Grey Wolf Optimizer (GWO) with Multi-Objective Optimization for Biodiesel Production from Waste Cooking Oil Using Central Composite Design (CCD)

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***Abstract*— This study utilized a central composite design (CCD) with the aim of attaining the ideal circumstances for multi-objective optimization (MOOP) so as to convert cooking oil waste into useable biodiesel. Reducing the overall capital cost (f_1) and lowering the cost of procedures (f_2) comprised the primary functions of MOOP. To resolve issues and contrast them with other techniques in Meta-heuristic to 5 well-known approaches, the Grey Wolf Optimizer (GWO) technique was applied. In an effort to establish the settings that offer optimization for the process used in biodiesel manufacturing, this research carried out an experiment employing CCD. Because it is one of the most commonly employed programs known to deliver valuable results, CCD was selected for the development of thirteen parameters. To assess the influences of the independent parameters on the mass fraction of FAME, % FAME purity, the mass fraction of glycerol, and % glycerol purity was included in the creation of this experimental set using CCD. The overall capital cost was US $8,302,990, while the operations cost was US $1,731,277 per year, as demonstrated by supplementary research involving optimization by CCD. It was revealed that a cost savings of roughly US $1,060 and US $6,310 annually was possible for overall capital cost and operations cost, respectively, when compared to the original process.**

***Index Terms*— multi-objective optimization, biodiesel production, central composite design, grey wolf optimizer**

I. Introduction

With the aid of a catalyst, the transesterification of vegetable oils including palm cotton seed, sunflower, soybean and animal fats results in biodiesel as a common derivative. Thus, biodiesel and glycerin comprise the primary byproducts of the transesterification process. Still, limitations exist in the production of alkyl esters through chemical transesterification or acid catalyzed processes. High quantities of glycerin, restricted forms of catalyst, and the high energy utilization needed are examples of this. For the manufacture of biodiesel in the future, the enzymatic method provides a potential technological alternative [1].

Over the last two decades, meta-heuristic optimization algorithms are very popular and have been used for obtaining optimal solutions in many scientific or engineering fields. Among these algorithms, the Bee Algorithm [2], bat algorithm [3, 4], Particle Swarm Optimization (PSO) [5, 6], and Genetic Algorithm (GA) [7] are fairly well-known. Meta-heuristic algorithms search in a search space for a global optimum by creating random solutions for a given problem. The random solutions, also called the set of candidate solutions, are improved during the iteration until satisfying the terminating condition. The iterative improvement process is considered to find a more accurate approximate value of the global optimum than the original random solutions. The mechanism makes meta-heuristics become prominent common and intrinsic advantages: simplicity, flexibility, derivation independency, and escaping from local minima.

GWO [8] is a state-of-the-art Swarm Intelligence (SI) algorithm inspired by the social hierarchy and hunting for the prey behavior of grey wolf packs. However, the linear convergence factor to control the exploration and exploitation limits the performance of GWO as an

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algorithm is considered to search as broadly as possible during the exploration and converge as fast as possible in the exploitation. Besides, GWO algorithm does not consider the diff erence between wolves in the social hierarchy.

Adapted from the work of Zhang et al. [9], the enhancement of the process used to manufacture biodiesel from virgin oil is detailed in this work by employing 6 meta-heuristic techniques including the Firefly algorithm (FA) [10], Bat algorithm (BA), Elephant herding optimization (EHO) [11], Crow search optimization (CSO) [12], Monarch butterfly optimization (MBO) [13] and GWO.

II. METHODOLOGY

A. GWO Algorithm

The hunting behavior and the social hierarchy of grey wolves are imitated by the GWO. Pack hunting is another interesting societal behavior by grey wolves in addition to their social hierarchy. Surrounding, stalking and attacking prey comprise the main aspects of GWO. This section provides the algorithmic stages of GWO.

