Pradeep Bedi[1], Sunil Kumar[2], Seema Saini[3], Nupur Goyal[3], Akshay Kumar[2], Mangey Ram[3]*

MULTI-OBJECTIVE OPTIMISATION OF SUPERSTRUCTURE FOR BIODIESEL PRODUCTION FROM BIOMASS

MULTI-OBJEKTNA OPTIMIZACIJA SUPERSTRUKTURE ZA PROIZVODNJU BIODIZELA IZ BIOMASE

Originalni naučni rad / Original scientific paper
UDK /UDC:

Rad primljen / Paper received: 6.04.2021

Adresa autora / Author's address:
1) Department of Computer Science and Engineering, Lingaya's Vidyapeeth, Faridabad, Haryana, India
2) Depart. of Math., Graphic Era Hill Univ. Dehradun, India
3) Department of Mathematics, Graphic Era (deemed to be) University Dehradun, India email: sainiseema1@gmail.com

Keywords
- biomass
- biodiesel production
- superstructure
- optimisation
- multiple objective functions

Abstract

Biodiesel is composed of a long chain of fatty acids that are extracted from lipid-containing biomass or feedstock. It is termed a complex task to produce biodiesel from the feedstock. There is a need to optimize the production process to make it a cost-effective method to produce biodiesel. In this research work, superstructure optimisation is performed by the Multi-Objective Optimisation Algorithm. The optimisation will result in a determination of optimal production of output with specified input raw material. The proposed model will be designed with an objective function to minimize the processing costs, maximize catalyst produced, maximize end products, and maximize overall profit.

Ključne reči
- biomasa
- proizvodnja biodizela
- superstruktura
- optimizacija
- multi-objektne funkcije

Izvod

Biodizel se sastoji iz dugog lanca masnih kiselina, koje se dobijaju ekstrakcijom iz lipidne biomase ili sirovine. Proizvodnja biodizela iz sirovine se smatra vrlo složenim postupkom. Potrebno je optimizovati proizvodni proces da bi postao isplativa metoda za proizvodnju biodizela. U radu je izvedena optimizacija superstrukture primenom Multi-Objektnog Optimizacionog Algoritma. Optimizacija se ogleda u određivanju rezultata optimalne proizvodnje i specifičnim ulaznim sirovinama. Predloženi model se projektuje sa objektnom funkcijom sa minimalnim troškovima postupka, maksimalnom katalizom proizvodnje, maksimalnim završnim proizvodima i maksimalnim sveukupnim profitom.

INTRODUCTION

The improvement in the sustainable production of energy fuel is an increasing concern due to multiple concerning factors that include rapidly escalating greenhouse gas emissions, falling fossil fuel reserves, and unsteady petroleum fuel costs. Biofuels are reasonably cleaner energy resources and by developing means of making use of them as transportation fuels and other electricity resources. Transesterification is the process most extensively recognized and commercially adopted a process for biodiesel production from biomass. However, due to their struggle and consequences with the food market, this process is well-thought-out to be unsustainable, definitely not at a level that it is proficient enough of lessening warming. Microalgae is mainly adopted as feedstock for biofuel production as it grows fast, has excessive oil contents, considered to be an exceptional alternative because it is enriched with an excessive amount of lipids and enzymes, /1/.

The biorefinery is the key concept for gaining various products from the microalgae (biofuels and various other products) by employing various processes. The biorefinery is expressed as the term for manufacturing of diverse products of biofuels and chemicals by utilizing biomass via a combination of bioprocessing and chemical technology having suitable low environmental consequences in a low cost and no environmental adverse impacts /2/. The process is carried out by first cultivation of the microalgae in algal farming facility with CO_2 mitigation, then the bio reactive products are extracted from the algal biomass while harvesting. After separation, then in a sequence, the chemical, biochemical processing is carried out followed by high-value chemical extraction. At last, the contained biofuels are upgraded and transformed according to their applications /3/.

The main objective of this article is to identify the key issues for designing optimised biorefineries by using system engineering (SE) tools and techniques. Firstly a review is presented on methods or pathways for the production of biofuels from biomass such as microalgae, etc. A further superstructure-based framework is modelled to optimise system design for sustainable and robust biodiesel production from biomass. A superstructure network model is presented with an optimised pathway for an optimal solution for biodiesel production from biomass. Multiple objective functions are described to optimise the processing pathway.

