Neutrosophic Set Hybrid MCDM Methodology for Choosing Best Surfactant-Free Microemulsion Oils within Performance and Emission Criteria Over a Wide Range of Engine Loads

Ahmed Abdel-Monem[1], Mohammed K. Hassan[2], Ahmed Abdelhafeez[3], Shimaa S. Mohamed[4]

[1]Faculty of Computers and Informatics, Zagazig University, Zagazig 44519, Sharqiyah, Egypt; aabdelmounem@zu.edu.eg

[2]Mechatronics department, Faculty of Engineering, Horus University - Egypt (HUE)

mkhassan@horus.edu.eg

[3]Faculty of Information Systems and Computer Science, October 6th University, Cairo, Egypt; aahafeez.scis@o6u.edu.eg

[4]Faculty of Computers and Informatics, Zagazig University, Zagazig 44519, Sharqiyah, Egypt; shimaa_said@zu.edu.eg

* Corresponding: aabdelmounem@zu.edu.eg

Abstract: Microemulsion fuels, also known as surfactant-free fuels, are fuels made from a combination of two immiscible liquids, hydrocarbon fuel, and water, with a trace quantity of a co-solvent. Surfactants are often used in conventional microemulsion fuels, however surfactant-free microemulsion fuels instead depend on the thermodynamic features of the combination to generate a stable emulsion. In this paper, the multi-criteria decision-making (MCDM) model for choosing microemulsion fuel with surfactant-free. Various helpful and harmful criteria were evaluated for ten fuels at varying motor loads, according to performance and emission characteristics. This paper integrated the neutrosophic set with the TOPSIS method. The neutrosophic set is used to deal with uncertain data. The TOPSIS method is used to rank the different fuels.

Keywords: Neutrosophic Set, TOPSIS Method, Microemulsions, Renewable Energy, Diesel.

1. Introduction

More fossil fuels are being used to meet the ever-increasing energy needs of a growing global population and rising quality of life. Acid rain, global warming, carbon dioxide, and other health dangers are only some of the ecological problems that may be traced back to our reliance on fossil fuels. The Paris Agreement of 2015 stipulates that countries will work together to keep global warming below 2°C. Interest in cleaner and more sustainable substitutes for power has increased in response to more stringent environmental regulations and worries about power and financial security. Most of the world's energy needs are met by fossil fuels, despite the extensive study of renewable alternatives. As its economy has grown rapidly, Asia has become one of the world's largest consumers of energy. Fossil fuel emissions are increasing the artificial aging of the atmosphere, according to studies. Renewable power has an opportunity to reduce ecological pollution, but only if it is affordable, readily accessible, and consistently used. Biodiesel and hydrogen, two examples of alternative fuels, are either costlier than traditional fuels like petrol and diesel or need a separate fuel system[1], [2].

Microemulsions are a special kind of colloidal system that has been the subject of substantial research because of its potential use in several industries, such as the pharmaceutical, cosmetic, oil recovery, and food processing sectors. Microemulsions have excellent solubilization capability for hydrophilic and hydrophobic substances, are thermodynamically stable, and are transparent. Due to these characteristics, microemulsion formulations are very desirable for several uses[3], [4].

To keep their stability, microemulsions often include a third party, such as a surfactant or co-surfactant, in addition to two immiscible liquids incompatible. The interfacial tension is decreased, and the emulsion is stabilized by the layer of surfactant molecules that is positioned at the interface between the two liquids. The co-surfactant is included to further decrease the interfacial tension and increase the solubilization capability. The resultant microemulsion has a large surface area and a tiny droplet size range (usually 10 to 100 nanometers)[4], [5].

Microemulsions' special qualities make them useful in many contexts. Due to their excellent solubility and bioavailability, microemulsions are employed in the pharmaceutical sector for medication delivery. Microemulsions have dual purposes in cosmetics, both hydrating the skin and transporting other substances. Microemulsions are used in the food business to increase the stability and longevity of various goods. Microemulsions are employed in improved oil recovery to lower interfacial tension and increase oil recovery from reservoirs[6], [7].

Several obstacles must be overcome before microemulsions may realize their full potential. The complexity of microemulsion formulation and processing contributes to its prohibitively high production cost. The surfactants employed to stabilize microemulsions may also be toxic, limiting their usefulness in certain situations. Furthermore, temperature, pH, and the presence of pollutants all have a significant role in deciding a microemulsion's stability, which might restrict its usage in certain situations.

