

## 1 **Support Information**

2 The basic chemical characteristics of Indulin AT<sup>TM</sup> are shown in **Table S1, S2, and S3**

3 [1]. More details can be found in the paper written by Hu, et al..

### 4 **Preparation of catalysts**

5 The S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-K<sub>2</sub>O/TiO<sub>2</sub> catalyst was prepared by the impregnation method. To prepare the  
6 catalyst which contained 40 wt% S<sub>2</sub>O<sub>8</sub><sup>2-</sup> and 40 wt% K<sub>2</sub>O, 1 g of TiO<sub>2</sub>, 0.8586 g of KNO<sub>3</sub>  
7 and 0.4754 g of (NH<sub>4</sub>)<sub>2</sub>S<sub>2</sub>O<sub>8</sub> were added to 50 mL distilled water. The mixture was stirred  
8 at 400 rpm for 48 h and then dried in an oven at 105 °C. After that, the catalyst was  
9 calcined at 550 °C for 3 h in a tube furnace under air atmosphere in order to remove the  
10 precursor. After grinding, the catalyst was stored in a dessicator before use. The S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-  
11 K<sub>2</sub>O/TiO<sub>2</sub> modified by 5%Ni was prepared by the same method with an additional step of  
12 adding 0.2477 g Ni(NO<sub>3</sub>)<sub>2</sub>·6H<sub>2</sub>O to the distilled water.

### 13 **Calculation of the volume ratio of the solvent**

14 The volume ratio of the solvent was calculated through solubility coefficients. The  
15 solubility coefficient of Indulin AT is about 12 and other solubility coefficients can be  
16 easily got from open published literatures. According to the amount of substance of the  
17 two solvents (n<sub>A</sub> and n<sub>B</sub>), we can make the solubility coefficient of the mixed solvent  
18 equal 12. Then, we can get the volume ratio of the two solvents. The formula was as  
19 below:

20 
$$n_A \times SC_A + n_B \times SC_B = 12 \quad (1)$$

21 
$$n_A + n_B = 1 \quad (2)$$

22  $SC_A$  and  $SC_B$  were the solubility coefficients of the two solvents.

23  $n_A$  and  $n_B$  were the variables of amount of substance of the two solvents.

#### 24 **Depolymerization of lignin**

25 Before the reaction, four kinds of solvents namely 30 mL 1,4-dioxane and 1 mL  
26 distilled water, 30 mL 1,4-dioxane and 6 mL methanol, 30 mL 1,4-dioxane and 0.5 mL  
27 tetrahydrofuran or 30 mL 1,4-dioxane and 3 mL formic acid were respectively prepared.  
28 The volume ratio of two solvents was calculated by dielectric constant. The  
29 depolymerization reaction was conducted in a stainless steel autoclave reactor. 0.5 g of  
30 lignin was first dissolved in a solvent under ultrasonic condition and 0.2 g of the catalyst  
31 was added. The resulting mixture was transferred into the reactor. After passing a leak test  
32 and completely purging out the air from the reactor, the reactor was pressurized to 4.0  
33 MPa with  $H_2$ . The reactor was then heated to the reaction temperature for various times  
34 (1 h, 6 h, 12 h, 24 h) under stirring at 900 rpm. The effects of different reaction times,  
35 reaction temperatures, solvents and catalysts on lignin depolymerization were  
36 investigated. At the end of a specified reaction time, the reactor was cooled down by  
37 immersion in cold water, and the residual solid was separated from the liquid product by  
38 filtration. For the liquid product, a tiny aliquot was set aside for GC and GC/MS analysis.