BIOMASS TO BIOFUELS PRODUCTION PATHWAY

Biomass is one of those renewable energy resources that can be used in transportation as they can be stored in a liquid state and can be brought to use whenever necessary.

It can be said that amongst all the renewable energy resources, biofuel is the only resource that can reduce the dependence on foreign oil products for transportation which can make changes in the vehicle fleet, /4/.

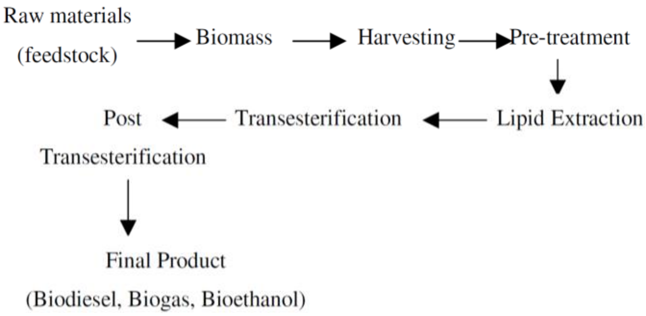

Figure 1. Pathway of biofuels production from biomass.

The main steps for biodiesel production consist of the following steps (Fig.1):

- Feedstock selection and harvesting. In this step, the collection of biomass raw products from fields is performed. The collection of biomass should be done concerning moisture content and its efficiency in terms of the end product.
- Pre-treatment before extraction. Before biodiesel production, pre-processing of harvested feedstock is done. In this step, different techniques are adopted such as drying, pyrolysis, palettization. Out of which drying and pyrolysis are the most common methods. The drying of biomass reduces its moisture content whereas the pyrolysis process is the thermal decomposition of feedstock in absence of oxygen.
- Lipid extraction. This is the most important step for biodiesel production that decides the quality, quantity, and cost-efficiency of the method. This step results in the production of bio-oil.
- Trans-esterification. This is the process in which the bio-oils (lipids) are chemically reacted with alcohol and catalyst. Mainly glycerol is used as a catalyst. Basically in this step, the viscosity of nonedible bio-oil is reduced by the conversion of triglycerides into ester.
- Post-transesterification filtration and biofuel extraction. Finally in this step, filtration of low viscous biofuel obtained in the above step is performed for usage.

Apart from biodiesel production, some by-products are also generated such as glycerol that can be further utilized in many industries, /5/.

Biomass feedstocks

Of all the energy-producing resources such as coal, petrol, diesel, whose formation cycle requires millions of years in development, biomass as an energy resource can be easily collected, stored, produced, and recycled, which does not create any adverse impact on the natural environment as well. Biomass utilizes the carbon dioxide fixation process to utilize and capture carbon from the environment, /6-8/.

Terrestrial feedstocks

For production of biofuels, a large amount of biomass is utilized as feedstock. The classification of the terrestrial biomass is being done in two major categories, in which corn grain, sugarcane, soybean, oilseed, etc., form the first group of terrestrial biomass. These products when converted into bioethanol and biodiesel turn out to produce better yield and are estimated to be exceptionally rich in sugar and lipids. In the recent era, their production cost is low as well as have good technology to harness them, and hence the majority of the biofuels are prepared from these feedstocks.

Cellulosic biomass is the second group of feedstocks that are found to possibly reduce these implications and unfavourable influences on food supply. The source for cellulosic biomass feedstocks is obtained from residues from the farm, forest, etc. Agricultural farm after harvesting produces residues in the field such as corn stover which form a source for feedstocks, also manure and wastes after food processing falls under this category. In forest logging operations, land clearing and management of forests can result in enriched plant material suitable for feedstocks along with secondary residues such as mill wastes. Certain energy crops are intensively and abundantly grown for energy production causes. They are fast-growing crops like poplar, switchgrass, Miscanthus, etc.

