International Journal of Industrial Engineering & Production Research

September 2013, Volume 24, Number 3
pp. 189-206

http://IJIEPR.iust.ac.ir/

ISSN: 2008-4889

Issues in Biodiesel Production: A Review and an Approach for Design of Manufacturing Plant with Cost and Capacity Perspective

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KEYWORDS

Biodiesel,
Production Plant Design,
Design Issues,
Mathematical Model

ABSTRACT

This paper aims at the study and analysis of existing contributions related to issues in Biodiesel production. It discusses key issues and related contributions which include chemical processes, reactor designing, plantation, blending and applications. It summarizes the analysis of other prominent contributions to process model, design, production, cost, optimization, feasibility, safety, effects, challenges and future of Biodiesel production and also presents discussion on open issues. An approach based on the mathematical model is suggested for design of Biodiesel manufacturing plant in view of cost and capacity. This paper can be a stimulant to the beginners in the domain of renewable energy research.

1. Introduction

Today, an enormous amount of energy is consumed by the machinery in industries and household appliances. The need of mechanical machinery is all pervading in human life, vehicle engines in particular. In industry or for household appliances, consumption of the energy is increasing day by day and to mitigate this problem, the energy conversion concept is important. It becomes necessary to develop economically new technique/methodology or technology to solve and manage energy crisis.

One of the areas explored by researchers is the generation of fuel by using the things available in nature. Biodiesel is a fuel which is generated by using the plant seeds or plant fruits/wastage, animal fats. These plant or animal fats are generally referred as the feedstocks for Biodiesel. Biodiesel is generally used in the engines (vehicle engines, industry or household appliances based on engines). Biodiesel is a renewable fuel and can contribute to greenhouse gas reduction. Researchers in India, prompted by the events of World War II, extended their investigations on 10 vegetable oils for development as domestic fuels [1]. Work on vegetable oils as diesel fuel ceased in India when petroleum-based diesel fuel became easily available at low cost [2].

Biodiesel is an alternative for petrodiesel or it can also be used along with petrodiesel. In recent years, the area of Biodiesel manufacturing attracted number of researchers wherein the researchers have contributed a lot.

This paper particularly focuses on the design issue of Biodiesel production plant, study and review of Biodiesel production. Though different reviews and study papers exist regarding Biodiesel, yet this paper is different from existing review papers in many ways. It not only discusses the key and open issues in Biodiesel production plant, but also suggests an approach to evaluate the design of Biodiesel production plant from management and economic point of view.

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Paper first received Nov, 23, 2011, and in accepted form Oct, 06, 2012.

This paper is organized as follows- Section 2 presents brief summary of existing literature. The key issues and process model is discussed in section 3 and section 4 respectively. Section 5 to section 7 summarizes the work related to design and production: cost, optimization and feasibility, and safety, effects, challenges and future. Section 8 focuses on open issues in Biodiesel production. Approach for evaluation of the design of Biodiesel production plant is suggested in Section 9. Finally, section 10 takes up discussion and conclusion followed by the references.

2. Existing Review and Research Contributions

Existing research contribution focuses on various aspects of Biodiesel production. Present study consists of critical analysis of more than ninety research and review papers together. All referred articles or papers are categorized on the basis of following important issues- Feedstocks, Plantation, Chemical Process, Catalyst, Methanol, Reactor Design, Process Modeling, Design Issues, Production Issues, Simulation, Cost and Modeling, Optimization, Safety Issues, Opportunities and Challenges, Blending, Applications, and Feasibility Analysis. The categorization of the referred papers is summarized in Table 1.

Tab. 1. Summary of All Referred Articles or Papers

Issues / Parameters	Discussed in the References
Feedstocks	[1-2, 4-5, 7, 9-10, 13-14, 17, 19-21, 23-34, 43-48, 50, 52-53, 56, 60-64, 66, 68-72, 75, 77, 79, 81-82, 84-87, 89, 92-93, 95-98]
Plantation	[9, 43, 61, 66, 70, 72, 91, 96]
Chemical Process	[4, 6-7, 10-11, 15, 17-18, 23-42, 45-48, 51, 55, 57, 62-63, 68, 71, 73, 75-76, 78-79, 83, 85-89, 93-95, 98]
Catalyst	[7, 15, 17, 19, 23-34, 52, 55, 63, 71, 73, 75-76, 85, 87, 89, 93-95]
Methanol	[7, 17, 19, 23-34, 52]
Reactor Design	[32-33, 35-42]
Process Modeling	[4, 6, 9-10, 13-14, 27, 31, 33, 36-37, 50-55]
Design Issues	[3, 6, 9, 13-14, 50, 52, 56, 68, 71, 73, 75, 77]
Production Issues	[5, 8-9, 12, 14, 19, 23, 25, 58-64, 67, 71-73, 77, 79, 81-84, 89-92, 94-95, 97-98]
Simulation	[14, 53-54, 57, 68, 71-72, 74, 83]
Cost and Modeling	[2-3, 5-6, 8, 10, 12-13, 15, 20-21, 26, 50, 52-54, 65-73, 75-78, 83-84, 89, 91-93, 95]
Optimization	[31, 36, 47, 55, 77-78, 81-84, 86-88]
Safety Issues	[7-8, 10, 16-17, 54, 76, 80, 84, 89]
Opportunities and Challenges	[1-3, 7-8, 15, 17, 20-21, 28, 33, 57, 60-61, 63-64, 66, 69-70, 89-91, 93, 96-98]
Blending	[7, 16-18, 22, 46-49, 89, 93-94]
Applications	[1-2, 7, 22, 28, 48-49, 59, 65]
Feasibility Analysis	[3, 5, 12-13, 51-51, 54, 62, 65, 74, 84, 89, 91]

The literature on [7, 8, 16-23, 59-61, 92-93, 96-98] is related to overviews, reviews, surveys and state of art of Biodiesel in today's scenario. The most prominent contribution exists related to refinement of chemical processes [24-34], reactor designing [35-42] and plantation [43-49]. Process modeling literature is also reported in [4, 6, 9-10, 13-14, 50-55]. Apart from above list of literature, [56-64] describes the design and production related work; [3, 5, 12-13, 65-89] consists of cost, optimization and feasibility related work; and the safety, effects, challenges and future related work exist in [8, 90-98]. Biodiesel manufacturing plant design related issues are most important from management and economic point of view. It is found that few contributions related to design issues [3, 6, 9, 13, 14, 50, 52, 56, 68, 71, 73, 75, 77] have been reported in literature. The literature [8, 59-61, 92-93, 96-98] from existing overviews, reviews, surveys and state of art of Biodiesel is discussed in the concerned sections of this paper, while [7, 15-23] is discussed below in brief.

The handbook [7], first, presents the history of vegetable oil-based diesel fuels and basics of diesel engines and diesel fuels. It also discusses fundamentals of the transesterification reaction and alternate feedstocks and technologies for Biodiesel production. It further discusses analytical methods for Biodiesel, various fuel properties, effect of Biodiesel fuel on pollutant emissions from diesel engines as well as influence of Biodiesel, and different petrodiesel fuels on exhaust emissions and health effects. It takes into account the current status of Biodiesel industries in United States, European Union, Asia, Australia, and South Africa. In its end this handbook throws light on environmental implications of Biodiesel, uses of Biodiesel, Biodiesel standards and Internet resources.

Contribution in [15] discusses progress and recent trends in Biodiesel fuels where Demirbas focused his study right from the feedstocks analysis to future of Biodiesel.

Details of chemical processes involved in manufacturing of Biodiesel are discussed in his study. He further states the advantages and disadvantages of Biodiesel and elaborates the cost-benefit analysis. Basic design related issues which should be considered in Biodiesel plant design are not elaborated in [15].