39 The monomers in liquid product were identified on a gas chromatography/mass  
40 spectrometry (GC/MS, QP2010S, Shimadzu, Japan) equipped with an Rtx-5MS column

41 (30 m×25 mm×0.25 μm). The oven temperature was programmed as 40 °C held for 3  
42 min, ramped up to 180 °C with 4 °C/min and then to 260 °C with 10 °C /min. At last it  
43 was held for another 10 min. Helium was the carrier gas. Quantitative analysis of the  
44 monomer products was determined by GC-2010 gas chromatograph with a FID and a  
45 WondaCAP5 column. The oven temperature was held at 50 °C for 3 min, ramped up to  
46 250 °C at 10 °C/min and then held for another 10 min. The yield was calculated by using  
47 acetophenone as an internal standard. The details of the internal standard method was  
48 shown in SI.

49 All the reactions were done 3 times for the standard deviation analysis and get the  
50 error bar.

51 The C, H, O, N and S contents (wt%) in the liquid product were measured by an  
52 element analyzer (VarioELIII). The higher heating value (HHV) of the samples was  
53 calculated by the Dulong's formula [45-46]:

$$54 \quad \text{HHV (MJ/kg)} = 0.335 \times C + 1.428 \times (H - O/8) - 0.145 \times N + 0.095 \times S$$

55 where C, H, O, N and S represent the weight percentages of carbon, hydrogen, oxygen,  
56 nitrogen and sulphur respectively.

57 The liquid product was evaporated in a rotary evaporator at 40 °C, and was weighed  
58 and dissolved in 1 mL of acetone. The solution was then added dropwise into 200 mL  
59 petroleum ether with stirring at 400 rpm for 5 min. The sediment formed was separated  
60 from the supernatant by centrifuging at 10000 rpm for 5 min. The supernatant was  
61 evaporated with rotary evaporator at 40 °C. The remaining part of solution was weighed.

62 The yields of the liquid product, solid product, gas product, and PE-soluble product  
63 were calculated as follows:

64  $\% \text{ Yield of liquid product} = W_{LP}/W_L \times 100$

65  $\% \text{ Yield of solid product} = (W_R - W_C)/W_L \times 100$

66  $\% \text{ Yield of gas product} = 100 - \text{Yield of liquid product} - \text{Yield of solid product}$

67  $\% \text{ Yield of petroleum ether soluble} = W_P/W_L \times 100$

68  $W_{LP}$ : the weight of the liquid product

69  $W_P$ : the weight of the PE-soluble product

70  $W_R$ : the weight of the residual solid

71  $W_L$ : the weight of the lignin (Indulin AT)

72  $W_C$ : the weight of the catalyst

73

74 **TABLE S1.** Component compositions of Indulin AT<sup>TM</sup> (Wt %)

Indulin AT	
Klason lignin	88.8
Acid-soluble lignin	4.1
Total lignin	92.9
Arabinan	0.2
Galactan	0.56
Glucan	0.21
Xylan	0.56
Total Sugars	1.53
Ash	2.01

75

76

77 **TABLE S2.** Elemental and methoxyl contents

Indulin AT	
C (%)	65.5
H (%)	5.6
O (%)	25.2
N (%)	0.4
S (%)	3.3
MeO (%)	13.6

78

79

80 **TABLE S3.** Substructures estimated by 2D-HSQC NMR and <sup>13</sup>C NMR

Substructures per 100 Ar*	Indulin AT	Pine milled wood lignin
A: β-O-4'	8.2	41
B: β-5'	1.1	9
C: Dibenzodioxocin	0.6	8
E: β-β' pinoresinol	1.2	2
F: β-β' secoisolariciresinol	3.1	2
K: Enol ether	1.5	-
H: Stilbene	6.7	-
I: Coniferyl alcohol	0.3	4
J: G-CH(OH)-COOH	0.4	-
Primary aliphatic OH**	31	
Secondary aliphatic OH**	18	
Total aliphatic OH**	49	114
Phenolic OH**	63	28
OCH <sub>3</sub> **	68	95
Degree of condensation**	68	40

