

# Evaluation of Diethyl Ether (DEE) as a Renewable Transport Fuel in Sudan

Mohamed Yagoub Alkhalil Karar, Hamid M. Mustafa, and Eltjani EL. Hago

**Abstract** — This study was conducted to investigate physicochemical properties, copper corrosion test and test the diesel engine performance of diethyl ether diesel blend fuel. With aid of distillation characteristic, the blends percentage were selected as DEE5%, DEE10, DEE15 and DEE20%. Stabinger Viscometer apparatus was used to determine the Kinematic viscosities, Digital Density Analyzer was used to determine the densities. ASTM D 4737 – 03 Test Method are used to determined calculated Cetane index. Copper strip corrosion device was used to determine corrosiveness of copper from diesel and DEE diesel blends. A single cylinder, four stroke diesel engines, mounted on a moving frame was used to conduct the engine test. From the study result we found that that blends physicochemical properties improved with diethyl ether ratio increased in the blends. While Cetane Index increased with diethyl ether ratio increased. At the higher load, the best result of Break thermal efficiency found at DEE10%, where at the low load, the best mechanical efficiency found at DEE5%, DEE15% and DEE20 and at the higher load, the best mechanical efficiency found at DEE20%, on other hand at the low load, the best specific fuel consumption found at DEE15%, While at the higher load the best specific fuel consumption found at DEE10%. Due to availability of diethyl ether in Sudan, diethyl ether can be used up to 10% in diesel blend with no further changed in diesel engine design, and this can be contributed to overcome the diesel fuel crisis in Sudan, but further information and studies are needed for diethyl ether transportation and blending facilities, beside study the effect the addition of diethyl ether on diesel price.

**Index Terms** — Diesel engine; Oxygenates; Synthetic fuel; Diethyl ether; Optimum; Distillation; Blend; Transport; Renewable.

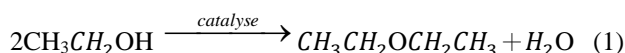
## I. INTRODUCTION

Sudan is considered has a potential to produce diethyl ether, in 2013 local government company launched a diethyl ether production plant based on Ethanol as feed stock under the catalysis of sulfuric acid. Ethanol supplied from local sources Sugar Company, that is owned an ethanol plant with the capacity to produce 65 million liters annually.[1] On the other hand, diethyl ether has promise best fuel properties, offer important environmental benefits as oxygenated fuel led to eliminate Green House gases generation form traditional fuels. Different studies talk about using diethyl

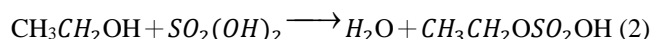
ether as blend fuel with different percentage, but there is a lack of comprehensive evaluation considering higher volatility of diethyl ether with flash point about (-45 °C) and the effect of addition diethyl ether on diesel corrosivity. This encourages the author to conducted comprehensive study of diethyl ether diesel blend, covering the distillation characteristics, effect of blended fuel on metal corrosion rate, so as to select appropriate blends percentage form the safety point of view, and satisfy the hot weather condition in Sudan, where the temperature was rise up to more than (45 °C) in the summer season.

### A. Principle for Manufacturing Diethyl Ether

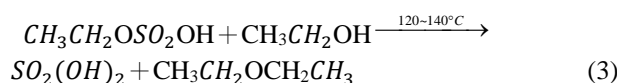
Two alcohol molecules can form into one ether molecule and one water molecule under the action of catalyst the reaction formula is shown as follows:



In fact, the reaction, making ether from alcohol under the catalysis of sulfuric acid, is divided into two steps. First alcohol reacts with sulfuric acid and forms into ester which is called ethyl sulfuric acid.



This resultant is stable at middle temperature, when heating ethyl sulfuric acid and the excessive alcohol up to (20~140 °C, ethyl sulfuric acid will be resolved into ether and sulfuric acid.



If this reaction is done at 120~140 °C and an alcohol is added into the reactor continuously, the producing ether and water will be distilled continuously. This reaction can keep going without end in theory, but because acid is diluted by water and some part of them is reduced to sulfurous acid, the etherification will stop at the end. [3], [4].