The technical report [16] sheds light on Biodiesel fundamentals which include the benefits and limitations of Biodiesel use, also the non-transportation applications. It also deals with quality specifications, properties, energy content, cleaning effect and material compatibility of Biodiesel. Biodiesel blends are also discussed in this report. Warranty issues, taxes and incentives, and safety, health, and environmental issues are presented in this report. Finally, this report concludes with energy policy act, information resources, and sample Biodiesel material safety data sheet.

Rutz and Janseen [17], in their biofuel technology handbook discussed biofuel policies, life cycle and different types of biofuels. They further discussed the environmental impacts of bioethanol, lipid biofuels, and biomethane.

Ma and Hanna [18] present their review on Biodiesel production where the direct use and blending is discussed. This review extends with discussion on chemical processes involved in Biodiesel production.

In this review, the authors concluded that used cooking oils can be utilized as raw material, adaption of continuous transesterification process and recovery of high quality glycerol from Biodiesel by-product (glycerol) are primary options to be considered to lower the cost of Biodiesel, also, the transesterification reaction is affected by molar ratio of glycerides to alcohol, catalysts, reaction temperature, reaction time and free fatty acids and water content of oils or fats.

Vasudevan and Briggs [19] reviewed Biodiesel as a renewable and environmentally friendly fuel. In their review, they examined different Biodiesel sources (edible and no edible), virgin oil versus waste oil, algae-based Biodiesel that is gaining increasing importance, role of different catalysts including enzyme catalysts, and the current state of art in Biodiesel production.

Tao and Aden [20] presents detailed comparative analysis on production economics of both current and future biofuels, including ethanol, Biodiesel, and butanol. Key technical and economic challenges faced by all these bio-fuels are also discussed. They have studied the impact of key parameters on the overall process economics (e.g., plant capacity, raw material pricing, and yield) and compared how next generation technologies and fuels will differ from today's technologies.

Johnston and Holloway [21] in their study present a consistent, national-level evaluation of potential Biodiesel volumes and prices, replicated across 226 countries, territories, and protectorates. Results taken from all over the globe are compared across a variety of economic, energy, and environmental metrics. This study highlights the untapped opportunities available in many developing countries, helping to address some of the most prominent perceived barriers to large-scale Biodiesel development.

Strong et al. [22] reviewed the literature regarding usage of Biodiesel and Biodiesel blend fuel in on-road applications. This review summarized Biodiesel's effects on engine performance and warranties. Storage, handling and transportation requirements were also addressed. Numerous emission studies have been conducted in this review.

Latest aspects of development of Biodiesel have also been discussed in [23]. Effect of molar ratio, moisture and water content, reaction temperature, stirring, specific gravity, etc. on Biodiesel production is evaluated in this study. Biodegradability, kinetics involved in the process of Biodiesel production, and its stability have been critically reviewed. Emissions and performance of Biodiesel has also been reported. Summary of all above papers discussed in this section is presented in Table 2.

Tab. 2. Summary of Biodiesel Study Papers

Study of Biodiesel		
Authors	**Publication Type**	**Issues Handled**
G. Knothe et al. [7]	Handbook	Vegetable oil-based diesel fuels; transesterification reaction and alternate feedstocks; technologies; pollutant emissions; health effects; uses and standards of Biodiesel
A. Demirbas [15]	Study Paper	Feedstocks analysis; chemical process; advantages and disadvantages of Biodiesel; cost-benefit analysis
K. S. Tyson [16]	Technical Report	Quality, properties, energy content, cleaning effect, material compatibility of Biodiesel; blends; warranty, taxes, incentives, safety, health, energy policy; information Resources
D. Rutz and R. Janseen [17]	Handbook	Biofuel policies, life cycle and the different types of biofuels; environmental impacts of bioethanol, lipid biofuels, and biomethane
F. Ma and M. Hanna [18]	Review Paper	Direct use and blending; chemical processes
P. T. Vasudevan and M. Briggs [19]	Review Paper	Different Biodiesel sources (edible and non-edible), virgin oil versus waste oil; enzyme catalysts, and the current state-of-the-art in Biodiesel production
L. Tao and A. Aden [20]	Comparative Analysis	Production economics of both current and future biofuels, including ethanol, Biodiesel, and butanol; technical and economic challenges facing all of these biofuels
M. Johnston and T. Holloway [21]	Comparative Analysis	Untapped opportunities present in many developing countries, helping to address some of the most prominent perceived barriers to large-scale Biodiesel development.
C. Strong et al. [22]	Review Paper	Usage of Biodiesel and blend fuel in on-road applications; Biodiesel's effects on engine; Storage, handling and transportation requirements ; emissions studies
Y. C. Sharma et al. [23]	Review Paper	Latest aspects of development of Biodiesel; Effect of molar ratio, moisture and water content, etc. on Biodiesel production; Emissions and performance of Biodiesel

3. Key Issues in Biodiesel Production

In previous section, the various review and overview papers are analyzed and discussed. There are certain key issues which are very important in Biodiesel production. The literature related to these issues is discussed in following subsections.

3-1. Chemical Process Related Work

The transesterification of vegetable oils with methanol as well as the main uses of the fatty acid methyl esters are reviewed in [24]. The general aspects of this process and applicability of different types of catalysts are described. Several applications of fatty acid esters are described.

Costa et al. [25] have studied the process in order to use alternative raw materials with high acidity and low cost, as waste oil, acid greases and brown greases. They have developed the process with sulfuric acid as catalyst, to convert fatty acids to methyl esters and reduce the acidity, followed by the alkaline catalyst reaction. Authors have worked on the kinetics and thermodynamics of this reaction with different amounts of methanol and sulfuric acid; and they found that the esterification equilibrium constants values are similar for different raw materials.

Akbar et al. [26] analyzed chemical and physical properties of the lipid fraction of Jatropha oil seed and found that it could be useful as Biodiesel feedstock. It is less expensive which indirectly reduces Biodiesel production cost. The continuous production of Biodiesel by the transesterification reaction of coconut oil and palm kernel oil in supercritical methanol without using any catalyst is studied in [27]. The regression model by Least-Squares method of experimental data is also evaluated.

Abdullah et al. [28] analyzed the critical technical areas of Biodiesel as a fuel and provided the study of these technical areas where one can improve Biodiesel technology from future perspective because the future success in Biodiesel application depends on how well the problem of these technical areas are resolved.

Foglia et al. [29] have developed a high performance liquid chromatographic method for quantifying blends of Biodiesel in petrodiesel. It is claimed that the method can also be used for quantifying similar levels of oils or fats in petrodiesel.

The study in [30] shows that the efficient methanolysis of Jatropha oil is possible by lipase catalysis in presence of t-butanol as solvent. This work is a comprehensive study on the reaction parameters influencing the enzymatic synthesis of Biodiesel. The study in [31] evaluated the alkaline catalyst effects on Biodiesel yield and soap formation in transesterifying methanol and canola oil at different catalyst concentrations, reaction temperatures, and methanol-to-oil molar ratios and the operating conditions for maximizing Biodiesel yield and minimizing soap formation are evaluated based on statistical optimization.

Boucher et al. [32] presents the quantitative performance data for a laminar flow Biodiesel reactor/separator to achieve high conversion to Biodiesel and simultaneous separation of the by-product glycerol. Ibrehem and Al-Salim [33] proposed a mathematical model to capture the batch reactor characteristics of reacting compounds where the model is applied to batch reactor for the production of Biodiesel from palm oils. Viswanathan and Ramaswamy [34] describe the various types of heterogeneous solid acids and bases as promising catalysts for efficient Biodiesel production via transesterification process.