82 The monomer yield was calculated as follows (internal standard method):

83 
$$\text{Weight of one monomer} = \lambda * W_A / P A_A * P A_M$$

84  $W_A$ : the weight of acetophenone

85  $P A_A$ : the peak area of acetophenone

86  $P A_M$ : the peak area of the monomer

87  $\lambda$ : the correcting coefficient, calculated by the sample of the monomer through the above

88 formula

89 There were some unknown peaks in the GC chromatograph. The correcting  
90 coefficients of these unknowns cannot be determined. Therefore, these unknown peaks  
91 were estimated using the average of all correcting coefficients of known monomeric  
92 products [2]. All the correcting coefficients are shown in **Table S4**. The yield of total  
93 monomers was calculated as follows:

94 
$$\text{Yield} = \text{Weight} / \text{Weight of lignin (0.5g)} * 100\%$$

95 
$$\text{Yield of total monomers} = \text{Yield of all identified monomers} + \text{Yield of all unknown}$$

96 monomers



97 **Table S4** The coefficients of monomers

Monomer	Coefficient
Phenol	0.97
2-Methoxyphenol	0.91
Veratrole	0.87
4-Ethylphenol	0.84
4-Methylguaiacol	0.87
3,4-Dimethoxytoluene	0.90
4-Ethylguaiacol	0.90
Syringol	0.76
Eugenol	0.96
4-Propylguaiacol	0.98
Vanillina	0.69
Isoeugenol	0.69
Acetovanillone	0.52
2,6-Di-tert-butyl-4-methylphenol	1.28
4-Hydroxyl-3-Methoxypropiophenone	0.77
Homovanillic acid	0.21
Unknown monomer	0.83

98

99

100 **Table S5** The desorption of NH<sub>3</sub>-TPD

NH <sub>3</sub> -TPD	WA	SA	SSA
	/°C (μmol·g <sup>-1</sup> )	/°C (μmol·g <sup>-1</sup> )	/°C (μmol·g <sup>-1</sup> )
40%S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> - 0%K <sub>2</sub> O/TiO <sub>2</sub>	105-430 <sup>a</sup> (236.73) <sup>b</sup>	620-810 (157.03)	
40% S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -20%K <sub>2</sub> O/TiO <sub>2</sub>	120-280 (39.115)	670-920 (211.13)	950-1100(794.71 <sup>d</sup> ) + <sup>c</sup>
40% S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -40%K <sub>2</sub> O/TiO <sub>2</sub>	100-260 (122.54)		1020-1200(653.24 <sup>d</sup> ) <sup>+c</sup>
20% S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -40%K <sub>2</sub> O/TiO <sub>2</sub>		620-790 (4304.8)	
0% S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -40%K <sub>2</sub> O/TiO <sub>2</sub>		540-745 (1924.5)	
20% S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -20%K <sub>2</sub> O/TiO <sub>2</sub>	110-270 (104.72)		1060-1200(714.37 <sup>d</sup> ) <sup>+c</sup>

101 <sup>a</sup> Temperature range of the peak.

102 <sup>b</sup> Desorbed amount corresponding to the area of the peak.

103 <sup>c</sup> The highest permitted temperature of the instrument is 1200 °C and the temperature was  
 104 adjusted to 1100 °C to protect the instrument. It had no effect on the results.

105 <sup>d</sup> It was the desorbed amount corresponding to the area of the partial peak.

106

107 **Table S6** The desorption of CO<sub>2</sub>-TPD

CO <sub>2</sub> -TPD	WB	SB	SSB
	/°C (μmol·g <sup>-1</sup> )	/°C (μmol·g <sup>-1</sup> )	/°C (μmol·g <sup>-1</sup> )
40% S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> - 0%K <sub>2</sub> O/TiO <sub>2</sub>	190-370 <sup>a</sup> (87.618) <sup>b</sup>	620-830 (130.24)	
40% S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -20%K <sub>2</sub> O/TiO <sub>2</sub>	200-360 (26.215)	680-870 (239.78)	940-1100(320.57 <sup>c</sup> )+
40% S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -40%K <sub>2</sub> O/TiO <sub>2</sub>	90-270 (56.294)		900-1100(367.59 <sup>c</sup> )+
20% S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -40%K <sub>2</sub> O/TiO <sub>2</sub>		580-765 (2123.1)	
0% S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -40%K <sub>2</sub> O/TiO <sub>2</sub>		540-730 (663.5)	
20% S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -20%K <sub>2</sub> O/TiO <sub>2</sub>	90-410 (212.14)		930-1100(341.93 <sup>c</sup> )+