Because of variations in efficiency and pollution output, deciding the best fuel choice often needs the use of a multi-criteria decision-making (MCDM) methodology. The TOPSIS approach was used to determine the best crop for making biodiesel[8], [9]. The choice of the best crop for making biodiesel in Egypt is based on various characteristics and performance emissions.

The term "neuropathy" was coined by Smarandache. Neutrality studies examine how various ideational spectra interact with one another and how they came to be. Classic sets, fuzzy sets, interval-valued fuzzy sets, intuitionistic fuzzy sets, interval-valued intuitionistic fuzzy sets, paraconsistent sets, dialetheist sets, paradoxist sets, and tautological sets are all generalized by the strong and broad formal framework known as the neutrosophic set[10], [11].

The neutrosophic set is a philosophical generalization of the sets. From a scientific or technical perspective, it is necessary to specify the neutrosophic set and set-theoretic operators. Alternatively, implementing it in the actual world would be challenging. That's why Wang et al. suggested a single-valued neutrosophic set (SVNS) and laid out its set-theoretic operators and other features[12], [13].

Here is how the rest of the paper is laid out. In Section 2, we supply information about performance and emission characteristics. Section 3 supplies the alternatives to diesel. Section 4 introduces the neutrosophic TOPSIS method. Section 5 introduces the results and discussion. Concluding Section 6 presented the conclusions.

2. Performance and Emission Characteristics

Recent interest in alternative fuels has been spurred by the scarcity of supplies and the unavoidable emission rates from fossil fuels. Diesel is one widely used fossil fuel because of the great thermal effectiveness it provides to the engine. The atomization and vaporization of vegetable oils prevent them from being employed in motors as diesel substitutes. Other alternative oxygenating fuels that aid reduce CO and smoke emissions include alcohol. Nevertheless, they often split and diminish the fuel's warming potential[2], [3].

To avoid splitting of phases and ease emulsification, alcohol in diesel requires the use of surfactants. Nevertheless, emulsions are only robust kinetically, and their huge droplet dimensions lead to phase splitting if they are not disturbed. Vegetable oils and alcohols each have their own set of drawbacks, but there have been several suggested solutions, like mixing, transesterification, and micro emulsification, for working around them.

Because they need no chemical reactions during manufacture, microemulsions are among the most practical options. They also contribute to biodiesel's enhanced pour point and ignition latency. Microemulsions, in contrast to emulsions, have droplet dimensions of fewer than 200 nm and are thermally inert. Microemulsions of Colza oil, diesel, and water were shown to remain stable for more than nine months. Because the vapor depth and liquid duration of the gasoline in the vehicle are identical to those of petro-diesel, microemulsions do not need any adjustments to the motor. Even at a high insertion pressure of 1500 bar, droplet dimension distribution was found to be unaffected. Droplet dimensions in microemulsions dropped as the mixing rate rose to 1000 rpm, but thereafter rose, maybe because the continuous stage was more evenly distributed throughout the dispersed phase[14], [15].

When combined with alcohol, microemulsions have also been employed to alter the consistency of vegetable oils. For instance, increasing the proportion of ethanol in microemulsions causes the viscosity of soybean oil, coconut oil, and algal oil microemulsions to decrease. Blends of biodiesel and diesel have also made use of alcohols to enhance their low-temperature fluidity and stiffness. In addition, they aid in reducing PM's dimensions, amount, and bulk, typically by 50%, 60%, and 30%, correspondingly. Reduced NO_x and soot production is another benefit of using lower alcohols. The smoke emissions from diesel, palm-biodiesel, and alcohol mixes were all much lower than those from pure diesel. Ethanol's greater latent heat compared well to other lesser alcohols in reducing NOx emissions. However, the greater wait for ignition and lower evaporation speed of ethanol resulted in higher HC emissions.

Microemulsions of alcohol and diesel aid lower exhaust gas particulate matter, nitrogen oxide, carbon monoxide, and hydrocarbon emissions. Employing ethanol as a sustainable oxygenated ingredient, Mehta et al. developed diesel microemulsions that were stabilized by Span-80. Similar characteristics to diesel were seen in the microemulsions. Nevertheless, the calorific value, cetane index, and flash point all dropped when ethanol was added. The microemulsions enhanced thermal efficiency and had energy consumption comparable to diesel. The amount of ethanol in these microemulsions has been linked to cooler exhaust gas, which likely contributes to decreased NOx emissions[16], [17].

