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Quality Improvement of Sudanese Petrodiesel Fuel by Furfural

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Abstract

The main objective of this project is quality improvement of Sudanese petrodiesel fuel by the use of furfural. The Gas Chromatography Mass Spectrometry GC/MS technique was performed to analyze organic compounds for marked petrodiesel fuel before and after treatment by furfural, physicochemical characteristics of petrodiesel fuel were investigated before and after treatment according to American Society for Testing and Materials (ASTM), characteristics include: density, distillation, cloud point, viscosity, ash content, micro carbon residue, water content, flash point, colour, copper strip corrosion, sulfur content and calculated cetane number. Elements composition of petrodiesel sample has been determined by Inductively coupled plasma (ICP). The furfural showed high ability in extraction of aromatic, cyclo and branched hydrocarbons, a total of 81 organic compounds that exhibit a negative effect on quality of petrodiesel have been removed by furfural. All physicochemical characteristics of petrodiesel fuel were improved within permissible limits assigned by ASTM. The furfural has shown no effect on colour of Sudanese Petrodiesel, which cetane number has increased from 54.46 to 58.36. The concentration of Na, Mg, Ca, Fe, Al and As have been decreased after treatment by furfural, these results have led to decrease of ash content.

Keywords

Sudanese Petrodiesel, Furfural, Khartoum Refinery

1. Introduction

The most important property of diesel fuel is cetane number [1], the refineries in the world and researchers in this area are working to improve the cetane number by using environment friendly materials [2]. Cetane number improvers raise the cetane number of the fuel. Within a certain range, a higher number can reduce combustion noise and smoke and enhance ease of starting the engine in cold climates [3]. The magnitude of the benefit varies among engine designs and operating modes, ranging from no effect to readily perceptible improvement [3].

2-Ethylhexyl nitrate (EHN) is the most widely used cetane number improver. It is also called octyl nitrate. EHN is thermally unstable and decomposes rapidly at high temperatures in the combustion chamber [4].

The increase in cetane number from a given concentration of EHN varies from one fuel to another. It is greater for a fuel which natural cetane number is already relatively high. The incremental increase gets smaller as more EHN is added, so there is little benefit in exceeding a certain concentration. EHN typically is used in the concentration range from 0.05 to 0.4 percent mass and may yield a three to eight cetane number benefit [5] [6] [7]. In the study, the furfural was used to improve the Sudanese petrodiesel fuel because the furfural is an available material.

2. Materials and Methods

2.1. Materials

All chemicals used were of analytical reagent grade (AR): Nitric acid, Furfural. Deionized water and Petrodiesel sample.

2.2. Instrumentation

2.2.1. Gas Chromatography Mass Spectrometry

(Thermo Scientific Co. Thermo GC-TRACE ultra ver.: 5.0, Thermo MS DSQ II). Experimental conditions of GC-MS system were as follows: TR 5-MS capillary standard non-polar column, dimension: 30 Mts, ID: 0.25 mm, Film thickness: 0.25 μm. Flow rate of mobile phase (carrier gas: He) was set at 1.0 ml/min. In the gas chromatography part, temperature program (oven temperature) was 75˚C raised to 250˚C at a rise of 5˚C/min, and held for 30 min.

2.2.2. Inductively Coupled Plasma

The analytical determination of metals was carried out by ICP (Inductively Coupled Plasma): ELAN 9000 (Perkin Elmer Sciex Instrument, Concord, Ontario, Canada).

2.3. Procedures

The experimental work was conducted at chemistry lab—Omdurman Islamic University, Central lab—University of Khartoum and central lab—Khartoum Refinery, Khartoum and Central Petroleum Laboratories—SUDAN.

2.3.1. Treatment of Petrodiesel Fuel by Furfural

Petrodiesel fuel sample (1000 mL) was treated by furfural (500 mL) in separating funnel then upper layer was separated and washed with deionized water (1000 mL).

2.3.2. Physicochemical Properties of Petrodiesel Fuel [8] [9] [10] [11]

The Physicochemical Properties were characterized before and after treatment by furfural according to standard method described by ASTM. Tests includ: Density (D4052), flash point (D93), cloud point (D5773), distillation (D86), kinematic viscosity (D7042), color (D1500), sulfur Content (D5453), water content (D95), copper strip corrosion (D130), carbon Residue (D4530), ash content (D482) and cetane number (D613).

