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Modelling and Optimisation of Biodiesel Production from Margarine Waste Oil Using a Three-Dimensional Machine Learning Approach

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INTRODUCTION

Biofuels ingenuity has been backed by many governments policies in the pursuit of lowering dependency on fossil fuels and the quest for energy security through partially replacing the limited fossil fuels and decreasing the threat to the environment from exhaust emissions (greenhouse gases) and global warming, biodiesel is an alternative. Transesterification is the main used method of biodiesel production, which triglyceride reacts with alcohol to produce methyl esters (biodiesel) and glycerol (Mwenge et al., 2019).

Approximately 75% of the production cost of biodiesel is attributed to the oil feedstock, which leads to biodiesel production costs reaching almost 1.5 times higher than commercial diesel. Waste oils are about 2–3 times cheaper than virgin vegetable oil (Linganiso et al., 2022). Closed to 5 tons per month are produced in butter and margarine, which are mostly disposed of and can be used as a low-cost feedstock for biodiesel production (Mwenge et al., 2019)

Machine learning (ML) offers a powerful approach and revolutionising biodiesel production by enabling predictive modeling and process optimisation (Gupta et al, 2021). Machine learning provides the best predictive modelling with the highest accuracy, inspired by the brain's autolearning and self-improving capability to solve the study's complicated questions; therefore, it is beneficial for modelling transesterification processes (Xing et al., 2021).

This work presents the use of three-dimensional machine learning approaches, namely response surface methodology (RSM), artificial neural network (ANN), and adaptive neuro-fuzzy inference system (ANFIS) to optimise and model biodiesel production from margarine waste oil.

METHOD

The effect of process parameters: methanol to oil ratio (3-15 mole), catalyst ratio (0.3-1.5wt. %), reaction time (30-90 minutes), and reaction temperature (30-70 °C) were studied using a batch scale Lab reactor as shown in Figure 1. Optimisation used central composite design in RSM. The transesterification reaction was catalysed by Potassium hydroxide.

Oil was placed in the conical flask heated to the set temperature, once the set temperature was reached the methoxide was added to the reacting vessel and the timer was started.