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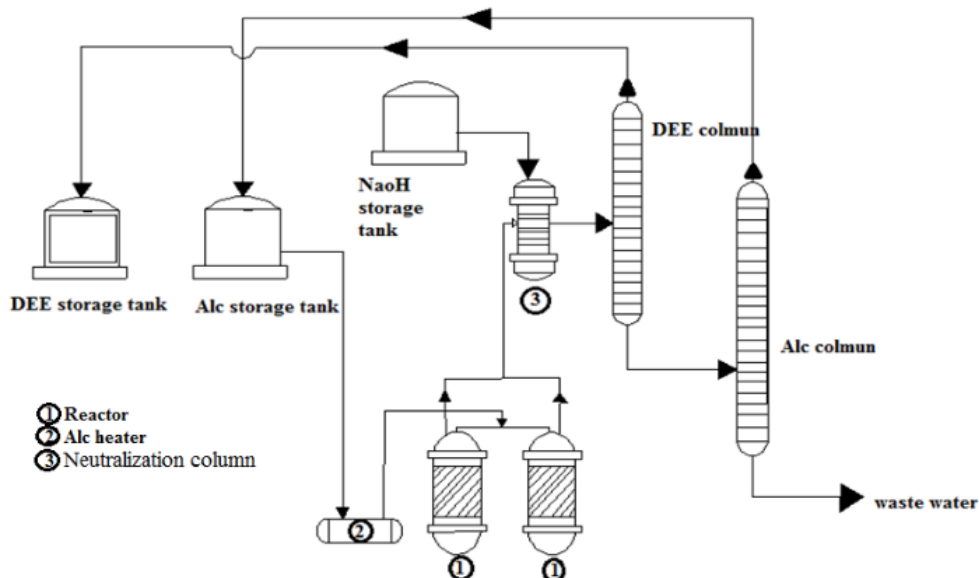


Fig. 1. Ether manufacturing flow diagram typical Sudan plant.

TABLE I: PHYSICO-CHEMICAL PROPERTIES OF DIESEL FUEL AND DIETHYL ETHER. TYPICALLY PRODUCED IN SUDAN

NO	Property	Diesel	Diethyl ether
1	Molecular Weight	181 g/mol	74.1216 g/mol
2	Molecular Formula	C <sub>13</sub> H <sub>24</sub>	C <sub>4</sub> H <sub>10</sub> O
3	Appearance	Light yellow liquid	Colorless liquid
4	Density	850 kg/m <sup>3</sup>	719 kg/m <sup>3</sup>
5	Boiling point	266 °C	34.6 °C
6	Flash point	81 °C	-45 °C
7	Volatility	Volatile	Highly volatile
8	Kinematic viscosity @ 40oC	3.05 cSt	0.223 cSt
9	Auto-ignition temperature	316o°C	160°C
10	Heating value	43000 kJ/kg	33892 kJ/kg
11	Surface tension @ 20°C	0.023 N/m	376 N/m
12	Flammability	Flammable	Flammable
13	Cetane number	(45 - 55)	(85- 89)
14	Carbon content (% weight)	(84 - 87)	64.86
15	Hydrogen content (% weight)	33-16	13.5
16	Oxygen content (% weight)	0	21
17	Stoichiometric air-fuel ratio	15	11.1
18	Latent heat of vaporization	250 kJ/kg	376 kJ/kg

## B. Statement of the Problem

### 1) Overview

Sudan largely dependent on crude oil for producing transport fuel but it lost 350,000 barrels per day after the cessation of the South Sudan and this resulted in a lack of transport fuel. On the other hand, Sudan has a Global commitment for reducing Green House emissions [5]. According to above mentioned statement there is need of arrangements to introduce renewable sources of fuel in Sudan.

### 2) Diethyl Ether Diesel Blend Preparation

The volatility behaviour of a fuel has a direct impact on the performance of diesel engines, if the volatility is high, it can lead to the fuel explosion in the combustion chamber and in the line, and since the diethyl ether is more volatile

than diesel, thus the one of the very important steps of diethyl ether diesel blends preparation is to identify the safer diethyl ether diesel blends percentage. To overcome this problem, Batch Distillation test was used to determine the volatility of diesel and blends that is gives accurate indicator about diesel and blends volatility [6].