2.3.3. Gas Chromatography Mass Spectrometry (GC/MS) Analysis of Petrodiesel Fuel

The GC/MS analysis of petrodiesel fuel before and after treatment by furfural was performed on a GC-MS equipment. The injection volume was 1 µl and sample was injected in splitless mode. Finally the sample was run fully at a range of 50 - 650 m/z and the results were compared by using Wiley Spectral library search program [12] [13].

2.3.4. Characterization of Elements Composition of Petrodiesel Sample by ICP Technique

The elements composition of petrodiesel fuel was characterized before and after treatment by furfural.

a) Calibration

The ICP calibration was carried out by external calibration with the blank solution and three working standard solutions (10, 20 and 30 µg/L) for all elements.

b) Preparation of Sample

About 30 ml of solvent methyl isobutyl-ketone was taken, 5 ml of buffer solution added and then 0.1 g of iodine weighted and transferred to the solution; 5 ml of petrodiesel fuel was also added to the solution and the solution finally completed to mark in a 100 ml volumetric flask with methyl isobutyl ketone [14].

3. Results and Discussion

3.1. GC/MS of Petrodiesel before and after Treatment by Furfural

The organic compounds in petrodiesel sample before and after treatment are shown in Table 1 and Table 2, respectively.

The data obtained from GC/MS revealed that the furfural has shown high ability to extract aromatic, branched and cyclo organic compounds (Table 3).

The extracted aromatic, branched and cyclo compounds from petrodiesel sample has confirmed the improvement of its quality, although furfural has extracted Nonadecane yet this has shown high positive effect on CN.

3.2. The Physicochemical Characteristics of Petrodiesel before and after Treatment by Furfural

All physicochemical characteristics of petrodiesel sample before and after treatment by furfural were found to be within permissible limits assigned by ASTM Table 4.

Table 1. Organic compounds of petrodiesel sample before treatment by furfural.

P. No	Compound Name	RT	M. Wt	Area%	Formula
1	Octane	4.614	114	0.20	C8H18
2	Ethylcyclohexane	5.521	112	0.10	C8H16
3	1,1,3-Trimethylcyclohexane	5.610	126	0.11	C9H18
4	n-Dodecane	6.455	170	0.31	$C_{12}H_{26}$
5	1-Phenyl-3,3-dimethylbutane	6.667	162	0.42	C12H18
6	1-Ethyl-4-methylcyclohexane	7.158	126	0.10	C9H18
7	n-Nonane	7.592	128	1.73	C9H20
8	1-Ethyl-4-methylcyclohexane	7.772	126	012	C9H18
9	cis-Hexahydroindan	8.175	124	0.12	C9H16
10	Cyclohexane	8.537	126	0.28	C9H18
11	3-Methylnonane	8.681	142	0.52	C10H22
12	(3E)-6-Methyl-3-undecene	8.920	168	0.14	C12H24
13	1-Pentadecyne	9.063	208	0.05	C15H28
14	1-Ethyl-2,3-dimethylcyclohexane	9.211	140	0.04	C10H20
15	1,1,2,3-Tetramethylcyclohexane	9.374	140	0.38	C10H20
16	4-n-Methylnonane	9.629	142	0.21	C10 H22
17	2-Methyl-nonane	9.716	142	0.26	C10H22
18	3-Methylnonane	9.937	142	0.32	C10H22
19	1-Methyl-3-propylcyclohexane	10.401	140	0.17	C10H20
20	Ethylpropylcyclopentane	10.484	140	0.10	C10H20
21	1,3,5-Trimethylbenzene	10.565	120	0.11	C9H12
22	n-Dodecane	10.743	170	0.45	C12H26
23	5-Ethyl-2-methylheptane	10.949	142	3.82	C10H22
24	1-Cyclohexylbutane	11.668	140	0.76	C10H20
25	pentyl-(CAS) Pentylcyclopentane	11.957	140	0.32	C10 H20
26	3,7-Dimethylnonane	12.098	156	0.11	:C11H24
27	trans-Decahydronaphthalene	12.196	138	0.11	C10H18
28	2,4,6-Trimethyloctane	12.710	156	0.12	C11H24
29	2-Methyl-5-ethylheptane	12.821	142	0.27	C10H22
30	n-Cetane	12.924	226	0.36	C16H34
31	3-Methyldecane	13.043	156	0.52	C11H24
32	p-Cymol	13.255	134	0.25	C10H14
33	n-Undecane	13.808	156	0.47	C11H24
34	Decahydro-2-methylnaphthalene	14.263	152	5.06	C11H20

