USING A GENETIC ALGORITHM FOR THE STUDY OF DIESEL AND BIODIESEL MIXTURES

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Abstract. A new methodology for optimizing the composition of a mixture of diesel and biodiesel fuel using a genetic algorithm that determines the optimal percentage ratio of components is proposed. The main components of the biofuel mixture are diesel fuel and biodiesel, made 100% from bioresources. The resulting mixture was evaluated using a fitness function that took into account the fuel density. The simulation results may be useful for further production and research of new fuel mixtures, because they demonstrate the effectiveness of using a functional approach compared to random laboratory experiments.
Keywords: Genetic algorithm; fuel mixture; biodiesel, diesel fuel.

1. Introduction

The constant increase in fuel demand and limited oil reserves have prompted scientists to search for renewable and sustainable energy sources that can replace fossil fuels. The latter has a significant negative impact on the environment, including causing global warming, climate change, excessive greenhouse gas emissions, and deforestation. Therefore, there is a need to use alternative, renewable, and biodegradable fuels, such as biodiesel.

According to [1], with the global demand for fuel increasing, biodiesel has become one of the main alternatives to traditional diesel fuel in recent decades. [2] It can be used in conventional diesel engines without the need for modifications to the fuel delivery or treatment system. Biodiesel is known as an effective substitute or additive to diesel fuel, and is produced from fats and oils of vegetable or animal origin [3, 4].

As noted in [5], with the increasing global demand for renewable energy sources, biodiesel, as an environmentally friendly fuel, is increasingly being used in various industries. It can be directly used as a substitute or a component of a blend with petroleum diesel fuel. Biodiesel is widely used in transportation, agricultural machinery, power equipment and other sectors. In recent years, many countries and regions have supported the production and use of biodiesel by implementing policy incentives and regulatory requirements, aimed at reducing dependence on fossil fuels and reducing greenhouse gas emissions [6–8].

2. Disadvantages:

After a 4.5% decline in 2020 due to COVID-19 restrictions, global energy consumption grew by 5% in 2021. The impact of societal development was estimated to be 3 points higher than the average of 2% per year for the period 2000–2019 [9]. Due to the reduction of gas supplies by the aggressor country to Europe in recent years, as well as the growth of global demand, energy prices have increased significantly. Historically, fossil fuels have been the basis of human development, but their widespread use has created a serious global problem: traditional sources of diesel fuel are limited and, critically, extremely harmful to the environment.

The key disadvantage of diesel fuel is its high emissions of greenhouse gases and toxic substances, which create environmental risks and limit its further acceptance by society. Due to these environmental and resource constraints, as well as against the backdrop of growing global demand and instability of energy supplies, numerous research efforts are now focused on increasing the performance of complex fuel and energy systems and evaluating alternative options, including biofuels. Modern scientists are striving to offer real, cleaner alternatives that can almost identically replace traditional diesel fuel.

3. Purpose

The purpose of this article is to develop a special experimental technique that allows determining the optimal composition of the fuel mixture with the best density indicator.

4. New approach in research

A new approach to optimizing the composition of the biodiesel blend is based on the use of evolutionary computing methods. To achieve the optimal result, a genetic algorithm was applied. Genetic algorithms (GAs), due to their ability for global search and efficiency in solving nonlinear, non-convex, and discrete problems, are widely used in the optimization of various industrial processes [10].

The specified algorithm is distinguished by high predictive capabilities and accuracy, which puts it on a par with the most effective laboratory methods used in biodiesel production. In addition, it forms the optimal fuel mixture, taking into account the availability of raw materials and various parameters necessary to predict the best fuel composition. The use of a genetic algorithm made it possible to propose an approach based on the combination of standard diesel fuel with biodiesel derived from vegetable oils. As part of the study, a number of experiments were conducted, the results of which provided valuable information about the properties of both components of the fuel mixture.

This study analyzed the relationship between fuel density and the percentage of components in optimal mixtures. It was found that with increasing mixture density, both engine power output and fuel efficiency increase. The density indicator is used as an input parameter in the operation of the genetic algorithm and when conducting relevant experimental simulations.

The new decision support tool will be useful for laboratory research, helping to improve optimal fuel mixture formulas. The genetic algorithm allows you to quickly determine the best combination of components for experiments among a large number of possible options. This approach increases the efficiency of the fuel production process, making the new type of biodiesel more competitive and attractive compared to other fuels.