108 <sup>a</sup> Temperature range of the peak.

109 <sup>b</sup> Desorbed amount corresponding to the area of the peak.

110 <sup>c</sup> It was the desorbed amount corresponding to the area of the partial peak.

111

112 **Table S7** The GC results of monomer products

	S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -	Ni-S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -	S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -	Ni-S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -	S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -	Ni-S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -
	K <sub>2</sub> O/TiO <sub>2</sub>	K <sub>2</sub> O/TiO <sub>2</sub>	K <sub>2</sub> O/TiO <sub>2</sub>	K <sub>2</sub> O/TiO <sub>2</sub>	K <sub>2</sub> O/TiO <sub>2</sub>	K <sub>2</sub> O/TiO <sub>2</sub>
	260 °C	260 °C	320 °C	320 °C	320 °C	320 °C
	1 h/%	1 h/%	1 h/%	1 h/%	12 h/%	12 h/%
Phenol	0.00±0.00	0.00±0.00	0.04±0.00	0.03±0.00	0.10±0.02	0.12±0.01
2-Methoxy-phenol	0.76±0.07	0.33±0.07	1.97±0.22	1.85±0.31	0.50±0.05	0.90±0.15
Veratrole	0.00±0.00	0.14±0.03	0.49±0.04	0.05±0.01	0.37±0.02	0.39±0.08
4-Ethylphenol	0.00±0.00	0.00±0.00	0.20±0.02	0.04±0.01	0.44±0.06	0.08±0.03
4-Methyl-guaiacol	0.75±0.06	0.74±0.08	0.88±0.05	1.13±0.21	1.76±0.18	1.15±0.10
3,4-Dimethoxy-toluene	0.00±0.00	0.00±0.00	0.14±0.01	0.08±0.02	0.65±0.07	0.32±0.06
4-Ethyl-guaiacol	0.07±0.02	0.05±0.01	0.76±0.10	0.92±0.12	1.33±0.07	1.23±0.12
Syringol	0.00±0.00	0.00±0.00	0.15±0.02	0.22±0.05	1.38±0.18	0.52±0.13
Eugenol	0.00±0.00	0.03±0.00	0.16±0.01	0.16±0.05	0.04±0.00	0.05±0.02
4-Propyl-guaiacol	0.00±0.00	0.00±0.00	0.19±0.04	0.32±0.03	0.08±0.03	0.36±0.06
Vanillina	0.27±0.05	0.36±0.02	0.06±0.01	0.23±0.08	0.13±0.01	0.18±0.04
Isoeugenol	0.22±0.06	0.28±0.06	0.22±0.03	0.38±0.07	0.33±0.05	1.16±0.13
Aceto-vanillone	0.17±0.05	0.14±0.02	0.08±0.02	0.31±0.08	0.52±0.01	0.36±0.06
2,6-Di-tert-butyl-4-methylphenol	0.04±0.01	0.03±0.00	0.06±0.01	0.06±0.02	0.59±0.07	0.22±0.02
4-Hydroxyl-3-Methoxypropiofenone	0.04±0.01	0.00±0.00	0.04±0.01	0.09±0.02	0.04±0.02	0.10±0.01
Homovanillic acid	0.70±0.09	1.00±0.12	0.38±0.10	1.66±0.23	0.63±0.07	0.66±0.03
Total unknown monomers/%	6.78±0.17	5.43±0.29	7.56±0.41	7.43±0.26	20.07±0.64	17.17±0.52
Total identified monomers	3.01±0.12	3.10±0.09	5.81±0.35	7.52±0.42	8.89±0.41	7.80±0.50
Total monomers	9.79±0.22	8.53±0.37	13.37±0.62	14.95±0.57	28.96±0.72	24.97±0.83