3-2. Reactor Designing Related Work

Reyes et al. [35] assessed the rate of Biodiesel formation in a transesterification reactor stirred with a dual jet flow close loop. Leevijit et al. [36] performed a simulation to optimize a mixing performance of a continuous reactor for producing saleable Biodiesel from palm oil and to predict required residence times at the selected purities for transesterification of palm oil in optimized reactor. Sotoft et al. [37] proposed an approach for process synthesis of Biodiesel production and illustrated the importance by an example of Biodiesel production from waste animal fats. Ghazi et al. [38] discussed the concept of a continuous process in producing Biodiesel from Jatropha oil by using an oscillatory flow Biodiesel reactor. Sani and Hasnan [39] developed and fabricated two different mechanically agitated reactor vessels in mini scale size to produce Biodiesel. Chen et al. [40] demonstrates the applicability of using immobilized lipase and a packed-bed reactor for continuous Biodiesel synthesis. Kiss [41] explains an energy-efficient integrated production of Biodiesel from hydrous bioethanol. Singh et al. [42] developed and studied a reactor system using reactive distillation technique for Biodiesel preparation from yellow mustard oil seed.

3-3. Plantation, Blending and Applications Related Work

Ariza-Montobbio and Lele [43] studied the agronomic and economic viability and livelihood impacts of Jatropha curcas plantations from individual farmer's perspective in Tamil Nadu, India. They found that Jatropha yields are much lower than expected and its cultivation is currently unviable, and even its potential viability is strongly determined by water access. Bachmann [44] describes the basic processes involved in small-scale oilseed processing where he proposes the different methods and equipments used for oil extraction. He also provided the list of different raw materials.

Singh and Padhi [45] developed the equation to study the properties of the Jatropha oil for Biodiesel preparation point of view. They have compared the experimental evaluation values with the theoretically obtained values. In this paper they have presented the comparison between the various edible and non edible oils by referring certain properties where they claimed that the Jatropha is the proper feedstock to prepare Biodiesel. The basic properties of several palm oil Biodiesel–diesel fuel blends were measured in [46]. The basic properties, that is, density; heating value; three different points of the distillation curve; cloud point; cetane index, and viscosity are predicted using the evaluation of Kay's and Arrhenius mixing rules respectively. In order to predict these properties, mixing rules are evaluated as a function of volume fraction of Biodiesel in the blend. Sarin et al. [47] examined the blends of Jatropha and Palm Biodiesel to study their physical-chemical properties and to get an optimum mix of them to achieve better low temperature properties, with improved oxidation stability. Kalbande et al. [48] developed Biodiesel processor for the production of Biodiesel from non-edible oil of Jatropha and Karanj, where, Biodiesel and its blends with diesel were tested for power generation in a diesel engine generator set. Pre-decided processing parameters were used for capacity of Biodiesel processor and processing of vegetable oil. It is claimed in [48] that the fuel properties, namely, kinematic viscosity and specific gravity, were within the limits of BIS (Bureau of Indian Standards) specifications, also Biodiesel processor worked satisfactorily without any vibrations or any leakages in the system of the processor, and finally, concluded that Biodiesel processor based on alkali-catalyzed transesterification process can be used for quality Biodiesel production from edible and non-edible vegetable oils. Ozkan et al. [49] elaborated the performance analysis of Biodiesel, traditional Diesel and Biodiesel with glycerin. They have evaluated the performance with direct injection compression ignition engine. It is claimed in [49] that all the fuels yielded approximately similar results, also it is suggested that fuel systems should be optimized for Biodiesel fuels, because of the high density and gumming properties. Table 3 represents the summary of chemical process related work; Table 4 represents the summary of reactor designing related work. Plantation, blending and application related work is summarized in Table 5.

Tab. 3. Summary of Chemical Process Related Work

Chemical Process Related Work		
Authors	**Publication Type**	**Issues Handled**
U. Schuchardt et al.[24]	Review Paper	The transesterification of vegetable oils with methanol, uses of the fatty acid methyl esters, applicability of different types of catalysts, applications of fatty acid esters
B. O. D. Costa et al.[25]	Research Paper	Alternative raw materials with high acidity and low cost, process with sulfuric acid
E. Akbar et al.[26]	Research Paper	Analysis of chemical and physical properties of the lipid fraction of Jatropha oil seed
K. Bunyakiat et al.[27]	Research Paper	Transesterification reaction of coconut oil and palm kernel oil in supercritical methanol without using any catalyst
A. Z. Abdullah et al.[28]	Research Paper	Critical technical areas of Biodiesel as a fuel and scope of improvement
T. A. Foglia et al. [29]	Research Paper	Liquid chromatographic method for quantifying blends of Biodiesel in petrodiesel
A. Kumari et al.[30]	Research Paper	Lipase catalysis in presence of t-butanol as solvent, study on the reaction parameters influencing the enzymatic synthesis of Biodiesel.
A. Singh et al.[31]	Research Paper	Alkaline catalyst effects on Biodiesel yield and soap formation in transesterifying methanol and canola oil
M. B. Boucher et al.[32]	Research Paper	Quantitative performance data for a laminar flow Biodiesel reactor
A. S. Ibrehem and H. S. Al-Salim [33]	Research Paper	Mathematical model to capture the batch reactor characteristics of reacting compounds
B. Viswanathan and A. V. Ramaswamy [34]	Research Paper	Various types of heterogeneous solid acids and bases as promising catalysts

Tab. 4. Summary of Reactor Designing Related Work

Reactor Designing Related Work		
Authors	**Publication Type**	**Issues Handled**
J. F. Reyes et al. [35]	Research Paper	Rate of Biodiesel formation in a transesterification reactor stirred with a dual jet flow close loop
T. Leevijit et al. [36]	Research Paper	Simulation to optimize a mixing performance of a continuous reactor
L. F. Sotoft et al. [37]	Research Paper	Process synthesis of Biodiesel production
A. T. I. M. Ghazi et al. [38]	Research Paper	Continuous process in producing Biodiesel from Jatropha oil by using an oscillatory flow reactor
W. Sani and K. Hasnan [39]	Research Paper	Two different mechanically agitated reactor vessels in mini scale size to produce Biodiesel
H-C Chen et al. [40]	Chemical Process	Applicability of using immobilized lipase and packed-bed reactor for continuous Biodiesel synthesis
A. A. Kiss [41]	Research Paper	Energy-efficient integrated production of Biodiesel from hydrous bioethanol
A. P. Singh et al. [42]	Research Paper	Reactor system using reactive distillation technique for Biodiesel from yellow mustard seed oil

Tab. 5. Summary of Plantations, Blending and Applications Related Work

Plantations, Blending and Applications Related Work		
Authors	**Publication Type**	**Issues Handled**
P. Ariza-Montobbio and S. Lele [43]	Study Paper	Study of agronomic and economic viability and livelihood impacts of Jatropha curcas plantations
J. Bachmann [44]	Study Paper	Processes involved in small-scale oilseed processing, different methods and equipments used for oil extraction, different raw materials.
Singh and Padhi [45]	Comparative Analysis	Properties of the Jatropha oil for Biodiesel preparation point of view, comparison between the various edible and non edible oils
P. Benjumea et al.[46]	Research Paper	The basic properties of several palm oil Biodiesel–diesel fuel blends, mixing rules are evaluated as a function of the volume fraction of Biodiesel in the blend
R. Sarin et al. [47]	Research Paper	Physical-chemical properties of blends of Jatropha and Palm Biodiesel
S. R. Kalbande et al. [48]	Research Paper	Biodiesel processor for the production of Biodiesel from non-edible oil of jatropha and karanj
M. Ozkan et al. [49]	Research Paper	Performance analysis of Biodiesel, traditional Diesel and Biodiesel with glycerin

4. Process Model Related Work

This section presents the analysis of the literature related to the process model.

