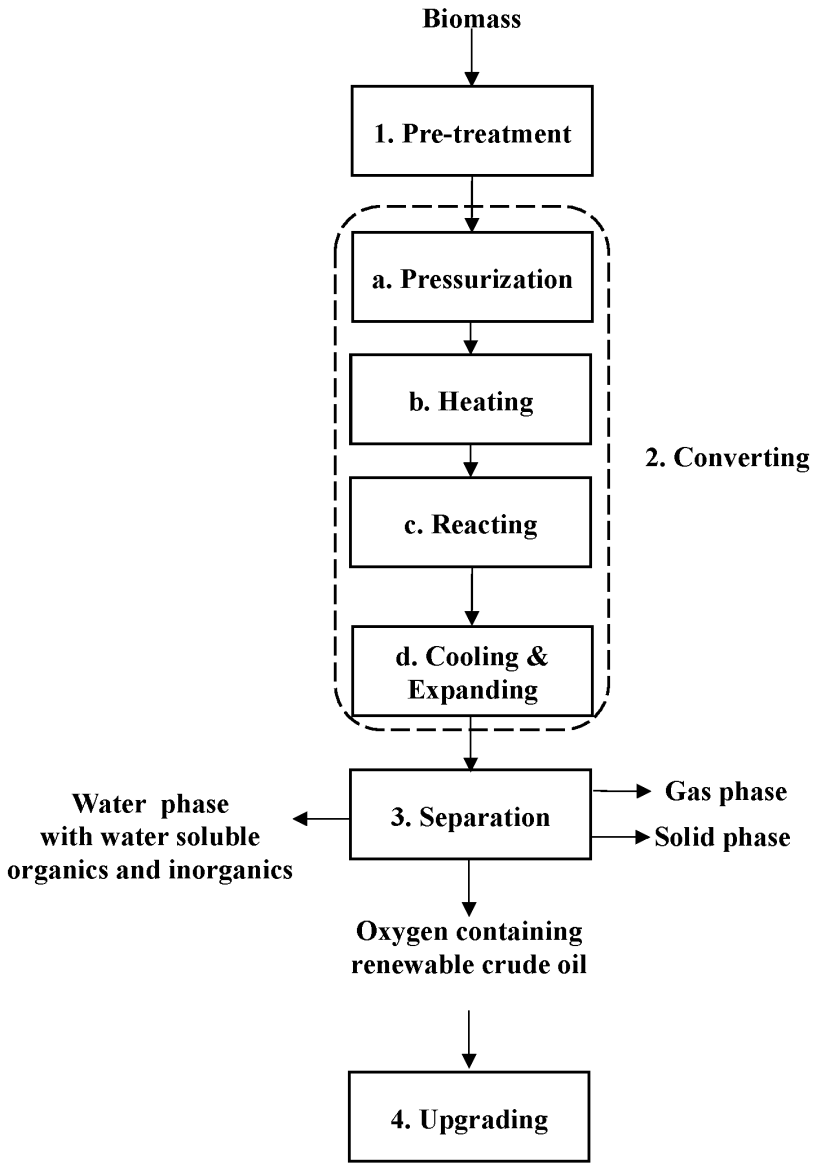

Biomass
1. Pre-treatment
a. Pressurization
b. Heating
c. Reacting
d. Cooling & Expanding
2. Converting
3. Separation
Water phase with water soluble organics and inorganics
Gas phase
Solid phase
Oxygen containing renewable crude oil
4. Upgrading

Fig. 1

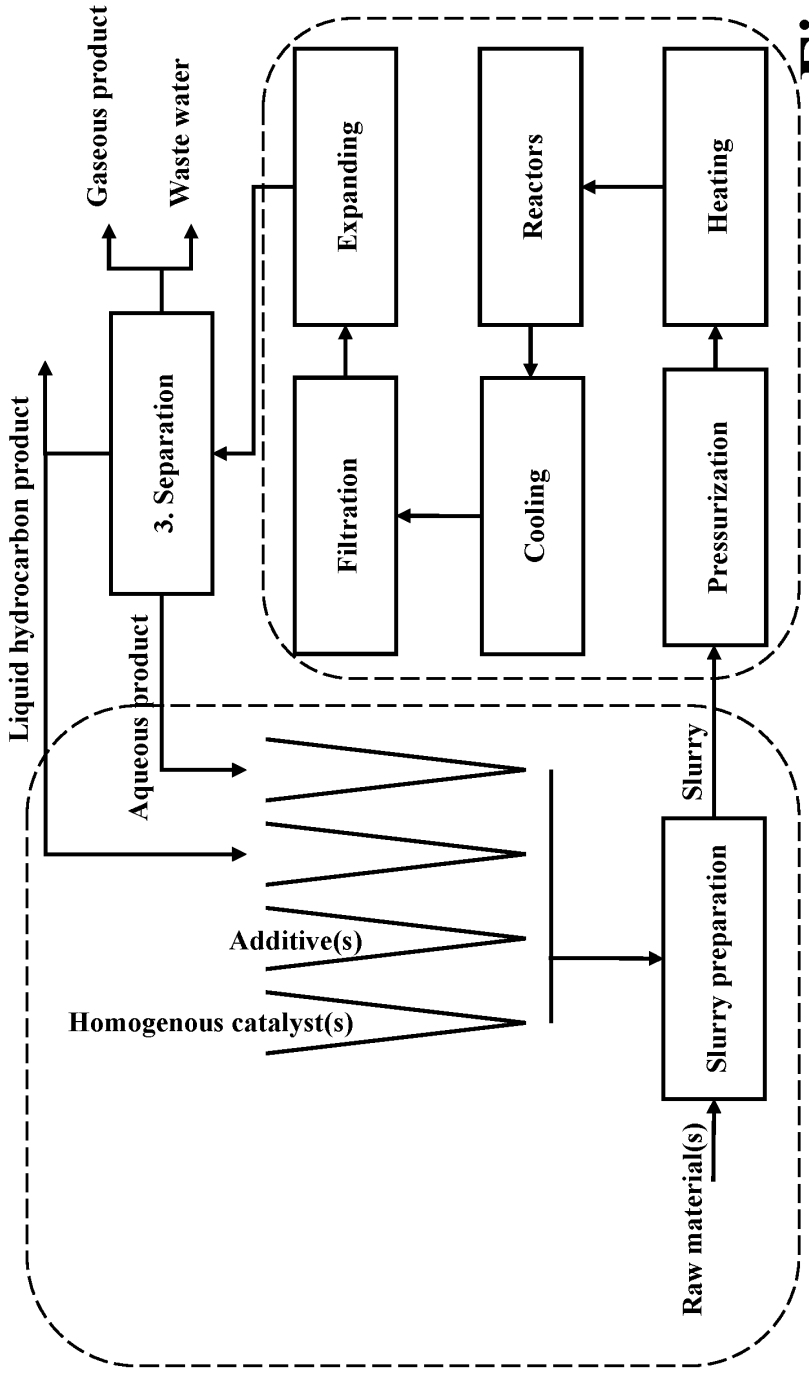

Gaseous product
Waste water
Expanding
Reactors
Heating
Liquid hydrocarbon product
3. Separation
Filtration
Cooling
Pressurization
2. Converting
Aqueous product
Slurry
Additive(s)
Homogenous catalyst(s)
Slurry preparation
Raw material(s)
1. Pretreatment

Fig. 2

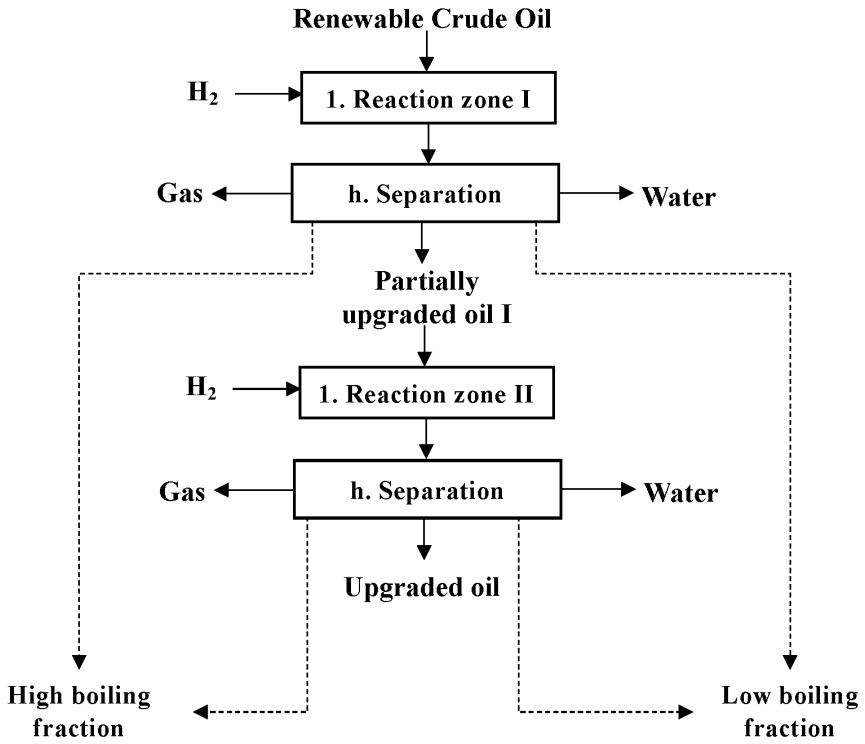

Renewable Crude Oil
H2
1. Reaction zone I
Gas
h. Separation
Water
Partially upgraded oil I
H2
1. Reaction zone II
Gas
h. Separation
Water
Upgraded oil
High boiling fraction
Low boiling fraction