### C. Scope of Work

To achieve the study, target the project was going focus on the below objectives:

1. Conducting blends distillation test to determine the volatility of diesel and blends and identify appropriate blends percentage
2. Investigate, physicochemical properties of diethyl ether and diesel blends fuel.
3. Investigate the effect of DEE diesel blend on metal corrosion rate and compare them with pure diesel.
4. Study the effect of DEE diesel blend on diesel engine performance.

## II. MATERIALS AND METHODS

Blend fuel distillation characteristic and physicochemical properties, beside copper corrosion test was carried out in Central Laboratory for Khartoum Refinery Company (KRC) using ASTM procedure. While diesel engine test was carried out at University of Karary.

### A. Lab Tests Apparatus & ASTM Methods

Batch Distillation unit and (ASTM D 86–08a). Standard test method for distillation of petroleum products at atmospheric pressure were used to determine the volatility of diesel and blends. Stabinger Viscometer apparatus and (ASTM D 7042 – 04) were used to determine the Kinematic viscosities, Digital Density Analyzer and (D 4052–96 ASTM) Standard test method was used to determine the densities. (ASTM D 4737–03) Method are used to determined calculated Cetane index for blends. Copper strip corrosion device is pressure vessel constructed from stainless steel was used to determine corrosiveness to copper from diesel and DEE diesel blends, the vessel shall be

capable to withstand a test pressure of 700 kPa gu (100 psi). and (ASTM.D130-04) Standard test method for corrosiveness to Copper from Petroleum Products by Copper Strip Test was used to study the effect of diethyl on cooper corrosion rate. Lower Heating Value was calculated by Mixing rule applied by García et al. and Clements [7].

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#### DISTILLATION AUTOMATIC ANALYZER



Fig. 2. Batch Distillation Analyzer.



Fig. 3. Density Meter.

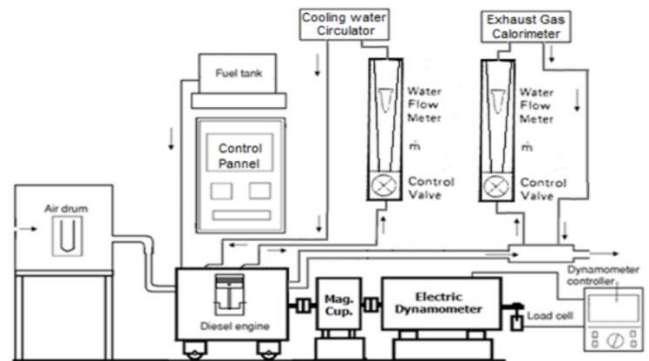


Fig. 4. Viscometer.

#### B. Test Engine Rig

A single cylinder, four stroke diesel engines compression engine, mounted on a moving frame was used for the conducted the engine test. The general specifications of the engine were described in Table II.

No	Item	Specification
1	Displacement	499cc
2	Bore diameter	85 mm
3	Stroke	87.8 mm
4	Orifice diameter	22 mm
5	Generator efficiency $\eta$	85%



experimental setup

Fig. 5. Test Rig layout.

### III. RESULTS AND DISCUSSIONS

#### A. Results

The results of test of distillation, density, Kinematic viscosity, heating value, Cetane index, Copper Corrosion Test, Brake thermal efficiency, Mechanical efficiency, Specific fuel consumption were shows in Fig.6-14. Respectively.

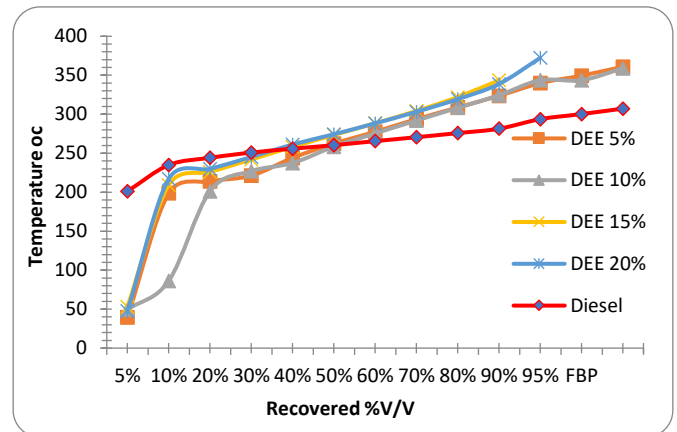


Fig. 6. Distillation Curves for Diethyl Ether Diesel Blends.