5. Biofuel mixture modeling

The goal of the modeling is to optimize the percentage ratio of diesel fuel (ω_1) and biodiesel fuel (ω_2) by weighted calculation, i.e., approximation to the minimum, of a generalized indicator determined based on the normalized density values of each component. Accordingly, the functional value of the fuel mixture (TMFV) will have the form (1):

$$TMFV = \sum_{i=1}^{2}(\,\omega_i \times \left(\frac{d_i}{d_{max}}\right)^4 \times p_i \quad (1)$$

where: ω_i - is the weighting factor assigned to the i-th fuel to further control the impact of each fuel on the objective function; degree 4 is the TMFV minimization index, which performs the function of amplifying the impact of density deviation from the maximum value; p_i – is the percentage content (fraction) of diesel fuel or biodiesel fuel in the mixture, which is an optimization variable.

The task of raw material optimization is to reduce the functional index of the new fuel mixture, i.e. TMFV→min.

Let us specify the constraints and input data for the mathematical model (1) of optimizing the mixture of diesel and biodiesel fuels, where i = 1 corresponds to diesel fuel, and i = 2 to biodiesel.

For:

- min ingredient percentage, % ≤ p_i ≤ max ingredient percentage, %;
- i = 1: the actual density of pure diesel fuel d1 = 0.8191 g/cm3 and the limits on the percentage of diesel in the mixture are within 1% ≤ pi ≤ 99%;
- i = 2: the actual density of pure biodiesel d2 = 0.8855 g/cm3 and the restrictions on the percentage of biodiesel in the mixture are within 1% ≤ pi ≤ 30%;
- the weighting factor ω_i (0% ≤ ω ≤ 100 %), which gives weight to the density criterion.

The density of the components: d_1 = 0.8191 g/cm³ (diesel fuel at 5°C) and d_2 = 0.8855 g/cm³ (biodiesel at 5°C), are used to calculate the final density of the mixture according to the formula:

$$0.8191 \text{ g/ cm}^3 \times 75\% + 0.8855 \text{ g/ cm}^3 \times 25\% = = 0.8357 \text{ g/ cm}^3.$$

It follows that the density of the final mixture (B25) is 0.8357 g/ cm³. Since 0.8357 is within the range between the density of pure diesel fuel (0.8191) and pure biodiesel fuel (0.8855). Accordingly, the calculation is physically acceptable and correct for use in diesel engines.

6. The process of working of the genetic algorithm

The paper analyzes the problem of creating a biodiesel fuel mixture, which is solved using an evolutionary approach based on GA (Fig. 1). Such algorithms gradually improve the chromosomes of a population over several generations using mechanisms of selection, crossover, and mutation [11].

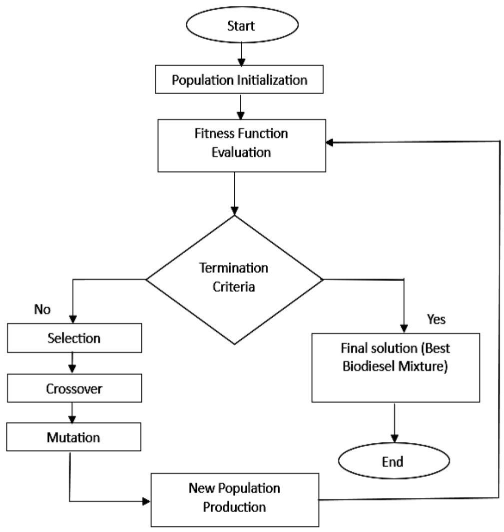


Fig. 1. Block diagram of the genetic algorithm

The presented flowchart demonstrates the iterative process of multi-criteria optimization, built on the principles of evolutionary GA calculations. The algorithm is aimed at determining the optimal composition of the fuel mixture, taking into account a set of technical parameters. Such an algorithmic model provides an effective search for optimal solutions in a multidimensional parameter space, taking into account the complex relationships between the properties of the fuel mixture, operating conditions, and technical and economic constraints.

7. Generation of genetic algorithm generations.

7.1. Generation generation process.

The structure of fuel mixture generation consists in creating a new generation, where each subsequent generation is built on the basis of the previous one using different optimization strategies [11]. The generation process involves two distinct phases. First, the first generation is formed by randomly creating viable mixtures, and then, in subsequent phases, the formation of chromosomes for the generations follows a three-step process.

This scheme demonstrates a balanced "exploitation-exploration" strategy, i.e. 10% is for preserving the best solutions (elite generation), 60% is for intensive local search around the optimum and 30% is for global exploration of the solution space. This structure provides efficient convergence of the algorithm while maintaining the ability to find the global optimum in a complex multidimensional space of fuel mixture parameters.