The GWO algorithm can be expressed concisely using the steps below:

Step 1: Comprising the search agents (Gs), design variable size (Gd), vectors a, A, C and upper limit of iterations ($iter_{max}$), prime the GWO parameters.

$$\overrightarrow{A.} = 2\overrightarrow{a}.rand_1 - \vec{a} \quad (1)$$

$$\overrightarrow{C.} = 2.rand_2 \quad (2)$$

During the sequence of iterations, the values of $\vec{a}$ are linearly reduced from 2 to 0.

Step 2: Casually based on the size of the pack, create wolves. Precisely, Equation 3 can be used to convey these wolves.

$$Wolves = \begin{bmatrix} G_1^1 & G_2^1 & G_3^1 & \dots\dots & \dots\dots & G_{Gd-1}^1 & G_{Gd}^1 \\ G_1^2 & G_2^2 & G_3^2 & \dots\dots & \dots\dots & G_{Gd-1}^2 & G_{Gd}^2 \\ \vdots & \vdots & & \vdots\ \dots\dots & \dots\dots\ \vdots & \vdots & \\ G_1^{Gs} & G_2^{Gs} & G_3^{Gs} & \dots\dots & \dots\dots & G_{Gd-1}^{Gs} & G_{Gd}^{Gs} \end{bmatrix} \quad (3)$$

Where, G_j^i is the initial value of the j^{th} pack of the i^{th} wolves.

Step 3: As seen in Equation 4, assess the qualification measure of each hunt agent using Equations (1)-(2).

$$\vec{D} = \left|\overrightarrow{C}.\overrightarrow{G_p}(t) - \vec{G}(t)\right| \qquad \vec{G}(t+1) = \overrightarrow{G_p}(t) - \overrightarrow{A}.\vec{D} \quad (4)$$

Step 4: Employ Equations (5)-(10) to classify the ideal hunt agent (G_α), the second-best hunt agent (G_β) and the third-best hunt agent (G_δ).

$$\overrightarrow{D_\alpha} = \left|\overrightarrow{C_1}.\overrightarrow{G_\alpha} - \overrightarrow{G}\right| \quad (5)$$

$$\overrightarrow{D_\beta} = \left|\overrightarrow{C_2}.\overrightarrow{G_\beta} - \overrightarrow{G}\right| \quad (6)$$

$$\overrightarrow{D_\delta} = \left|\overrightarrow{C_3}.\overrightarrow{G_\delta} - \overrightarrow{G}\right| \quad (7)$$

$$\overrightarrow{G_1} = \overrightarrow{G_\alpha} - \overrightarrow{A_1}.(\overrightarrow{D_\alpha}) \quad (8)$$

$$\overrightarrow{G_2} = \overrightarrow{G_\beta} - \overrightarrow{A_2}.(\overrightarrow{D_\beta}) \quad (9)$$

$$\overrightarrow{G_3} = \overrightarrow{G_\delta} - \overrightarrow{A_3}.(\overrightarrow{D_\delta}) \quad (10)$$

Step 5: Use Equation (11) to restore the position of the existing hunt agent

$$\vec{G}(t+1) = \frac{\overrightarrow{G_1}+\overrightarrow{G_2}+\overrightarrow{G_3}}{3} \quad (11)$$

Step 6: Assess the qualification measure of all hunts

Step 7: Revise the significance of G_α ,G_β and G_δ

Step 8: Verify the stopping specification, i.e. if the $Iter$ achieves$Iter_{max}$. Print the best value for the solution if so, but go to step 5 if not.

B. Process Simulation of Biodiesel Production from Waste Cooking Oil

The principal units involved in processing are the reactors, heat exchangers, distillation columns, extraction columns, separators, and pumps. Due to a lack of availability of in-depth information regarding kinetics, a basic conversion reactor model involving 95% and 97% conversion of oil to fatty acid methyl esters (FAME) was employed for both alkaline and acidic transesterification reactions. The reactor was assumed to be a continuous, stirred tank reactor with a fill factor denoting the ratio of reaction to reactor volumes selected to be 0.5. The theoretical reaction intermediates, diacylglycerols and monoacylglycerols, have been shown in our own laboratory work to occur solely during the initial phases of the reaction on account of the ratio of methanol to oil. For this reason, the intermediates were not taken into account for the purposes of this study.