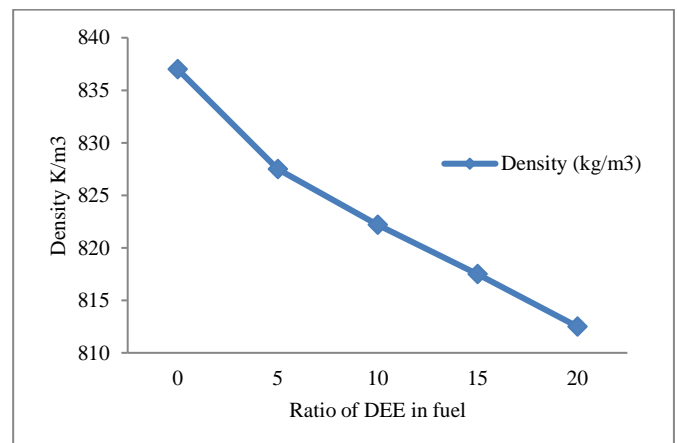


Fig. 7 Density of Diethyl Ether Diesel Blends.

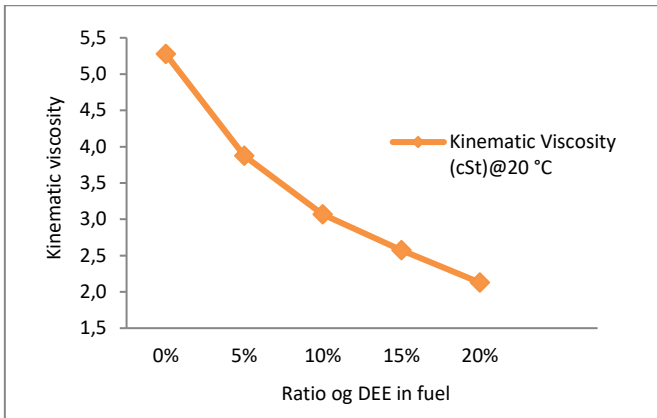


Fig. 8. Kinematic viscosity of Diethyl Ether Diesel Blends.

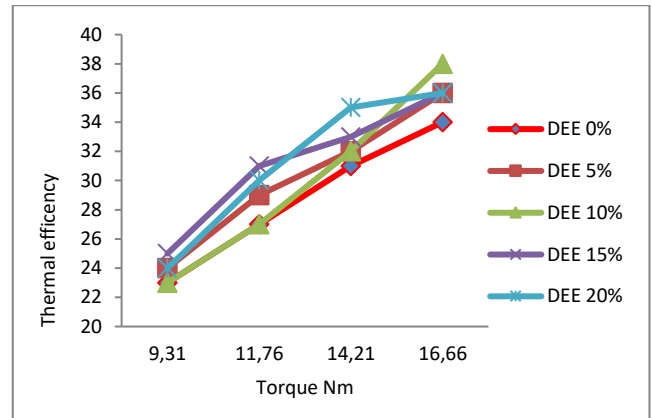


Fig. 12. Break Thermal Efficiency V.S Load for Diethyl Ether Diesel Blends.

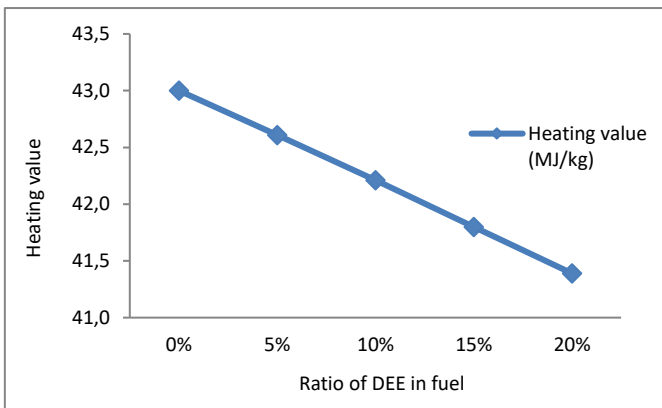


Fig. 9. Heating Value of Diethyl Ether Diesel Blends.

