

**Treatment of Oil-Contaminated Soil from Kuwaiti Dry Oil Lakes:Development  
of a New Processing Technology**

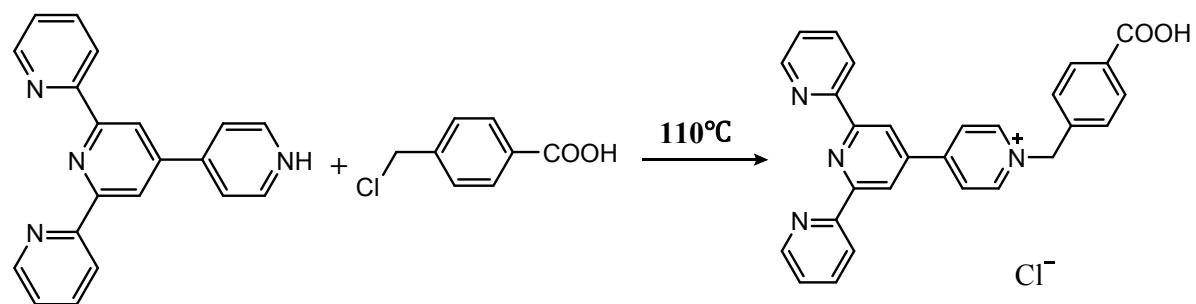
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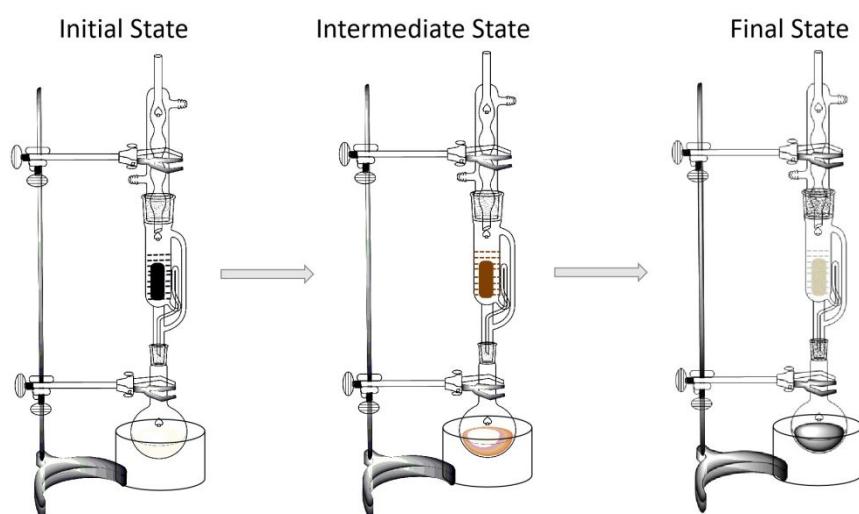
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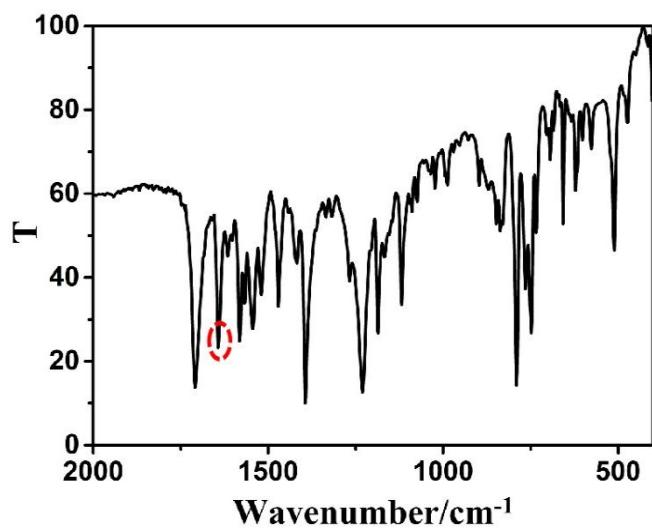
**Fig. S1.** The synthesis process of L-COOH-Cl by molecular formula expression



**Fig. S2.** Soxhlet extraction of oil-contaminated soil

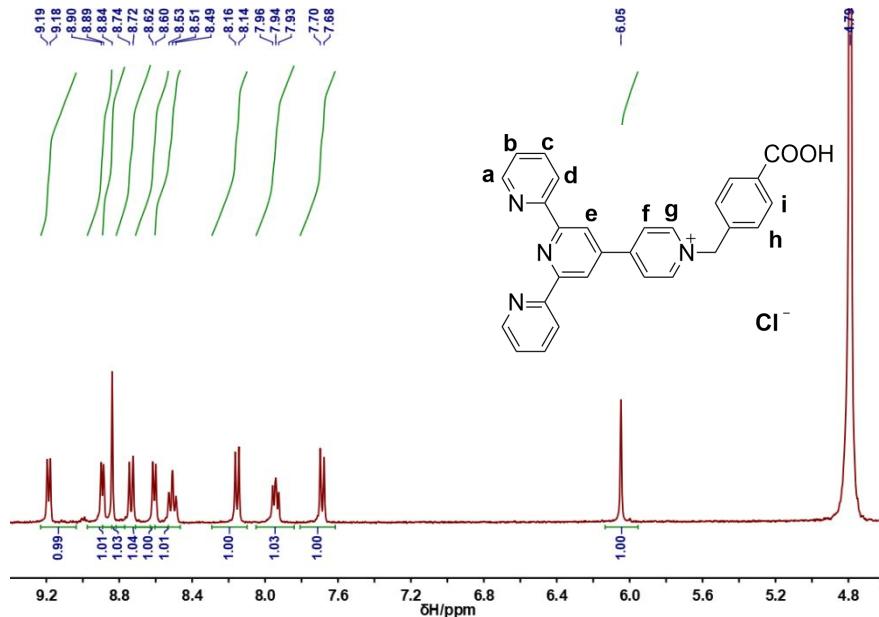


**Fig. S3.** FTIR spectra of the L-COOH-Cl



The IR spectrum of L-COOH-Cl was characterized by the C≡N bond stretching vibration of the pyridinium ring at  $\sim 1637 \text{ cm}^{-1}$ , the COOH bond stretching at  $\sim 1699 \text{ cm}^{-1}$ .