Fig. 3

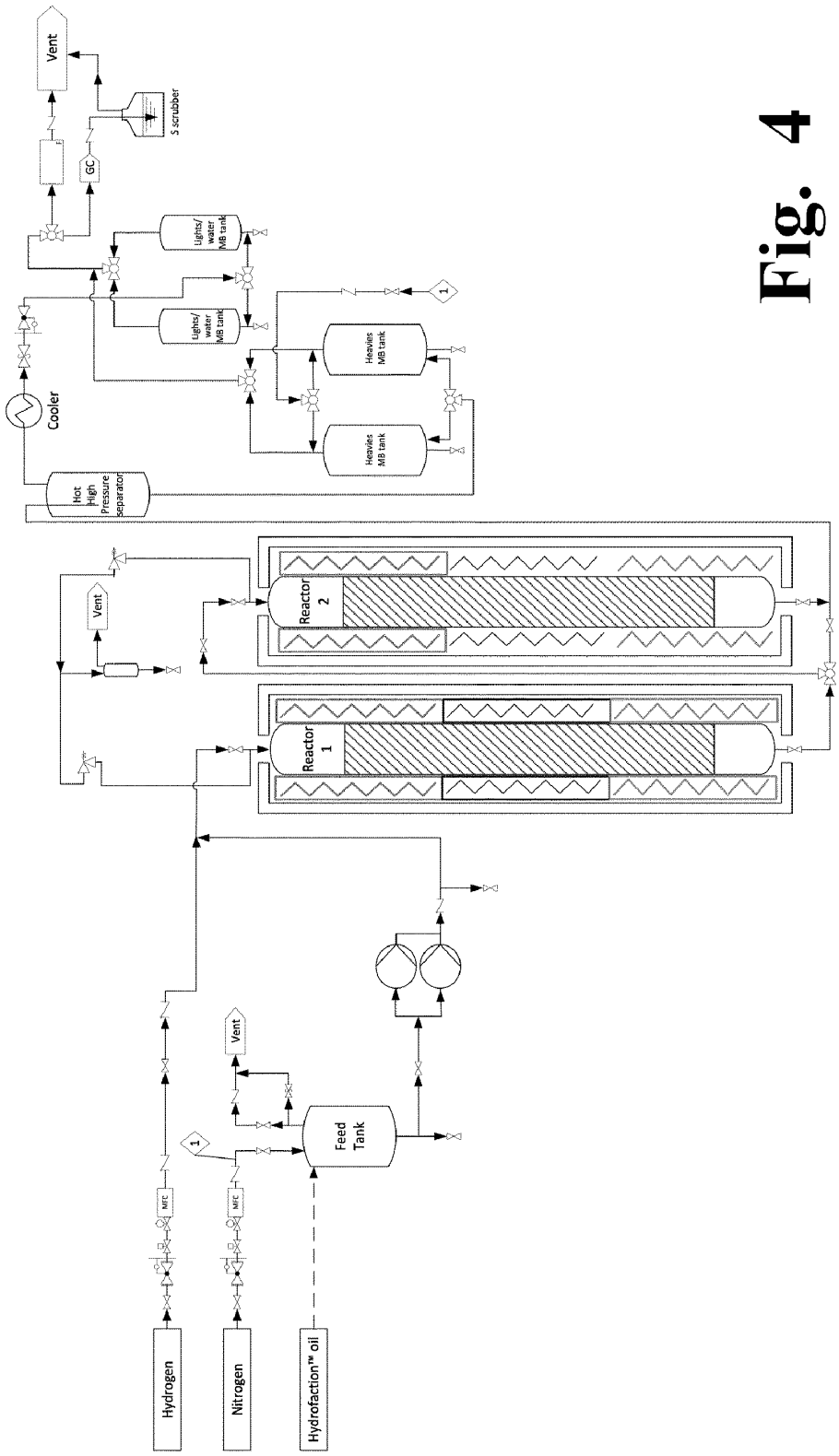

Vent
S scrubber
GC
Lights/ water MB tank
Lights/ water MB tank
Heavies MB tank
Heavies MB tank
Cooler
Hot High Pressure Separator
Vent
Reactor 2
Reactor 1
Vent
Feed Tank
MFC
MFC
Hydrogen
Nitrogen
Hydrofaction™ oil

Fig. 4

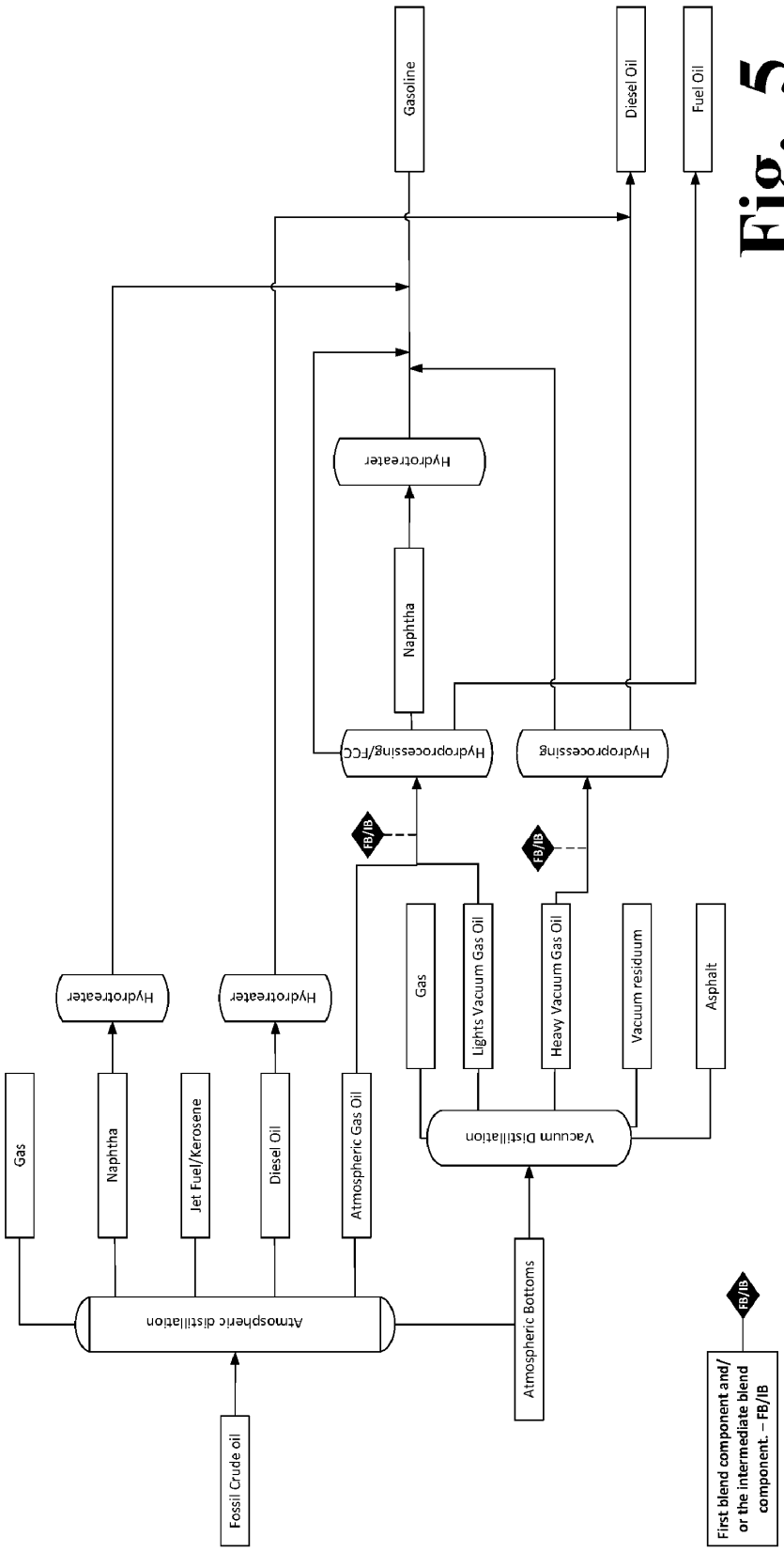

Gasoline
Diesel Oil
Fuel Oil
Hydrotreater
Naphtha
Hydroprocessing/FCC
Hydroprocessing
FB/IB
FB/IB
Hydrotreater
Hydrotreater
Gas
Lights Vacuum Gas Oil
Heavy Vacuum Gas Oil
Vacuum residuum
Asphalt
Gas
Naphtha
Jet Fuel/Kerosene
Diesel Oil
Atmospheric Gas Oil
Vacuum Distillation
Atmospheric distillation
Atmospheric Bottoms
Fossil Crude oil
FB/IB
First blend component and/ or the intermediate blend component. – FB/IB