After creating the initial population, a structure is implemented that covers the range of the optimization parameter (Integrated Particle Life Span) ±*IPLS* (local ingredient percentage search, %) from the best percentages of chromosomes. This structure facilitates the optimization process by focusing on the optimal solution around the best chromosome from the previous generation. Each generation randomly selects a new IPLS value in a specified range. The proposed method is oriented to the primary solution domain from the previous generation, obtaining values in the range (2):

$$\{\min IPLS = 1\% : \max IPLS = \max \text{In}\, Per - -(\min \text{In}\, Per + 1)\} \quad (2)$$

where *InPer* – ingredient percentage; *Min (Max) Ingredient Percentage* – minimum (maximum) *InPer*; *IPLS* – local ingredient percentage search, %; *Min IPLS, Max IPLS* – minimum and maximum IPLS values, respectively.

7.2. Mixture parameter correlation.

The performance of the proposed GA methodology was evaluated using a set of experiments classified by mixture temperatures: 5°C, 10°C, 15°C, 20°C and 25°C centered on density. In the *TMFV* scoring function, the weight values of $\boldsymbol{\omega_1}$ and $\boldsymbol{\omega_2}$ are greater than or equal to 50%.
The density of the ingredients was 0.8191 g/cm3 for diesel fuel and 0.8883 g/cm^3 for sunflower oil biodiesel at 5°C and 0.8891 g/cm^3 for rapeseed oil biodiesel at 5°C and varied with temperature from 5 to 25°C (Table 1).

At a temperature range of 5 - 25°C in 5°C increments, the density of diesel fuel ranges from 0.8191 - 0.8249 g/cm^3, biodiesel fuel from sunflower oil - 0.8883 - 0.8726 g/cm^3, and biodiesel fuel from rapeseed oil - 0.8891 - 0.8755 g/cm^3.

General density indicators of biodiesel from rapeseed and sunflower oils are given in Table 2.

Table 1. Minimum and maximum relative composition of the mixture (%), density

Fuel temperature	Min, %	Max, %	Density, g/cm3
Diesel fuel 5°C	1	99	0,8191
Biodiesel (from sunflower oil) 5°C	1	30	0,8883
Biodiesel (from rapeseed oil) 5°C	1	30	0,8891
Diesel fuel 10°C	1	99	0,8206
Biodiesel (from sunflower oil) 10°C	1	30	0,8835
Biodiesel (from rapeseed oil) 10°C	1	30	0,8855
Diesel fuel 15°C	1	99	0,8220
Biodiesel (from sunflower oil) 15°C	1	30	0,8815
Biodiesel (from rapeseed oil) 15°C	1	30	0,8821
Diesel fuel 20°C	1	99	0,8234
Biodiesel (from sunflower oil) 20°C	1	30	0,8774
Biodiesel (from rapeseed oil) 20°C	1	30	0,8785
Diesel fuel 25°C	1	99	0,8249
Biodiesel (from sunflower oil) 25°C	1	30	0,8726
Biodiesel (from rapeseed oil) 25°C	1	30	0,8755

Table 2. General density indicators of biodiesel from rapeseed and sunflower oils

Type of raw material	Density, g/cm3	Temperature measurement	Standard/Notes
Biodiesel standard	860−900	Various (usually 150C or 200C)	Ukrainian and European standards (for example, EN 14214 requires 900 kg/m3 at 150C).
Rapeseed biodiesel	860−900	150C or 200C	Rapeseed oil is one of the most common bases for biodiesel in Europe.
Sunflower biodiesel	≈876	200C	Actual indicator obtained in laboratory conditions.

Based on a comparative analysis of physicochemical properties, in particular density, it was found that biodiesel obtained from rapeseed oil (RME) and sunflower oil (SME) demonstrate almost identical values in the operating temperature range. These values meet the established regulatory requirements for biodiesel (FAME). Given the similar density of RME and SME, and to optimize the research process, further research will focus exclsively on rapeseed biodiesel as a representative object.

8. Experimental results.

The tests conducted to evaluate the effectiveness of the proposed genetic algorithm included a significant number of independent simulations for a certain temperature and different combinations of weight coefficients ($\boldsymbol{\omega_1}$ and $\boldsymbol{\omega_2}$). Table 3 presents the experimental results for the temperature range from 5°C to 25°C, where each column contains information about: the combination of weighting factors $\boldsymbol{\omega_1}$ and $\boldsymbol{\omega_2}$, the diesel ingredient in percentage (%) in the mixture, the percentage of the biodiesel ingredient in the mixture (%), the value of the mixture evaluation function *TMFV*, and the mixture density.

