ASEC 2024 Conference
The 5th International Electronic Conference on Applied Sciences
04–06 December 2024 | Online
MDPI

Optimisation of Biodiesel Production from Waste Margarine Oil Using Response Surface Methodology

Pascal MWENGE, Salvation MUTHUBU and Hilary RUTTO
Department of Chemical and Metallurgical Engineering, Vaal University of Technology, Vanderbijlpark 1900, South Africa

INTRODUCTION & AIM

Biodiesel is a biodegradable, non-toxic fuel derived from organic sources. Using waste margarine, which often ends up as landfill waste, not only provides an eco-friendly energy solution but also addresses waste management issues.[1]

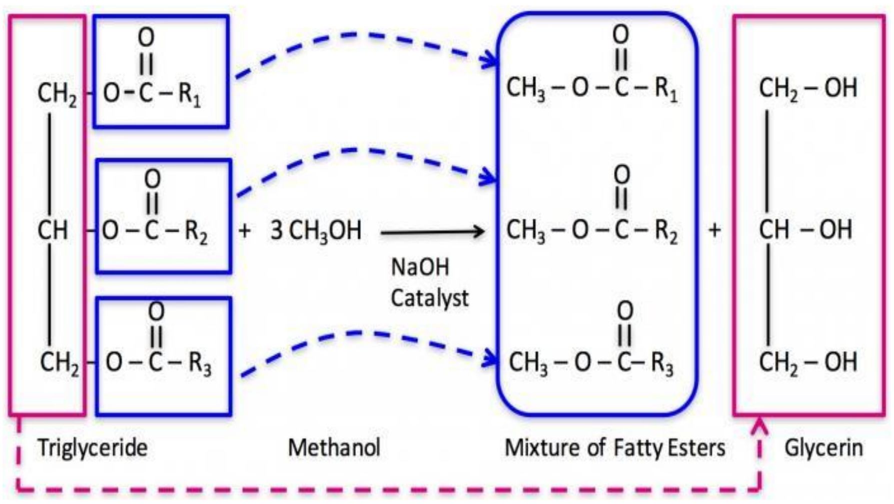

Figure 1: Transesterification reaction

To produce biodiesel at a lower cost requires using cheap feedstock, such as waste cooking oil [2] and waste margarine oil.[1] Waste oils are about 2–3 times cheaper than virgin vegetable oil.[3]

Closed to 5 tons per month of waste oil is produced in butter and margarine manufacturing plants, which are mainly disposed of and can be used as a low-cost feedstock for biodiesel production.[1]

Catalysts used in biodiesel production are classified as homogeneous, heterogeneous and enzymatic.[4]

The kinetics of the transesterification process is performed by examining variables such as time, temperature, the methanol-to-oil ratio and catalyst loading.[5]

This study aims at optimising biodiesel production from waste margarine oil using central composite design (CCD) response surface methodology (RSM) for process optimisation and performing kinetics.

METHOD

The waste margarine was sourced from a local margarine manufacturing plant. Potassium hydroxide (85%) was used as a catalyst for the transesterification, with Methanol (99.5%), Phenolphthalein which was used as an indicator, were sourced from ACE (Associate Chemical Enterprises)