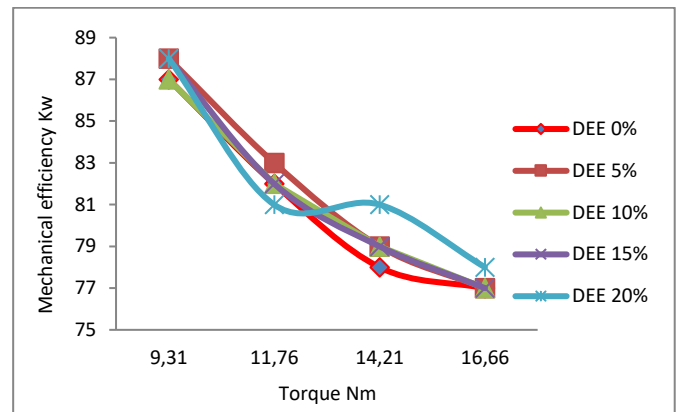


Fig. 13. Mechanical efficiency V.S Load for Diethyl Ether Diesel Blends.

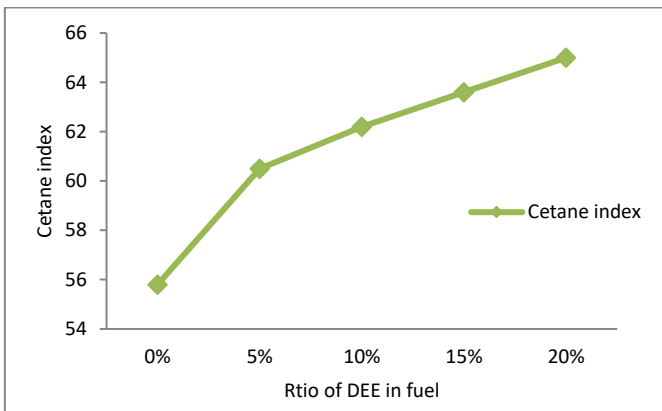


Fig. 10. Cetane Index of Diethyl Ether Diesel Blends.

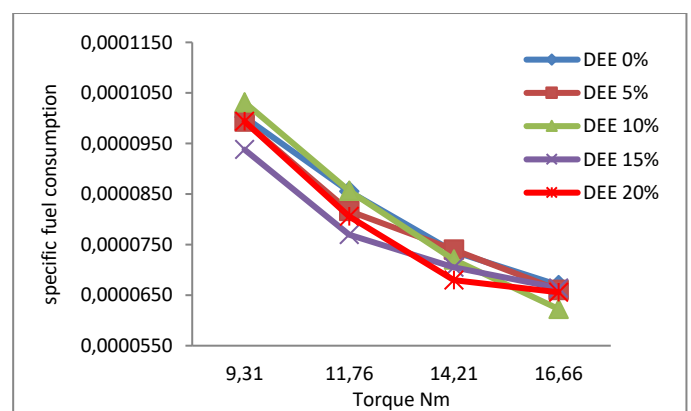


Fig.14. Specific Fuel Consumption V.S Load for Diethyl Ether Diesel Blends.



Fig. 11. Copper strip corrosion standard result of Diethyl Ether Diesel Blends.

### B. Discussions

Fig. 6 shows that the initial boiling point IBP for DEE5% started at 39.5 °C and recovered temperature gradually increase up to 300.2 °C at R95 and the sample totally recovered at (307.2 °C). For DEE10% the initial boiling point IBP started at 49.5 °C and recovered temperature gradually increase up to R95 and the sample totally recovered at 360.9 °C. For DEE15% the initial boiling point IBP started at 53. °C and recovered temperature gradually increase up to R70 and the sample totally recovered at R80. For DEE20% the initial boiling point IBP started at 47.7 °C and recovered temperature gradually increase up to R80 and the sample totally recovered at R90 °C.