The weighting factors $\boldsymbol{\omega_1}$ and $\boldsymbol{\omega_2}$ always sum to 100%. The percentage of diesel fuel ingredients ranges from 74.89% to 75.02%, and the percentage of biodiesel ingredients is 24.98 – 25.12%. The values of the TMFV evaluation function range from -0.8852 to -0.0681 and negatively emphasize the density criterion. TMFV at the indicated temperatures are negative, but close to 0 (especially at $\boldsymbol{\omega_1}$=50% and $\boldsymbol{\omega_2}$=50% at different temperature values), which leads to a neutral assessment of the criterion.

The range of values of the density criterion, which varies from 0.8340 g/cm^3 to 0.8397 g/cm^3, corresponds to the limitations of the international standard ASTM D1298-99: 0.8200 g/ cm^3 – 0.8450 g/cm^3.

The optimal mixture at a temperature of 20 °C, when $\boldsymbol{\omega_1}$=10%, $\boldsymbol{\omega_2}$=90%: percentage of diesel fuel: 74.88%; percentage of biodiesel fuel: 25.12%; TMFV: −0.8852; mixture density: 0.8397 g/cm^3.

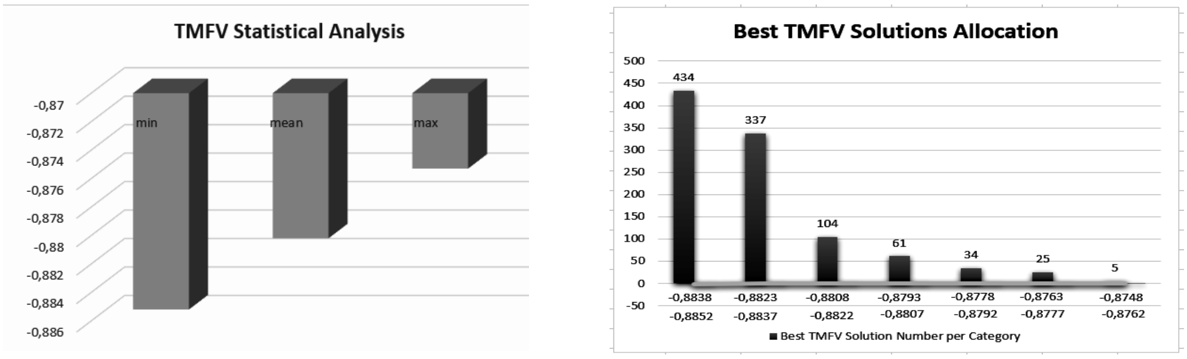
In a series of 1000 independent trials, the lowest recorded value of the total mixture function (TMFV) was -0.8852, while the highest achieved TMFV was -0.8753. The difference between the min and max TMFV values is 0.0099. Meanwhile, the average TMFV value across all trials is -0.8802 with a standard deviation of 0.0018 (Fig. 5(a))

The effectiveness of the method is illustrated in Fig. 5(b), where the majority of the optimal solutions, which are 936 mixtures, are in the range of -0.8852 to -0.8793 TMFV (where -0.8852 is the min TMFV). Based on the distribution of the best solutions, only 64 mixtures (6.4%) had values between -0.8792 and -0.8748 (the max TMFV of the mixture is -0.8753).

Regarding the density of the mixture presented in Table 5, the min density of the mixture is 0.8397 g/cm^3 and the max density of the mixture is 0.8442 g/cm^3 in the proposed 1000 individual tests. The average density of the mixture is 0.8422 g/cm^3 with a standard deviation of 0.0045, with a difference of 0.0029 between the min and max densities (Fig. 6 (a)).