Continued

35	2-Butyl-1-octanol	14.558	186	0.25	C12H26O
36	1,2,3,4-Tetramethylbenzene	14.770	134	0.37	C10H14
37	Trans-2-Tridecen-1-ol	14.949	198	0.16	C13H26O
38	1-Cyclohexylpentane	15.086	154	0.60	C11H22
39	Hexylcyclopentane	15..326	154	0.35	C11H22
40	5-Methylindane	15.462	132	0.17	C10H12
41	2-Ethylcaproic acid chloride	15.891	162	0.15	C8H15ClO
42	2,3,6,7-Tetramethyloctane	15.954	170	0.42	C12H26
43	2-Methylundecane	16.108	170	0.34	C12H26
44	3-Methylundecane	16.246	170	0.54	C12H26
45	1-methyl-2-pentyl-Cyclohexane	16.448	168	0.35	C12H24
46	1-(Cyclohexylmethyl)-4-methylcyclohexane	16.946	194	0.38	C14H26
47	(1,1,3,3,5-Pentamethyl-4-hexenyl)benzene	17.072	230	0.23	C17H26
48	n-Heptadecane	17.267	240	0.14	C17H36
49	3,6-Dimethylundecane	17.408	140	4.98	C13H28
50	1,2,3,4-tetrahydro-2-methyl-naphthalene	17.785	146	0.82	C11H14
51	10-Heneicosene	17.954	294	0.32	C21H42
52	4-Methylpentylcyclohexane	18.063	168	0.08	C12H24
53	3-Tetradecene	18.223	196	0.28	C14H28
54	6-Methyldodecane	18.543	114	0.45	C13H28
55	1-Ethyl-1-methylindane	18.637	160	0.19	C12H16
56	11-Benzylheneicosane	18.933	386	0.11	C28H50
57	4-Methyldodecane	18.988	184	0.21	C13H28
58	2,10-Dimethylundecane	19.128	184	0.13	C13H28
59	1,2,3,4-tetrahydro-6-methyl-Naphthalene	19.266	146	0.42	C11H14
60	2,7,10-Trimethyldodecane	19.457	212	0.57	C15H32
61	3,7,11,15-Tetramethylhexadecanol	19.525	298	0.34	C20H42O
62	Heptadecyl octanoate	19.714	382	0.20	C25H50O2
63	2-Pentadecyl-1,3-dioxolan-4-yl)methyl acetate	19.871	356	0.08	C21H40O4
64	1,6-Dimethylindane	19.941	146	0.09	C11H14
65	2-methyl-4-(2-methylpropyl)-Cyclopentanone	20.026	154	0.20	C10H18O
66	n-Tridecane	20.373	184	5.79	C13H28
67	Isododecane	20.833	170	0.32	C12H26