Methanol recovery was performed using multi-stage distillation, while purification of the FAME and glycerine products was accomplished through the same technique. Methanol, FAME, and glycerol have atmospheric boiling points of 65 ^{O}C, 320 ^{O}C, and 300 ^{O}C respectively, but the simulations indicated that it would not be possible to obtain the required purities of biodiesel and glycerol (to exceed 90 wt.%) using a simple flash unit. The acid- and alkali-catalyzed processes in this work applied the ASTM (American Society for Testing and Materials) standard for biodiesel product purity (99.65 wt.%), but in this case the fact that there is a significant difference in the components' boiling points simplifies the distillation process. It is necessary to use only five or six theoretical stages in the columns in order to obtain biodiesel and glycerine of a suitably high quality. Our experimental simulations assumed a tray efficiency of 60% to 70%. Since both FAME and glycerol can undergo thermal decomposition at respective temperatures exceeding 250 ^{O}C and 150 ^{O}C it was necessary apply vacuum conditions for the processes of FAME and glycerine purification in order to maintain an appropriately low temperature. The separation of FAME from glycerol, methanol, and the catalyst (water washing column T-301) was achieved through liquid–liquid extraction. Sizing calculations for the process equipment are given in detail by Zhang et al. (2003) [9].

Once the input information was applied in establishing the operating unit models, Aspen Plus was used to conduct the steady-state simulation. This allowed the mass balance, energy balance, and operating conditions to be determined for each unit. The pressure drops which result from the pipelines and heat exchangers were not taken into account for the purposes of this study. Process design of Alkali-catalyzed process using virgin vegetable oil. Which will show the original process simulation in Fig. 1 and there will be 7 steps as follows:

1. Transesterification
2. Methanol recovery
3. Water washing
4. FAME purification
5. Alkali removal
6. Glycerine purification
7. Waste treatment

Table I shows the principal simulation outcomes using Aspen Plus and Table II shows the main simulation outcomes from Aspen economics analyzer.

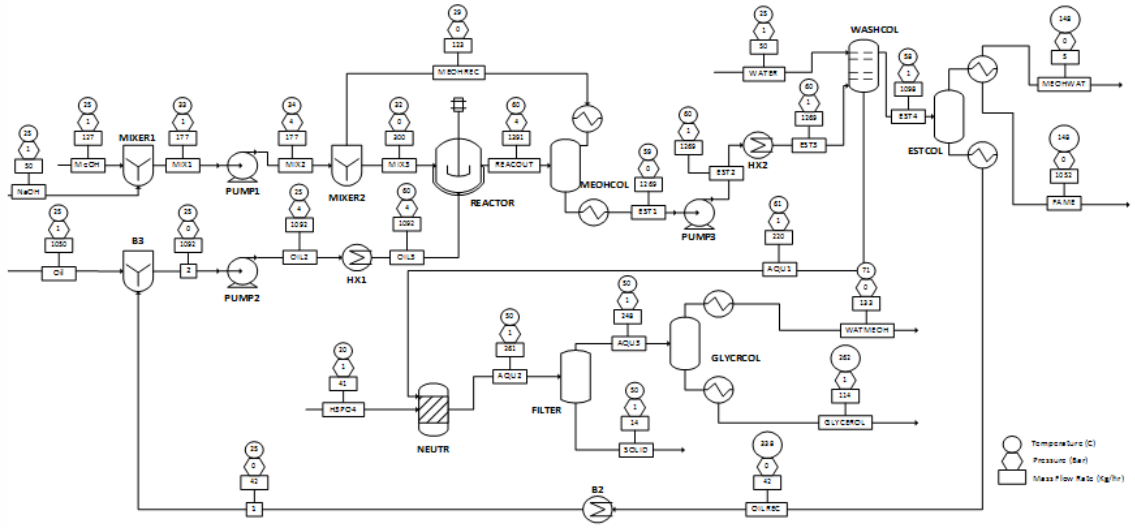

Figure 1. Alkali-catalyzed process to produce biodiesel from waste cooking oil [9].