Gerpen [4] developed processes to produce Biodiesel from recycled restaurant grease, animal fats, and soapstock.

He reviewed that the reaction parameters are most important for fuel quality and process complexity arise due to quality of the feedstock. Haas et al. [6] have developed a spreadsheet computer model to estimate the capital and operating costs of a Biodiesel production facility. They found that largest contributors to the equipment cost were storage tanks which contain feedstock and product. They inferred that the process or physical plant can be modified to estimate the effects of changes in capital and production costs.

Ramesh et al. [9] fabricated Biodiesel pilot plant of capacity 250 litres/day. They found that the Jatropha Biodiesel blend is better solution for high diesel demand and oil imports. They concluded that wasteland in India can be used effectively for cultivation of jatropha plants in view of agricultural enterprises and rural employment.

Anderson et al. [10] presents erudite information during the construction of the large capacity Biodiesel plant in US. Authors concern revolve around the key issues such as feedstock specifications, product specifications, lab analysis, storage and transportation, safety, construction and cost of the capital investment for successful operation of a large -scale Biodiesel plant.

Skarlis et al. [13] in his work evaluated design and feasibility analysis of a new Biodiesel plant in Greece with respect to the unit production cost and various other technical and economical parameters. Authors carried out design analysis on the basis of production process, Capacity of the plant, Production cost, Equipment cost and land requirement.

They found that it is difficult to standardize the total investment and production cost as they are subject to market price fluctuations. They concluded that the feasibility and the financial efficiency of the plant depend on raw materials cost and Biodiesel selling price.

Abbasi and Diwekar [14] evaluated the impact of uncertainties like feedstock compositions, operating parameters and mechanical equipment design on the production of Biodiesel.

They quantified uncertainties in the form of probability distribution function and stochastic modeling was implemented in the ASPEN (Advanced Simulator for Process Engineering) software to evaluate output.

They summarized that impacts of uncertainties on Biodiesel production and plant efficiency are significant.

Tapasvi et al. [50] developed Biodiesel process model to evaluate and compare different available feedstocks, and process parameters for Biodiesel production. They identified and estimated various process input and output parameters using mass and energy balance equations.

This model can be used for economic feasibility studies of Biodiesel production and design of various equipments which can be specified, based on the various stream flow rates and the desired process conditions.

Campus and Mcgill [51] designed and developed a pilot-plant to analyze the performance of Biodiesel production by changing from a batch production to a continuous production. They evaluated the feasibility of continuous flow production in order to assess its potential for future commercial utilization. Van Kasteren and Nisworo [52] developed Biodiesel production process model for three different capacities from waste cooking oil.

They found that the raw material price, plant capacity, glycerol price and capital cost are key factors for economic feasibility of plant. They conclude that the supercritical process for the conversion of waste cooking oil to Biodiesel is a better alternative and also economically viable.

Zhang et al. [53] have done the process design and technological assessment of Biodiesel production from virgin vegetable oil and waste cooking oil using HYSYS (Process Simulation Software developed by Hyprotech Ltd.) for four different processes. They found that all the processes are feasible for producing a high quality Biodiesel and a glycerine by-product. They conclude that the process using virgin vegetable oil as the raw material required low cost process equipment units and a high raw material cost. The use of waste cooking oil to produce Biodiesel reduced the raw material cost.

Diwekar and Rufin [54] have done stochastic modeling of chemical process in the ASPEN process simulator. They summarized that stochastic modeling capability is useful for performance analysis, economic analysis, comparisons of different technologies, determination of over design factors, error and sensitivity analysis, risk analysis, feasibility studies, identification of process, R&D (Research and Development) priorities and research management and planning.

Berrios et al. [55] applied the factorial design of experiments to Biodiesel production from lard via an alkali catalyst.

In order to optimize some reaction conditions, a factorial design of experiments is applied to study the effect of the variables on the process and the interaction among those variables [55]. Table 6 represents the summary of the process model related literature. Table 6 presents the results and the briefing of the issues handled in the articles which are discussed in this section.

Tab. 6. Summary of Process Modeling Related Work

Process Modeling Related Work		
Authors	**Publication Type**	**Issues Handled**
J. V. Gerpen [4]	Research Paper	Processes for recycled restaurant grease, animal fats, and soapstock
M. J. Haas et al. [6]	Research Paper	Model to estimate the capital and operating costs of a Biodiesel production facility
D. Ramesh et al. [9]	Research Paper	Biodiesel pilot plant of capacity 250 litres/day
D. Anderson et al. [10]	Study Paper	Information during the construction of the large capacity Biodiesel plant in US
S. Skarlis et al. [13]	Study Paper	Design and feasibility analysis of a new Biodiesel plant in Greece
S. Abbasi and U. Diwekar [14]	Research Paper	Impact of feedstock compositions, operating parameters and mechanical equipment design on the production of Biodiesel
D. Tapasvi et al. [50]	Research Paper	Process model for different available feedstocks, and process parameters
M. Campus and J. Mcgill [51]	Research Paper	Pilot-plant to analyze the performance of Biodiesel production by changing from a batch production to a continuous production
J.M.N. van Kasteren and A.P. Nisworo [52]	Research Paper	Biodiesel production process model for three different capacities from waste cooking oil
Y. Zhang et al. [53]	Research Paper	Process design and technological assessment of Biodiesel production using process simulation software, HYSYS for four different processes
U. M. Diwekar and E. S. Rufin [54]	Research Paper	Stochastic modeling of chemical process in the ASPEN process simulator
M. Berrios and et al. [55]	Research Paper	Factorial design of experiments to Biodiesel production from lard via an alkali catalyst

5. Design and Production Related Work

This section discusses the existing contributions related to the design and production of Biodiesel plant.

Al-Zuhair et al. [56] proposed pilot plant which has been designed to produce 1 ton per hour Biodiesel from waste/used-vegetable-oil using enzymatic approach. The main goal of the study in [57] is to analyze the existing and recently published data related to design of large scale plant for Biodiesel synthesis at supercritical conditions. A continuous process flow sheet for Biodiesel production from triglycerides under supercritical conditions of alcohol was analyzed and influence of triglycerides degree of conversion on overall energy consumption in supercritical conditions of alcohol was examined. A comparison between the homogenous alkali-catalyzed alcoholysis and the supercritical methanolysis of triglyceride was made in order to point out the advantages and disadvantages of each of analyzed process. Cruz et al. [58] presents a discrete-time input-output model for the analysis of the dynamics of bioenergy supply chains. The main feature of the dynamic model is that each sector in the system adjusts its output level based on the weighted influences of the surplus or deficit of the flows of products, intermediate goods, emissions or natural resources throughout the system in the previous time period. A simple two-sector example is used to illustrate the features of the model, and the implications of the dynamics for policy on biofuels are discussed.

Basha et al. [59] presented a review on Biodiesel production, combustion, emissions and performance where they analyzed the reports of about 130 scientists who published their results between 1980 and 2008. Ballat [60] presented a review on the use of edible oils for Biodiesel production where he addressed various characteristics and throughput for the different edible oils; also, he debated on the issue of edible oils as food and fuel.

Karmarkar et al. [61] reviewed the physical-chemical properties of the plant and animal resources that are being used as feedstocks for Biodiesel production; also, the potential resources that can be transformed into Biodiesel successfully for meeting the ever increasing demand of Biodiesel production.

Shuit et al. [62] investigated the feasibility of in situ extraction, esterification and transesterification of Jatropha seeds to Biodiesel.

Predojevic [63] critically analyzed the three methods of purification and concluded that in order to obtain high yields of Biodiesel from waste frying oils with elevated acid values, two-step alkali transesterification with the silica gel or phosphoric acid purification treatment could be better.