Continued

68	6-methyl-Tridecane	21.008	198	0.51	C14H30
69	1,2,3,4-Tetrahydro-2,6-dimethylnaphthalene	21.124	160	0.11	C12H16
70	(2,2-dimethyl-1-methylenepropyl)-benzene	21.338	160	0.10	C12H16
71	1-Ethyl-1-methylindane	21.436	160	0.13	C12H16
72	3,5-Dimethyldodecane	21.568	198	0.39	C14H30
73	1,4-Dicyclohexylbutan	21.637	122	0.13	C16H30
74	Decylcyclopentane	21.752	120	0.34	C15H30
75	6-Methyltridecan	21.828	198	0.19	C14H30
76	5-Methyltetradecane	21.968	212	0.28	C15H32
77	2,3-Dimethyldodecane	22.112	198	0.59	C14H30
78	n-Pentadecane	22.302	212	0.32	C15H32
79	3,5-Dimethyldodecane	22.465	198	0.81	C14H30
80	2,7,10-Trimethyldodecane	22.907	212	0.37	C15H32
81	(7E)-17-Chloro-7-heptadecene	23.159	272	5.40	C17H33Cl
82	n-Tetradecane	23.228	198	0.27	C14H30
83	2,6,10-Trimethylpentadecane	23.885	254	0.28	C18H38
84	Methyl phenyl pentanal	23.957	174	0.14	C12H14O
85	4-(4-propyl)bicyclo hexyl	24.192	298	0.23	C22H34
86	Do decane 2-cyclo hexane	24,417	252	0.81	C18H36
87	Tetradecane	24.650	212	0.33	C15H32
88	Tetradecane	24.750	198	0.82	C14H30
89	2-N-Butyl-8-N-hexyldecahydronaphthalene	24.875	278	0.31	C20H38
90	3-Metyl Tetradecane	24.975	212	0.23	C15H32
91	1-H-hydro indeneocta	24.975	208	0.36	$C_{15}H_{28}$
92	2,2,4,4,7,7-methyl-trans heta	25.136	212	0.30	$C_{15}H_{32}$
93	Penta decane nona decane	25.784	268	5.00	$C_{19}H_{40}$
94	1-methyl-(6-ethyl-3-decyloxy)-1-silay-dohexane	25.961	298	0.13	$C_{18}H_{38}$
95	Diteradodecyl Bicyclo(4-1)heproan-2-1Disulfide	26.5	402	0.12	$C_{24}H_{50}S_2$
96	1-phenyl 1-endo	26.6	188	0.11	$C_{24}H_{16}o$
97	5-(2-methyl lapropyl)Ranane	26.733	184	0.11	$C_{13}H_{36}$
98	4-cycohexyl Undecane	26.925	238	0.14	$C_{17}H_{34}$
99	4-methyl Tetradecane	27.133	212	0.42	$C_{15}H_{32}$

Continued

100	2-methyl Tridecane	27.225	198	0.27	$C_{14}H_{30}$
101	Eicosane	27.342	282	0.20	$C_{20}H_{42}$
102	3-methyl Pentade	27.408	226	0.11	$C_{16}H_{34}$
103	14-methyl-8-hetadecane-1	27.525	254	0.25	$C_{17}H_{34}$
104	1-one4-methyl-4phenyl-2-cyclohexan	27.633	186	0.13	$C_{13}H_{14}o$
105	3-5,24-trimethyl Tetra eontane	27.750	604	0.10	$C_{43}H_{88}$
106	Hexadecane	28.042	220	0.19	$C_{16}H_{34}$
107	3,6-di methylUndecane	28.300	184	5.20	$C_{13}H_{28}$
108	3-cydohexyl, dodecane	29.417	252	0.58	$C_{18}H_{36}$
109	Octodecane	29.642	254	0.61	$C_{18}H_{38}$
110	3-methyl hexa decane	29.750	240	0.32	$C_{17}H_{36}$
111	Hepta decane	29.933	240	0.30	$C_{17}H_{36}$
112	2,6,10,14 Tetra methyl Pema decane	30.650	268	4.98	$C_{19}H_{40}$
113	9,Octyl Hepta decane	30.750	352	0.98	$C_{17}H_{52}$
114	3-methyl-Hepta decane	32.017	254	0.31	$C_{18}H_{38}$
115	Heptadecane	32.200	240	0.18	$C_{17}H_{36}$
116	2,6,10,10,14, Tetra methyl Hexadecane	32.883	282	4.67	$C_{20}H_{42}$
117	Hexadecane	33.050	226	0.65	$C_{16}H_{34}$
118	Octodecane	34.200	254	0.38	$C_{18}H_{38}$
119	Heneicosane	35.008	296	4.65	$C_{21}H_{44}$
120	4-cyclohexyl Tridecane	36.242	266	0.26	$C_{19}H_{38}$
121	Eicosane	36.417	282	0.37	$C_{20}H_{42}$
122	Heneicosane	37.025	296	4.01	$C_{21}H_{44}$
123	Heneicosane	38.950	296	3.58	//
124	Cudo Hexane	40.048	238	0.15	$C_{17}H_{34}$
125	Henei cosine	40.338	296	0.13	$C_{21}H_{44}$
126	Pentacosane	40.756	352	2.81	$C_{25}H_{52}$
127	Henei cosine	40.842	296	0.10	$C_{21}H_{44}$
128	Heneicosane	42.517		2.10	//
129	Pentacosane	44.207	352	1.35	$C_{25}H_{52}$
130	Henei cosine	45.942	296	0.85	$C_{21}H_{44}$
131	Hexa cosane	48.007	366	0.49	$C_{26}H_{54}$
132	Hexa cosane	50.548	366	0.37	$C_{26}H_{54}$