Aquatic feedstocks

Several macroalgae, microalgae, and cyanobacteria have the capability of performing photosynthesis that accelerates the growth of biomass. Certain traces of microalgae make extraordinarily efficient use of light and vitamins. Since microalgae can be easily developed and grown in the nutrient-rich floating medium, it is not essentially required to produce cellulose (a structural compound) for various parts such as stems, roots, and leaves, and due to this microalgae are expected to attain growth rate more rapidly when compared to former terrestrial crops. Also, it was studied that the growth of algae can be more rapid in magnitude as compared to that of terrestrial plants. The number of harvests can be possible with the algae in a short time interval due to its capability of growing fast and allowing 1-10 days harvesting cycle, which is an approach differing from that related to yearly vegetation. Algae are capable of removing and recycling the nutrients such as nitrogen and phosphorus from water. In evaluation, relying on the type of microalgae and cyanobacteria, their cultivation methods have varied depending upon the challenges and advantageous effects. Photoautotrophic or heterotrophic methods are key methods for algae production and management. The photoautotrophic method utilizes sunlight and carbon dioxide for its operation, whereas the heterotrophic method mainly consumes efficient feedstock such as lignocellulosic sugars for its growth. The algae cultivation process can be either an open pond or closed bioreactor and out of these, the latter one produces low water wastage and also yields better biomass quality. However, it is found that the closed bioreactor based harvesting has scalability issues.

Biomass to biodiesel

In recent years, the demand for alternatives to fossil fuels has accelerated due to environmental impacts. Amongst all the other alternatives, biodiesel seems to be the best one. The reason being it is of a renewable and eco-friendly nature. Also, it is less toxic than its counterparts. Analysing the production methods for biodiesel in depth will primarily aid in figuring out alternatives concerning the materials used and the technologies involved. Oils (edible or non-edible) can be used for the synthesis of biodiesels. For instance non-edible oils such as vegetable oils and waste cooking oils can be very easily utilized to prepare biodiesels. The primary benefit is that they do not depend on the food chain. Also, they are very cheap. To search for a production method that can be sustained economically, it is necessary to dig into the economic aspect of the process deeper and to take every necessary step to optimise the procedure. Our focus lies in figuring out alternate biomass for biodiesel synthesis. As per the facts, the major source for the production of greenhouse gases and pollution of the environment is fossil fuel, /4-6/. Due to these reasons, researchers across the world have focussed on searching for an alternative. The primary benefits of biodiesel include the following, /7, 8/:

- better lubrication,
- renewable source,
- sulphur free,
- non toxic nature.

When compared to traditional fuels such as petro-diesels, biodiesel has several benefits. Some of them include lesser greenhouse emissions, renewability, non-toxic nature, and no air pollution. Based on the feedstock, a few generations of biodiesels have evolved over the past couple of years. About 69% of the biodiesel synthesized globally in the year 2015 is based on edible vegetable oil sources, which include reseeding oil, soya bean oil, and palm oil, /9/. The rapid exploitation of vegetable oils has gradually raised the fuel versus food concern. Increased use of edible oils may increase the prices of the product and raise concerns over food security.

The economic growth of rural areas could accelerate through oil crop cultivation, but for longer durations, employing large areas for such cultivation is not a good practice. Several researchers across the world have analysed the production procedures related to a variety of feedstocks. In the recent past, the focus of research has shifted to sources that are not based on food. For instance, animal fat, castor oil, non-edible oil, waste cooking oil, and ligno-cellulosic materials /10/. China has made certain attempts to restrict the use of edible oils, a step that proves the avoidance of edible oil usage for the synthesis of biodiesel. The biodiesel of the third generation came into existence, to bring down the usage of edible and nonedible oils. Algal biomass is the prominent source that dominates this generation. Despite the successes experienced in the biodiesel industry as stated previously, there remain major challenges in the biodiesel industry that affect the cost of biodiesel such as:

- the cost of raw materials,
- the cost of processing,
- reuse of the catalyst,
- time complexity.