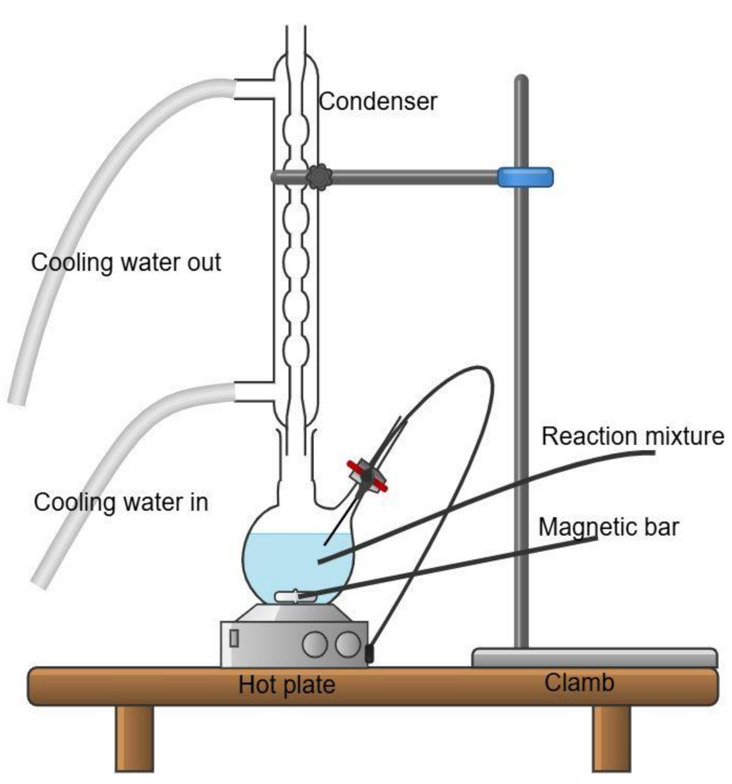

Figure 2: Experimental **setup**

Lab scale reactor as shown in Figure 1 was used for the transesterification. The methanol-to-oil molar ratio and catalyst ratio, reaction time, and temperature were varied according to the experimental design. When the reaction time elapsed, the mixture was emptied into a separating funnel, separating the biodiesel and the glycerol layers into two layers. Biodiesel was quantified and yield as calculated as per Equation (1).

The reaction kinetics was studied by following the equations as shown in equation 2-8.

$$TG + 3M \overset{KOH}{\leftrightarrow} G + 3M \quad (2)$$

$$r = -\frac{d[TG]}{dt} = k[TG] \quad (3)$$

$$X = 1 - \frac{[TG]}{[TG_o]} \quad (4)$$

$$[TG] = [TG_o](1 - X) \quad (5)$$

$$\frac{dX}{dt} = k(1 - X) \quad (6)$$

$$-\ln(1 - X) = k_1 t \quad (7)$$

$$lnk = lnA - \frac{Ea}{RT} \quad (8)$$

$$k = Ae^{[\frac{Ea}{RT}]} \quad (9)$$

Table 1: Experimental Design

Input	Level				
Variables	-2	-1	0	+1	+2
Methanol/Oil (wt. %)	3	6	9	12	15
Catalyst ratio (wt. %)	0.2	0.6	0.9	1.2	1.5
Time (min)	30	45	60	75	90
Temperature (°C)	30	40	50	60	70

The biodiesel was then washed with distilled water at 60˚C; this was done to ensure that any traces of methanol and KOH were 3 times washed off from the biodiesel. The washed biodiesel was then dried using a heating plate at 105˚C for 1 h until no trace of water was observed.