Table 2. Organic compounds of petrodiesel sample after treatment by furfural.

P. NO	Compound Name	RT	M. Wt	Erea%	Formula
1	Octane	5.517	114	0.21	C_8H_{18}
2	Carboxal dehyde furan	6.683	96	3.67	$C_5H_4O_2$
3	5_methyl Undecane	7.592	170	0.20	$C_{12}H_{26}$
4	3_methyl Octane	7.825	128	0.35	C_9H_{20}
5	1_ethyl_4_methyl-Cyclohexane	8.317	126	0.11	C_9H_{18}
6	Nonane	8.808	128	1.68	C_9H_{20}
7	3_methyl nonane	9.958	142	0.46	$C_{10}H_{22}$
8	4_methyl nonane	10.942	142	0.32	$C_{10}H_{22}$
9	2_methyl n nane	11.025	142	0.21	$C_{10}H_{22}$
10	3_methyl nonane	11.258	142	0.27	$C_{10}H_{22}$
11	1,3,5_trimethyl benzene	12.067	120	0.31	C_9H_{22}
12	Decane	12.283	142	4.41	$C_{10}H_{22}$
13	5_methyl_2_methyl Heptanes	13.033	142	0.81	$C_{10}H_{22}$
14	Butyl cycloheptane	13.308	140	0.34	$C_{10}H_{20}$
15	5_Methyl decane	14.200	156	0.21	$C_{11}H_{29}$
16	2_methyl_5_ethyl heptanes	14.300	142	0.33	$C_{10}H_{22}$
17	Hexadecane	14.425	226	0.53	$C_{16}H_{34}$
18	3_Methyl decane	14.333	156	0.24	$C_{11}H_{24}$
19	Undecane	15.333	156	5.60	$C_{11}H_{24}$
20	Tridecanaldehyde	16.467	198	0.61	$C_{13}H_{20}O$
21	Pentyl cyclohexane	13.708	154	0.45	$C_{11}H_{22}$
22	1,1_Bis(iso pentyloxy)hexadecane	17.492	398	0.35	$C_{26}H_{54}O_2$
23	2_methyl undecane	17.633	170	0.65	$C_{12}H_{26}$
24	3,8_methyl undecane	17.842	170	0.32	$C_{12}H_{26}$
25	Tridecane	18.783	184	5.96	$C_{13}H_{28}$
26	3,6_dimethyl undecane	19.167	184	0.72	$C_{13}H_{28}$
27	Tridecane	21.742	184	5.88	$C_{13}H_{28}$
28	2,7,10_trimethyl dodecane	23.842	212	0.46	$C_{15}H_{28}$
29	Bentadecane	23.483	212	0.81	$C_{15}H_{32}$
30	ISO tetrodecane	24.525	198	6.45	$C_{14}H_{30}$
31	2,6,10,14_tetremethyl hexadecane	26.125	282	1.45	$C_{20}H_{42}$
32	N_pentadecane	27.142	212	6.08	$C_{15}H_{32}$
33	N_hexadecane(cetane)	29.625	226	6.59	$C_{16}H_{34}$
34	Heptadecane	31.967	240	6.15	$C_{14}H_{36}$