Fig. 5

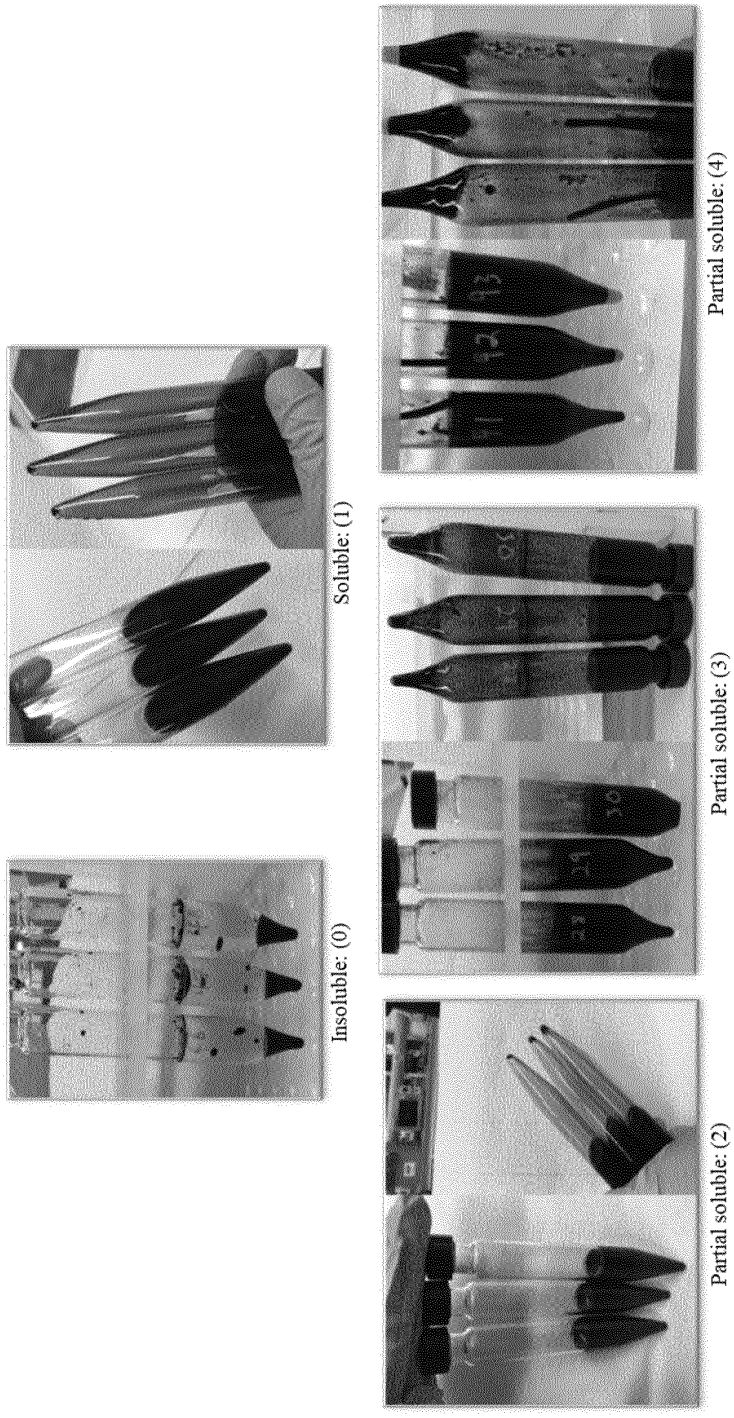

Insoluble: (0)
Soluble: (1)
Partial soluble: (2)
Partial soluble: (3)
Partial soluble: (4)