MULTI-OBJECTIVE OPTIMISATION

Progressive methodologies have been proposed in the 1960s as an important biomass search heuristic industry and popularly used for the solution of mathematical optimisation problems with combination or non-convex systems. They use methodologies of natural biological procedures to optimise or near-optimise solutions. In short, they use paradigms of natural evolution. This idea is generalized by multi-objectify evolutionary algorithms (MOEAs), typically aimed at approaching Pareto solutions that are optimally distributed across Pareto. As no single best solutions in multi-target optimisation exist in general, there are distinct choice strategies of these algorithms to those used throughout the optimisation of single objectives. Basically there are three main MOEA design paradigms. The following are:

– Pareto-based: in such type of MOEAs, a two-level ranking system is used. The Pareto supremacy relationship controls the first position, and second level ranking points to diversity.
– Indicator-based: such type of MOEAs use some indicators such as R2 to optimise the solution sets according to changes in this indicator.
– Decomposition-based: such type of MOEAs divide the main problem into sub problems based on some parametrized (or weighted) factors for each sub problem.

No matter how many applications engineering solutions are used for multiple purpose optimisation (MOPs), successful solution algorithms remain uncertain. Two approaches for solving MOPs are multi-objective evolutionary algorithms (MOEAs), and mixed integer linear programming (MILP) algorithms. MILP, unlike MOEA, will ensure that the MOP approaches discovered are effective. MOEAs, on the other hand, are commonly used due to the following advantages over MILP:

- computational scalability for large networks through the implementation, without pre-specifying target preferences, of efficient parallelism algorithms;
- compatibilities with nonlinears and restrictions;
- biased sampling of Pareto optimal solutions.

The fitness of candidates' solutions which represent individuals in a population, is improved iteratively using heuristic rules based on a more standard meaning of computation system known as evolutionary algorithms (i.e., objective function values). MOEAs that solve a number of objective problems (i.e. issues with four or more objectives) that are often important for real-world applications but difficult to solve with traditional MOEAs have recently received a lot of attention /20/. Moreover, it is possible to explore a more diverse design space, with the best solver algorithms, which helps in improved selections for experiments.

SUPERSTRUCTURE OPTIMISATION FOR BIODIESEL PRODUCTION

To cope with difficulties and problems faced during biofuel/biodiesel production from biomass can be resolved by the application of system engineering (SE). Under SE, superstructure design and optimisation are being used as fruitful tools to reach an optimal cost-effective solution /11, 12/. Superstructure design and optimisation includes mathematical programming to find the optimal chemical process according to objective function /13-15/. A general superstructure representation is illustrated in Fig. 2.

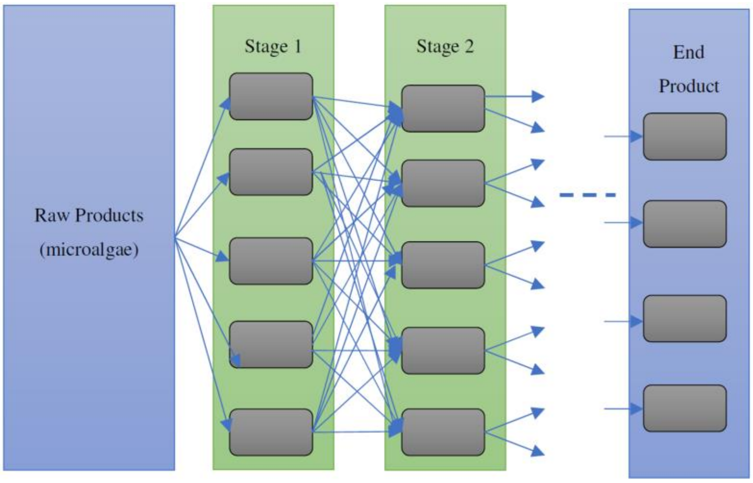

Figure 2. General superstructure framework.

To design and develop a superstructure for biorefineries, it is required to identify all the possible processing stages/ steps that can lead to end products. Figure 3 represents the example of the superstructure with all possible alternatives for the processing stage. Depending on the desired end-products, the processing pathways are added to the superstructure /16/. In superstructure optimisation, four main steps are performed as /17/:

- problem identification to determine the scope of the metrics selection;
- collection of data for required raw materials, process, and all possible alternative techniques;
- establishment of connection among alternatives of the process;
- conversion of raw materials into desired products.

The most important step in superstructure design is to formulate the objective function for optimisation, /18/. An objection function determines the equality and inequality constraints to reach the best possible solution. In most of the research work, mixed-integer linear programming (MILP) is used. A general superstructure-based optimisation representation is illustrated in Fig. 3.