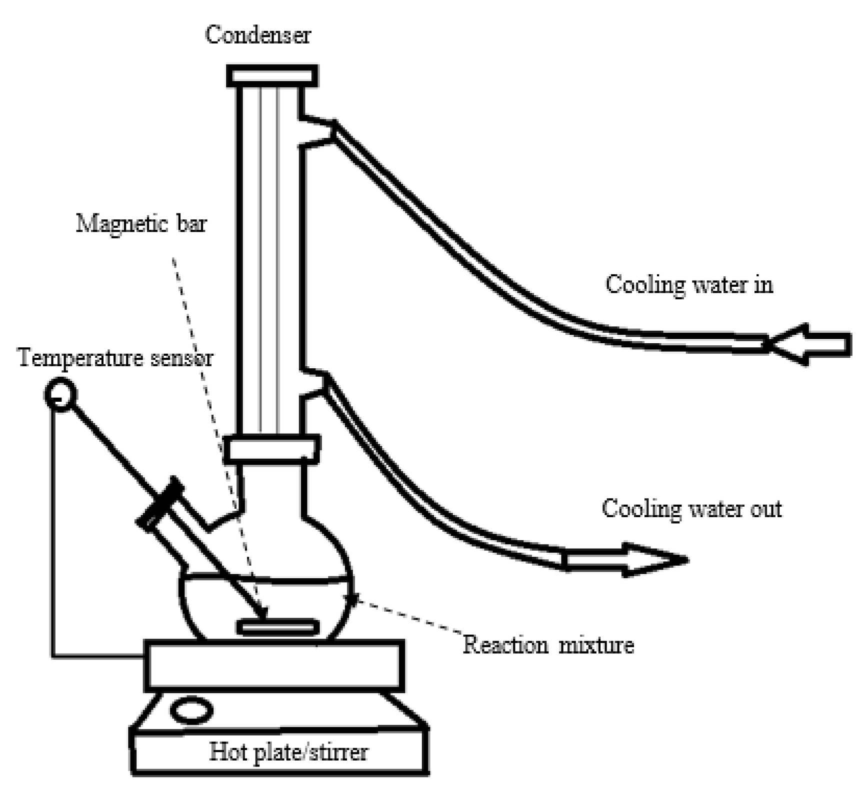

Figure1: Experimental setup

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 then emptied into a separating funnel where it separated into two layers the biodiesel and the glycerol layer. Biodiesel was quantified and yield as calculated as per Equation (1)

Table 1: Experimental Design

Input			Level			Output
Variables	-2	-1	0	+1	+2	Yield (%)
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 are washed off from the biodiesel. The washed biodiesel was then dried using a heating plate at 105˚C until no trace of water was observed.

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

RESULTS & DISCUSSION

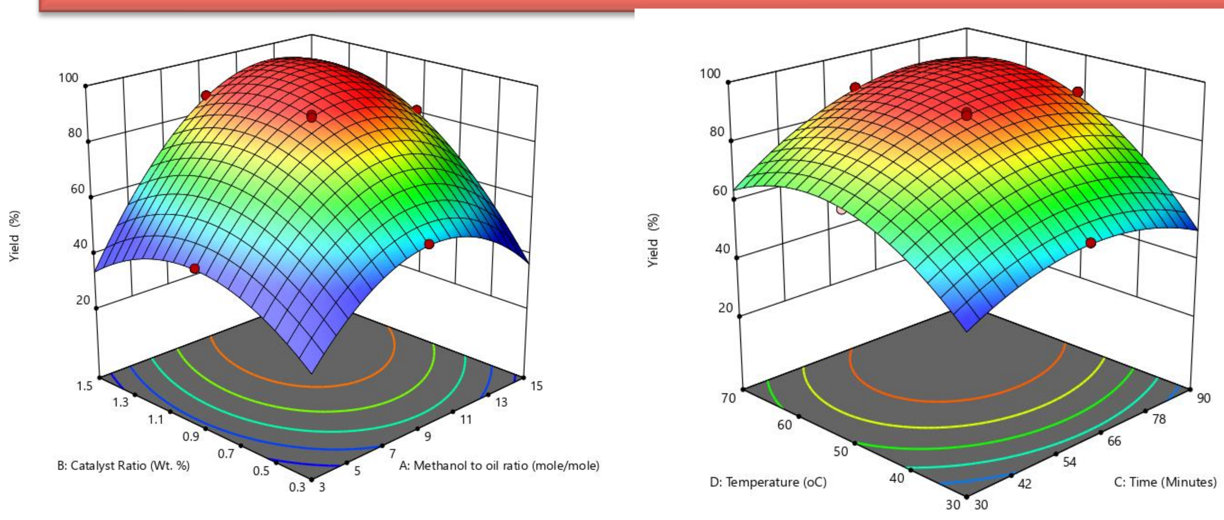

Figure 2. The 3-D surface plots of Biodiesel yield using the 4 process parameters