3. Alternatives to diesel

There are five alternatives are options of diesel-like:

Renewable biofuels are produced from various plant and animal byproducts. They are compatible with diesel engines and may result in lower emissions of greenhouse gases than conventional diesel fuel.

Electric automobiles: Unlike conventional vehicles, which rely on fuels like diesel, electric vehicles may run only on electricity. As battery technology advances, they are gaining in popularity.

Fuel cells that run on hydrogen and oxygen create energy with just water as a byproduct of the process. They may replace dirty diesel with something eco-friendlier.

Natural gas: Natural gas is a fossil fuel that, with certain adaptations to engines, may be used in place of diesel. There are fewer emissions compared to diesel.

Some kinds of engines may be converted to run-on propane since it burns cleaner than diesel. It's readily accessible, and in some places, it's even cheaper than diesel[18], [19].

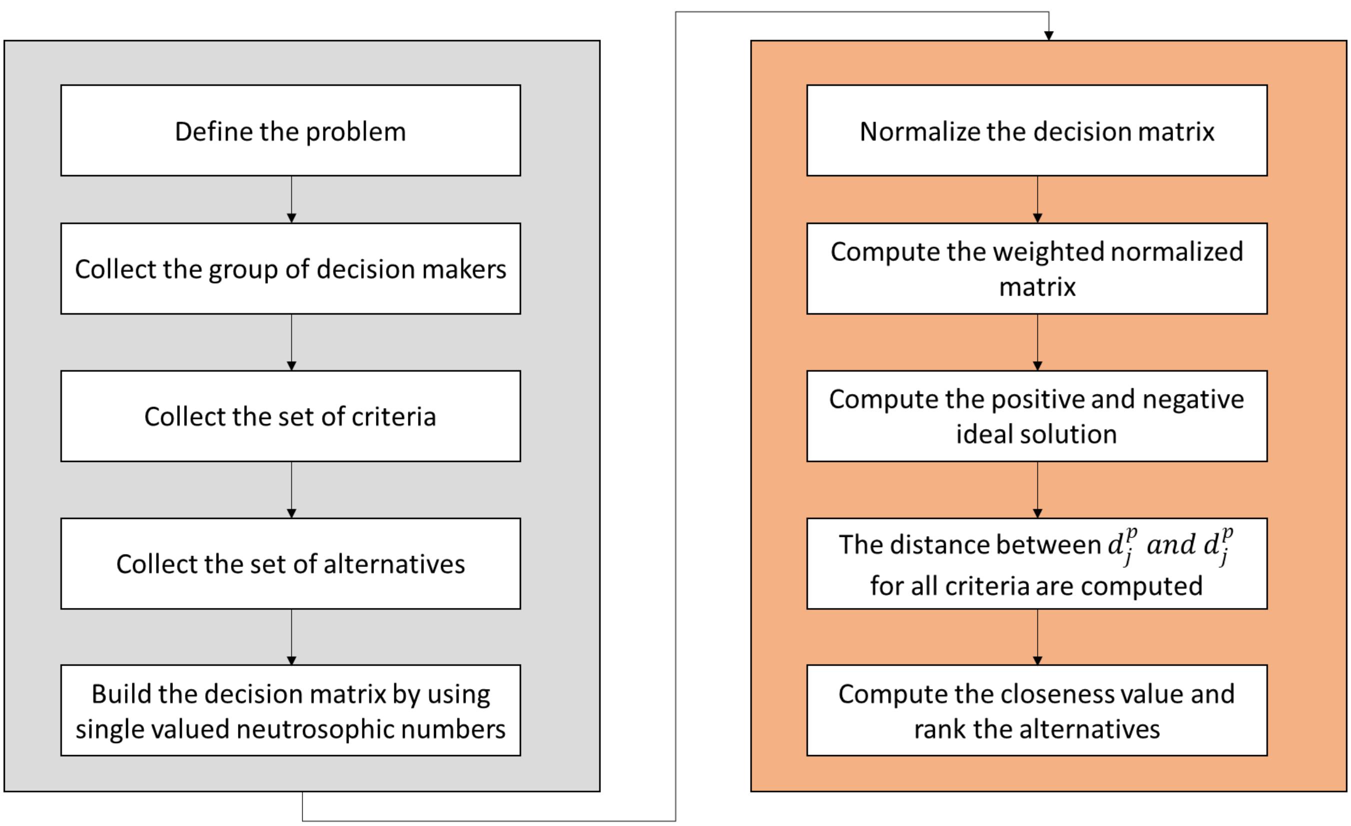

Figure 1. The framework for choice SFME fuels.