TABLE I. MAIN SIMULATION FINDINGS FROM ASPEN PLUS

Simulation results	Value	Units
Plant capacity (pure FAME)	9.19	MM kg/yr
Oil feed	1050	kg/hr
Methanol feed	127.1	kg/hr
Catalyst feed	50	kg/hr
H_3PO_4 feed	40.8	kg/hr
Water feed for washing	50	kg/hr
Transesterification reactor biodiesel composition	0.756	Mass fraction
Transesterification reactor oil conversion	0.980	1 h
Product FAME purity	0.997	Mass fraction
Product Glycerol purity	1	Mass fraction

The sum of the constituent triglycerides and diglycerides serves to make up the oil feed, while the sum of the methyl esters amounts to the FAME product.

TABLE II. MAIN SIMULATION FINDING FROM ASPEN ECONOMICS ANALYZER

Simulation results	Value	Units
Total Capital Cost	8,395,540	US $
Total Operating Cost	1,739,460	US $/Year
Total Utilities Cost	103,132	US $/Year
Equipment Cost	421,300	US $
Total Installed Cost	2,224,600	US $

C. *Multi-objective for Biodiesel Optimization Format Equation*

In terms of minimization or maximization, more than one objective function is concerned. As shown in Equation (12), the response is a set of solutions that express the ideal trade-off between contending objectives.

$$\text{Min } F(x) = w_1 f_1 + w_2 f_2$$

In this work is set to w_1=1 and w_2=4.83.

Subject to:

$$g_1(x) \geq 1030,$$
$$g_2(x) \geq 0,$$
$$g_3(x) \geq 99,$$
$$g_4(x) \geq 0,$$

where

$$x_i^{(L)} = [115, 45, 45, 0.8, 55, 1030, 45, 108, 1.8, 0.8, 97, 1.8, 100]$$
$$x_i^{(U)} = [120\ 55\ 55\ 1.2\ 65\ 1080\ 55\ 114\ 2.2\ 1.2\ 103\ 2.2\ 106]$$
$$x_i^{(L)} \leq x_i \leq x_i^{(U)}, \quad i = 1,2,\ldots,13$$

Finally, to increase the efficiency of biodiesel and reduction of cost whereas the quality remains standard, the equation is as follows:

Objective function

f_1 is the minimum total capital cost in US $

f_2 is minimum operating cost in US $/year

Constrained function

g_1 is maximum mass of FAME in kg/hr

g_2 is density of FAME at 15 ^{o}C

g_3 is maximum purity percentage of glycerolwhich must over 99%

g_4 is maximum mass of glycerol in kg/hr

III. Result

A. Central Composite Design (CCD) Experiments

CCD experiments designed by the program were carried out to designate the minimum total capital cost (f_1) in US $, minimum operating cost (f_2) in US $/year, maximum mass of FAME (g_1), density of FAME at 15 ^{o}C (g_2), maximum %purity of glycerol (g_3), and maximum mass of glycerol (g_4) to evaluate the effects of the parameters investigated, flowrate of MeOH (f_m), flowrate of NaOH (f_s), flowrate of H_3PO_4 (f_f), resident time (τ), Temperature of transesterification (T_t), Flowrate of Oil (f_o), Temperature of washing (T_w), Distillate rate of MEOHCOL(α_m), Reflux ratio of MEOHCOL (γ_m), Reflux ratio of ESTCOL (γ_e), Bottom rate of ESTCOL (β_e), Reflux ratio of GLYCRCOL (γ_g), and bottom rate of GLYCRCOL (β_g) .The model equations obtained by program are proposed real values as pointed out in Equations (13) and (18):