Table 3. Experiments on the density of mixtures for the temperature range 5°C – 25°C

Fuel temperature	$\boldsymbol{\omega_1}$ and $\boldsymbol{\omega_2}$	Diesel fuel, %	Biodiesel, %	TMFV	Density, g/cm^3
5 °C	50% / 50%	75,00%	25,00%	-0,0771	0,8340
	60% / 40%	74,99%	25,01%	-0,2267	0,8355
	70% / 30%	74,98%	25,02%	-0,4167	0,8358
	80% / 20%	74,97%	25,03%	-0,6378	0,8366
	90% / 10%	74,95%	25,05%	-0,8451	0,8379
10 °C	50% / 50%	75,01%	24,99%	-0,0727	0,8349
	60% / 40%	74,99%	25,01%	-0,2588	0,8357
	70% / 30%	74,96%	25,04%	-0,4506	0,8364
	80% / 20%	74,96%	25,04%	-0,6428	0,8378
	90% / 10%	74,93%	25,07%	-0,8322	0,8381
15 °C	50% / 50%	75,00%	25,00%	-0,0715	0,8356
	60% / 40%	74,98%	25,02%	-0,2684	0,8361
	70% / 30%	74,97%	25,03%	-0,4754	0,8369
	80% / 20%	74,94%	25,06%	-0,6682	0,8380
	90% / 10%	74,92%	25,08%	-0,8481	0,8384
20 °C	50% / 50%	75,01%	24,99%	-0,0704	0,8367
	60% / 40%	74,99%	25,01%	-0,2791	0,8373
	70% / 30%	74,96%	25,04%	-0,4984	0,8379
	80% / 20%	74,96%	25,07%	-0,6709	0,8386
	90% / 10%	74,93%	25,09%	-0,8687	0,8390
25 °C	50% / 50%	75,02%	24,98%	-0,0681	0,8371
	60% / 40%	75,00%	25,00%	-0,2981	0,8375
	70% / 30%	74,96%	25,04%	-0,5603	0,8382
	80% / 20%	74,92%	25,08%	-0,6991	0,8389
	90% / 10%	74,88%	25,12%	-0,8852	0,8397



a *b*

Fig. 5. (a) - statistical analysis of TMFV, (b) - distribution of the best TMFV solutions.

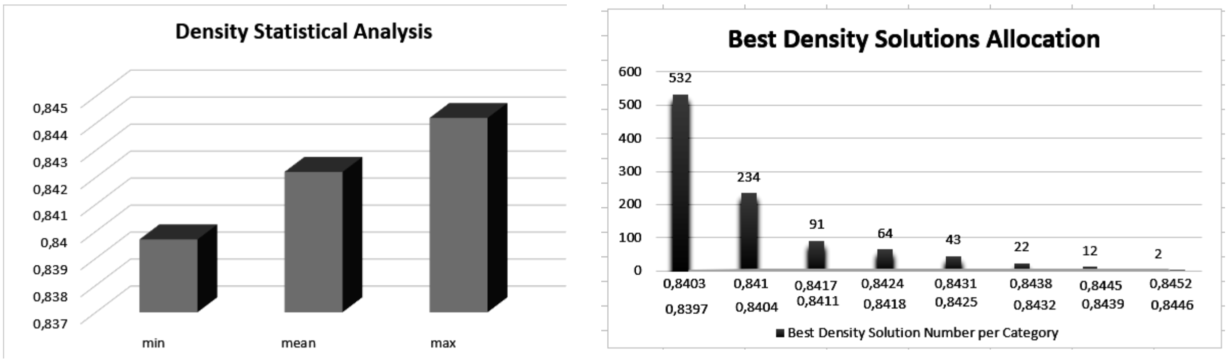


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Fig. 6. (a) statistical analysis of density and (b) distribution of best density solutions.

The distribution of the best density mixtures is presented in Fig. 6(b). The majority of the best mixtures, 921, are between 0.8397 g/cm^3 and 0.8424 g/cm^3 (min mixture density 0.8397 g/cm^3), compared to a total of 79 that were between 0.8425 g/cm^3 and 0.8452 g/cm3 (max mixture density 0.8431 g/cm^3).

9. Conclusions

Thus, the development of a new method for biodiesel production using diesel and biodiesel fuel using a genetic algorithm (GA) demonstrates that:

1. optimization of mixtures was carried out by iterative experiments at temperatures of 5 – 25°C;

2. the percentage content of components was determined through the coefficients ω_1 and ω_2, which reflect the priority of each fuel in the mixture;

3. minimization of costs and production duration was achieved;

4. environmentally friendly and competitive bio-diesel mixtures were obtained.

The evolutionary GA approach demonstrates its ability to adequately address complex fuel blend problems and can be recommended as a suitable and effective approach for addressing emerging biodiesel production challenges.

Prospects

• Further development of GA and research into additional factors to improve fuel quality.

• Possibility of applying the technology to other biodiesel component mixtures.

Conflict of Interest

The authors state that there are no financial or other potential conflicts regarding this work.

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