Fig. 6

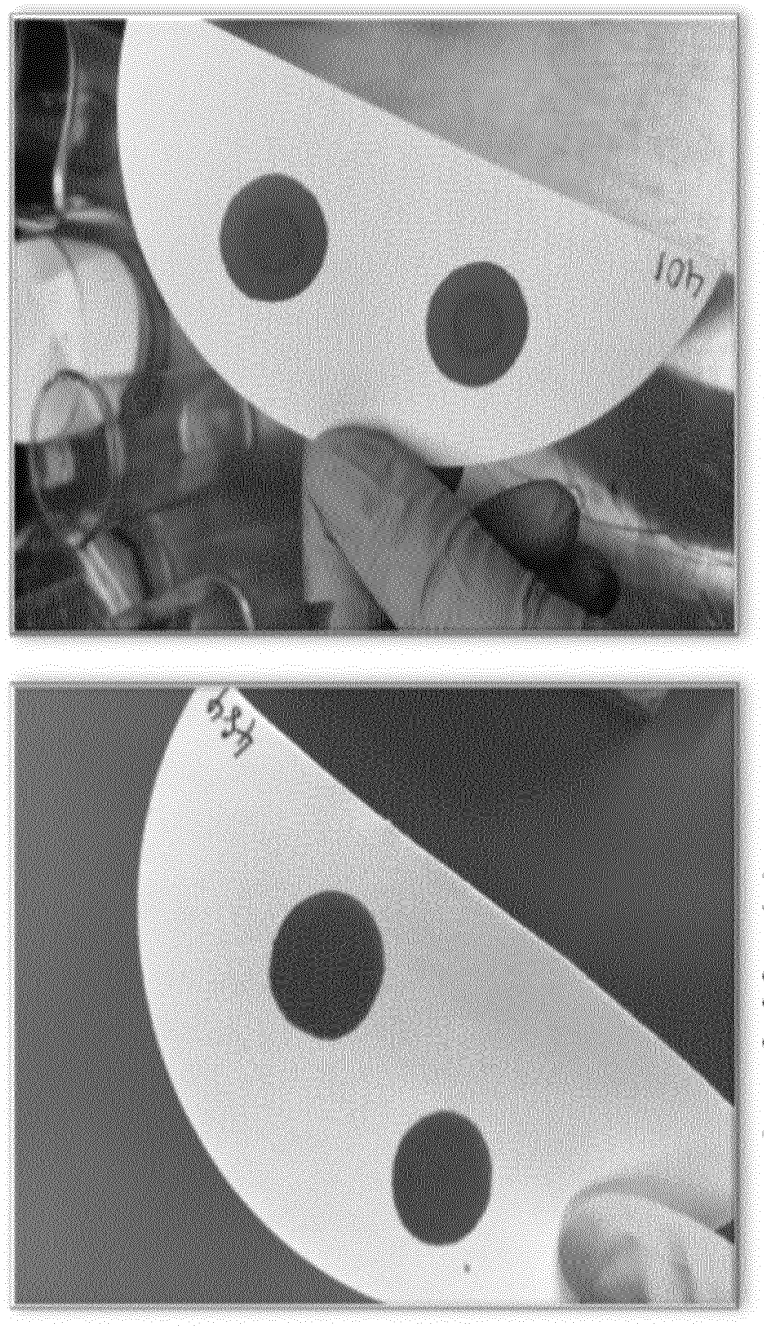


Fig. 7

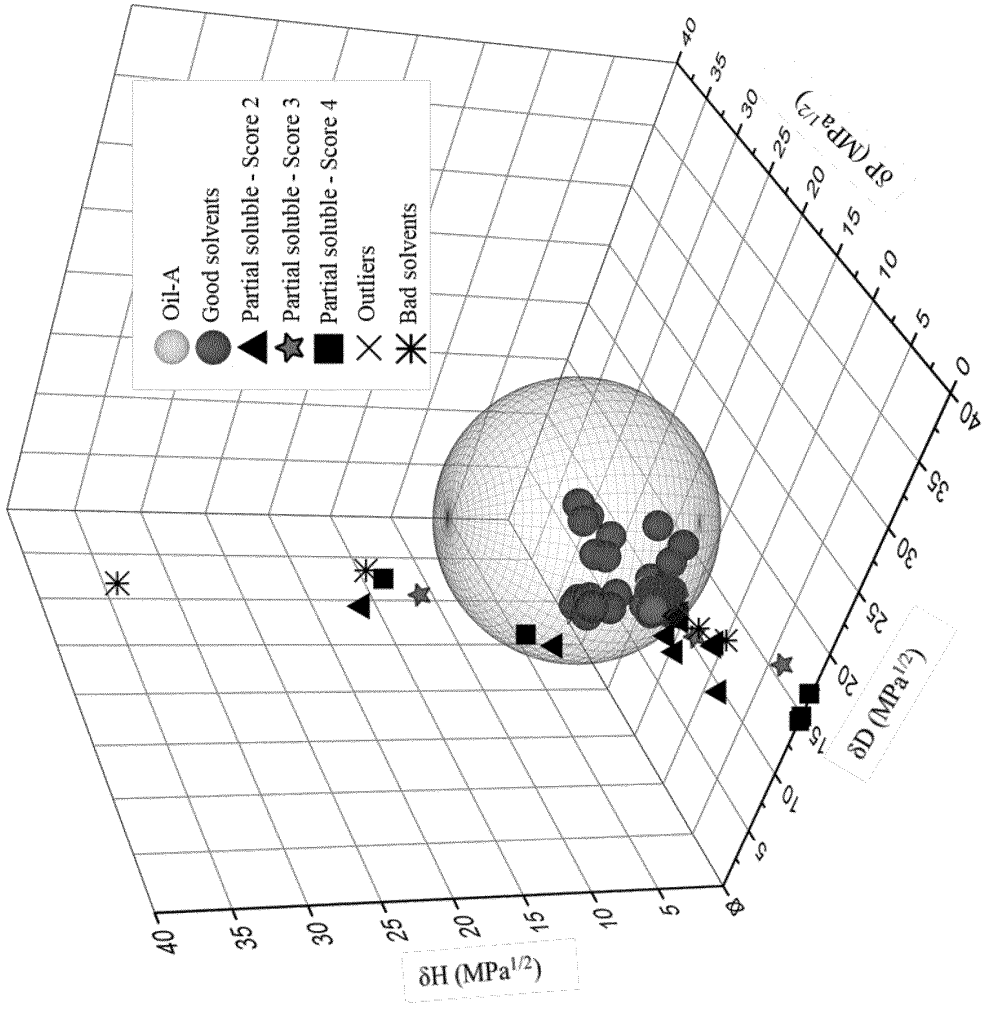

Oil-A
Good solvents
Partial soluble - Score 2
Partial soluble - Score 3
Partial soluble - Score 4
Outliers
Bad solvents
δH (MPa1/2)
δD (MPa1/2)
δP (MPa1/2)

Fig. 8

ANY REFERENCES TO FIGURES 8A, 8B AND 12A SHALL BE CONSIDERED NON-EXISTENT

	Solvents	Parameters [Mpa$^{1/2}$]			Oil A		Oil B		Oil C		Partially Upgraded Oil		Upgraded Oil		Fossil crude 2	
		δ_{DI}	δ_{PI}	δ_{HI}	Score	Red	Score	Red	Score	Red	Score	Red	Score	Red	Score	Red
1	Glycerol	17.4	11.3	27.2	0	1.754	0	2.578	0	2.662	0	3.015	-	-	-	-
2	Water	15.5	16	42.3	0	3.398	0	4.957	0	5.013	4	5.755	4	7.46	0	7.191
3	Hydrogen Peroxide	15.5	12.2	42.7	0	3.445	-	-	-	-	-	-	0	7.407	-	-
4	Acetylacetone	16.1	10	6.2	1	1.007*	1	0.889	1	0.749	1	0.983	1	0.73	2	1.136
5	Acetylchloride	16.2	11.2	5.8	1	0.964	1	0.913	1	0.797	1	0.998	-	-	-	-
6	m-Cresol	18.5	6.5	13.7	1	0.903	1	0.8	1	0.805	1	0.995	-	-	-	-
7	Cyclopentanone	17.9	11.9	5.2	1	0.794	1	0.77	1	0.688	1	0.829	1	0.978	1	0.999
8	Furfural	18.6	14.9	5.1	1	0.712	1	0.999	1	1	2	1.089	2	1.612	2	1.496
9	o-Methoxyphenol	18	7	12	1	0.849	1	0.598	1	0.558	1	0.753	1	0.978	2	1.514
10	1-Methyl Imidazole	19.7	15.6	11.2	1	0.166	1	0.886	2	1.038	2	1.001	-	-	2	2.142
11	Phenol	18.5	5.9	14.9	1	1.003*	1	0.99	1	1	2	1.214	-	-	3	1.037
12	Tricresyl Phosphate	19	12.3	4.5	1	0.802	1	0.896	1	0.842	-	-	-	-	-	-
13	Tetrahydrofurfuryl Alcohol	17.8	8.2	12.9	1	0.755	-	-	-	-	-	-	-	-	-	-
14	Acetaldehyde	14.7	12.5	7.9	2	1.066	-	-	-	-	-	-	-	-	-	-
15	Acetone	15.5	10.4	7	2	1.035	-	-	-	-	-	-	-	-	-	-
16	Acetonitrile	15.3	18	6.1	2	1.091	-	-	-	-	-	-	-	-	-	-
17	1-Butanethiol	16.3	5.3	4.5	2	1.397	-	-	-	-	2	1.477	-	-	1	0.83
18	1-Butanol	16	5.7	15.8	2	1.254	-	-	-	-	-	-	-	-	-	-
19	Diethyl Ether	14.5	2.9	4.6	2	1.773	-	-	-	-	-	-	-	-	-	-
20	Dimethyl Disulfide	17.6	7.8	6.5	2	0.970*	-	-	-	-	2	0.798*	1	0.252	1	0.64
21	Ethyl Acetate	15.8	5.3	7.2	2	1.318	-	-	-	-	2	1.345	-	-	3	1.178
22	Glycidyl Methacrylate	16.3	8.5	5.7	2	1.099	-	-	-	-	2	1.056	-	-	-	-
23	Methyl Ethyl Ketone - MEK	16	9	5.1	2	1.145	-	-	-	-	-	-	1	0.797	3	1.013
24	Methyl n-Amyl Ketone	16.2	5.7	4.1	2	1.401	-	-	-	-	2	1.495	1	0.998	-	-
25	Methylene Dichloride	17	7.3	7.1	2	1.029	-	-	-	-	-	-	1	0.235	1	0.827
26	Tetrahydrofuran	16.8	5.7	8	2	1.146	-	-	-	-	-	-	1	0.541	-	-
27	Lactic Acid (dl)	17	8.3	28.4	2	1.982	-	-	-	-	4	3.263	-	-	4	4.473
28	Hexanal	15.8	8.4	5.3	2	1.193	-	-	-	-	2	1.223	1	0.812	-	-
29	Anisole	17.8	4.4	6.9	3	1.236	-	-	-	-	-	-	-	-	-	-
30	Methanol	14.7	12.3	22.3	3	1.52	-	-	-	-	-	-	-	-	4	3.742

Fig. 9a

	Solvents	Parameters [Mpa$^{1/2}$]			Oil A		Oil B		Oil C		Partially Upgraded Oil		Upgraded Oil		Fossil crude 2	
		δ_{Dt}	δ_{Pt}	δ_{Ht}	Score	Red	Score	Red	Score	Red	Score	Red	Score	Red	Score	Red
31	Toluene	18	1.4	2	3	1.767	-	-	-	-	-	-	2	1.823	1	0.996
32	Cyclohexane	16.8	0	0.2	4	2.051	-	-	-	-	-	-	-	-	-	-
33	Ethylene Glycol	17	11	26	4	1.661	-	-	-	-	-	-	3	3.888	0	4.112
34	Hexane	14.9	0	0	4	2.201	-	-	-	-	-	-	3	2.517	0	1.858
35	Pentane	14.5	0	0	4	2.238	-	-	-	-	-	-	-	-	-	-
36	1-Propanol	16	6.8	17.4	4	1.243	-	-	-	-	-	-	-	-	-	-
37	1-Methyl Imidazole/ Tricresyl Phosphate 66/34	19.7	15.6	11.1	1	0.169	-	-	-	-	-	-	-	-	-	-
38	MEK/Ethylenglycol 90/10	16.1	9.2	7.2	1	0.996	-	-	-	-	-	-	-	-	-	-
39	Acetylacetone/Methanol 79/21	15.6	10.8	11.8	1	0.869	-	-	-	-	-	-	-	-	-	-
40	MEK/Methanol 70/30	15.5	10.4	12.2	1	0.91	-	-	-	-	-	-	-	-	-	-
41	1-Methyl imidazole/ Dichloromethane 57/43	17.9	12.6	10.6	1	0.362	-	-	-	-	-	-	-	-	-	-
42	MEK/ Ethylene Glycol 90/10	16.1	9.2	7.2	1	0.996	-	-	-	-	-	-	-	-	-	-
43	1-Methyl Imidazole/ Dimethyl carbonate 53/43	17.9	12.6	10.6	1	0.362	-	-	-	-	-	-	-	-	-	-
44	1-Methyl Imidazole/ Guaiacol 63/37	19.4	14.2	11.3	1	0.066	-	-	-	-	-	-	-	-	-	-
45	1-Methyl Imidazole/ Acetylacetone 61/39	19.3	14.9	10.6	1	0.119	-	-	-	-	-	-	-	-	-	-
46	MEK/Ethylenglycol 90/10	16.1	9.2	7.2	1	0.996	-	-	-	-	-	-	-	-	-	-
47	isopropyl acetate/ 1-Methyl imidazole 32/68	18.2	12	10.2	1	0.376	-	-	-	-	-	-	-	-	-	-
48	MEK/Ethanol 66/34	15.9	8.9	12.1	1	0.931	-	-	-	-	-	-	-	-	-	-
49	DCM/Acetone 53/47	16.3	8.8	7.1	2	0.999*	-	-	-	-	-	-	-	-	-	-
50	MEK/ Acetonitrile 57/43	15.7	12.9	5.5	2	1.012	-	-	-	-	-	-	-	-	-	-
51	MEK/DCM 42/58	16.6	8	6.3	2	1.061	-	-	-	-	-	-	-	-	-	-
52	Acetone/Toluene 40/60	17	5	4	2	1.392	-	-	-	-	-	-	-	-	-	-
53	Acetone/Toluene 60/40	16.5	6.8	5	2	1.236	-	-	-	-	-	-	-	-	-	-
54	Acetone/Toluene 80/20	16	8.6	6	2	1.113	-	-	-	-	-	-	-	-	-	-
55	Acetone/ethanol 77/23	15.6	10	9.9	2	0.930*	-	-	-	-	-	-	-	-	-	-
56	Toluene/Anisole 26/74	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.683
57	DCM/Toluene 51/49	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.56
58	MEK/m-cresol 66/34	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.952
59	Acetylacetone/m-Cresol 64/36	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1.116