Total capital cost (f_1) (13)

$$= 2.16307E + 07 - 76932.13343f_m + 2996.95290f_s + 45921.69459f_p + 2.41024E + 06\tau - 1.75192E + 05T_t - 7270.69643f_o - 68124.60588T_n - 26488.20464\alpha_m\ 6.31039E + 05\gamma_m + 4.95076E + 05\gamma_e - 15959.42844\beta_2\ 86691.43550\gamma_g + 39110.94633\beta_g + 73.42738(f_m.f_o) + 210.00536(f_s.T_w) - 6953.17465(f_s.\beta_g) - 8191.06553(f_p.\gamma_g) - 294.36595(f_p.\beta_g) - 720.56610(\tau.f_o) - 12609.18685(\tau.\alpha_m) - 1.58370E + 05(\tau.\gamma_m) - 10326.70422(T_t.\gamma_e) - 425.10595(T_t.\beta_g) + 476.37713(T_w.\alpha_m) + 5256.20811(T_w.\gamma_e) + 7404.91013(\alpha_m.\gamma_m) + 8924.57984(\beta_e.\gamma_g) + 1879.64376(T_t^2)$$

Operating cost (f_2)

$$= 1.57814E + 06 + 3861.69048f_m + 3194.64667f_s - 1.11952E + 05\tau + 2613.63531T_t + 495.25745f_o - 2839.28825T_w - 5442.49969\alpha_m - 66989.83406\gamma_m + 43098.12760\gamma_e + 3438.63451\beta_e + 33856.18644\gamma_g - 5265.48693\beta_g - 38.05786(f_m.\beta_e) - 2.37764(f_s.f_o) + 219.32623(f_s.\gamma_m) - 519.46668(f_s.\gamma_g) - 120.89849(\tau.f_o) + 628.07209(\tau.\beta_g) - 2.86071(T_t.f_o) + 9.97340(T_t.T_w) - 468.76702(T_t.\gamma_e) + 22.07830(T_w.\beta_e) + 611.61025(\alpha_m.\gamma_m) + 40.72182(\alpha_m.\beta_g) - 4725.16451(\gamma_e.\gamma_g) + 90994.36432(T_t^2)$$

Mass of FAME (g_1)

$$>= 5909.84223 - 9.56291f_m - 2.48632f_s + 0.720070f_f - 585.16909\tau - 29.43670T_t - 3.01398f_o + 7.38091T_w + 2.81512\alpha_m - 64.20922\gamma_m - 147.26423\gamma_e - 0.718334\beta_e - 475.00844\gamma_g - 33.02263\beta_g - 0.136488(f_m.f_f) + 2.82362(f_m.\tau) + 0.143147(f_m.T_t) + 2.53606(f_m.\gamma_g) - 0.008300(f_s.f_o) - 0.053697(f_s.\alpha_m) + 0.062288(f_s.\beta_e) + 0.103443(f_s.\beta_g) + 0.133385(f_f.T_t) + 1.52817(f_f.\gamma_g) + 0.038994(f_f.\beta_g) - 1.37606(\tau.T_t) + 0.426655(\tau.f_o) - 53.22433(\tau.\gamma_g) + 0.012057(T_t.f_o) - 0.042545(T_t.T_w) + 0.741758(T_t.\gamma_m) - 2.24068(T_t.\gamma_g) + 0.339656(f_o.\gamma_g) + 0.024642(f_o.\beta_g) - 0.047863(T_w.\beta_e) + 73.86840(\gamma_m.\gamma_e) - 28.62132(\gamma_m.\gamma_g)$$

Density of FAME (g_2)

$$>= 873.60187 - 0.000031f_s - 0.000400\ \tau + 0.000027T_t - 3.04754E - 06f_o$$

% Purity of glycerol (g_3)

$$>= 100.00006 + 6.38577E - 06f_s - 9.10640E - 06\tau - 4.04624E - 07T_t - 5.52574E - 07f_o - 0.000038\gamma_g$$

