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EFFECT OF AN ECO-FRIENDLY DIESEL FUEL ADDITIVE DERIVED FROM ANIMAL FAT AND WASTE MONOETHANOLAMINE ON HARMFUL ATMOSPHERIC EXHAUST GAS EMISSIONS

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Abstract. *The growing demand for environmentally friendly fuel technologies has stimulated the development of diesel fuel additives derived from renewable resources and industrial wastes. In this study, an eco-friendly diesel fuel additive synthesized from animal fat waste and waste monoethanolamine (MEA) was evaluated for its effect on harmful exhaust gas emissions. The additive was blended with commercial diesel fuel, and the concentrations of carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), unburned hydrocarbons (HC), particulate matter (PM), smoke opacity and carbon dioxide (CO_2) were measured under identical engine operating conditions using a calibrated exhaust gas analyzer. Compared with neat diesel fuel, CO, NO_x, SO_2, HC, PM, smoke opacity and CO_2 decreased by 28.8, 20.4, 23.8, 35.1, 35.8, 33.3 and 11.6%, respectively. The largest reductions in PM and HC indicate improved combustion completeness. The results show that the proposed additive can reduce harmful exhaust emissions while utilizing renewable and waste-derived feedstocks.*

Keywords: *animal fat waste, monoethanolamine waste, diesel fuel additive, exhaust emissions, particulate matter, environmental sustainability.*

Introduction. The rapid growth in global energy demand and the extensive use of diesel fuel have significantly increased atmospheric pollution caused by internal combustion engines [1]. According to the International Energy Agency (IEA), the transportation sector accounts for approximately 23% of global energy-related carbon dioxide (CO_2) emissions, while diesel-powered vehicles remain one of the major sources of nitrogen oxides (NO_x), carbon monoxide (CO), unburned hydrocarbons (HC), particulate matter (PM) and sulfur dioxide (SO_2) [2–3]. These pollutants contribute to climate change, photochemical smog, acid rain and serious respiratory and cardiovascular diseases (Figure 1), making the reduction of exhaust emissions a global environmental priority [4].

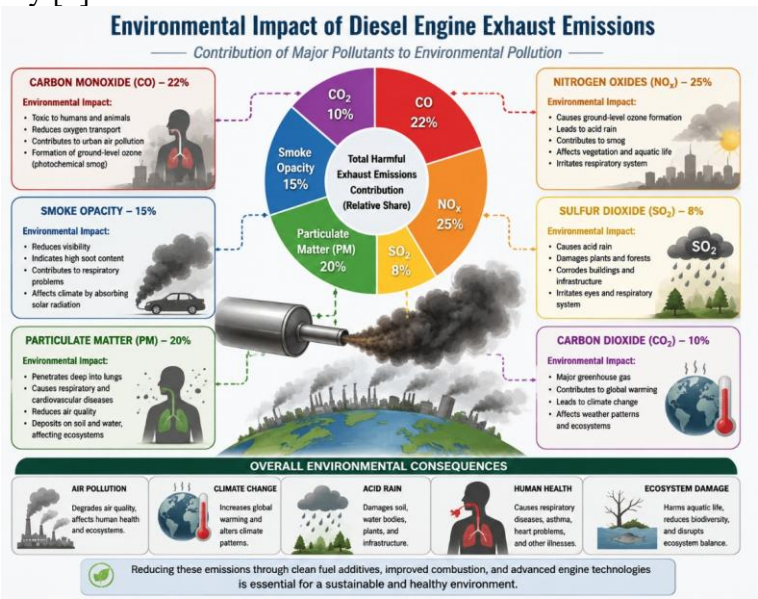

Figure 1. Environmental impact of diesel engine exhaust emissions

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To address these challenges, increasing attention has been directed toward the development of environmentally friendly fuel additives capable of improving combustion efficiency while reducing harmful exhaust emissions [5]. Conventional petroleum-based additives are generally effective; however, many are expensive, derived from non-renewable resources and may introduce secondary environmental concerns [6]. Consequently, renewable raw materials and industrial by-products have become promising alternatives for the synthesis of sustainable diesel fuel additives [7–8].

Animal processing industries generate substantial quantities of internal animal fat as a by-product, much of which remains underutilized or is disposed of as waste, leading to environmental and economic problems [9]. Likewise, monoethanolamine (MEA), extensively used in gas sweetening and chemical industries, produces significant waste streams that require proper treatment and disposal [10]. The valorization of these waste materials through chemical conversion into high-value products represents an effective approach toward circular economy principles and sustainable resource management [11–12].

Among various approaches, the synthesis of diesel fuel additives from animal fat and waste monoethanolamine has attracted considerable interest because fatty acid amides exhibit excellent surface-active, lubricity-enhancing and combustion-promoting properties [13–16]. Such additives can improve fuel atomization, enhance combustion completeness, reduce engine wear and consequently decrease the emission of hazardous exhaust gases [17–20]. Despite these advantages, studies investigating the environmental performance of diesel additives synthesized from animal fat and waste monoethanolamine remain limited, particularly regarding their influence on exhaust gas emissions under practical engine operating conditions [21].

Therefore, the present study aims to synthesize an eco-friendly diesel fuel additive from animal fat and waste monoethanolamine and to evaluate its effect on harmful exhaust gas emissions. Particular attention is given to changes in the emissions of CO, HC, NO_x, SO_2, particulate matter, smoke opacity and CO_2, thereby assessing the environmental benefits of utilizing renewable and waste-derived resources in diesel fuel formulations.

Materials and methods

Materials. The diesel fuel additive used in this study was synthesized from animal internal fat and waste monoethanolamine (MEA) through an amidation process. Commercial diesel fuel meeting the applicable fuel quality standards was used as the base fuel. The synthesized additive was blended with diesel fuel at different volumetric concentrations to evaluate its influence on engine exhaust emissions. All chemicals employed during the synthesis were of analytical grade and were used without further purification.