Fig. 7 shows that the blend densities, were found to be 2.7%, 3.22.8%, 3.8% and 4.4% less than pure diesel for



DEE5%, DEE15%, DEE15% and DEE20% blends respectively and this due to diethyl ether has a less density than the pure diesel.

Fig. 8 shows that kinematic viscosity of blends they were found to be 26.5%, 41.8%, 51.2% and 59.6% less viscous than pure diesel fuel (5.275 (cSt) @20 °C) for DEE5%, DEE15%, DEE15% and DEE20% blends respectively and this due to diethyl ether has a low Kinematic viscosity than pure diesel.

Fig. 9 shows that the heating value of blends decreased by 0.91%, 1.8%, 2.8%, and 3.7% for DEE5%, DEE10%, DEE15% and DEE20%, respectively, compared to pure diesel, and this due to diethyl ether has a lower heating value than pure diesel.

Fig. 10 shows that blends Cetane index continuously increased by 8.4%, 11.5%, 14%, and 16.5% for DEE5%, DEE10%, DEE15%, and DEE20%, blends respectively this due to higher Cetane index of pure ether which was (85).

Fig. 11 shows that there is no colour change was observed to cooper strip under test for all blends that is reading **1a**, the result there is no effect observed on diesel corrosivity when DEE ratio increases in the blends.

Fig. 12 indicate the Brake thermal efficiency vs. load. The BTE was proportional increase with the load increases for each blend. This because diethyl ether has an Oxygen content which enhance the diesel combustion, but at the higher load the best Break thermal efficiency found at DEE10%.

Fig. 13 Indicate the mechanical efficiency vs. load, the mechanical efficiency was inversely proportional to the load increase for all blends, at the low load the optimum value found at DEE5%, DEE15% and DEE20%, at the higher load the optimum value found at DEE20%.

Fig. 14 indicate the specific fuel consumption vs. load, at the low load the optimum value of specific fuel consumption found at DEE15%, while at the higher load the optimum specific fuel consumption value found at DEE10%. In generally the specific fuel consumption was little improved by increase diethyl ether ratio in the blend and this because it has an Oxygen atom which enhance the diesel fuel combustion.

#### IV. CONCLUSIONS AND RECOMMENDATIONS

##### A. Conclusion

Addition of diethyl ether to pure diesel up to 20% improve the physicochemical properties of the diesel such as density and kinematic viscosity and slightly lowering the heating value. While Cetane index increased with the increased diethyl ether ratio increased in the blends, and there was no effect on diesel corrosivity to the metal have been observed. On the other hand, improvement of the diesel engine performance such as Break thermal efficiency, mechanical efficiency, and specific fuel consumption have been observed, and best values found at DEE10% and DEE15%.

##### B. Recommendations

This study can be use as preliminary guidelines and recommendation for deployment and implementation of

diethyl ether as alternative transport fuel in Sudan, and the author recommended that:

1. Diethyl ether can be used up to 10% in diesel blend with no further changed in diesel engine design
2. Utilized the existing diethyl ether plant infrastructure, for storage and suppling diethyl ether since the material used for sample blend preparation, was supplied from this plant.
3. Khartoum refinery company is a main source of diesel in Sudan, is nearby diethyl ether plant, about only four Kilometer away, and this facilitate the transportation of diethyl ethe from production area to refinery area so that the blending pool can be stablish there.
4. further information and studies are needed for diethyl ethe transportation and blending facilities.
5. There is need for study the effect of addition of diethyl ethe in diesel price.

#### LIST OF ABBREVIATIONS

DEE	Diethyl Ether
ASTM	American Society for Testing and Materials
KRC	Khartoum Refinery Company
DEE 5%	Five present of diethyl ether diesel in Diesel
DEE10%	Ten present of diethyl ether diesel in diesel
DEE15%	Fifteen present of diethyl ether diesel in diesel
DEE20%	Twenty present of diethyl ether diesel in diesel
IBP	Initial Boiling Point
R70	Seventy Percent of Volume Recovered
R80	Eighty Percent of Volume Recovered
R90	Ninety Percent of Volume Recovered
R95	Ninety Five Percent of Volume Recovered
HV	Heating Value
LHV	Lower Heating Value
B.T. E	Break Thermal Efficiency
SFC	Specific Fuel Consumption

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