Kyyt and Olt [64] investigated, analyzed and explained about the issues concerning the selection of production appliances that are best for local oil manufacturing in order to ensure the production of high-quality plant-oil and press-cake. Summary of the design and production related work is presented in Table 7, it summarizes the outcomes and the briefs on the issues handled in the articles which are discussed in this section.

6. Cost, Optimization and Feasibility Related Work

Cost estimation, optimization of the chemical processes and the resources, and feasibility study of Biodiesel plant is analyzed in this section.

Amigun et al. [12] carried out the cost review studies of Biodiesel production for Germany which enable them to develop a framework for determining Biodiesel feasibility in Africa. Radich [65] presents a brief history of diesel engine technology and an overview of Biodiesel, including performance characteristics, economics, and potential demand, where the performance and economics of Biodiesel are compared with those of petroleum diesel. Randelli [66] has done the economic assessment of biofuels on the basis of total production cost. Author also evaluated impact on agriculture and energy balance of first generation alternative fuels. He concluded that the second generation biofuels could be a better solution because first generation biofuels has high production cost, limited land availability and low net energy balance.

Haase et al. [67] analyze the economic viability of small-scale Biodiesel production system. Factors considered for study are labour hours, energy consumed and total cost of construction. They opined that key economic viability Biodiesel production depends on petroleum based diesel fuel prices and the cost of labour for production. Kapilakarn and Peugtong [68] designed and simulated Biodiesel production process to minimize the operating cost and to identify the parameters affecting the purity of Biodiesel using HYSYS simulation software. They found that the cost of Biodiesel is higher than petroleum diesel. They stated that waste oil is an alternative for reducing the cost of Biodiesel.

Eidman [69] studied the impact of price of petroleum, price of the feedstock and policy on the profitability of ethanol and Biodiesel production. He summarized that the feedstock is a major factor limiting the growth of Biodiesel industry. Hill et al. [70] evaluated and compared Biodiesel from soybean and ethanol bio-fuel on the basis of net energy gain, environmental benefits, and economy. They found that Biodiesel releases less air pollutants per net energy gain than ethanol and requires low agricultural inputs and does more efficient conversion of feedstock to fuel. Finally they concluded that the soybean Biodiesel has major advantages over corn grain ethanol.

Marchetti and Errazu [71] have developed a Biodiesel production plant using supercritical methanol and acid oils as raw materials. This technology is compared not only on the technical aspects but also on the economic results.

A process simulator is also employed to produce the conceptual design and simulate each technology. Pohit et al. [72] highlights the importance of sound pricing policy focusing on the entire value chain of Biodiesel production. This analysis is based on field level data from Chhattisgarh, the leading state in the production of Jatropha. They have carried out the simulation exercises both at the plantation stage as well as in the production processes for pricing model.

Tab. 7. Summary of Design and Production Related Work

Design and Production Related Work		
Authors	**Publication Type**	**Issues Handled**
S. Al-Zuhair et al. [56]	Research Paper	Pilot plant design to produce 1 ton per hour Biodiesel from waste/ used vegetable oil using enzymatic approach
S. Glisic and D. Skalaa [57]	Study Paper	Analysis of the existing and recently published data related to design of larger scale plant for Biodiesel synthesis at supercritical conditions
J. B. Cruz et al. [58]	Research Paper	Discrete-time input-output model for the analysis of the dynamics of bioenergy supply chains
S. A. Basha et al. [59]	Review Paper	Biodiesel production, combustion, emissions and performance
M. Ballat [60]	Review Paper	Use of edible oils for Biodiesel production; characteristics and throughput for the different edible oils
A. Karmarkar et al. [61]	Review Paper	Physical-chemical properties of the plant and animal resources; the potential resources
S. H. Shuit et al. [62]	Research Paper	Feasibility of in situ extraction, esterification and transesterification of Jatropha seeds to Biodiesel
Z. J. Predojevic [63]	Research Paper	Investigation of the three methods of purification
A. Kyyt and J. Olt [64]	Research Paper	Selection of productions appliances that are the best for local oil manufacturing

Apostolakou et al. [73] studied the economics of Biodiesel production plants that use classical alkali-catalyzed transesterification as a function of plant installed capacity. Schade and Wiesenthal [74] carried out a systematic risk assessment for the bio-fuel simulation model, where two illustrative policy options have been assessed. Schade and Wiesenthal [74] shows that risk assessment of distinct policy options is possible even under conditions of high uncertainty parameter of economic model.

Zhang et al. [75] have carried out the economic assessment and sensitivity analysis for four continuous alkali- and acid-catalyzed processes using virgin oil or waste cooking oil as the raw material in Biodiesel production. Pokoo-Aikins et al. [76] have made a detailed economic analysis and a safety evaluation on the process involving extraction of triglycerides and fatty acids, pre-treatment of fatty acids, and transesterification of triglycerides to Biodiesel. A safety metric is introduced to enable comparison of the various solvent extraction processes, also, the usefulness and insights of this approach is demonstrated by the case study.

Skarlis et al. [13] have done the analysis of a Biodiesel production plant design and the feasibility of a plant is evaluated. Myint and El-Halwagi [77] designed and optimized a Biodiesel production process from soybean oil. They also estimated the operating cost of the process and profitability analysis carried out by return on investment and the payback period. They found that the single most important contributor to production cost is the price of soybean oil.

Mayer et al. [78] present a method to determine globally optimal schedules for cyclically operated plants where activities are scheduled on limited resources. Alamu et al. [79] tested PKO (Palm Kernel

Oil) as an alternative source of diesel fuel amongst other alternatives for renewable energy and the effect of varying mixing time on PKO Biodiesel yield. Mc Leod and Rivera [80] discuss a model to optimize the risk in bio-fuel plants with respect to human error for new installation. Sayyar et al. [81] optimized extraction of Jatropha oil from seeds using organic solvent for achieving maximum oil yield for various operating parameters. The kinetics of extraction was also investigated and its parameters were determined based on a second order model. Elms and El-Halwagi [82] developed an optimization formulation to determine scheduling and operation of flexible Biodiesel plants for a variety of feedstock to produce Biodiesel. West et al. [83] carried out simulation of a process for the economic assessment of Biodiesel production and the process is optimized by maximizing the after tax rate-of- return.

Refaat et al. [84] optimized the production procedures to study the feasibility of the production of Biodiesel from waste/recycled oils, to reduce the cost of Biodiesel and reduce waste and pollution coming from waste oils. Sahoo and Das [85] discussed the various methods of preparation of Biodiesel from non-edible oils and used various technical tools and processes for monitoring the transesterification reactions. Patil and Deng [86] compared fuel properties of Biodiesel produced from different edible and non-edible vegetable oils in order to optimize Biodiesel production process. Bautista et al. [87] developed and optimized the catalyzed synthesis of fatty acid methyl esters (FAME) production from waste cooking oil using a factorial design of experiments and a central composite design. Rahayu and Mindaryani [88] performed various experiments to determine the optimum conditions of the washing and to find a correlation of the extracted variables.

Fortenbery [3] has presented a Biodiesel feasibility study where he discussed the basic advantages and disadvantages of Biodiesel; he also evaluated the physical plant characteristics, operating cost and cost competitiveness of Biodiesel. Mendez [5] has presented a study about feasibility of the installation of a Biodiesel plant from oil seeds where he compared Biodiesel with other transport fuels; also, he evaluated the types of Biodiesel, technology, supply chain, execution alternatives, operating plant issues and plant cost. The discussion is extended with the presentation of plant case study. Feasibility report for small scale Biodiesel production is presented in [89], where, various issues related to Biodiesel are discussed. Summary of the cost, optimization and feasibility related work is presented in Table 8 (a) and Table 8 (b). Outcomes and briefing of issues handled in the articles, which are discussed in this section, are summarized in these tables.