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

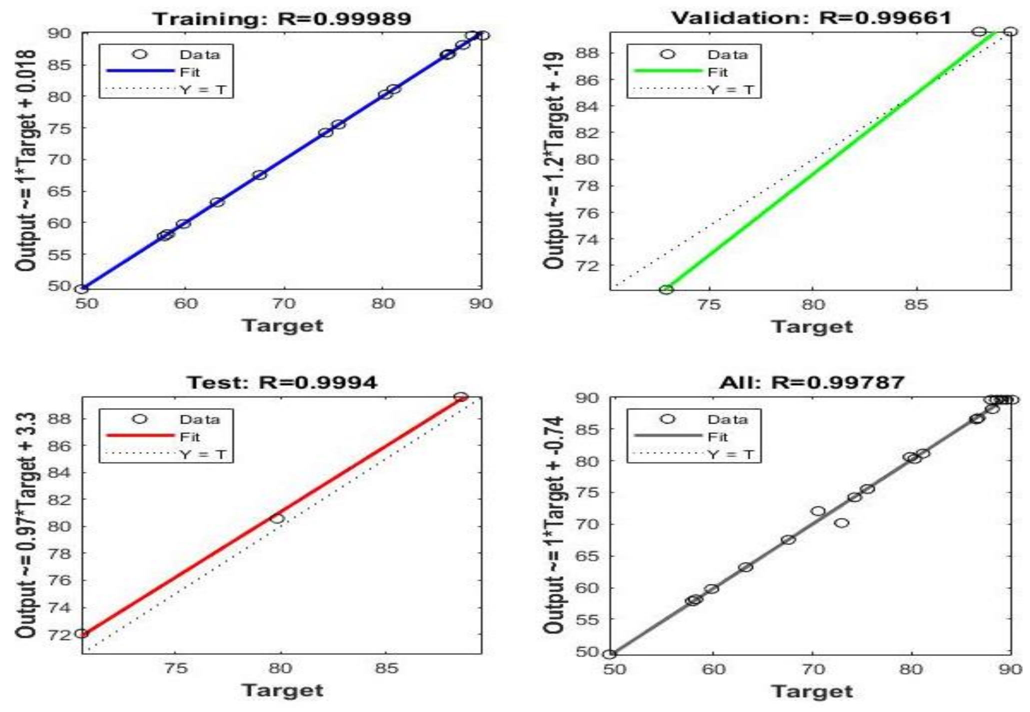

Figure 3: Training, validation, and testing for the Levenberg-Marquardt algorithm.

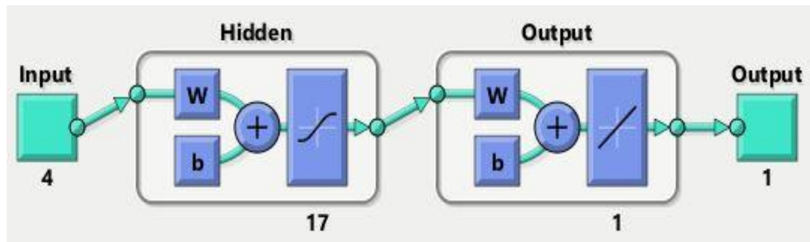

Figure 4. The architecture of the ANN model.

RSM was applied in Design Expert 13, and Neural Network Modular and Neuro-fuzzy were built with an NN toolbox using MATLAB 2021. 21 experimental data were randomly divided into 70 % for training and 30% for validation and testing. The ANN architecture is shown in Figure.

Figure depicts how the network interacts with the training, testing, and validation data. The correlation coefficients for the training, testing, validation, and test data were found to be 0.999, 0.996, 0.999, and 0.998, respectively. The straight line also demonstrates the linear connection.