Mass of glycerol (g_4)

$$>= 690.63313 - 1.10029f_m - 0.335473f_s - 0.347142f_f - 67.62378\ \tau - 3.03829T_t - 0.357223f_o + 0.775407T_w - 7.21068\gamma_m - 20.29296\gamma_e + 0.298654\beta_e - 54.76473\gamma_g - 3.87093\beta_g - 0.012247(f_m.f_f) + 0.349506(f_m.\tau) + 0.014741(f_m.T_t) + 0.247376(f_m.\gamma_g) - 0.000824(f_s.f_o) + 0.011040(f_s.\beta_g) + 0.013620(f_f.T_t) + 0.163208(f_f.\gamma_g) + 0.005933(f_f.\beta_g) - 0.169686(\tau.T_t) + 0.046589(\tau.f_o) - 5.78977(\tau.\gamma_g) + 0.001279(T_t.f_o) - 0.004909(T_t.T_w) + 0.079893(T_t.\gamma_m) - 0.220945(T_t.\gamma_g) + 0.041210(f_o.\gamma_g) + 0.002872(f_o.\beta_g) + 0.101985(T_w.\gamma_e) - 0.005819(T_w.\beta_e) + 7.60141(\gamma_m.\gamma_e) - 2.71627(\gamma_m.\gamma_g)$$ (14)

The parameters used by all six algorithms in the performance test are obtained from the review of the literature. Table III and Table IV presents the MATLAB™ findings.

B. Process Simulation and Optimization

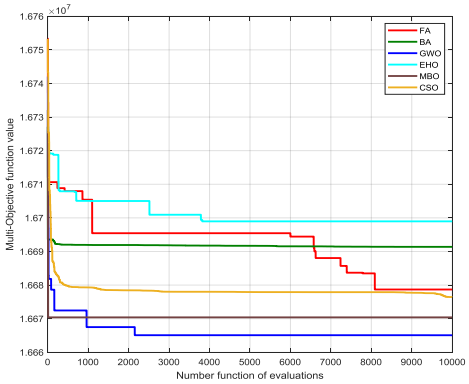

Figure 2. Multi-optimized convergence rate in the production of biodiesel.

The MATLAB™ findings are indicated in Table III for the multi-objective function; the total capital cost is 1 while the operating cost is 4.83. For the number of iterations, the maximum is 10,000. The GWO generates a multi-objective (F_x) leading to the best value of 16665061.6334862. This shows that f_1 is 8302990.18122774 while f_2 is 1731277.73338684. When comparing converge rates, it can be observed that the GWO algorithm converges more rapidly than the other tested approaches, as indicated in Fig. 2. The resulting action factors influencing the production of biodiesel are listed as follows: flowrate of MeOH is 120 kg/hr, flowrate of NaOH is about 45 kg/hr, flowrate of H_3PO_4 is 45.34 kg/hr, resident time is 0.91 hr, Temperature of transesterification is 60.97 ^oC, Flowrate of oil is 1030 kg/hr, Temperature of washing is 55^oC, Distillate rate of MEOHCOL 108 kg/hr, Reflux ratio of MEOHCOL is 1.8, Reflux ratio of ESTCOL is 0.8, Bottom rate of ESTCOL is 97 kg/hr, Reflux ratio of GLYCRCOL 1.8 kg/hr and bottom rate of GLYCRCOL is 106. Fig. 3 presents the simulation and improvement from original.

MBO, CSO and FA give the values for the multi-objective (F_x) are 16670392.6448677, 16676406.9829967, and 16678684.069914 respectively. However, EHO would be the worst approach in comparison to the other methods since the multi-objective (F_x) is 16670392.6448677. It can therefore be concluded that GWO offers an alternative means to optimize the production of biodiesel while cutting the capital costs and also reducing the overall operating cost.