Tab. 8 (a). Summary of Cost, optimization and feasibility Related Work

Cost, optimization and feasibility Related Work		
Authors	**Publication Type**	**Issues Handled**
T. R. Fortenbery [3]	Study Paper	Biodiesel feasibility study, advantages and disadvantages of Biodiesel, physical plant characteristics, operating cost and cost competitiveness of Biodiesel
M. C. Mendez [5]	Study Paper	Feasibility of the installation of a Biodiesel plant from oil seeds, types of Biodiesel, technology, supply chain, execution alternatives, operating plant issues and plant cost
B. Amigun et al. [12]	Review Paper	Cost review studies of Biodiesel production for Germany
S. Skarlis et al. [13]	Study Paper	Design and feasibility analysis of a new Biodiesel plant in Greece
A. Radich [65]	Study Paper	History of diesel engine technology and an overview of Biodiesel, including performance characteristics, economics, and potential demand
F. Randelli [66]	Study Paper	Economic assessment of biofuels on the basis of total production costs
S. Haase et al. [67]	Study Paper	Economic viability of small-scale Biodiesel production system
K. Kapilakarn and A. Peugtong [68]	Research Paper	Design and simulation of Biodiesel production process to minimize the operating cost and to identify the parameters affecting the purity of Biodiesel using HYSYS simulation software
V. R. Eidman [69]	Study Paper	Impact of price of petroleum, price of the feedstock and policy on the profitability of ethanol and Biodiesel production
J. Hill et al. [70]	Comparative Analysis	Comparison of Biodiesel from soybean and ethanol biofuel on the basis of net energy gain, environmental benefits, economy
J.M.Marchetti and A.F. Errazu [71]	Research Paper	Biodiesel production plant using supercritical methanol and acid oils as raw materials
S. Pohit et al. [72]	Research Paper	Importance of a sound pricing policy focusing on the entire value chain of Biodiesel production
A. A. Apostolakou et al. [73]	Study Paper	Economics of Biodiesel production plants that use classical alkali-catalyzed transesterification as a function of plant installed capacity
B. Schade and T. Wiesenthal [74]	Research Paper	Risk assessment for the biofuel simulation model
Y. Zhang et al. [75]	Research Paper	Economic assessment and sensitivity analysis for four continuous alkali- and acid-catalyzed processes using virgin oil or waste cooking oil as the raw material
G. Pokoo-Aikins et al. [76]	Research Paper	Economic analysis and a safety evaluation on a process involving extraction of triglycerides and fatty acids, pre-treatment of fatty acids, and transesterification of triglycerides to Biodiesel
L. L. Myint and M. M. El-Halwagi [77]	Research Paper	Design and optimization of a Biodiesel production process from soybean oil

Tab. 8 (b). Summary of Cost, optimization and feasibility Related Work

Cost, optimization and feasibility Related Work		
Authors	**Publication Type**	**Issues Handled**
E. Mayer et al. [78]	Research Paper	Method to determine globally optimal schedules for cyclically operated plants
O. J. Alamu et al. [79]	Comparative Analysis	PKO as an alternative source of diesel fuel amongst others for renewable energy
J. E. N. Mc Leod and S. S. Rivera [80]	Research Paper	Model to optimize the risk in biofuel plants with respect to human error
S. Sayyar et al. [81]	Research Paper	Optimized extraction of Jatropha oil from seeds using organic solvent based for achieving maximum oil yield for various operating parameters
R. D. Elms and M. M. El-Halwagi [82]	Research Paper	Optimization formulation for scheduling and operation of flexible Biodiesel plants accommodating a variety of feedstock to produce Biodiesel
A. H. West et al. [83]	Research Paper	Simulation of a process for the economic assessment of Biodiesel production
A. A. Refaat et al. [84]	Research Paper	Optimization of production procedure
P. K. Sahoo and L. M. Das [85]	Research Paper	Methods of preparation of Biodiesel from non-edible oils
P. D. Patil and S. Deng [86]	Comparative Analysis	Comparison of fuel properties of Biodiesel produced from different edible and non-edible vegetable oils
L. F. Bautista et al. [87]	Research Paper	Fatty acid methyl esters production from waste cooking oil using a factorial design of experiments and a central composite design
S. Sri Rahayu and A. Mindaryani [88]	Research Paper	Optimum conditions of the washing and to find a correlation of the extraction variables
Feasibility Report [89]	Study Paper	Feasibility analysis

7. Safety, Effects, Challenges and Future Related Work

Though Biodiesel is a source for the renewable energy but risks are associated with its production. From this point of view, safety issues are important and one should discuss it. Also chemical process involved in Biodiesel production does have some chemical effects, this should also be addressed. The literature related to safety issues and effects are discussed in this section. In India, presently, few Biodiesel production plants are installed and constrained by the typical feedstocks, as the feedstocks vary according to the geographical locations. It becomes necessary to launch new plantation from feedstocks availability point of view. Perspective analysis of bio-fuel is also important in Biodiesel study.

The literature related to the opportunities, challenges and future of Biodiesel is also discussed in this section. Salzano et al. [90] put forth the insights of risks within Biodiesel production plant. Yang et al. [91] discussed the water and land requirements for bio-fuel production, based on aggregated values of water and land footprints, in China. This study provided some insights into the possible consequences of bio-fuel development under various alternatives regarding types of feedstocks, land and water use, and spatial distribution. Canakci and Sanli [92] reviewed that the waste cooking oils, restaurant greases, soapstocks and animal fats are potential feedstocks for Biodiesel production to lower the cost of Biodiesel. This review paper presents both Biodiesel productions from various feedstocks and their effects on the fuel properties. Moser [93] reviewed different processes involved in Biodiesel production, where he discussed about use of different types of catalysts, influence of free fatty acids, use of different monohydric alcohols, influence of Biodiesel composition on fuel properties, influence of blending Biodiesel with other fuels on fuel properties, alternative uses for Biodiesel, and value-added uses of glycerol, a by-product of Biodiesel production. It particularly focuses on alternative feedstocks for Biodiesel production. Karavalakis et al. [94] investigated the impact of various synthetic phenolic antioxidants on the oxidation stability of Biodiesel blends.

In this study, a commercially available Biodiesel was treated with different phenolic antioxidants and blended with a typical automotive diesel fuel. Regarding Biodiesel blends it was found that with increasing Biodiesel content, the stability of finished blend decreases. In this paper, it is found that oxidation stability can be adversely affected by storage conditions and time, leading to induction times below the minimum specification limit as mentioned in the paper, also, for all Biodiesel blends, the acid value and to a lesser extent kinematic viscosity, tended to increase over storage time. Gopinathan and Sudhakaran [8] reviewed the status of Biodiesel production in India.

They studied the various opportunities and challenges in India with respect to the production of Biodiesel. From this point of view, they analyzed the land requirements, global policies, commercial market, constraints, etc. in India. Bothast [95], in his paper, validates new technologies for producing ethanol more cost effectively from corn. Wang et al. [96] presented a review where they intended to provide an introduction to the distribution and development of bio-fuel crops and bio-fuel industries in China.

Songstad et al. [97] presented an overview of bio-fuel which consists of historical and perspective analysis of bio-fuel. Scott et al. [98] reviewed the properties and suitability of Pierre for large- scale vegetable oil production required by a sustainable Biodiesel industry. This review assesses and integrates the biological, chemical and genetic attributes of the Pierre plant. Safety, effects, challenges and future related work is presented in Table 9 and it summarizes outcomes and briefing of issues handled in the articles, which are discussed in this section.