PROPOSED METHODOLOGY

This paper illustrates the advantages for application of optimisation algorithms for biodiesel production. Optimisation algorithms input a set of experiments for reliable and adequate yield measurements of biodiesel. The optimisation algorithm applies mathematical operations to select and determine the best possible data and alternatives for the superstructure design that results in production of maximal (or minimal) response.

To solve the problem of optimisation of biodiesel production from organic and animal waste, the superstructure model will be designed based on a multi-objective optimisation problem. Optimisation will result in a determination of optimal production of output with specified input raw material. The proposed model will be designed with an objective function to minimize processing costs, the amount of waste generated, and processing time along with maximization of catalyst production. In this work, multi-objective optimisation (artificial butterfly algorithm) is proposed

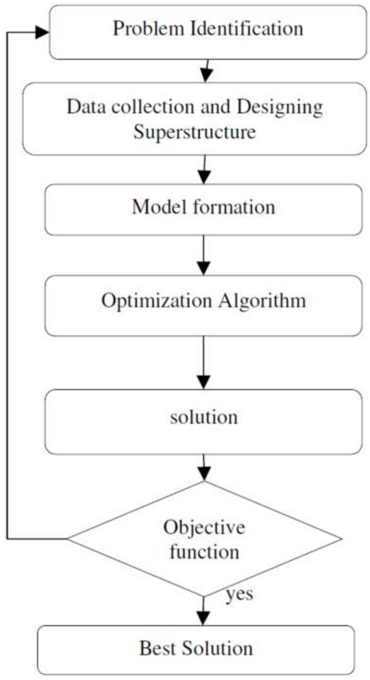

Figure 3. Superstructure optimisation flowchart.

that is designed for selection of feedstock, by-product, processing techniques, etc. for biodiesel production from biomass. To achieve better output, it is required to achieve the following objectives:

- maximize profits for overall processing, products, etc.;
- minimize wastage to improve the life-cycle.

In this section, the superstructure optimisation is proposed to describe optimal input parameters for increasing yield of biodiesel from biomass (microalgae). The optimisation technique selects best processing steps for desired end product, or by-products production. This paper aims in intending to obtain maximal catalyst, maximal end product, minimum processing cost with maximum profit. For a multi-objective optimisation problem, the aim is to find a vector $X^* = \{x_1, x_2, \dots, x_n\}$ which will satisfy the constraints as:

$$\min \sum_{i=1}^{n} x_i * PC_i \,, \tag{1}$$

$$\max \sum_{i=1}^{n} x_i * cat_i \,, \tag{2}$$

$$\max E_p \,, \quad E_p \geq \sum_{i=1}^{n} x_i \,, \tag{3}$$

$$\max(P) \,, \quad P \geq \sum_{i=1}^{n} x_i * \text{cost} \,, \tag{4}$$

where: x - processing steps; PC_i - processing cost.; cat_i - catalyst produced; E_p - end product, biodiesel; P - overall profit.

The steps of the proposed multi-objective optimised superstructure model are given below (Fig. 4):

- define input parameters such as raw materials, processing steps, delay time, limits of lower bound and upper bound, global and local constraints;
- model formation;
- calculate the fitness value of a multi-objective function of all available solutions;

- find the best solution that meets all constraints.

Out of all bio-inspired methods, one method is artificial butterfly optimisation, proposed by /19/, designed for multi-objective functions. This optimisation method is based on finding best butterfly for mating among them. The population of butterflies are sorted into groups according to their fitness values. The group having best fitness value is selected for further proceedings. The best fitness valued group is termed as sunspot butterflies, whereas others are termed as canopy butterflies.