TABLE III. MATLAB™ VALUES OBTAINED FOE EACH METHOD (MULTI-OBJECTIVE, OBJETIVE AND CONSTRAINED FUNCTION

Method	Current Model	FA	BA	EHO	MBO	CSO	GWO
F_x	16767572.00	16678684.06	16691376.13	16698962.98	16670392.64	16676406.98	16665061.63
f_1	8365980.00	8311311.64	8313591.85	8328458.74	8283610.96	8311732.91	8302990.18
f_2	1739460.00	1732375.24	1734530.90	1733023.65	1736393.72	1731816.57	1731277.73
g_1	1048.66	1030.73	1032.56	1035.71	1031.95	1028.67	1029.07
g_2	873.59	873.59	873.59	873.59	873.59	873.59	873.59
g_3	99.99	99.99	99.99	99.99	99.99	99.99	99.99
g_4	114.17	112.08	112.39	112.93	112.36	112.04	112.06

TABLE IV. FACTORS OF BIODIESEL PRODUCTION FACTOR OBTAINED USING MATLAB™ FOR EACH METHOD

Method	Current Model	FA	BA	EHO	MBO	CSO	GWO
f_m	117.2	117.53	119.99	116.49	120	118.78	120
f_s	50	45.12	54.99	45.70	55	45.08	45
f_f	50	50.22	50.26	45.88	55	47.01	45.34
τ	1	1.05	1.00	0.94	1.07	0.99	0.91
T_t	60	60.84	62.09	59.59	61.66	61.49	60.97
f_o	1050	1030.09	1030.00	1032.35	1030	1030.35	1030
T_w	50	54.87	45.01	48.65	45	53.59	55
α_m	111	112.21	113.99	110.82	114	112.78	108
γ_m	2	1.80	1.80	1.82	1.8	1.80	1.8
γ_e	1	0.80	0.80	0.80	0.8	0.80	0.8
β_e	100	97.19	98.21	98.57	97	101.80	97
γ_g	2	1.82	2.16	1.81	2.2	1.80	1.8
β_g	103	105.18	104.26	101.54	106	105.95	106

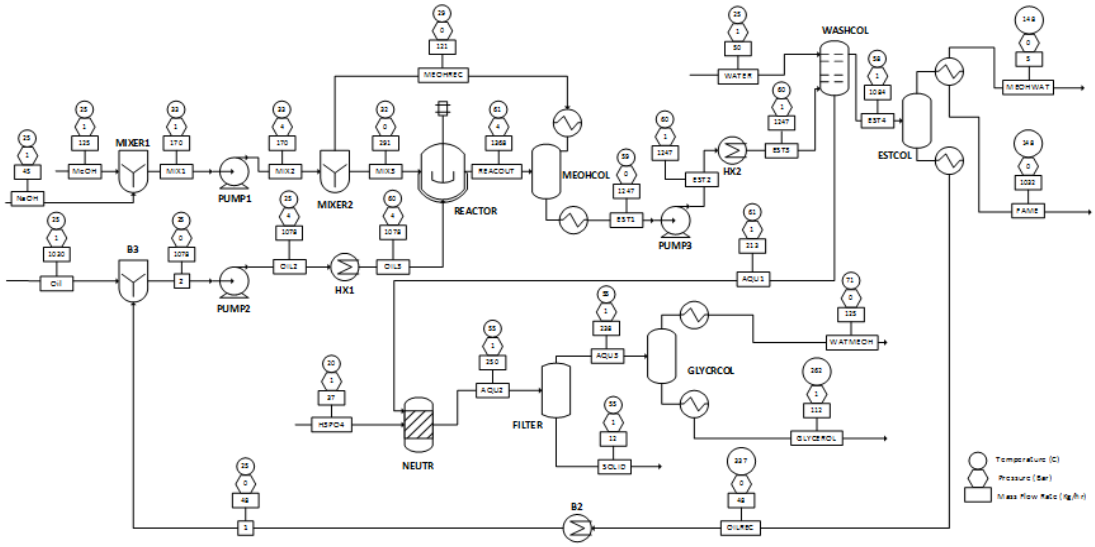

Figure 3. Process simulation by optimize of the GWO algorithm using waste cooking oil to obtain biodiesel production [9].

