DEVELOPMENT OF MESOSCALE OSCILLATORY BAFFLED REACTOR (MOBR) FOR BIOETHANOL PRODUCTION

SYAMSUTAJRI BINTI SYAMSOL BAHRI

MASTER OF ENGINEERING (CHEMICAL)
UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

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SYAMSUTAJRI BINTI SYAMSOL BAHRI

Thesis submitted in fulfilment of the requirements
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LIST OF ABBREVIATIONS

ALR	air-lift loop reactor
BCR	bubble column reactor
BR	batch reactor
CDW	cell dry weight
COBR	continuous oscillatory baffled reactor
CSTR	continuous stirred tank reactor
DNS	dinitrosalicyclic acid
FAME	fatty acid methyl ester
FBR	fed bed reactor
FR	fluidized reactor
HPLC	high performance liquid chromatography
KCl	potassium chlorite
MOBR	mesoscale oscillatory baffled reactor
NaOH	sodium hydroxide
NB	nutrient broth
OBB	oscillatory baffled bioreactor
OBBC	oscillatory baffled batch crystallizer
OBF	oscillatory baffled fermenter
OBR	oscillatory baffled reactor
OD	optical density
OFM	oscillatory flow mixing
OFR	oscillatory flow reactor
PBR	packed bed reactor

PFR	plug flow reactor
POF	pure oscillatory flow
rpm	revolutions per minute
rps	revolutions per second
RTD	residense time distribution
SPC	smooth periodic constrictions
STR	stirred tank reactor
TBR	tubular baffled reactor

LIST OF SYMBOLS

C_i	Tracer concentration
C_o	Orifice coefficient
d	Tube diameter, m
d_o	Orifice diameter, m
$\mathrm{E}(t)$	The age exit distribution @ RTD function
$\mathrm{E}(\theta)$	Distribution curve @ normalized RTD function
f	Oscillation frequency, Hz @ s^{-1}
Kla	Oxygen mass transfer coefficient
l	Mixing length, m
L	Baffle spacing, m
N	Number of tanks
N_o	Tracer
P_o	Power number
Q	Volumetric flow rate, ml.min^{-1}
Re_p	Pulsating Reynolds number
Re_o	Oscillatory Reynolds number
Re_n	Net flow Reynolds number
s @ γ	Skewness
S	Open cross-sectional area @ fractional open area of baffle
Str	Strouhal number
T	Time
Δt	Increment of time
u	Superficial velocity of the liquid, m.s^{-1}

u_p	Pulsating velocity
V	Reactor volume
X	Cell mass concentration, g.L^{-1}
x_o	Oscillation amplitude (centre-to-peak), m
Z	Column length, m

Greeks Letters

ε_v	Power density, W.m^{-3}
μ	Viscocity, m^2.s^{-1} @ Pa.s
ρ	Liquid density, kg.m^{-3}
Θ	Dimensionless form
ψ	Velocity ratio, Re_o/Re_n
τ	Mean residense time
σ	Variance
θ	Dimensionless time
v	kinematic viscocity of water, m^2.s^{-1}
ω	Angular frequency ($2\pi f$), rad.s^{-1}