114 **Table S8** Comparisons of the performance in lignin catalytic depolymerization

Ref.	Lignin	Catalyst	Reaction time	Reaction temperature	Yield of liquid products	Yield of monomer products
[34]	Organosolv lignin	Pd/C + CrCl <sub>3</sub>	5 h	280 °C	78.2%	20.8%
[35]	Organosolv lignin	Ni/ZrP	4 h	270 °C	87.3%	15.1%
[37]	Organosolv lignin	NaOH + Ru/C	4 h	260 °C	86.67%	12.69%
[38]	Organosolv lignin	Ru/C + MgO/ZrO <sub>2</sub>	3 h	350 °C	71.5%	17.51%
[38]	Kraft lignin	Ru/C + MgO/ZrO <sub>2</sub>	3 h	350 °C	81.7%	10.7%
This work	Kraft lignin	S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> -K <sub>2</sub> O/TiO <sub>2</sub>	12 h	320 °C	83.76%	28.96%

116 **Fig. S1 (a)** SEM images of  $\text{TiO}_2$ . **(b)** SEM images of  $\text{S}_2\text{O}_8^{2-}\text{-K}_2\text{O/TiO}_2$ . **(c)** EDS images  
117 of  $\text{S}_2\text{O}_8^{2-}\text{-K}_2\text{O/TiO}_2$