Tab. 9. Summary of Safety, Effects, Challenges and Future Related Work

Safety, Effects, Challenges and Future Related Work

Authors	Publication Type	Issues Handled
M. C. Gopinathan and R. Sudhakaran [8]	Review Paper	Status of Biodiesel production; opportunities and challenges; land requirements, global policies, commercial market, constraints, etc. in India.
E. Salzano et al. [90]	Research Paper	Risks within Biodiesel production plant
H. Yang et al. [91]	Study Paper	Water and land requirements for biofuel production in China
M. Canakci and H. Sanli [92]	Review Paper	Potential feedstocks for Biodiesel production; effects on the fuel properties.
B. R. Moser [93]	Review Paper	Processes; types of catalysts; influence of free fatty acids on Biodiesel production, effects on fuel properties; alternative feedstocks
G. Karavalakis et al. [94]	Research Paper	Impact of various synthetic phenolic antioxidants on the oxidation stability of Biodiesel blends
R. J. Bothast [95]	Research Paper	New technologies for producing ethanol more cost effectively from corn
F. Wang et al. [96]	Review Paper	Distribution and development of biofuel crops and biofuel industry in China.
D. D. Songstad et al. [97]	Review Paper	Historical and perspective analysis of biofuel.
P. T. Scott et al. [98]	Review Paper	Properties and suitability of Pierre for large- scale vegetable oil production

8. Open Issues in Biodiesel Production

This section focuses on the open issues in Biodiesel production. Performance optimization and plant design are the main open issues in Biodiesel production. In previous sections, various contributions are analyzed and it is found that Biodiesel production plant is still constrained with so many parameters. For example, the feedstock availability, chemical processes used, capital investment cost, production cost, net profit, etc. are the parameters which play very important role in installation of the plant. Following subsection elaborates the discussion on open issues.

8-1. Performance Optimization

Performance of any Biodiesel plant can be optimized by referring the basic key parameters. These parameters may be- Feedstocks availability, plantation for the feedstocks (if it is vegetable oil), chemical processes involved in production of Biodiesel, use of different catalysts in chemical process, use of Methanol in chemical process, specification of reactor design to carry out the heating process, usability of Biodiesel with blends, production capacity of the plant, storage tank size for Biodiesel and for other purpose, selling price of Biodiesel and the by-product, limitation of the capital cost, production or operating cost estimation, and profit analysis.

It is found that various process models, cost models, simulation models are reported in literature. Though, the research contribution related to above mentioned parameters exist, still, these parameters can be used as the base for designing of Biodiesel plant and one can develop the approach or the methodology for launching of the new Biodiesel plant.

An opportunity exists for use of new advanced optimization techniques. For instance, one can go for neural network based approach to estimate the cost related parameters or the production capacity related parameters. Other possible approaches may include use of the genetic algorithm by which the mathematical model of chemical process or production process can be optimized.

Various approaches can be possible using classical optimization techniques and non classical optimization techniques for optimization of design model, production process, chemical process, cost model, simulation model (chemical process, production process, cost estimation) etc. Plant design is one area where optimization is possible and is discussed in the next subsection.

8-2. Plant Design

Basic key and important issues in Biodiesel production are already discussed through the analysis of the available literature in section 3 to section 6. Prominent work related to plant design is reported in [3, 6, 9, 13-14, 50, 52, 56, 68, 71, 73, 75, 77], where most of the parameters, already discussed in previous sections, are used in formulation of the problem. Summarized analysis of these existing works is presented in Table 10 (a) and Table 10 (b).

Though, the contributions related to Biodiesel plant design exist in literature, still there is a scope to contribute in this area and it can be learnt from the Table 10 that capacity of plant, capital cost, operating cost, profit analysis and storage tank material are the important parameters which may be the base parameters in formulation of the problem. One can use different techniques or methodologies for formulation of the problem with use of some other parameters with these base parameters.

Tab. 10 (a). Parametric Analysis of Design Related Work

Feedstocks to Biodiesel	Capacity of Plant	Capital Cost	Operating Cost	Profit Analysis	Storage Tank Material
T. R. Fortenbery [3] **Approach:** Case study-Design analysis for market size of about 16 million gallons a year					
100 lbs. of feedstock + 10 lbs. of methanol → 100 lbs. of Biodiesel + 10 lbs. of glycerol	4, 10 million gallon per year	Equipment, Land, Storage Tanks, Civil and site work Building, Permits/misc, Working Capital	Raw Material, Utilities, Depreciation, Miscellaneous, Sale of Byproduct	Cost Competitiveness of Biodiesel (on the basis of the costs of production, and historical diesel prices and feedstock costs)	Not specified
M. J. Haas et al. [6] **Approach:** Simulation-Computer model to estimate the capital and operating costs based on changes in feedstock costs					
Not Specified	37,854,118 litre	Equipment cost	Soy oil, Methanol, HCL (Hydrochloric), NaOH (Sodium Hydroxide), Electricity, Natural gas, Water, labor, others	Not estimated	Carbon steel
D. Ramesh et al. [9] **Approach:** Pilot plant-Estimated Biodiesel requirement of India					
Not specified	250 litres / day	Cost is Rupees 2.5 lacs	Rupees 2.5 lacs (raw oil, production, Biodiesel processing, etc.)	Rupees 3/- per litre	Not specified
S. Skarlis et al. [13] **Approach:** Feasibility analysis-Biodiesel plant in Greece					
1000 Kg of oil + 110 Kg of methanol → 1000 Kg of Biodiesel + 110 Kg of glycerol	4000 tons per year	Vegetable Oils, Methanol, Catalyst, Water, Electricity, Natural Gas, Equipment cost	Chemical process cost, Operating cost	Depend on the raw material cost and Biodiesel cost	Not specified
S. Abbasi and U. Diwekar [14] **Approach:** Stochastic modeling-Biodiesel production plant efficiency					
10000 lb/hr of oil	Not specified	Not specified	Not specified	Not carried out	Not specified
D. Tapasvi et al. [50] **Approach:** Process model-Based on mass balance and energy balance using process-engineering principles					
100 kg/h crude oil entering the production plant	Can be assumed	Mass flow rates can be linked to cost data to calculate the feedstock cost	Cost can be calculated based on mass flow rates	Not carried out, Design of various equipments can be designed based on the mass flow rate	Not specified
J.M.N. van Kasteren and A.P. Nisworo [52] **Approach:** Process model-Conceptual design to estimate the cost of Biodiesel production					
Constant input of waste oil for whole production year	125,000; 80,000 and 8000 tones Biodiesel/year	Fixed (plant location, prod. capacity, present status of Biodiesel)	Fixed (plant location, prod. capacity, present status of Biodiesel)	Not carried out (factors are capital cost, capacity, raw material and glycerol price	Not specified
S. Al-Zuhair et al. [56] **Approach:** Pilot plant-Biodiesel from waste/used vegetable oil using enzymatic approach					
1138 kg per hour	1 ton per hour	Total capital investment of 620000 US$ (Dollar)	Total capital investment of 620000 US$	Total capital investment will be paid back within four years	Not specified