**Fig. S4.  $^1\text{H}$  NMR spectra of L-COOH-Cl in  $\text{D}_2\text{O}$**



$^1\text{H}$  NMR( $\text{D}_2\text{O}$ , ppm) 9.19 (2H, d,  $j = 4.0$ , H<sub>g</sub>), 8.90 (2H, d,  $j = 4.0$ , H<sub>f</sub>), 8.84 (2H, s, H<sub>e</sub>), 8.73 (2H, d,  $j = 8.0$ , H<sub>d</sub>), 8.61 (2H, d,  $j = 8.0$ , H<sub>a</sub>), 8.51 (2H, t,  $j = 16.0$ , H<sub>c</sub>), 8.15 (2H, d,  $j = 4.0$ , H<sub>i</sub>), 7.94 (2H, t,  $j = 12.0$ , H<sub>b</sub>), 7.69 (2H, d,  $j = 8.0$ , H<sub>h</sub>), 6.05 (2H, s, -CH<sub>2</sub>-)

**Table S1. Contaminated soil basic characteristics at various contaminated sites**

Contaminated Site	Average Depth (cm)	Area ( $\text{km}^2$ )	Volume ( $\text{m}^3$ )
Wet oil lake	64	7.19	$4.6 \times 10^6$
Dry oil lake	25	98.38	$24.5 \times 10^6$
Oil mound	173	8.59	$14.8 \times 10^6$
Oil ditch	351	1.63	$5.7 \times 10^6$

**Table S2. Property analysis of oil-contaminated soils**

Items	Oily sludge	Oily soil
Phase composition		
Water/wt (%)	0	0
Oil/wt (%)	24.8	4.52
Solid particles/wt(%)	75.2	95.48
SARA analysis/wt(%)		
saturates	18.63	12.33
Aromatics	23.12	25.85
Resins	32.82	33.98
Asphaltenes	25.43	27.84
Elemental content/wt(%)		
C	86.38	85.98
H	4.53	6.76
O	4.62	3.02
N	0.46	0.28
S	4.01	3.96
Density/g•cm <sup>-3</sup> (20°C)	1.08	1.13
Viscosity/ mm <sup>2</sup> •s <sup>-1</sup> (80°C)	4502.4	4674.8
Calorific value/ kJ•kg <sup>-1</sup>	34,906	37,740
pH	7.83	7.51

**Table S3. Particle size distribution and mineral composition of dry lake samples**

Particle size/ $\mu\text{m}$	Oily sludge	Oily soil	Oily sludge	Oily soil
	Content/wt%		Mineral composition	
>600	35.42	34.74	Quartz	Quartz
325-600	16.57	14.03	Feldspar	Feldspar
120-325	13.52	10.65	Mica	Mica
44-120	14.38	14.92	Palygorskite	Palygorskite
38-44	10.84	13.21	Halite	Calcite
<38	9.27	12.45		Muscovite

**Table S4. Reaction parameters of countercurrent extraction processes**

Item	Reaction rate constant k (min <sup>-1</sup> )		Activation energy Ea (kJ mol <sup>-1</sup> )
	308.15K	318.15K	
Oily sludge	0.040	0.056	27.425
Oily soil	0.018	0.034	51.839

**Table S5. Analysis and comparison of HEO, TEO and CEO from oily sludge**

Items	HEO	TEO	CEO
SARA analysis/wt(%)			
Saturates	52.99	20.74	22.86
Aromatics	30.62	25.89	26.05
Resins	14.85	30.96	29.71
Asphaltenes	1.54	22.41	21.38
Elemental content/wt(%)			
C	80.68	84.15	83.34
H	11.74	7.62	9.58
O	2.97	4.37	4.25
N	0.23	0.40	0.51
S	4.38	3.46	2.32
Density/g•cm <sup>-3</sup> (20°C)	0.9688	1.02	0.9978
Viscosity/ mm <sup>2</sup> •s <sup>-1</sup> (80°C)	954.12	3762.3	2458.6
Calorific value/ kJ•kg <sup>-1</sup>	42,250	37,998	40,074

**Table S6. Analysis and comparison of HEO, TEO and CEO from oily soil**

Items	HEO	TEO	CEO
SARA analysis/wt(%)			
Saturates	37.85	14.08	16.53
Aromatics	41.85	27.94	30.24
Resins	19.44	32.86	30.08
Asphaltenes	0.86	25.12	23.15
Elemental content/wt(%)			
C	80.36	84.76	83.55
H	12.08	8.43	9.92
O	2.47	2.84	3.22
N	0.19	0.24	0.76
S	4.90	3.73	2.75
Density/g•cm <sup>-3</sup> (20°C)	0.9754	1.03	0.9996
Viscosity/ mm <sup>2</sup> •s <sup>-1</sup> (80°C)	1361.48	3804.2	2944.5
Calorific value/ kJ•kg <sup>-1</sup>	42,680	39,419	40,732