Continued

35	2,6,10,14_tetramethyl p; entadecane	32.067	268	1.44	$C_{19}H_{40}$
36	Octadecane	34.200	254	5.73	$C_{17}H_{36}$
37	2,6,10,10_tetramethyl Hexadecane	34.367	282	0.92	$C_{20}H_{42}$
38	Nonanedecane	36.325	268	5.90	$C_{19}H_{40}$
39	Eicosane	38.342	282	5.27	$C_{20}H_{42}$
40	Heneicosane	40.267	296	5.07	$C_{21}H_{44}$
41	Heneicosane	40.267	296	5.07	$C_{21}H_{44}$
42	Pentacosane	42.108	352	4.08	$C_{25}H_{52}$
43	Pentacosane	45.875	352	3.14	$C_{25}H_{52}$
44	Pentacosane	45.575	352	2.08	$C_{25}H_{52}$
45	Pentacosane	47.200	352	1.32	$C_{25}H_{52}$
46	Pentacosane	48.767	352	0.71	$C_{25}H_{52}$
47	Pentacosane	50.283	352	0.55	$C_{25}H_{52}$
48	Pentacosane	51.742	352	0.32	$C_{25}H_{52}$
49	Hexacosane	53.150	366	0.24	$C_{26}H_{54}$
50	Tetracontane	54.508	563	0.14	$C_{40}H_{82}$
51	Tetracontane	54.508	563	0.14	$C_{40}H_{82}$

Table 3. Extracted organic compounds by furfural.

P. No.	Compound Name	Rt	Erea%	M. wt
2	Ethylcyclohexone	5.517	0.10	112
3	1,1,3 Trimethyl cyclohexane	5.608	0.11	126
5	3,3-Dimethy, butylbenzene	6.667	0.42	162
9	IH-, Octahydro-cis Indene	8.172	0.12	124
10	Propyl cyclohexane	8.533	0.28	126
12	6 Methyl-(E)3-undecene	8.917	0.14	168
13	1-Pentadecyne	9.058	0.05	208
14	1- Ethyl-2,3 dimethyl cyclohexone	9.208	0.04	140
20	3-Cyclohexayl-propnol	10.483	0.10	142
21	Ethyl propyl cyclopentane	10.567	0.11	140
26	Pentyl cyclopentane	12.100	0.11	140
28	Deahydro-trans Naphthalene	12.708	0.12	138
29	Octane, 2,4,6 trimethyl	12.825	0.27	156
33	Methyl(1-methyl Ethyl)benzene	13.808	0.47	134
35	Decahydro-2-methyl Naphthalene	14.558	0.25	152

Continued

36	2-Butyl1-Octanol	14.767	0.37	186
37	1,2,3,4-Tetramethyl Benzene	14.950	0.16	134
40	Hexyl Cyclopentone	15.458	0.17	154
41	2,3 Dyhydro-4-methyl Indene	15.892	0.15	132
42	2-Ethyl Hexanoyl chloride	15.950	0.42	162
43	2,3,6,7-Ttetramethyl Octane	16.108	0.34	170
44	2-Methyl undecon	16.250	0.54	170
45	3-Methyl Undecon	16.450	0.35	170
46	1-Methyl-2-pentyl Cyclohexane	16.942	0.38	168
47	1-(Cyclohexyl methyl)-4 methylas Cyclohexane	17.075	0.23	194
48	2.4.4.6-Tetramethyl-1-phenyl-2-heptene	17.267	0.14	230
51	1,2,3,4 Tetrahydro-2-methyl Naphthalene	17.950	0.32	146
52	10-Heneicosene (c, t)	18.058	0.08	294
53	1,2,3,4, Tetrahydro-1-methyl Naphthalene	18.225	0.28	146
54	Cyclohexane, hexyl	18.542	0.45	168
55	3-Tetradecen, (E)	18.633	0.19	196
56	6-Methyl Dodecame	18.933	0.11	184
57	1-Ethyl-2,3 dihydro-1-methyl-1H-Indere	18.992	0.21	160
58	4-Methyl Dodecane	19.125	0.13	184
59	2,10-Dimethyl Undecane	19.267	0.42	184
60	1,2,3,4- Tetrahydro-5-methyl Naphthalene	19.458	0.57	146
62	3,7,11,15, Tetramethyl1-Hexadecanol	19.717	0.20	298
63	Hepta deoylester octanoic acid	19.875	0.08	382
64	2,3-Dihydro-4,7 dimethyl I H-Indene	19.942	0.09	146
65	3-Isobutyl-1-methyl-cyclopentane	20.025	0.20	154
67	Dodecane	20.833	0.32	170
68	1,2,3,4-Tetrahydro-2,6 dimethyl Naphthalene	21.008	0.51	160
69	(2,2-Dimethyl-1-methylenepropyl) Benzene	21.125	0.11	160
70	1-Ethyl-2,3-dihydro-1-methyl1H-Indere	21.342	0.10	160
71	3,5-Dimethyl dodcane	21.433	0.13	198
72	1,1-(1,4-butonediyl) Cyclohexane	21.567	0.39	222
73	Decylcyclopentane	21.633	0.13	210
74	6-Methyl Tridecane	21.750	0.34	198
75	5-Methyl Tridecane	21.825	0.19	212
76	Octadecanoic acid, 2-oxo-methyl ester	21.867	0.28	312