4. Neutrosophic TOPSIS Method

The broadest formal framework that generalizes the sets from a philosophical vantage point is the neutrosophic set, which is a part of neutrosophy (the study of the genesis, nature, and extent of neutralities and their interactions with diverse ideational spectra). This paper used the single-valued neutrosophic set with the TOPSIS method to rank the alternatives[20]–[22]. The steps of the proposed method are shown in Figure 1. The following steps discuss the neutrosophic TOPSIS method:

1) Build the decision matrix between criteria and alternatives

2) Normalize the decision matrix

The below equation is used to normalize the decision matrix.

$$z_{ij} = \frac{a_{ij}-a_j^-}{a_j^+-a_j^-} \tag{1}$$

Where z_{ij} refers to the normalization value, a_{ij} refers to the value in the decision matrix, a_j^- refers to the minimum value in the decision matrix and a_j^+ refers to the maximum value in the decision matrix.

3) Compute the weighted normalized matrix

$$O_{ij} = w_j * z_{ij} \tag{2}$$

Where w_j refers to the weights of the criteria. The weights of the criteria are computed by the average method.

4) Compute the positive and negative ideal solution

The positive and negative ideal solutions are computed by using a weighted normalized decision matrix.

The positive and negative ideal solutions are computed for the positive and negative criteria.

$$d_j^p = \max_i(O_{ij}) \tag{3}$$

$$d_j^n = \min_i(O_{ij}) \tag{4}$$

5) The distance between d_j^p and d_j^p for all criteria to be computed

$$T_i^p = \sqrt{\sum_{j=1}^{n}\left(O_{ij} - d_j^p\right)^2} \tag{5}$$

$$T_i^n = \sqrt{\sum_{j=1}^{n}\left(O_{ij} - d_j^n\right)^2} \tag{6}$$

6) Compute the closeness value

By using the distance values, the closeness value is computed.

$$S_i = \frac{T_i^n}{T_i^n+T_i^p} \tag{7}$$

7) Rank the alternatives

5. Results and Discussion

Despite the promising future of microemulsions, there are still certain obstacles to overcome in their research and use. Microemulsions may be challenging to make and regulate due to their complicated composition. The surfactants employed to stabilize microemulsions may also be toxic, limiting their usefulness in certain situations. Another potential barrier is the costly nature of manufacturing microemulsions.

This section introduces the results of the single-valued neutrosophic set with the TOPSIS method to select the best SFME fuels. This paper used eight criteria and 10 SFME fuels.

Table 1. The matrix of normalization decision.

	$DISC_1$	$DISC_2$	$DISC_3$	$DISC_4$	$DISC_5$	$DISC_6$	$DISC_7$	$DISC_8$
$DISA_1$	0.452768	0.186445	0.253596	0.273422	0.090987	0.154616	0.37225	0.140193
$DISA_2$	0.536614	0.36025	0.113781	0.157829	0.272962	0.138913	0.365188	0.076192
$DISA_3$	0.14134	0.291518	0.113781	0.175539	0.389101	0.142537	0.238078	0.566866
$DISA_4$	0.220994	0.442412	0.465247	0.189691	0.174578	0.339431	0.258255	0.158479
$DISA_5$	0.14134	0.181705	0.314343	0.416432	0.189372	0.581623	0.241105	0.546142
$DISA_6$	0.326999	0.291518	0.060747	0.192655	0.267784	0.574979	0.530632	0.224918
$DISA_7$	0.137747	0.35709	0.362699	0.19636	0.192331	0.235548	0.37225	0.154821
$DISA_8$	0.313224	0.428192	0.412695	0.416432	0.189372	0.157032	0.232026	0.074973
$DISA_9$	0.382697	0.291518	0.270952	0.093364	0.467513	0.154616	0.238078	0.478484
$DISA_{10}$	0.218598	0.202246	0.464282	0.634281	0.579952	0.219845	0.126101	0.14385

The criteria are collected based on diesel criteria and emission criteria. The criteria collected from earlier studies are:

Diesel fuel's high energy density implies it can supply more power per liter than most other fuels can.

