inner solution (KJ/s)
R, R', R'', R'''	Alkyl group
R'COOH	Organic acid
RCOOR', R'COOR''	Ester
Re	Reynolds number
r_A	The reaction rate of regent A
r_{AL}	The reaction rate of alcohol ($mol \cdot L^{-1} \cdot min^{-1}$)
r_{A1}	The reaction rate of the first reactor
r_{A2}	The reaction rate of the second reactor
r_{DG}	The reaction rate of diglyceride ($mol \cdot L^{-1} \cdot min^{-1}$)
r_E	The reaction rate of ester ($mol \cdot L^{-1} \cdot min^{-1}$)
r_{FFA}	The reaction rate of free fatty acid ($mol \cdot L^{-1} \cdot min^{-1}$)
r_{GL}	The reaction rate of glycerol ($mol \cdot L^{-1} \cdot min^{-1}$)
r_i	Inner radius (m)
r_{MG}	The reaction rate of monoglyceride ($mol \cdot L^{-1} \cdot min^{-1}$)
r_o	Outer radius (m)
r_{TG}	The reaction rate of triglyceride ($mol \cdot L^{-1} \cdot min^{-1}$)
r_{WT}	The reaction rate of water ($mol \cdot L^{-1} \cdot min^{-1}$)
S	The optimum fin spacing (m)
SFT	Saponification followed by transesterification
T_1	Temperature at outside reactor wall (°C)

NOMENCLATURES (Cont')

$T_{1\infty}$	Temperature of paraffin oil (°C)
T_2	Temperature of inside reactor wall (°C)
$T_{2\infty}$	Temperature of solution in reactor (°C)
TG	Triglyceride
TLC/FID	Thin Layer Chromatography/ Flame Ionization Detector
TSP	The two-stage process
[TG]	The concentration of triglyceride (mol/L)
t	The fin thickness (m)
t_s	The separation time (hr)
t_T	The mixing time (s)
U	The force convection relations ($W/m^2 \cdot °C$)
U_o	The outer surface reactor overall heat transfer coefficient ($W/m^2 \cdot °C$)
V	The volume of reactor (L)
V_A	The volume of axle (cm^3)
V_{AR}	The volume of axle ring (cm^3)
V_B	The volume of four cylindrical baffles (cm^3)
VBL	The volume of six-blade (cm^3)
VD	The volume of disc (cm^3)
V_R	The volume of reactor (cm^3)
V_1	The volume of the first reactor (L)
V_2	The volume of the second reactor (L)
W	Blade width (cm)
Ws	The width surface of reactor (m)
WT	Water
[WT]	The concentration of water
X	Conversion
X_1	The conversion of the first reactor
X_2	The conversion of the second reactor
x_B	Mole fraction in bottom product
x_D	Mole fraction in overhead product
x_i, x_j	Independent variables

NOMENCLATURES (Cont')

x_w	Thickness of tube (m)
y	Response
Z_{A1}	The heavy phase depth (a half of the liquid depth) and the height of feed mixture entrance
Z_{A2}	The height of the heavy liquid overflow
Z_T	The liquid depth (90 % of the full separated tank) and the height of the light liquid overflow
β_0, β_i, β_{ij}, β_{ii}	Coefficient
ΔT	Temperature difference of solution (°C)
ΔT_{lm}	The logarithm mean temperature difference solution
ΔT_p	Temperature difference of paraffin oil (°C)
α	The center point
α_{AB}	Relative volatility of component A to component B
ρ	The density of liquid (kg/m^3)
ρ_A	The density of liquid of solution A (kg/m^3)
ρ_B	The density of liquid of solution B (kg/m^3)
τ	The retention time (min)
μ	The viscosity of liquid (Pa.s)
μ_t	The total viscosity (cP)
v	The volumetric flow (L/min)
v_k	Kinematics viscosity, m^2/s
v_m	The mean velocity of liquid (m/s)
v_0	The volumetric flow (L/min)
(1)	Triglyceride
(2)	Alcohol
(3)	Ester
(4)	Glycerol