Continued

78	3,5-Dimethyl dodecane	22.300	0.32	198
79	2,7,10-Trimethyl Dodecan	22.467	0.81	212
80	17-Chloro7-Heptadecene	22.908	0.37	272
82	2,6,10-Trimethyl pentadecane	23.225	0.27	254
83	Octahydro 2,2,9,4,7,7-hexamethyl-1H-Indene	23.883	0.28	208
84	Methyl phenyl pentenal	23.958	0.14	174
85	4(4-Propyl bicyclohexyl) methyl benzene	24.192	0.23	298
86	2-Cyclohexyl Dodecane	24.417	0.81	252
87	4-Methyl tetradecan	24.650	0.33	212
89	2-N-Butyl-8-N-Hexyl daphthalene	24.875	0.31	278
90	3-Methyl tetra decane	24.975	0.23	212
91	Octa hydro-2,2,4,4,7,7-hexamethyl-trans1H-Indene	25.133	0.36	208
93	Nonadecane	25.958	5.00	268
94	1-Methyl-(6-ethyl-3-decyloxy)-1-silecyclohexane	26.533	0.13	298
95	Di-tert-dodecyl Disulfide	26.650	0.12	402
96	Bicyclo (4.1.0) heptan-2-01,1-phenyl endol	26.767	0.11	188
97	5-(2-Methyl propyl) Nonane	26.900	0.11	184
98	Undocane, 4-cyclohexyl	27.083	0.14	238
99	4-Methyl Tetradecane	27.183	0.42	212
102	3-Methyl Pentadecane	27.500	0.11	226
103	(R)-(-)-(2)-14-methyl-8-hexa dece-1-ol	27.600	0.25	254
104	1-One, 4-methyl, 4-phenyl2-cyclohexen	27.725	0.13	186
105	3,3,24-Trimethyl tetracontane	28.008	0.10	604
107	3,6-Dimethyl Undcoane	29.367	5.20	184
108	3-Cyclohexyl-3cyclohexyl Dodecane	29.592	0.58	252
110	3-Methyl Hexa decane	29.892	0.32	240
113	9-Octyl Heptadecane	31.983	0.98	352
114	3-Methyl Heptadecane	32.167	0.31	254
117	Hexadecane	34.150	0.65	226
120	4-Cyclohxyl Tridecane	36.383	0.26	266
124	Undecylcyclohexane	40.383	0.25	238

Table 4. Physicochemical properties of used petrodiesel sample before and after treatment.