Diesel fuel has a high combustion efficiency, meaning it burns cleanly and with fewer pollutants compared to other fuels.

Diesel fuel is readily accessible in many regions, making it a practical choice for a variety of uses.

Diesel fuel is more affordable than other fuel options, making it a desirable choice for many consumers.

Because diesel engines were developed to run on diesel fuel, diesel fuel must be compatible with diesel engines.

Cars, lorries, and other vehicles are restricted in the quantity of pollution they may release into the atmosphere by emissions rules.

Limits on pollutant emissions from fossil fuel-burning power plants are set up by emissions regulations.

The regulations for emissions from industrial operations set up maximum allowable concentrations of pollutants released by such activities.

We start with single-value neutrosophic numbers. Then build the decision matrix between criteria and alternatives. Then compute the weights of the criteria using the average method. Then normalize the decision matrix by using an equation. (1) as shown in Table 1. Then multiply the weights of the criteria by the normalization matrix by equation. (2), as shown in Table 2. Then compute the positive and negative ideal solutions by using Equations. (3–4). Then compute the distance between positive and negative ideal solutions by using Equations. (5–6). Then compute the closeness value by using the equation. (7) as shown in Figure 2. Alternative one is the best and alternative three is the worst.

Table 2. Weighted normalized decision matrix.

	$DISC_1$	$DISC_2$	$DISC_3$	$DISC_4$	$DISC_5$	$DISC_6$	$DISC_7$	$DISC_8$
$DISA_1$	0.119474	0.015358	0.046559	0.035216	0.003906	0.013816	0.047944	0.011255
$DISA_2$	0.141599	0.029675	0.02089	0.020328	0.011719	0.012412	0.047035	0.006117
$DISA_3$	0.037296	0.024013	0.02089	0.022609	0.016705	0.012736	0.030664	0.045508
$DISA_4$	0.058315	0.036443	0.085417	0.024431	0.007495	0.03033	0.033262	0.012723
$DISA_5$	0.037296	0.014968	0.057712	0.053635	0.00813	0.051971	0.031053	0.043844
$DISA_6$	0.086287	0.024013	0.011153	0.024813	0.011496	0.051377	0.068343	0.018056
$DISA_7$	0.036348	0.029415	0.06659	0.02529	0.008257	0.021047	0.047944	0.012429
$DISA_8$	0.082652	0.035272	0.075769	0.053635	0.00813	0.014031	0.029884	0.006019
$DISA_9$	0.100984	0.024013	0.049745	0.012025	0.020071	0.013816	0.030664	0.038412
$DISA_{10}$	0.057682	0.01666	0.08524	0.081693	0.024898	0.019644	0.016241	0.011548