$$\text{Biodiesel yield} = \frac{Mass\ of\ biodiesel}{Mass\ of\ Oil} \quad (1)$$

RESULTS & DISCUSSION

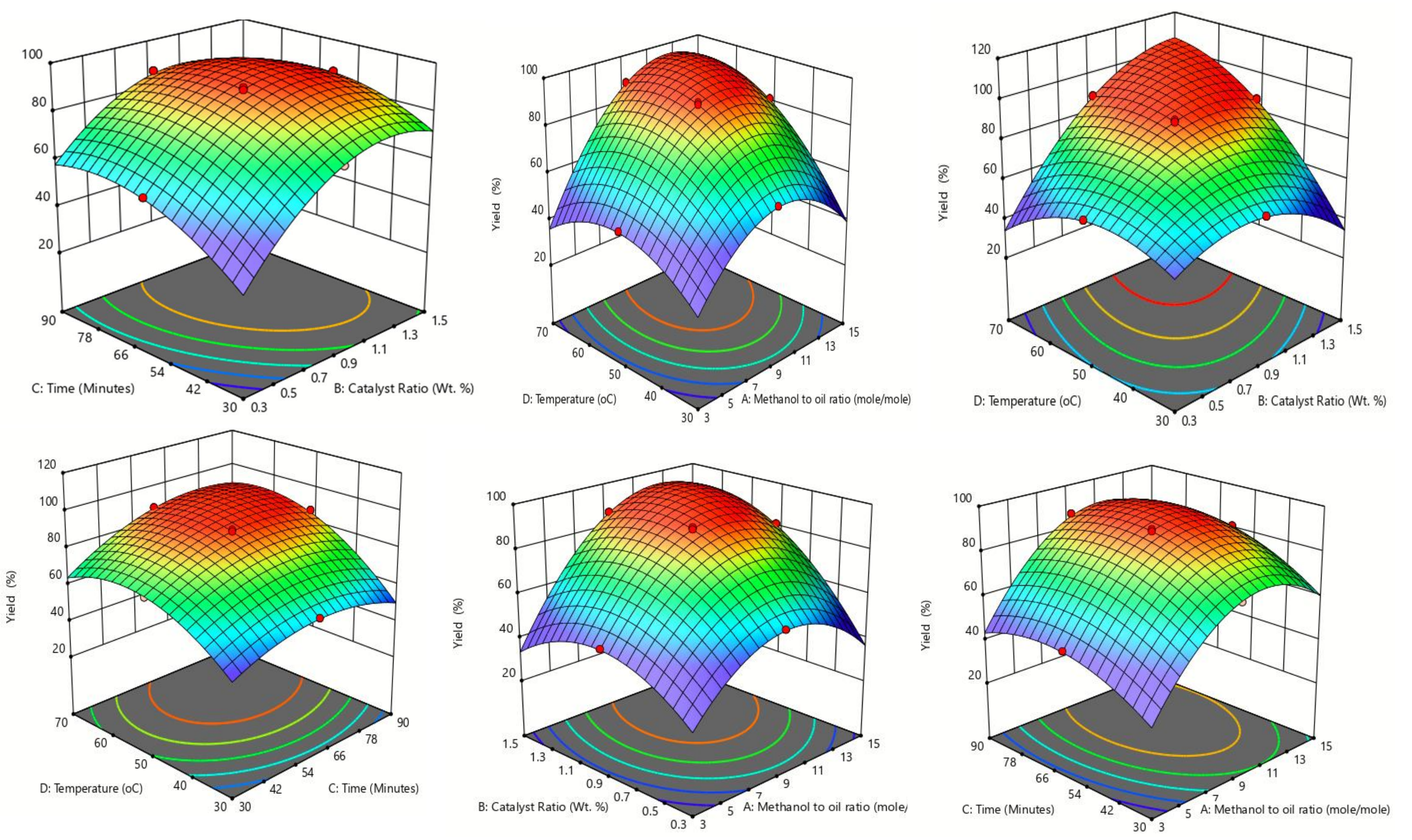

Figure 3: The 3-D surface plots of Biodiesel yield using the 4 process parameters

Analysis of variance (ANOVA) was used to evaluate the effect of process variables. As shown in Table 2, the methanol-to-oil ratio has more impact on the transesterification reaction. Using numerical optimisation, the optimum yield was obtained at a 9 mol ratio of 0.9 wt. % catalyst ratio, 60-minute reaction time, and 50 ˚C reaction temperature, with 89.09% yield.

Table 2. ANOVA for Quadratic model

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3168.83	14	226.35	142.98	< 0.0001	significant
A-Methanol to oil ratio	501.18	1	501.18	316.59	< 0.0001	
B-Catalyst Ratio	410.70	1	410.70	259.44	< 0.0001	
C-Time	212.50	1	212.50	134.24	< 0.0001	
D-Temperature	401.58	1	401.58	253.67	< 0.0001	
AB	37.98	1	37.98	23.99	0.0027	
AC	1.81	1	1.81	1.15	0.3255	
AD	33.44	1	33.44	21.12	0.0037	
BC	9.48	1	9.48	5.99	0.0500	
BD	117.78	1	117.78	74.40	0.0001	
CD	14.28	1	14.28	9.02	0.0239	
A^2	925.64	1	925.64	584.72	< 0.0001	
B^2	475.02	1	475.02	300.07	< 0.0001	
C^2	188.83	1	188.83	119.29	< 0.0001	
D^2	382.81	1	382.81	241.82	< 0.0001	
Residual	9.50	6	1.58			
Lack of Fit	6.80	2	3.40	5.04	0.0808	not significant