Fig. 9b

Sample	Cycle	Start-up oil	Feedstock	Viscosity [cP]	HHV[b] [MJ/kg]	C[b] [wt.%]	H[b] [wt.%]	N[b] [ppm]	S[b] [ppm]	O[c] [wt.%]	H/C
Oil A	5	CTO[f]	Birch	813[a]	38.0	80.8	9.1	2635	215	9.8	1.34
Oil B[d]	5	CTO[f]	Pine EW	14214[a]	37.6	80.5	9.4	-	-	10.1	1.39
Oil C[d]	5	CTO[f]	Pine EW	35218[a]	37.5	80.6	9.3	-	-	10.1	1.37
Partially Upgraded Oil - PUP	-	-	-	34[e]	43.3	88.6	13.4	424	764	0.26	1.84
Heavy fraction - PUO	-	-	-	6757[g]	42.4	90.5	9.6	-	-	0	1.26
Upgraded Oil - UO	-	-	-	-	44.3	87.4	12.7	0.8	-	0.0	1.72
Heavy Fraction - UO	-	-	-	-	43.1	89.4	10.6	-	-	0.0	1.42

/ at 40°C; [e] Viscosity at 20°C; [g] Viscosity at 50°C
asis
ence
g process performed at 3rd and 5th cycle – HTL process

Fig. 10

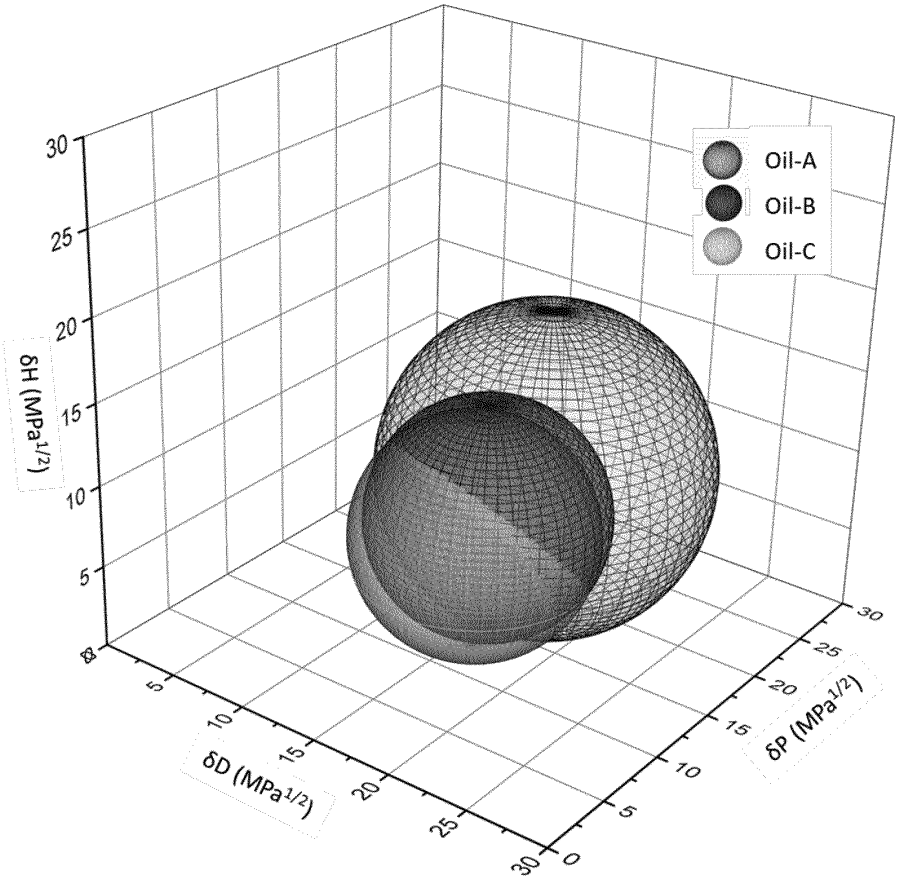


Fig. 11

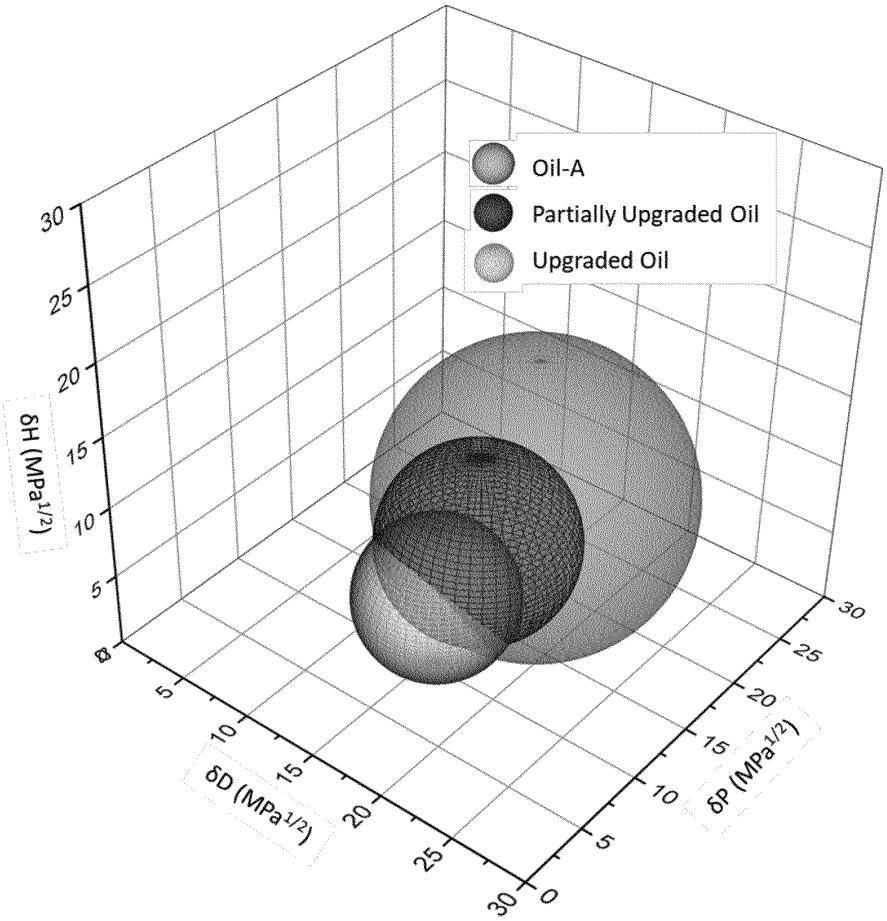

Oil-A
Partially Upgraded Oil
Upgraded Oil
δH (MPa1/2)
δD (MPa1/2)
δP (MPa1/2)
0
5
10
15
20
25
30