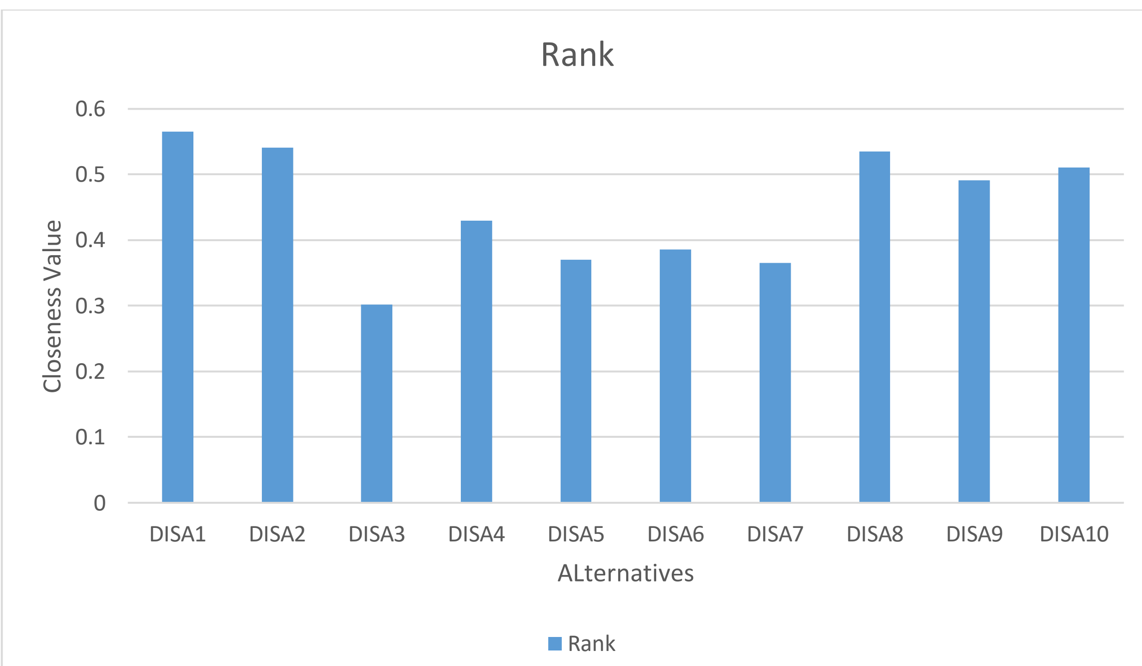

Figure 2. The closeness value by the TOPSIS method.

Surfactant-free microemulsion fuels have certain drawbacks, such as:

Surfactant-free microemulsion fuels are not as stable as their conventional counterparts and may degrade over time or under certain circumstances.

Some engine types and fuel systems may not be compatible with surfactant-free microemulsion fuels.

Some advantages of microemulsion fuels that do not need surfactants are:

Increased efficiency due to more thorough combustion because of the emulsion's tiny droplet size and enhanced atomization of the fuel.

Lower emissions of undesirable pollutants including nitrogen oxides (NOx) and particulate matter are a direct result of the higher combustion efficiency of surfactant-free microemulsion fuels.

Surfactant-free microemulsion fuels are safer than regular hydrocarbon fuels because they produce fewer explosive vapors.

6. Conclusions

Microemulsions are an interesting and potentially useful class of colloidal mixtures. The creation and usage of microemulsions present several problems, such as their complicated composition and toxicity, despite the numerous advantages they provide. This paper used the neutrosophic set with the TOPSIS method to rank the fuels of SFME. The single valued neutrosophic set is used to deal with uncertain data. Then the TOPIS method is used to compute the weights of criteria and rank the alternatives. This paper used eight criteria and ten alternatives.

The suggested MCDM framework's findings support alternative one as a long-term replacement for diesel over a wide range of engine loads and alternative three is the worst.

References

[1] G. Jiang *et al.*, "Insights into the deoiling efficiency of oil-based cuttings by surfactant-free microemulsions," *J. Environ. Chem. Eng.*, vol. 10, no. 2, p. 107306, 2022.

[2] X. Zhang, M. Song, J. Chai, X. Cui, and J. Wang, "Preparation, characterization, and application of a surfactant-free microemulsion containing 1-octen-3-ol, ethanol, and water," *J. Mol. Liq.*, vol. 300, p. 112278, 2020.

[3] X. Li, H. Lu, L. Wang, S. Dai, B. Wang, and Y. Wu, "Oil removal from a solid surface by using surfactant-free microemulsion regulated by CO2: A sustainable approach for treating oily waste," *J. Clean. Prod.*, vol. 345, p. 130990, 2022.

[4] J. Jing *et al.*, "pH-Responsive Regulation of a Surfactant-Free Microemulsion Based on Hydrophobic Deep Eutectic Solvents," *Langmuir*, vol. 38, no. 26, pp. 7898–7905, 2022.

[5] B. Sun, J. Chai, Z. Chai, X. Zhang, X. Cui, and J. Lu, "A surfactant-free microemulsion consisting of water, ethanol, and dichloromethane and its template effect for silica synthesis," *J. Colloid Interface Sci.*, vol. 526, pp. 9–17, 2018.

[6] V. Fischer, J. Marcus, D. Touraud, O. Diat, and W. Kunz, "Toward surfactant-free and water-free microemulsions," *J. Colloid Interface Sci.*, vol. 453, pp. 186–193, 2015.

[7] D. Liu, Z. Huang, Y. Suo, P. Zhu, J. Tan, and H. Lu, "CO2-Responsive surfactant-free microemulsion," *Langmuir*, vol. 34, no. 30, pp. 8910–8916, 2018.