TABLE V. OBJECTIVE AND CONSTRAINED FUNCTION OF GWO COMPARED WITH ORIGINAL PROCESS

Function	Current Model	GWO algorithm
f_1	8365980.0000	8302990.18122774
f_2	1739460.0000	1731277.73338684
g_1	1048.6691	1029.07314111273
g_2	873.5984	873.598654917448
g_3	99.9997	99.9996805536299
g_4	114.1723	112.067257067369

A comparison showing the objective function and the constrained function for both the current model and the MATLAB™ derived GWO algorithm is presented in Table V. The GWO algorithm findings show better cost-effectiveness compared to the current model in terms of both total capital cost and the cost of operation. The resulting biodiesel product meets the required standards for density and purity respectively with regard to the FAME and glycerol by-products.

TABLE VI. PERCENTAGE ERROR FOR THE PREDICTED AND ACTUAL VALUES

Function	Predict from GWO algorithm	Actual from Aspen plus	%Error
f_1	8302990.18122774	8364920.00	0.7404%
f_2	1731277.73338684	1733150.00	0.1080%
g_1	1029.07314111273	1028.6820	0.0380%
g_2	873.598654917448	873.5987	5.2E-06%
g_3	99.9996805536299	99.9997	1.9E-05%
g_4	112.067257067369	112.1051	0.0338%

It is necessary to establish that the DOE regression equation is both reliable and error-free. The values derived from MATLAB™ can be observed in Table VI, defined in real terms as the predicted values. The production process for biodiesel is simulated from Aspen plus. Very few tolerances exist in any of the test functions, so the reliability of Equations 13-18 can be confirmed, and therefore these can be used to improve the biodiesel production efficiency, at a level of significance of 95%.

TABLE VII. COST ESTIMATION AND SAVING COST

Function	Current Model	Actual	Saving cost
Total capital cost [US $]	8,365,980	8,364,920	1,060
Operating cost [US $/year]	1,739,460	1,733,150	6,310

It can be concluded that the GWO algorithm leads to improved efficiency and lower process costs when compared to the current model. This can therefore achieve a reduction in total annual capital costs of US $1,060, and in annual operating costs of US $6,310 shown in Table VII.

IV. CONCLUSION

In an effort to develop the alkali-catalyzed process to manufacture biodiesel from virgin oil by utilizing cooking oil to produce biodiesel, MOOP was found to be generally effective. Additionally, the GWO algorithm, together with SI algorithm to support deep learning, can be utilized in conjunction with the CCD process.

In order to define the least total capital cost (f_1) in US $, lowest operating cost (f_2) in US $/year to examine the effects of the independent parameters on the mass fraction of FAME, % FAME purity, the mass fraction of glycerol, and % glycerol purity, CCD experiments were conducted as devised by the program. Comprising the flow rate of MeOH, flow rate of NaOH, flow rate of H_3PO_4, resident time, Temperature of transesterification, Flow rate of Oil, Temperature of washing, Distillate rate of MEOHCOL, Reflux ratio of MEOHCOL, Reflux ratio of ESTCOL, Bottom rate of ESTCOL, Reflux ratio of GLYCRCOL, and bottom rate of GLYCRCOL are 120, 45, 45.34, 0.91, 60.97, 1030, 55, 108, 1.8, 0.8, 97, 1.8, and 106, respectively, the GWO approach was used to identify the impact of the parameters examined in order to resolve the problem.

Decreased total capital cost was US $1,060, while the cost of operations was reduced by US $6,310 annually, as revealed by supplementary research on MOOP using CCD and GWO as well as in comparison with the process employed in 2003 by Zhang et al.

Acceptable results were achieved based on the findings of this research using MOOP based on CCD as well as GWO for the process of manufacturing biodiesel from cooking oil waste. In summary, it was found this approach to enhancing the production process can provide a valuable source for the successful manufacture of stable and dependable biodiesel in the future.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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