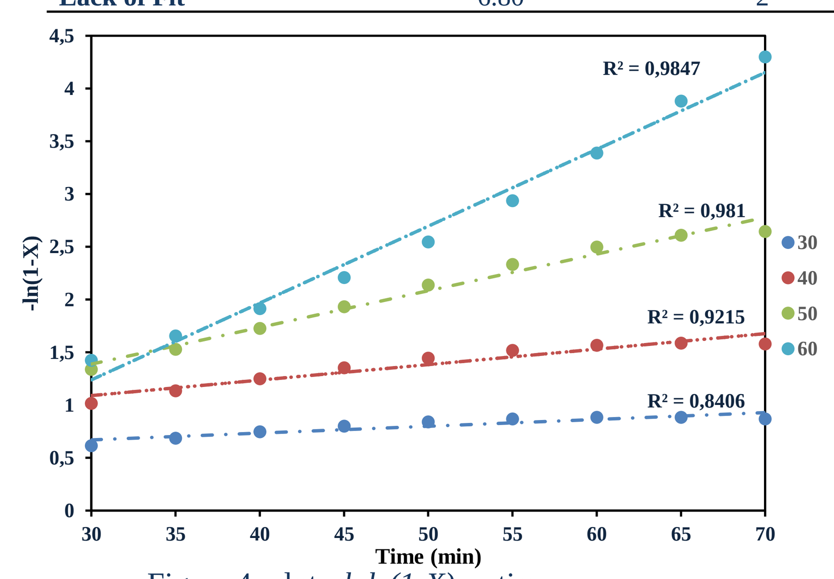

Figure 4: plot *-lnk (1-X)* vs time

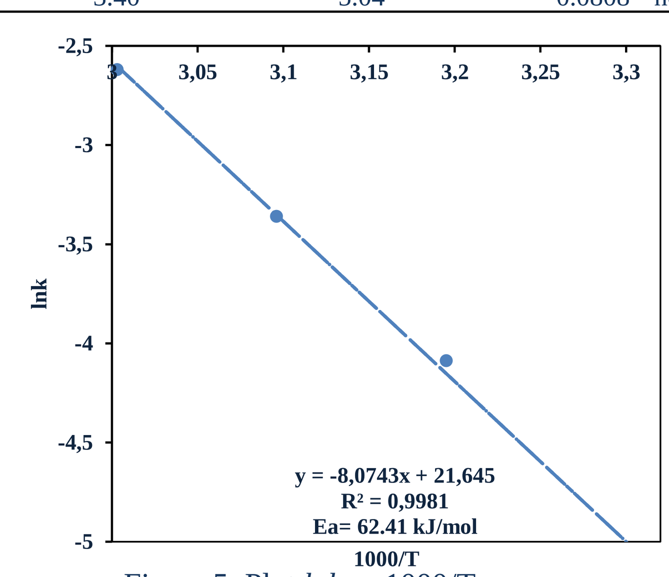

Figure 5: Plot *lnk* vs 1000/T

The Ea, was determined by the rate at which the k constant changes with temperature as shown in Figure 4, calculated using Equation 9.The significant linearity between lnk and 1,000/T over the 303–333K (30-60°C) is shown in Figure 5. The approximate activation energy of 62,41 kJ.mol^{-1} was obtained

CONCLUSION

A numerical optimum yield of 94.024% was obtained at a 9.6 mol ratio of 0.96 wt. % catalyst ratio, reaction time of 63 min, 52 °C and a low standard error of 0.576 %. ANOVA showed that the methanol to oil ratio had the highest influence on the biodiesel yield, followed by the catalyst ratio, and reaction time had the least impact after temperature. The kinetics study performed to obtain the activation energy was 62.41 kJ/mol. It was concluded that biodiesel could be produced using waste margarine oil as a cost-effective feedstock optimised by RSM.

FUTURE WORK / REFERENCES

[1] Mwenge, P.; Rutto, H.; Seodigeng, T. Modelling and Optimisation of Biodiesel Production from Margarine Waste Oil Using a Three-Dimensional Machine Learning Approach. In *The 3rd International Electronic Conference on Processes*; MDPI, **2024**; p 27.

[2] Abderamane Hassan, M.; Wang, W.; Dong, B.; Anwar, H.; Chang, Z.; Wei, D.; Khan, K. Production of Biodiesel from Waste Culinary Oil Catalyzed by S2O82−/TiO2–SiO2 Solid Super-Acid Catalyst Prepared with Recovered TiO2 from Spent SCR. *Mater. Today Sustain.* **2024**, *26*, 100730.

[3] Linganiso, E. C.; Tlhaole, B.; Magagula, L. P.; Dziike, S.; Linganiso, L. Z.; Motaung, T. E.; Moloto, N.; Tetana, Z. N. Biodiesel Production from Waste Oils: A South African Outlook. *Sustainability* **2022**, *14* (4), 1983.

[4] Hazrat, M. A.; Rasul, M. G.; Khan, M. M. K.; Ashwath, N.; Silitonga, A. S.; Fattah, I. M. R.; Mahlia, T. M. I. Kinetic Modelling of Esterification and Transesterification Processes for Biodiesel Production Utilising Waste-Based Resource. *Catalysts* **2022**, *12* (11), 1472.

[5] Mwenge, P.; Djemima, B.; Zwane, S.; Muthubi, S.; Rutto, H.; Seodigeng, T. Kinetics and Simulation of Biodiesel Production Using a Geopolymer Heterogenous Catalyst. *J. Environ. Sci. Health Part A* **2024**, 1–13.