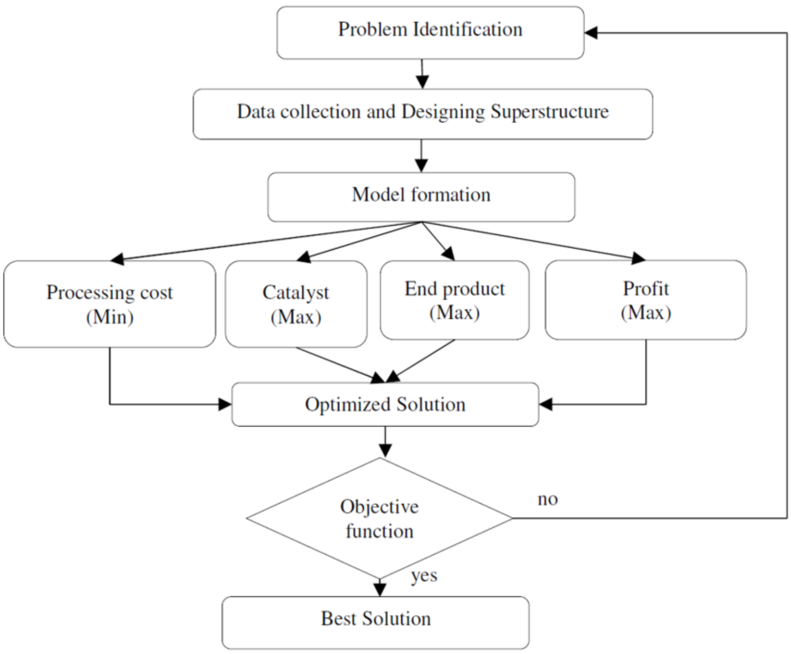

Figure 4. Superstructure optimisation flowchart.

So, ABO algorithm is operated in two modes:
– sunspot mode,
– canopy mode.

Rules that are applied are discussed as below (Fig. 5):
- to increase likeliness among female butterflies, all male butterflies move towards best sunspot location;
- each butterfly in each sunspot will move towards best sunspot in neighbour to occupy best sunspot;
- each butterfly in each canopy will move towards sunspot.

RESULT ANALYSIS

In this section the contribution of researchers is discussed and production of biodiesel from oils or waste products. Some researchers have focused on maximization of yield production, such as biodiesel, lipid extraction, etc. For maximization of yield production, bio-inspired optimisation methods are used, whereas some researchers have worked on the design of production process such as superstructure design to generate maximum profit with minimum raw products. In /20/ author had used ANN+PSO for prediction of highest yield by optimising the parameters and achieved approx. 90% of accuracy while prediction. While prediction, the minimum square error achieved is 0.999. So, this paper illustrates two performance evaluation parameters i.e. accuracy and minimum square error. In /21/, author presented a fuzzy PSO model on experimental data to optimise the bio

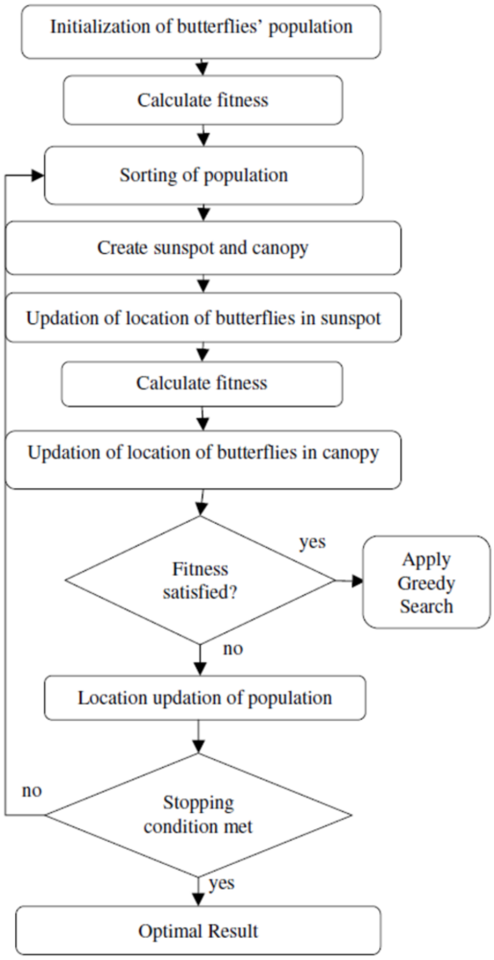

Figure 5. Artificial butterfly optimisation algorithm.

diesel production. In this paper author presented response surface methodology to evaluate the lipid extraction. In /22/ the author presented a Taguchi design to optimise the biodiesel production. Statistical analysis is performed for result evaluation. In /23/ author implemented the quadratic model to predict the biodiesel production prediction. The author presented the result comparison on the basis of R2. In /24/, the author applied mixed-integer nonlinear programming to design superstructure alternatives for biodiesel production.