Teas name		Unit	Before treatment	After treatment	ASTM Specification
Distillation	10%	˚C	213.3	221	Max 250
	50%	˚C	275.65	282.1	Max 300
	90%	˚C	338.55	344	Max 350
	95%	˚C	353.5	363	Max 370
Density @ 15˚C		g/mL	0.8345	0.830	Reported by countries
Cloud point		˚C	2.8	4.0	max12
Viscosity		mm^2/s	4.694	4.260	2.2 - 8.8
Ash content D482		%w/w	0.002	0.001	Max 0.01
Microcarbonresidue		%w/w	0.02	0.01	Max 0.05
Water content D95		%w/w	0.03	0.03	Max 0.05
Flash point D93		˚C	73	58	Min 57
Colour D1500		˚C	1.0	1.5	0.5 - 2
Cetane Index ASTM D4737		-	54.46	58.34	Min 45
Copper Strip Corrosion		-	1a	1a	1a and 1b
Sulfur Content		%w/w	0.0089	0.005	Min 0.05

No limits had been assigned for the density by ASTM, because they depend to a greater extent on the temperature prevailing in the country [15] [16] [17] The density has been decreased. Results were found to be within the Khartoum Refinery limit to operate diesel engines [18].

The viscosity of Sudanese petrodiesel sample was decreased after treatment; this result confirmed the quality improvement of petrodiesel fuel.

The decrease of flash point temperature was indicative of overall delay of flammability and hazard [15]. Cloud point was increased to 5.0˚C.

The colour of Sudanese petrodiesel is within ASTM specification [16] although has become intense, this result can be attributed to the brown colour of furfural.

Increase of ash content in diesel may lead to decrease of quality because it may precipitate in engine tank. The ash content of Sudanese petrodiesel sample has been decreased from 0.02% to 0.01% w/w.

Sulfur content has been decreased from 0.0089% to 0.005%. Showing the efficacy of furfural in abstracting sulfur compounds such as mercaptans, cyclo mercaptanes, thioether and cyclothioethers from used Sudanese petrodiesel, the treatment has no effected on copper strip corrosion property. The cetane number of petrodiesel sample has increased from 54.46 to 58.34, because the aromatic, cyclo, and branched hydrocarbons were removed by furfural.

Other physicochemical such as distillation, micro carbon residue and water content properties were improved by furfural and their results have been found within ASTM specification.

3.3. Elements Composition of Petrodiesel before and after Treatment by Furfural

The data depicted in Table 5 has revealed that the petrodiesel metal concentrations of As, Ca and Fe were the highest. It has shown slight decrease after improvement. A result which might have been the cause to decrease the ash content [19]. While some metal concentrations remained unchanged.

Furfural is an important renewable, non-petroleum based feedstock. It has acted as a selective solvent in refining petrodiesel fuel. Aromatics, cyclic and branched hydrocarbons were extracted and removed from petrodiesel by means of furfural extraction. Cetane number has increased without the decomposition of furfural, hence furfural can act as a biobased alternative to the thermally unstable 2-ethylhexyl nitrate.

4. Conclusions

Based on the previous discussion, conclusion can be summarized:

- The organic compounds of Sudanese petrodiesel sample have been evaluated by using Gas Chromatography Mass Spectrometry GC/MS technique, before and after treatment by furfural.
- A total of 81 organic compounds have been extracted from Sudanese petrodiesel sample. Most of the extracted compounds are aromatic, cyclic, and branched organic compounds.
- The physicochemical Characteristics of Sudanese Petrodiesel sample have been investigated before and after treatment by furfural according to American Society for Testing and Materials, characteristic include: density, viscosity, flash point, colour, cloud point, water content, ash content, micro carbon residue, copper strip corrosion, sulfur content and cetane number.

Table 5. Elements composition of sudanese petrodiesel before and after treatment by furfural.

Element	Before Treatment (ppm)	After Treatment (ppm)
Na	0.433	0.432
Mg	0.278	0.258
Ca	2.055	2.005
V	0.1	0.1
Fe	1.062	0.895
Ni	0.1	0.1
Cu	0.1	0.1
Al	2.636	2.615
As	0.142	0.1
Pb	0.1	0.1

- The furfural has shown a slight intensity on colour of Sudanese Petrodiesel but all other results were within permissible limits assigned by ASTM.
- The elements composition of Sudanese petrodiesel sample has been performed by Inductively Coupled Plasma Technique.
- The concentrations of Na, Mg, Ca, Fe, Al and As have been slightly decreased after treatment by furfural, these results led to decrease of ash content.
- Furfural has proved to be an efficient non-expensive, sulfur compound adsorbent and thermal stable cetane number improver for the quality improvement of Sudanese petrodiesel fuel.

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