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ABSTRACT

Oscillatory flow can enhance mass transfer, mixing in flocculation, low shear and controllable mixing conditions. A recent development in oscillatory baffled reactor technology is down-scaling the reactor, so that it can be used for applications such as small-scale continuous production of bioethanol. In the current study, a new design of mesoscale oscillatory baffled reactor (MOBR) with central baffle system was developed and fabricated at “mesoscales” (typically 5 mm diameter). The mixing conditions inside the MOBR were evaluated and the reactor performance was analyzed for bioethanol production. The mixing conditions inside the MOBR were analyzed by evaluating the residense time distribution (RTD) against the dynamic parameters of net flow Reynolds number (Re_n) at 4.2, 8.4 and 12.6 corresponding to flow rates of 1.0, 2.0 and 3.0 ml/min respectively, oscillatory Reynolds number (Re_o) between 62 to 622 and Strouhal number (*Str*) between 0.1 to 1.59. The effect of oscillation frequency, oscillation amplitude, net flow, oscillation flow on RTD performance and dependence of the fluid mixing on the velocity ratio were also studied at frequency, amplitude and velocity ratio ranging from 4 to 8 Hz, 1 to 4 mm and 1 to 118 respectively. Next, the reactor performance of the MOBR was compared with conventional stirred tank reactor (STR) to evaluate the bioethanol fermentation performance using *Sacchromyces cerevisiae* at similar power density of 24.21, 57.38, 112.35 and 193.67 Wm^{-3} by varying frequency (f), amplitude (x_o) and agitation speed. Then the biomass concentration, glucose consumption and bioethanol concentration were analyzed using cell dry weight (CDW), 3,5-dinitrosalicyclic acid (DNS) and high performance liquid chromatograph (HPLC) methods, respectively. It was observed that the MOBR improved the mixing intensity resulted in lower glucose consumption 0.988 gL^{-1} obtained after 12 hours and the bioethanol concentration 38.98 gL^{-1} at power density of 193.67 Wm^{-3}. Overall, an improvement of 24.1% yield of bioethanol was generated using MOBR as STR only produced the highest yield of 15.4%.

ABSTRAK

Aliran getaran boleh meningkatkan pemindahan jisim, percampuran dalam flokulasi, ricih yang rendah dan mengawal keadaan percampuran di dalam reaktor. Perkembangan terbaru dalam teknologi getaran dalam reaktor adalah menurunkan skala reaktor, supaya ia boleh digunakan untuk aplikasi seperti perusahaan kecil bioetanol secara berterusan. Dalam kajian semasa, reka bentuk reactor dengan sistem sesekat berpusat (MOBR) telah dibangunkan dalam skala ‘meso’ (5 mm diameter). Keadaan percampuran di dalam MOBR telah dinilai dan prestasi reaktor dianalisis untuk pengeluaran bioetanol. Keadaan ini dianalisis dengan menilai taburan masa residence (RTD) terhadap parameter dinamik nombor Reynolds (Re_n) pada 4.2, 8.4 dan 12.6 yang bersamaan dengan halaju bersih pada kadar 1.0, 2.0 dan 3.0 ml/min, nombor getaran Reynolds (Re_o) antara 62 hingga 622 dan nombor Strouhal (Str) antara 0.1 hingga 1.59. Kesan terhadap frekuensi getaran, amplitude getaran, halaju bersih dan aliran getaran terhadap taburan masa residence (RTD) juga dikaji pada frekuensi antara 4 hingga 8 Hz, amplitude antara 1 hingga 4 mm dan nisbah halaju antara 1 hingga 118. Seterusnya, prestasi reaktor MOBR itu dibandingkan dengan konvensional reaktor tangki (STR) untuk menilai prestasi penapaian bioetanol menggunakan *Sacchromyces cerevisiae* pada ketumpatan kuasa yang sama iaitu 24.21, 57.38, 112.35 dan 193.67 Wm^{-3} dengan mengubah kekerapan frekuensi (f), amplitude (x_o) dan kelajuan putaran. Kemudian kepekatan biojisim, kadar penyerapan glukosa dan kepekatan bioethanol dianalisis dengan menggunakan kaedah berat sel kering (CDW), asid 3,5-dinitrosalicyclic (DNS), dan cecair kromatografi berprestasi tinggi (HPLC). Secara keseluruhan, MOBR dapat meningkatkan intensiti percampuran dengan memperoleh kadar penyerapan glukosa lebih rendah iaitu 0.988 gL^{-1} selepas 12 jam dan kepekatan bioetanol sebanyak 38.98 gL^{-1} diperoleh pada ketumpatan kuasa 193.67 Wm^{-3}. Secara keseluruhan, peningkatan hasil bioetanol sebanyak 24.1% dapat dijana menggunakan MOBR berbanding STR yang hanya menghasilkan sebanyak 15.4%.

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