Tab. 10 (b). Parametric Analysis of Design Related Work

Feedstocks to Biodiesel	Capacity of Plant	Capital Cost	Operating Cost	Profit Analysis	Storage Tank Material
K. Kapilakarn and A. Peugtong [68] **Approach:** Simulation for Optimality-Optimal operating condition for Biodiesel production					
50 litre and 100 litre	Not specified	Total cost is evaluated for three processes	reaction time, temperatures and molars ratios of alcohol to oil affects the operating cost	Not carried out, Quality of Biodiesel for three processes is evaluated	Not specified
J.M.Marchetti et al. [71] **Approach:** Simulation-to produce the conceptual design and simulate each technology					
4550 kg per hour	36036 ton per year	Evaluation is carried out	Evaluation is carried out	Evaluation is carried out	Not specified
A. A. Apostolakou et al. [73] **Approach:** Economic analysis-Biodiesel production from vegetable oils					
Triolein + 3Methanol →3 Biodiesel + Glycerol	50 kton per year	Evaluation is carried out (equipment cost, etc.)	Evaluation is carried out (raw material cost, labor cost, etc.)	Evaluation is carried out	Stainless steel
Y. Zhang et al. [75] **Approach:** Economic analysis-Biodiesel production from waste cooking oil					
Waste cooking oil is used	8000 ton per year	Fixed	Evaluation is carried out	Evaluation is carried out	Not specified
L. L. Myint and M. M. El-Halwagi [77] **Approach:** Optimization-Biodiesel production from Soybean oil					
Soybean oil is used	40 million gallons per year	Capital cost estimation was carried out using the IPE (Icarus Process Evaluator) computer-aided tool linked to the results of the ASPEN Plus simulation.	The operating cost of the process was estimated based on process operation such as raw materials, utilities, and labor.	A profitability analysis was carried out by examining the return on investment and the payback period.	Not specified

9. Suggested Approach

This section discusses the suggested approach for design of Biodiesel manufacturing plant with cost and capacity perspective, and also the motivation behind it.

9-1. Motivation

After analyzing the available literature [1-98], it is found that the plant design is an open issue where the research scope exists. The gaps and observations identified in literature are summarized as follows.

(a) No concrete results are reported in literature regarding the launching/installation of new Biodiesel plant with variety of objectives.

(b) Existing approaches which are suggested in the literature for the plant design move around the cost parameters and the chemical processes with the fixed plant capacity.

(c) No approach exists as per our knowledge which can address the problem of design of Biodiesel plant with variety of capacities.

(d) No approach exists as per our knowledge which can address the problem of design of Biodiesel plant with cost and capacity perspective.

(e) No mathematical model based approach exists for designing of Biodiesel plant.

(f) The capacity of plant, capital cost, operating cost, profit analysis and storage tank material are the important basic issues to be considered in designing of any Biodiesel plant.

(g) Any plant design move around the parameters related to these basic issues.

Above mentioned gaps and observations are the key motivations for development of the mathematical model based approach for Biodiesel manufacturing plant design.

9-2. Approach

This paper aims to suggest an approach to formulate the approximate generalized model based on design data for the plant manufacturing Biodiesel. The suggested approach consists of the following two main steps.

Step-1: Generate the design data for various capacities.

Step-2: Formulate the model through dimensional analysis and multiple regression analysis.

Generation of the design data for various capacities:

Design data can be generated in consideration of certain assumptions and with reference to the basic issues mentioned in section 9.1 (*f*). Possible assumptions may be related to the following:

- Method of Biodiesel production (e.g. alkali catalytic methanol transesterification)
- Quality of raw material (e.g. as per standard required to produce Biodiesel)
- Plant operation (e.g. one batch per day)
- Integrated crushing (seeds) plant (e.g. without purchasing the direct oil, it will be produced in the plant itself)
- Construction and site preparation cost (e.g. can be or cannot be considered)
- Specifications of process equipments (e.g. equipment specification should accommodate all types of oils)
- Quality of Biodiesel (e.g. as per standard EN 14214- American standard / IS 15607- Indian standard)
- Plant layout design (e.g. can be developed in the Autocad as per the specification of equipments and required equipments as per process flow)

With reference to the basic issues discussed in section 9.1 (*f*), Biodiesel plant design related input and output parameters can be identified as given in Table 11.

Tab. 11. Inputs, Outputs and Estimation

Specification	Unit	Parameter	Estimation can be based on
Equipment Cost in Lacs	Rupees	Input	Design and supplier Quotations
Power	HP (Horsepower)	Input	Power rating of equipments
Water	Litre	Input	Estimated as per process requirement
Total Factory Area	Square meter	Input	Layout of plant plotted in AutoCAD
Oil Seeds	Kilogram	Input	Capacity of Biodiesel plant
Methanol	Litre	Input	Capacity of Biodiesel plant
Catalyst KOH	Kilogram	Input	Capacity of Biodiesel plant
Man-hours	Hours	Input	Human resource required for operation of plant
Production Turnover in Lacs (Kg. converted in Rupees)	Rupees	Output	Expected output at each stage of production
Maintenance Cost in Lacs	Rupees	Output	Expected failure causes and preventive maintenance scheduled for individual equipment
Operating Profit in Lacs	Rupees	Output	Production cost and revenue generated

Formulation of the model through dimensional analysis and multiple regression analysis:

To start Biodiesel production plant, one will have to decide what should be the capacity of plant in order to get maximum production turnover, operating profit and minimum maintenance cost.

These issues can be addressed if quantitative relationship between the inputs and outputs is formulated in terms of model. Relationship amongst the inputs and outputs can be established first, by doing the dimensional analysis of independent and dependant variables and followed by formulating multiple-linear-regression model. Formulated mathematical model will be based on the designed data. Mathematical model can be formulated for three outputs; production turnover, maintenance cost and operating profit.

Formulation of dimensional equation is the first step to formulate the model of Biodiesel production plant. The functional relationship among the inputs and outputs affecting Biodiesel production plant can be formulated using dimensional analysis. Following are the two methods for dimensional analysis:

- Buckingham's π – theorem
- Rayleigh's method

Above two methods provides the same results, in most of the cases but having slightly different approach of formulation. Rayleigh's method of dimensional analysis can be used in this work for formulation of dimensional analysis. Rayleigh's method of dimensional analysis expresses a functional relationship of inputs and outputs in the form of an exponential equation.

The method involves the following steps:

- Identification of the inputs those are likely to influence the output.
- If X is a variable that depends upon input variables $X_1, X_2, X_3, ..., X_n$, then the functional equation can be written as $X = F(X_1, X_2, X_3, ..., X_n)$.
- Write the above equation in the form where C is a dimensionless constant and $a, b, c, ..., m$ are arbitrary exponents.
- Express each of the quantities in the equation in some fundamental units in which the solution is required.
- By using dimensional homogeneity, obtain a set of simultaneous equations involving the exponents $a, b, c, ..., m$.
- Solve these equations to obtain the value of exponents $a, b, c, ..., m$.
- Substitute the values of exponents in the main equation, and form the non-dimensional parameters by grouping the inputs with like exponents.

Dimensional equation so obtained can be formulated into model using multiple-linear-regression analysis. Multiple-linear-regression analysis is a statistical tool that utilizes the relation between two or more quantitative variables so that one variable can predict from another. The variable to be predicted is called the output/response or dependent variable. The variable predicting this is called the inputs or independent variable. By using this methodology the different dimensional equations and model can be formulated for the different outputs. The formulated models can be evaluated on the basis of correlation and Root Mean Square Error between the computed values by model and the estimated values.

10. Discussion and Conclusion

Though the different review papers are available related to the study on Biodiesel production, this paper is different from the existing review paper contributions in many ways. This paper presents the category-wise analysis of the existing contributions. It particularly focuses the key important issue of design of Biodiesel production plant. It also discusses the suggested approach for the evaluation of the plant design. Based on the analysis of the existing literature the gaps are identified and summarized in section 9. To fulfill these gaps, the mathematical model based approach is suggested which includes the design engineering tasks with the cost and capacity perspective for Biodiesel production plant. Based on the suggested approach one can estimate or design Biodiesel plant as per the requirement of individual. This paper is useful for the researchers who are involved in the study of sources of renewable energy and also for the mechanical, industrial and production engineers from the designing and economics point of view. This paper exploits opportunity of the study of complex phenomena; it also demonstrates use of computational intelligence through the suggested approach as it is based on the mathematical model where the key concepts of mathematics- dimensional analysis and regression analysis are used.

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