[8] X. Peng and J. Dai, "Approaches to single-valued neutrosophic MADM based on MABAC, TOPSIS and new similarity measure with score function," *Neural Comput. Appl.*, vol. 29, pp. 939–954, 2018.

[9] Ahmed Abdelhafeez, Hoda K.Mohamed, Nariman A.Khalil, Rank and Analysis Several Solutions of Healthcare Waste to Achieve Cost Effectiveness and Sustainability Using Neutrosophic MCDM Model, Neutrosophic Systems with Applications, vol.2, (2023): pp. 25–37. (Doi: https://doi.org/10.5281/zenodo.8185213)

[10] V. Başhan, H. Demirel, and M. Gul, "An FMEA-based TOPSIS approach under single valued neutrosophic sets for maritime risk evaluation: the case of ship navigation safety," *Soft Comput.*, vol. 24, no. 24, pp. 18749–18764, 2020.

[11] Abduallah Gamal, Amal F.Abd El-Gawad, Mohamed Abouhawwash, Towards a Responsive Resilient Supply Chain based on Industry 5.0: A Case Study in Healthcare Systems, Neutrosophic Systems with Applications, vol.2, (2023): pp. 8–24. (Doi: https://doi.org/10.5281/zenodo.8185201)

[12] D. Karabašević *et al.*, "A novel extension of the TOPSIS method adapted for the use of single-valued neutrosophic sets and hamming distance for e-commerce development strategies selection," *Symmetry (Basel).*, vol. 12, no. 8, p. 1263, 2020.

[13] H. Garg, "A novel divergence measure and its based TOPSIS method for multi-criteria decision-making under single-valued neutrosophic environment," *J. Intell. Fuzzy Syst.*, vol. 36, no. 1, pp. 101–115, 2019.

[14] I. Kayali, C. K. Jyothi, K. Qamhieh, and U. Olsson, "Surfactant-free alternative fuel: Phase behavior and diffusion properties," *J. Colloid Interface Sci.*, vol. 463, pp. 173–179, 2016.

[15] I. Abrar and A. N. Bhaskarwar, "Effect of alcohol on the properties of water-in-diesel microemulsion fuels," *Environ. Prog. Sustain. Energy*, vol. 39, no. 5, p. e13422, 2020.

[16] T. ShenavaeiZare, A. Khoshsima, and B. ZareNezhad, "Development of surfactant-free microemulsion hybrid biofuels employing halophytic salicornia oil/ethanol and oxygenated additives," *Fuel*, vol. 292, p. 120249, 2021.

[17] I. Abrar and A. N. Bhaskarwar, "Effect of alcohols on water solubilization in surfactant-free diesel microemulsions," *Energy Reports*, vol. 8, pp. 504–512, 2022.

[18] I. Abrar and A. N. Bhaskarwar, "Performance and emission characteristics of a constant

speed diesel engine fueled by surfactant-free microemulsions," *Sustain. Energy Technol. Assessments*, vol. 47, p. 101414, 2021.

[19] T. Shenavaei Zare, A. Khoshsima, and B. ZareNezhad, "Production of new surfactant-free microemulsion biofuels: phase behavior and nanostructure identification," *Energy & Fuels*, vol. 34, no. 4, pp. 4643–4659, 2020.

[20] Maissam Jdid, Florentin Smarandache, Said Broumi, Inspection Assignment Form for Product Quality Control Using Neutrosophic Logic, Neutrosophic Systems with Applications, vol.1, (2023): pp. 4–13. (Doi: https://doi.org/10.5281/zenodo.8171135)

[21] G. Selvachandran, S. G. Quek, F. Smarandache, and S. Broumi, "An extended technique for order preference by similarity to an ideal solution (TOPSIS) with maximizing deviation method based on integrated weight measure for single-valued neutrosophic sets," *Symmetry (Basel).*, vol. 10, no. 7, p. 236, 2018.

[22] F. Karaaslan and F. Hunu, "Type-2 single-valued neutrosophic sets and their applications in multi-criteria group decision making based on TOPSIS method," *J. Ambient Intell. Humaniz. Comput.*, vol. 11, pp. 4113–4132, 2020.

Received: April 2, 2023. Accepted: July 18, 2023