Fig. 12

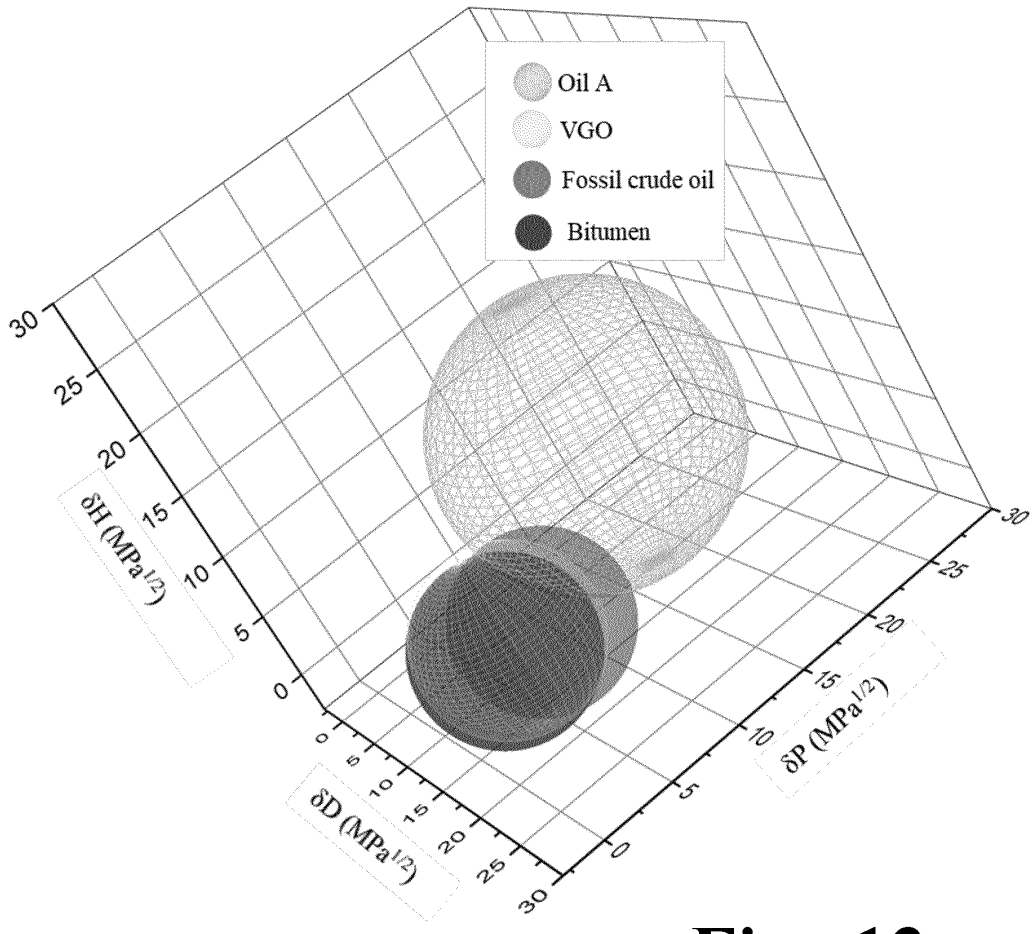

Oil A
VGO
Fossil crude oil
Bitumen
δH (MPa1/2)
δD (MPa1/2)
δP (MPa1/2)
0
5
10
15
20
25
30

Fig. 13a

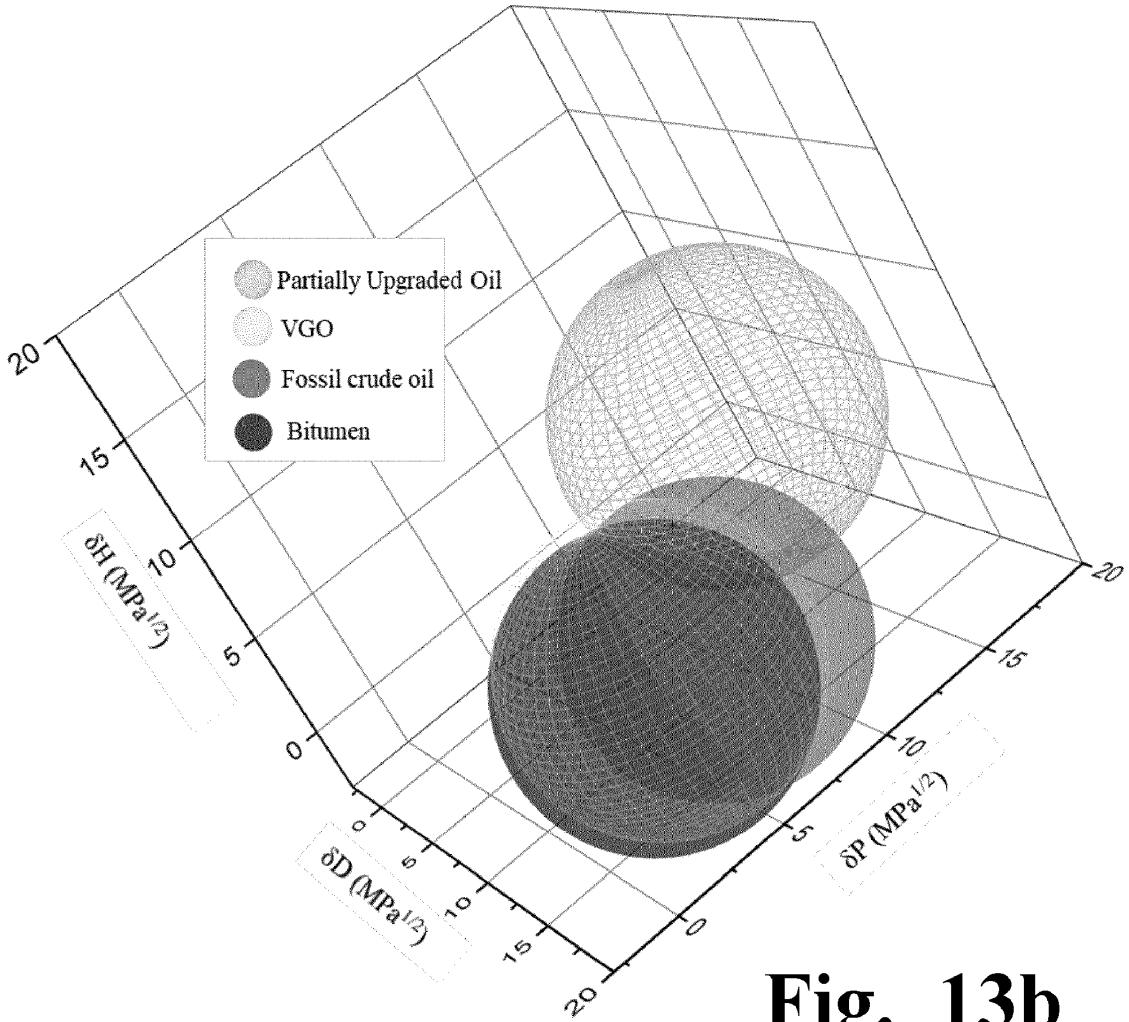

Partially Upgraded Oil
VGO
Fossil crude oil
Bitumen
δH (MPa1/2)
δD (MPa1/2)
δP (MPa1/2)
0
5
10
15
20