According to the study of existing systems, the following input parameters that effect optimisation are stated:
- methanol/oil molar ratio,
- raw materials weight,
- concentration of catalyst used,
- agitation speed,
- time required for reaction,
- temperature provided for entire reaction,
- pressure,
- number of iterations.

So, according to the study of different contribution (Table 1) it can be concluded that bio-inspired optimisation can be considered to be as most-effective method for effective yield of biofuels and maximization of profit. According to the study, the following parameters can be focused in the proposed methodology:
- lipid production,
- total yield,

- free fatty acid conversion,
- production cost.

Table 1. Comparative result analysis.

Feedstock	Optimisation	Parameters	Results	Ref
Sesame oil	ANN+PSO	total yield	highest yield of biodiesel is 90.58%	/20/
Microalgae	Fuzzy-PSO	total yield	lipid production is 78.7%	/21/
Castor oil	Taguchi	reaction time molar ratio	maximal free fatty acid conversion is 90.83%	/22/
Stone fruit oil	Response surface method	reaction time molar ratio density	fuel properties improved	/23/
Organic and animal waste	mixed-integer nonlinear programming	production cost	lower consumption with maximal profit	/24/

CONCLUSION

To minimize the processing cost, maximize catalyst production, and earn from the biodiesel production plant, it is required to decide before the number of production units and controllers to regulate end products. This paper has addressed these issues by superstructure designing. From the existing research, the proposed methodology formulated the Multi-Objective Optimisation Algorithm (MOOA) that will reduce the overall cost of the biodiesel production process as well as reusage of catalyst. From the aspect of the industry, the optimisation finds the optimum pathway, also the minimal cost, and may be beneficial for sustainable development due to the lower consumption. Overall, this research will successfully implement the system to optimise the design and cost estimation.

