

List of figures

Figures	Page Nos.
Chapter 1	
Figure 1.1 Global energy consumption in fraction of year 2017.....	2
Figure 1.2 Distribution of proved oil reserves in 2017.....	5
Figure 1.3 Global biodiesel production (2016).....	14
Chapter 2	
Figure 2.1 Transesterification of triglycerides.....	22
Figure 2.2 General equation of transesterification of triglycerides.....	22
Chapter 4	
Figure 4.1 Synthesis of $BaAl_2O_4$ by co-precipitation method.....	59
Figure 4.2 Thermal analysis (TGA-DTA) of uncalcined catalyst sample.....	61
Figure 4.3 X-ray diffractogram ($2\theta = 10-80^\circ$) of the catalyst $BaAl_2O_4$ sample...61	
Figure 4.4 The FT-IR spectra of $BaAl_2O_4$ catalyst.....	63
Figure 4.5 SEM micrographs of synthesized catalyst $BaAl_2O_4$ sample.....	64
Figure 4.6 EDX spectrum of synthesized catalyst $BaAl_2O_4$ sample.....	64
Figure 4.7 Synthesis of $K_2Al_2O_4$ by physicochemical method.....	67
Figure 4.8 Thermal analysis (TGA-DTA) of uncalcined catalyst sample.....	69

Figure 4.9 X-ray diffractogram (A) $2\theta = 20-80^\circ$ and (B) $2\theta = 25-45^\circ$ of potassium aluminum oxide synthesized by solid state method.....	70
Figure 4.10 The FT-IR spectra of $K_2Al_2O_4$ catalyst.....	71
Figure 4.11 (A) Lower and (B) higher magnification SEM image of the synthesized catalyst $K_2Al_2O_4$	72
Figure 4.12 EDX spectrum of the catalyst $K_2Al_2O_4$	73

Chapter 5

Figure 5.1 Effect of methanol: oil molar ratio (12:1 - 24:1) on methyl ester conversion (%) of used vegetable oil [catalyst dose (4 wt%); reaction time 0-180 min; temperature $65\pm 0.5^\circ\text{C}$ and stirring speed 600 rpm].....	79
Figure 5.2 Effect of catalyst dose (1-5 wt%) on methyl ester conversion (%) of used vegetable oil [methanol: oil molar ratio 21:1; reaction time 0-180 min; temperature $65\pm 0.5^\circ\text{C}$ and stirring speed 600 rpm].....	80
Figure 5.3 Effect of reaction temperature ($35-65\pm 0.5^\circ\text{C}$) on methyl ester conversion (%) of used vegetable oil [methanol: oil M ratio 21:1; catalyst dose 4 wt%; reaction time 0-180 min; and stirring speed 600 rpm].....	82
Figure 5.4 Effect of stirring speed (300-700 rpm) on methyl ester conversion (%) of used vegetable oil [methanol: oil molar ratio 21:1; catalyst dose 4 wt%; reaction time 0-180 min; temperature $65\pm 0.5^\circ\text{C}$].....	82
Figure 5.5 Reusability test for the $BaAl_2O_4$ catalyst at optimized conditions [methanol: oil molar ratio 21:1; catalyst dose 4 wt%; reaction time 0-180 min; temperature $65\pm 0.5^\circ\text{C}$].....	84

Figure 5.6 Kinetic plots of $-\ln(1-X)$ versus reaction time (min) at different reaction temperatures.....	85
Figure 5.7 Arrhenius plot $\ln k$ vs. $(1/T)$ of transesterification of used vegetable oil using $BaAl_2O_4$ catalyst.....	86
Figure 5.8 Eyring- Polanyi plot $(\ln k/T)$ versus $1/T$ of transesterification of used vegetable oil using $BaAl_2O_4$ catalyst.....	87
Figure 5.9 1H NMR spectrum of synthesized biodiesel from used vegetable oil.....	89
Figure 5.10 ^{13}C NMR spectrum of synthesized biodiesel from used vegetable oil.....	90
Figure 5.11 Effect of methanol: oil molar ratio (9:1 - 21:1) on methyl ester conversion (%) of kusum oil [catalyst dose (4 wt%); reaction time 0-180 min; temperature 65 ± 0.5 °C and stirring speed 600 rpm].....	94
Figure 5.12 Effect of catalyst dose (0.5 – 4.5 wt%) on methyl ester conversion (%) of kusum oil [methanol: oil molar ratio 18:1; reaction time 0-180 min; temperature 65 ± 0.5 °C and stirring speed 600 rpm].....	95
Figure 5.13 Effect of temperature (35 - 65 ± 0.5 °C) on methyl ester conversion (%) of kusum oil [methanol: oil molar ratio 18:1; catalyst dose 3.5 wt %; reaction time 0-180 min; and stirring speed 600 rpm].....	96
Figure 5.14 Effect of stirring speed (300-700 rpm) on methyl ester conversion (%) of kusum oil [methanol: oil molar ratio 18:1; catalyst dose 3.5 wt%; reaction time 0-180 min; and temperature 65 ± 0.5 °C].....	98
Figure 5.15 Reusability test for the $BaAl_2O_4$ catalyst at optimized conditions [methanol: oil molar ratio 21: 1; catalyst dose 4 wt%; reaction time 0-180min; temperature 65 ± 0.5 °C].....	99