Fig. 13b

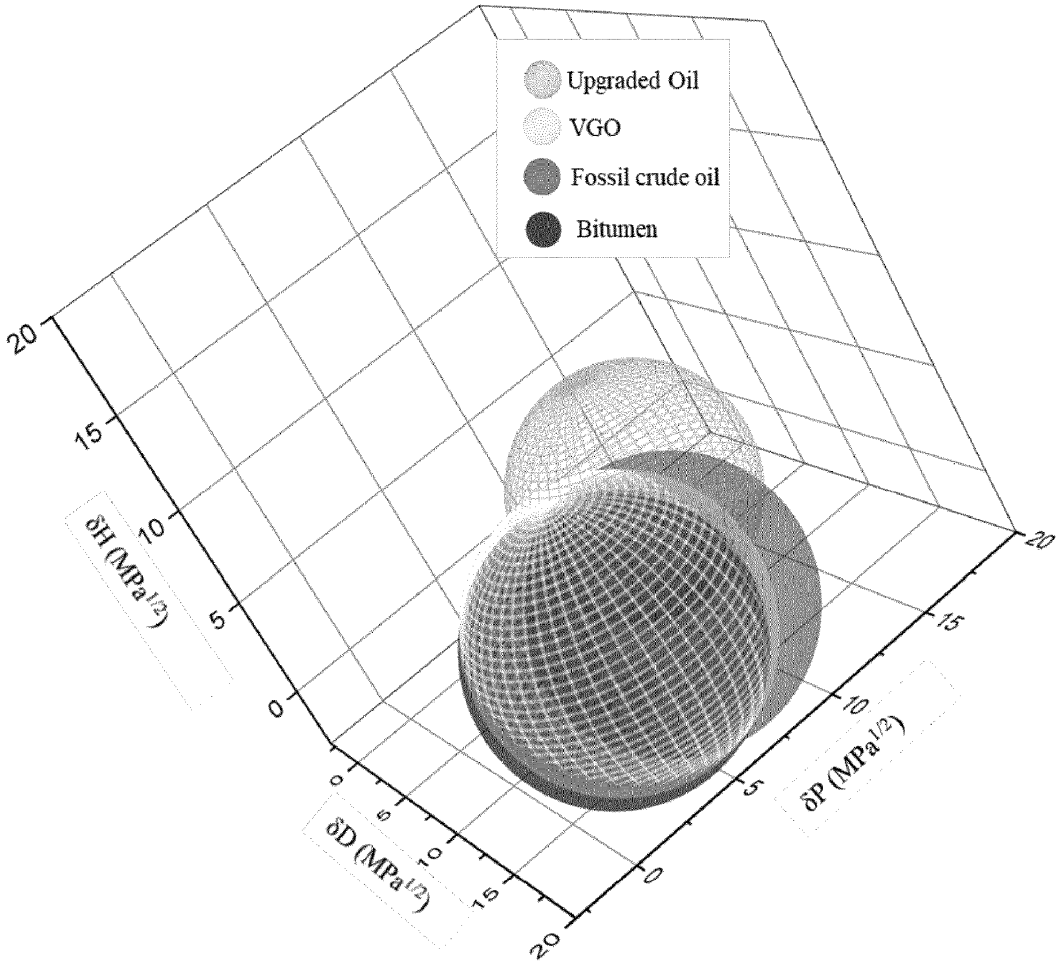

Upgraded Oil
VGO
Fossil crude oil
Bitumen
δH (MPa1/2)
δD (MPa1/2)
δP (MPa1/2)
0
5
10
15
20

Fig. 13c

Sample	δ_D [MPA$^{1/2}$]	δ_P [MPA$^{1/2}$]	δ_H [MPA$^{1/2}$]	R_0	Wrong in[b]	Wrong out[c]	Data fit[d]
Oil A	19.19	14.52	11.61	9.3	3	2	0.965
Oil B	18.36	10.43	10.06	6.7	0	0	1.000
Oil C	18.13	9.59	9.24	6.8	0	0	1.000
Partially Upgraded Oil - PUO	17.95	10.96	9.96	5.9	1	3	0.646
Heavy fraction - PUO	17-19	7.5-12	7-10	5-9	-	-	-
Upgraded Oil - UO	17.36	8.01	7.59	4.8	0	0	1.000
Heavy Fraction - UO	17-19	7-9.5	7-10.5	4-8	-	-	-
Fossil Crude oil I	18.47	6.67	3.58	5.6	0	0	1.000
Fossil Crude oil II[a]	17.7	4.0	0.6	9.3	3[e]	-	0.936
Bitumen[a]	18.4	3.9	3.6	5.76	3[e]	-	0.980
VGO	19.1-19.4	3.4-4.2	4.2-4.4	4-6	-	-	-
ULSFO	18-19.7	3-6	3-4.5	4-6.5	-	-	-
HSFO	18-19.7	3-6	3-6	4-6	-	-	-

[a] P. Redelius, "Bitumen solubility model using hansen solubility parameter," *Energy and Fuels*, vol. 18, no. 4, pp. 1087–1092, 2004
[b] Solvents that do not dissolve the solute but are inside the sphere
[c] Solvents that dissolve the solute but are outside the sphere
[d] Fit accuracy
[e] Outliers

Fig. 14

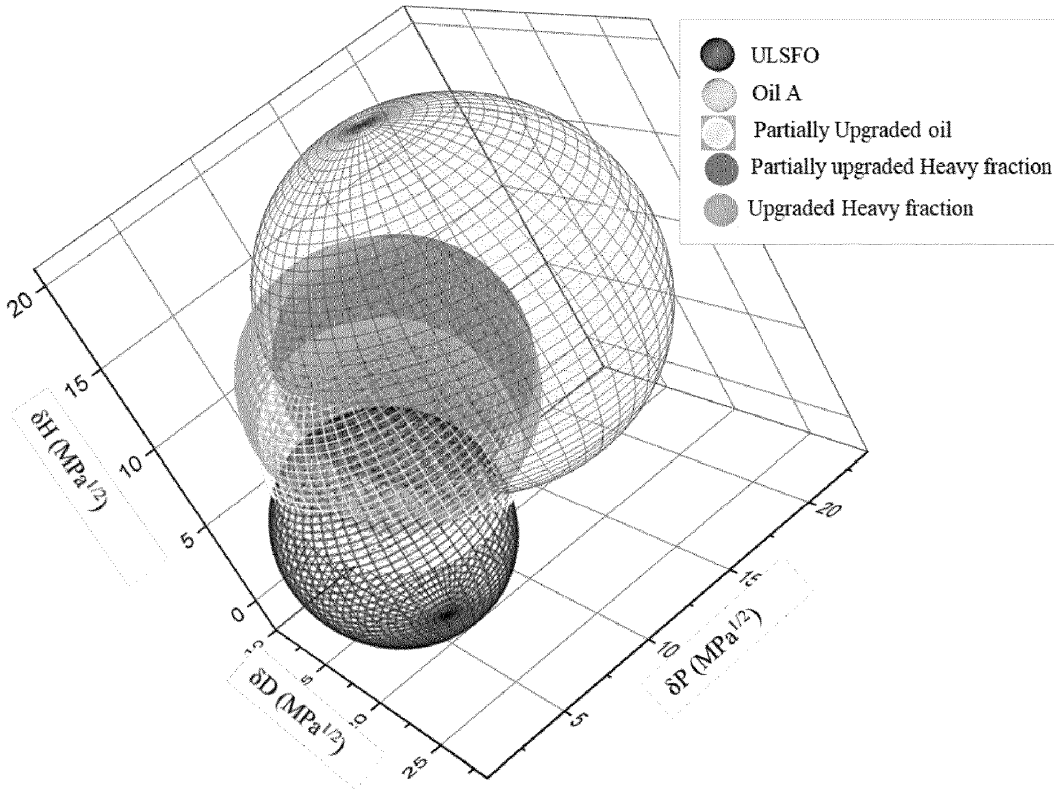

ULSFO
Oil A
Partially Upgraded oil
Partially upgraded Heavy fraction
Upgraded Heavy fraction
δH (MPa1/2)
δD (MPa1/2)
δP (MPa1/2)