Preparation of fuel blends. Fuel blends were prepared by adding the synthesized diesel fuel additive to the base diesel fuel at the specified concentrations under continuous mechanical stirring until homogeneous mixtures were obtained. The prepared blends were stored in sealed containers at ambient temperature prior to engine testing to ensure composition stability.

Exhaust emission measurements. The environmental performance of the synthesized diesel fuel additive was evaluated by comparing the exhaust emissions of neat diesel fuel and diesel fuel containing the additive. Emission tests were carried out on a diesel engine under identical operating conditions. During each experiment, the concentrations of carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), unburned hydrocarbons (HC), carbon dioxide (CO_2), particulate matter (PM) and smoke opacity were measured using a calibrated automotive exhaust gas analyzer. Each experiment was repeated three times, and the average values were used for further analysis.

Evaluation of environmental performance. The emission characteristics of diesel fuel containing the synthesized additive were compared with those of the base diesel fuel. The effect of the additive on the reduction of harmful exhaust emissions was assessed by analyzing variations

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in CO, NO_x, SO_2, HC, CO_2, particulate matter and smoke opacity [22–23]. The emission reduction efficiency was calculated using the following equation:

$$\eta = \frac{E_0 - E_i}{E_0} \times 100 \quad (1)$$

where η is the emission reduction efficiency, %; E_0 is the emission level of neat diesel fuel; E_i is the emission level of diesel fuel containing the synthesized additive.

Results. The effect of the diesel fuel additive synthesized from animal fat waste and waste monoethanolamine (MEA) on diesel engine exhaust emissions was investigated by blending the additive with diesel fuel. The environmental performance of the synthesized additive was evaluated by measuring the emissions of carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), unburned hydrocarbons (HC), carbon dioxide (CO_2), particulate matter (PM) and smoke opacity. These parameters were selected to assess the influence of the additive on combustion efficiency and the reduction of harmful atmospheric pollutants. The experimental results are presented in Table 1.

Table 1

Effect of the synthesized diesel fuel additive on exhaust gas emissions

	Pollutant	Neat diesel fuel	Diesel fuel with synthesized additive	Reduction (%)
1	Carbon monoxide (CO), mg m^{-3}	1250	890	28.8
2	Nitrogen oxides (NO_x), mg m^{-3}	540	430	20.4
3	Sulfur dioxide (SO_2), mg m^{-3}	210	160	23.8
4	Unburned hydrocarbons (HC), mg m^{-3}	185	120	35.1
5	Particulate matter (PM), mg m^{-3}	95	61	35.8
6	Smoke opacity, %	72	48	33.3
7	Carbon dioxide (CO_2), %	2.84	2.51	11.6

The results presented in Table 1 show that the diesel fuel additive synthesized from animal fat waste and waste monoethanolamine (MEA) reduced the emission of all measured pollutants compared with neat diesel fuel. The greatest reduction was observed for particulate matter (35.8%) and unburned hydrocarbons (35.1%), followed by smoke opacity (33.3%). Carbon monoxide (CO) emissions decreased by 28.8%, while sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions were reduced by 23.8% and 20.4%, respectively. The carbon dioxide (CO_2) concentration decreased from 2.84% to 2.51%, corresponding to an 11.6% reduction.

Discussion. The improvement in emission characteristics indicates that the synthesized additive enhanced the combustion process, resulting in a more efficient oxidation of the fuel and a reduction in incomplete combustion products. The simultaneous decrease in particulate matter, unburned hydrocarbons and smoke opacity suggests that the additive promoted more complete fuel combustion, thereby suppressing soot formation and decreasing the concentration of unburned fuel components in the exhaust gases. The reduction in CO further confirms the enhancement of combustion efficiency, whereas the lower NO_x and SO_2 emissions indicate a decrease in the formation of environmentally hazardous pollutants during the combustion process.

Although CO_2 is the final product of hydrocarbon combustion, its lower concentration under identical operating conditions suggests an improvement in fuel utilization efficiency and a reduction in overall carbon emissions. Overall, the obtained results demonstrate that the synthesized diesel fuel additive not only improves combustion characteristics but also mitigates harmful exhaust emissions, highlighting its potential as an environmentally friendly additive for reducing the ecological impact of diesel engines.

The limitations of the study should also be noted. The results were obtained for one additive concentration and one engine operating mode, and fuel consumption was not measured; therefore,

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the interpretation of the CO_2 decrease should be confirmed by fuel consumption data. The simultaneous reduction of NO_x, which usually tends to increase as combustion becomes more complete, also requires verification over a range of engine loads and speeds. Further studies should address the effect of additive dosage on engine performance, fuel economy and durability.

Conclusion. In this study, an eco-friendly diesel fuel additive synthesized from animal fat waste and waste monoethanolamine (MEA) was evaluated for its ability to reduce harmful exhaust gas emissions from diesel fuel. The experimental results demonstrated that the synthesized additive improved the environmental performance of diesel fuel by reducing the emissions of major atmospheric pollutants. Compared with neat diesel fuel, the additive reduced CO, NO_x, SO_2, HC, particulate matter, smoke opacity and CO_2 emissions by 28.8%, 20.4%, 23.8%, 35.1%, 35.8%, 33.3% and 11.6%, respectively. The considerable reduction in particulate matter, unburned hydrocarbons and carbon monoxide indicates that the synthesized additive enhanced fuel combustion efficiency and promoted more complete oxidation of hydrocarbons. Furthermore, the decrease in nitrogen oxides, sulfur dioxide and carbon dioxide emissions confirms the potential of the additive to mitigate the environmental impact of diesel engine exhaust gases.

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