Figure 5.16 Kinetics plots of $-\ln(1 - X)$ versus reaction time (min) at different reaction temperatures.....	100
Figure 5.17 Arrhenius plot $\ln k$ vs. $1/T$ relation of transesterification of kusum oil using $BaAl_2O_4$ catalyst.....	101
Figure 5.18 Eyring- Polanyi plot ($\ln k/T$) versus $1/T$ of transesterification of kusum oil using $BaAl_2O_4$ catalyst.....	102
Figure 5.19 1H NMR spectrum of synthesized biodiesel from kusum oil.....	104
Figure 5.20 ^{13}C NMR spectrum of synthesized biodiesel from kusum oil.....	105

Chapter 6

Figure 6.1 Effect of methanol: oil molar ratio (9:1 - 21:1) on methyl ester conversion (%) of used vegetable oil [catalyst dose (2.5 wt%); reaction time 0-90 min; temperature 65 ± 0.5 °C and stirring speed 600 rpm].....	111
Figure 6.2 Effect of catalyst dose (1-3 wt%) on methyl ester conversion (%) of used vegetable oil [methanol: oil molar ratio 18:1; reaction time 0-90min; temperature 65 ± 0.5 °C and stirring speed 600 rpm].....	113
Figure 6.3 Effect of reaction temperature ($35-75 \pm 0.5$ °C) on methyl ester conversion (%) of used vegetable oil [methanol: oil molar ratio 18:1; catalyst dose 3 wt%; reaction time 0-90 min; and stirring speed 600 rpm].....	113
Figure 6.4 Effect of stirring speed (300-700 rpm) on methyl ester conversion (%) of used vegetable oil [methanol: oil molar ratio 18:1; catalyst dose 2.5 wt%; reaction time 0-90 min; temperature 65 ± 0.5 °C].....	115
Figure 6.5 Reusability test for the $K_2Al_2O_4$ catalyst at optimized conditions [methanol: oil molar ratio 18:1; catalyst dose 2.5 wt%; reaction time 75 min; temperature 65 ± 0.5 °C and stirring speed 600 rpm].....	116

Figure 6.6 Kinetics plots of $-\ln(1-X)$ versus reaction time (min) at different reaction temperatures.....	117
Figure 6.7 Arrhenius plot $\ln k$ vs. $(1/T)$ relation of transesterification of used vegetable oil using $K_2Al_2O_4$	119
Figure 6.8. Eyring- Polanyi plot $(\ln k/T)$ versus $1/T$ of transesterification of used vegetable oil using $K_2Al_2O_4$	119
Figure 6.9 1H NMR spectrum of synthesized biodiesel from used vegetable oil.....	121
Figure 6.10 ^{13}C NMR spectrum of synthesized biodiesel from used vegetable oil.....	122
Figure 6.11 Effect of methanol: oil molar ratio (6:1-18:1) on methyl ester conversion (%) of kusum oil [catalyst dose (2.0 wt%); reaction time 0-90 min; temperature 65 ± 0.5 °C and stirring speed 600 rpm].....	126
Figure 6.12 Effect of catalyst dose (0.5 – 2.5 wt%) on methyl ester conversion (%) of kusum oil [methanol: oil molar ratio 15:1; reaction time 0-90 min; temperature 65 ± 0.5 °C and stirring speed 600 rpm].....	128
Figure 6.13 Effect of temperature ($35-65\pm 0.5$ °C) on methyl ester conversion (%) of kusum oil [methanol: oil molar ratio 15:1; catalyst dose 2.0 wt%; reaction time 0-90 min; and stirring speed 600 rpm].....	128
Figure 6.14 Effect of stirring speed (300-700 rpm) on methyl ester conversion (%) of kusum oil [methanol: oil molar ratio 15:1; catalyst dose 2.0 wt%; reaction time 0-90 min; and temperature 65 ± 0.5 °C].....	130
Figure 6.15 Reusability test for the $K_2Al_2O_4$ catalyst at optimized conditions [methanol: oil molar ratio 15:1; catalyst dose 2.0 wt%; reaction time 75 min; temperature 65 ± 0.5 °C].....	131

Figure 6.16 Kinetics plots of $-\ln(1-X)$ versus reaction time (min) at different reaction temperatures.....	132
Figure 6.17 Arrhenius plot $\ln k$ vs. $1/T$ relation of transesterification of kusum oil using $K_2Al_2O_4$ catalyst	134
Figure 6.18. Eyring- Polanyi plot ($\ln k/T$) versus $1/T$ of transesterification of kusum oil using $K_2Al_2O_4$ catalyst	134
Figure 6.19 1H NMR spectrum of synthesized biodiesel from kusum oil.....	136
Figure 6.20 ^{13}C NMR spectrum of synthesized biodiesel from kusum oil.....	137

List of Tables

Chapter 1

Table1.1 Biofuel policies of various countries and their mandate.....	11
--	----

Chapter 2

Table 2.1 First, second and third generation of feedstocks for biodiesel production.....	26
Table 2.2 Leading biodiesel producers worldwide in 2016, by country (in billion litres) and their major feedstock.....	27