Fig. 15a

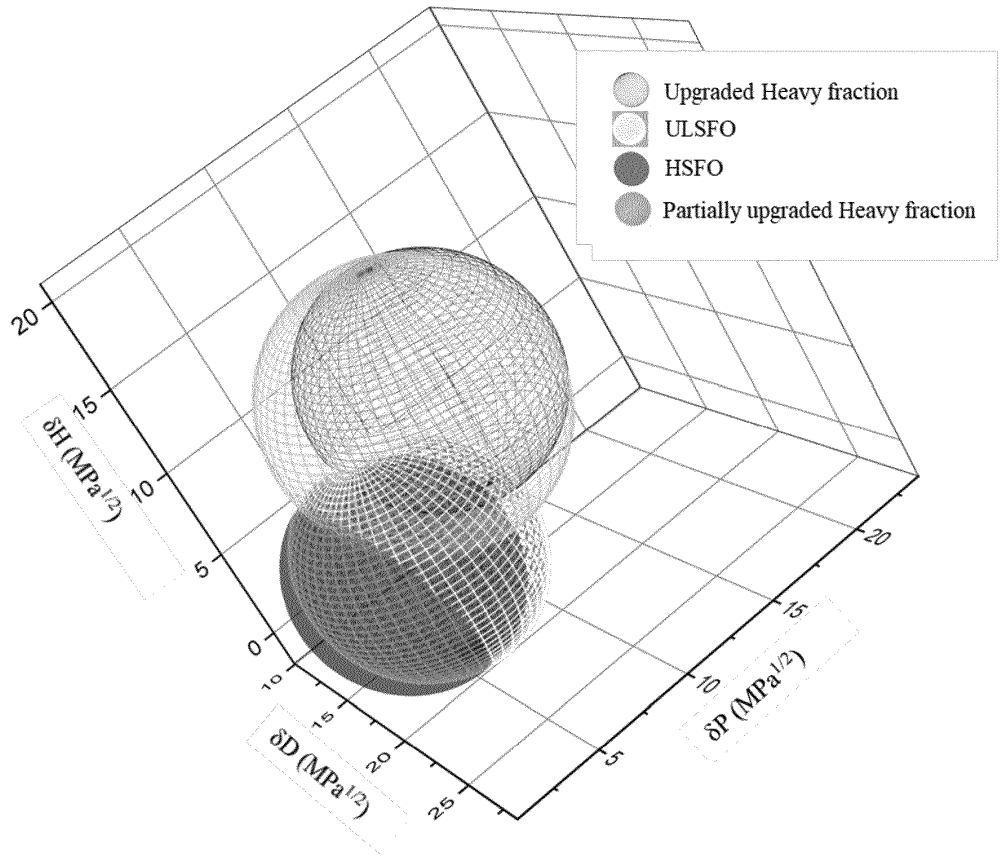
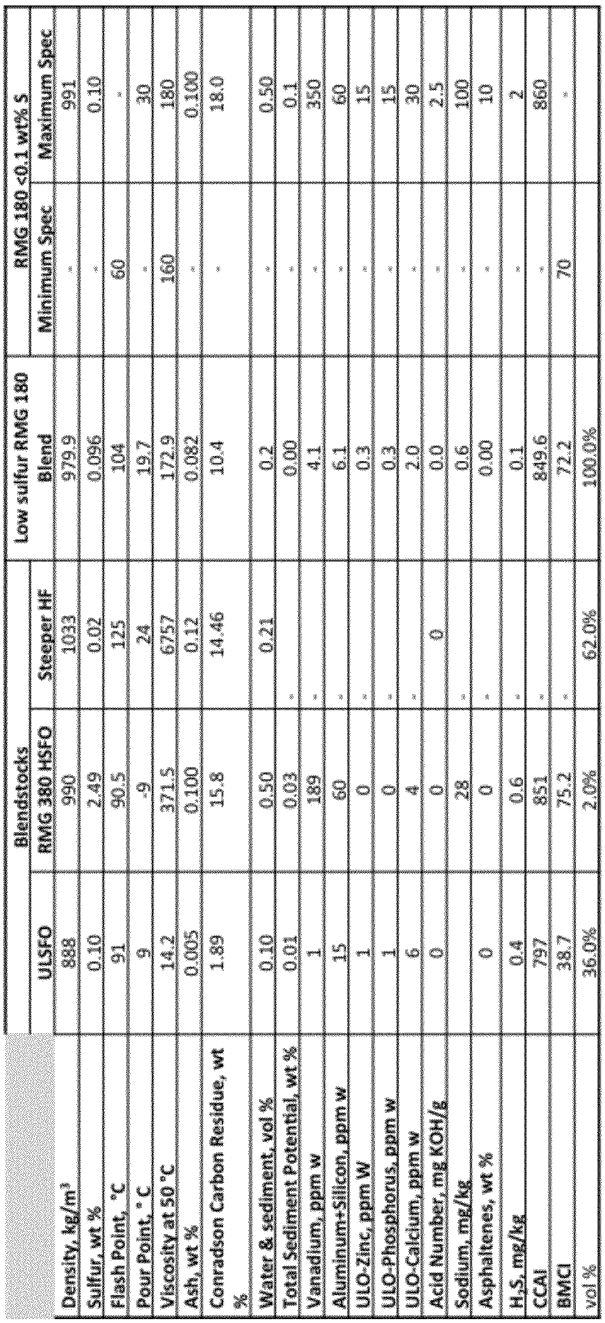

Upgraded Heavy fraction
ULSFO
HSFO
Partially upgraded Heavy fraction
δH (MPa1/2)
δD (MPa1/2)
δP (MPa1/2)

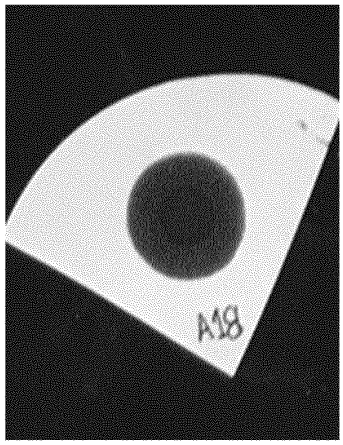
Fig. 15b



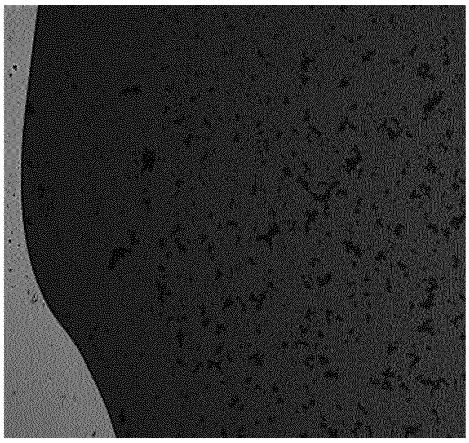
	Blendstocks			Low sulfur RMG 180	RMG 180 <0.1 wt% S	
	ULSFO	RMG 380 HSFO	Steeper HF	Blend	Minimum Spec	Maximum Spec
Density, kg/m³	888	990	1033	979.9	-	991
Sulfur, wt %	0.10	2.49	0.02	0.096	-	0.10
Flash Point, °C	91	90.5	125	104	60	-
Pour Point, ° C	9	-9	24	19.7	-	30
Viscosity at 50 °C	14.2	371.5	6757	172.9	160	180
Ash, wt %	0.005	0.100	0.12	0.082	-	0.100
Conradson Carbon Residue, wt %	1.89	15.8	14.46	10.4	-	18.0
Water & sediment, vol %	0.10	0.50	0.21	0.2	-	0.50
Total Sediment Potential, wt %	0.01	0.03	-	0.00	-	0.1
Vanadium, ppm w	1	189	-	4.1	-	350
Aluminum+Silicon, ppm w	15	60	-	6.1	-	60
ULO-Zinc, ppm W	1	0	-	0.3	-	15
ULO-Phosphorus, ppm w	1	0	-	0.3	-	15
ULO-Calcium, ppm w	6	4	-	2.0	-	30
Acid Number, mg KOH/g	0	0	0	0.0	-	2.5
Sodium, mg/kg		28	-	0.6	-	100
Asphaltenes, wt %	0	0	-	0.00	-	10
H_2S, mg/kg	0.4	0.6	-	0.1	-	2
CCAI	797	851	-	849.6	-	860
BMCI	38.7	75.2	-	72.2	70	-
vol %	36.0%	2.0%	62.0%	100.0%		

Fig. 16

50 wt.% HFPUO (3% Oxygen)/ 50 wt.% MGO

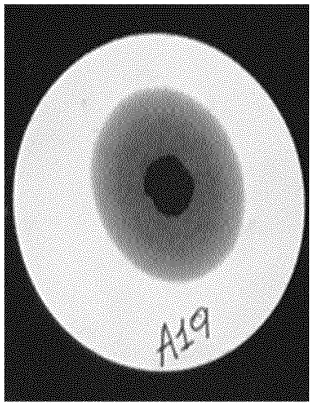


Incompatible by spot test

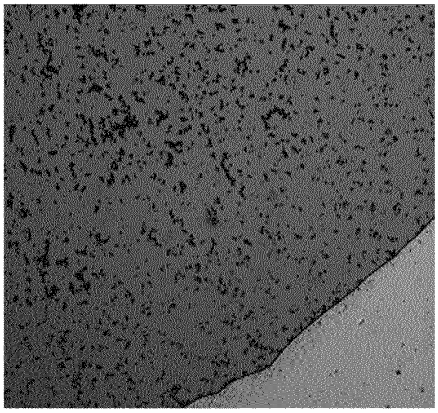


Solids by Microscope

25 wt.% HFPUO (3 Oxygen)/ 75 wt.% MGO



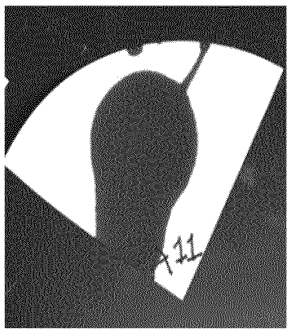
Incompatible by spot test



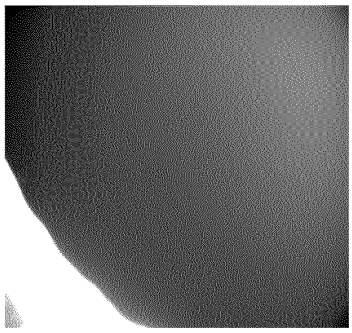
Solids by Microscope

Fig. 17

a. 50 wt.% HFPUO (3% Oxygen)/50 wt.% HSFO



Compatible by spot test

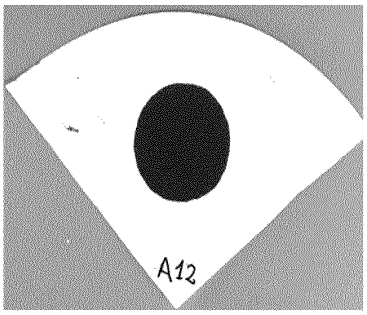


Compatible by Microscope



Suitable for Marine blend stock

b. 25 wt.% HFPUO (3% Oxygen)/ 75 wt.% HSFO



spot test



Compatible by Microscope



Suitable for Marine blend stock

Fig. 18