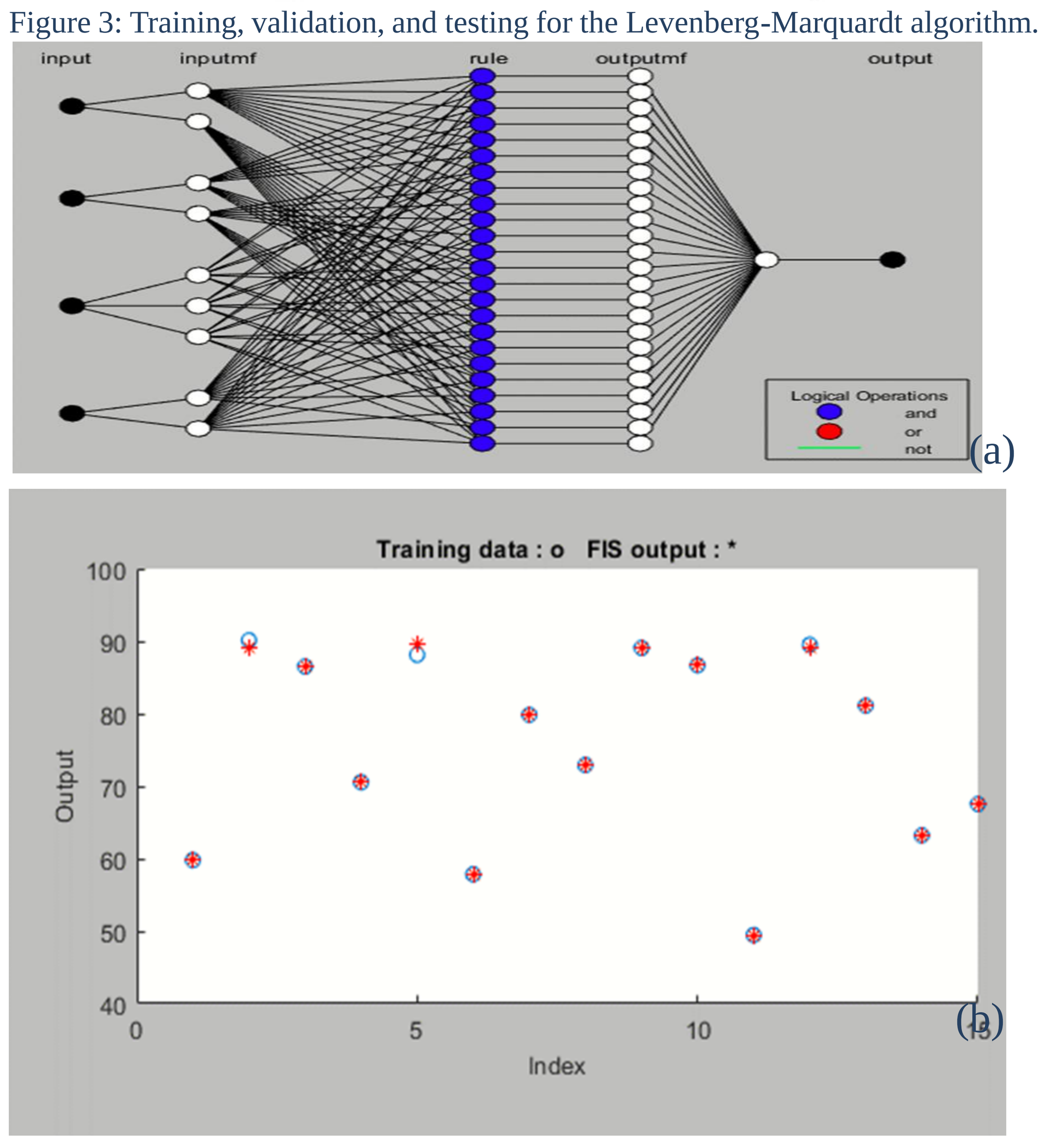

Figure 4. (a) The architecture of the ANFIS model.
(b) Actual and Predicted Adsorption Data for ANFIS.

Table 2: Error metrics used to evaluate the models

Error metrics	RSM	ANN	ANFIS
R^2	0.997	0.998	0.9947
MSE	0.4504	0.3208	0.8535
RMSE	0.6711	0.5664	0.9238
MAE	0.5676	0.2665	0.5021
MAPE	0.745986	0.333205	0.626254
ARE	0.0075	0.0033	0.0063
MPSD	4.5027	2.1142	3.9828

From the error metrics which were used to evaluate the effectiveness of the models, All the predictive modelling used are suitable to predict the yield of biodiesel produced was waste margarine, as the was not much difference, as shown in Table 2.

CONCLUSION

According to the results, the developed three-dimensional machine learning approach—the RSM, ANN, and ANFIS models- is a potential method for optimising and modelling the producing biodiesel from waste margarine oil.

The study results may be used to create sustainable, efficient, and economical solutions for recycling waste margarine oil.

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