REFERENCES

1. Demirbas, A. (2011), *Competitive liquid biofuels from biomass*, Appl. Energy, 88(1): 17-28. doi: 10.1016/j.apenergy.2010.07.016
2. Rizwan, M., Almansoori, A. Elkamel, A. (2019), *An overview on synthesis and design of microalgal biorefinery configurations by employing superstructure-based optimization approach*, Energy Syst. 10: 941-966. doi: 10.1007/s12667-018-0296-6
3. Rizwan, M., Superstructure-based identification of optimal processing pathways for microalgae-based biorefinery, PhD Thesis, KAIST, South Korea, 2015.
4. Kumar, D., Singh, B. (2019), *Algal biorefinery: An integrated approach for sustainable biodiesel production*, Biomass Bioenergy, 131: 105398. doi: 10.1016/j.biombioe.2019.105398
5. Kalavathy, G., Baskar, G. (2019), *Synergism of clay with zinc oxide as nanocatalyst for production of biodiesel from marine Ulva lactuca*, Bioresour. Technol. 281: 234-238. doi: 10.1016/j.biortech.2019.02.101
6. Gnanasekaran, R., Dhandapani, B., Iyyappan, J. (2019), *Improved itaconic acid production by Aspergillus niveus using blended algal biomass hydrolysate and glycerol as substrates*, Bioresour. Technol. 283: 297-302. doi: 10.1016/j.biortech.2019.03.107
7. Wei, X., Hellier, P., Baganz, F. (2020), *Impact on performance and emissions of the aspiration of algal biomass suspensions in the intake air of a direct injection diesel engine*, Ener. Convers. Manag. 205: 112347. doi: 10.1016/j.enconman.2019.112347
8. Akubude, V.C., Nwaigwe, K.N., Dintwa, E. (2019), *Production of biodiesel from microalgae via nanocatalyzed transesterification process: A review*, Mater. Sci. Energy Technol. 2(2): 216-225. doi: 10.1016/j.mset.2018.12.006
9. Goh, B.H.H., Ong, H.C., Cheah, M.Y., et al. (2019), *Sustainability of direct biodiesel synthesis from microalgae biomass: A critical review*, Renew. Sust. Energ. Rev. 107(C): 59-74. doi: 10.1016/j.rser.2019.02.012
10. Suganya, T., Varman, M., Masjuki, H.H., Renganathan, S. (2016), *Macroalgae and microalgae as a potential source for commercial applications along with biofuels production: A biorefinery approach*, Renew. Sustain. Energy Rev. 55: 909-941. doi: 10.1016/j.rser.2015.11.026
11. Naylor, R.L., Higgins, M.M. (2018), *The rise in global biodiesel production: Implications for food security*, Glob. Food Sec. 16: 75-84. doi: 10.1016/j.gfs.2017.10.004
12. Azad, A.K., Rasul, M.G., Khan, M.M.K., et al. (2015), *Prospect of moringa seed oil as a sustainable biodiesel fuel in Australia: A review*, Procedia Eng. 105: 601-606. doi: 10.1016/j.proeng.2015.05.037
13. Frombo, F., Minciardi, R., Robba, M., et al. (2016), *A dynamic decision model for the optimal use of forest biomass for energy production*, Energy Syst. 7(4): 615-635. doi: 10.1007/s12667-015-0188-y
14. Liu, P., Pistikopoulos, E.N., Li, Z. (2010), *Energy systems engineering: methodologies and applications*, Front. Energy Power Eng. China, 4(2): 131-142. doi: 10.1007/s11708-010-0035-8
15. Yue, D., You, F., Snyder, S.W. (2014), *Biomass-to-bioenergy and biofuel supply chain optimization: Overview, key issues and challenges*, Comput. Chem. Eng. 66: 36-56. doi: 10.1016/j.compchemeng.2013.11.016
16. Yeomans, H., Grossmann, I.E. (1999), *A systematic modeling framework of superstructure optimization in process synthesis*, Comput. Chem. Eng. 23(6): 709-731. doi: 10.1016/S0098-1354(99)00003-4
17. Grossmann, I.E. (1996), *Mixed-integer optimization techniques for algorithmic process synthesis*, In: John, L.A. (ed.) Adv. Chem. Eng. 23: 171-246. doi: 10.1016/S0065-2377(08)60203-3
18. Farkas, T., Rev, E., Lelkes, Z. (2005), *Process flowsheet superstructures: Structural multiplicity and redundancy: Part II: Ideal and binarily minimal MINLP representations*, Comp. Chem. Eng. 29(10): 2198-2214. doi: 10.1016/j.compchemeng.2005.07.008
19. Qi, X., Zhu, Y., Zhang, H. (2017), *A new meta-heuristic butterfly-inspired algorithm*, J. Comp. Sci. 23: 226-239. doi: 10.1016/j.jocs.2017.06.003
20. Soltani, H., Karimi, A., Falahatpisheh, S. (2020), *The optimization of biodiesel production from transesterification of sesame oil via applying ultrasound-assisted techniques: comparison of RSM and ANN-PSO hybrid model*, Chem. Prod. Proc. Model.: 0200076. doi: 10.1515/cppm-2020-0076
21. Nassef, A.M., Sayed, E.T., Rezk, H., et al. (2019), *Fuzzy-modeling with Particle Swarm Optimization for enhancing the production of biodiesel from Microalga*, Ener. Sour. Part A: Recov. Utiliz. Environ. Effects, 41(17): 2094-2103. doi: 10.1080/15567036.2018.1549171
22. Karmakar, B., Dhawane, S.H., Halder, G. (2018), *Optimization of biodiesel production from castor oil by Taguchi design*, J Env. Chem. Eng. 6(2): 2684-2695. doi: 10.1016/j.jece.2018.04.019
23. Anwar, M., Rasul, M.G., Ashwath, N., Rahman, M.M. (2018), *Optimisation of second-generation biodiesel production from Australian native stone fruit oil using response surface method*. Energies, 11(10): 2566. doi: 10.3390/en11102566
24. Nuh, M.Z., Nasir, N.F. (2017), *Superstructure-based design and optimization of batch biodiesel production using heterogeneous catalysts*, IOP Conf. Ser.: Mater. Sci. Eng. 226: 012001. doi: 10.1088/1757-899X/226/1/012001