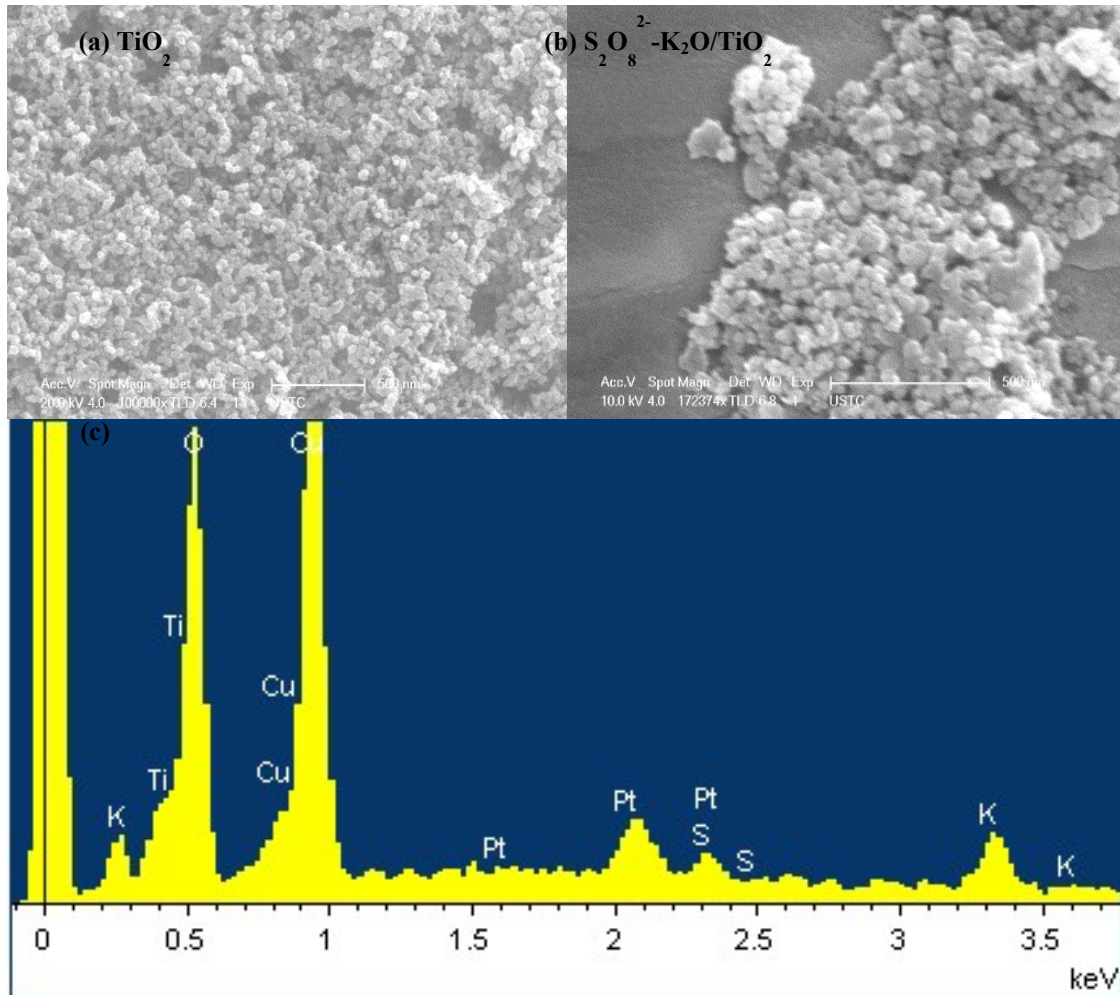
118

119

120

121

122



128

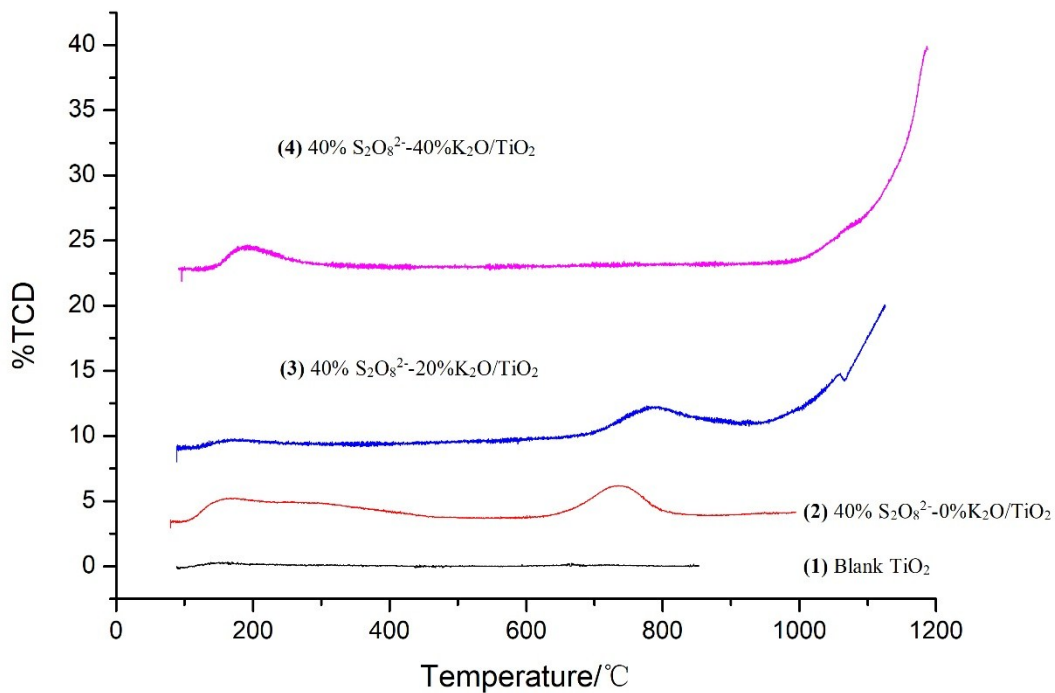
129

130

131

132

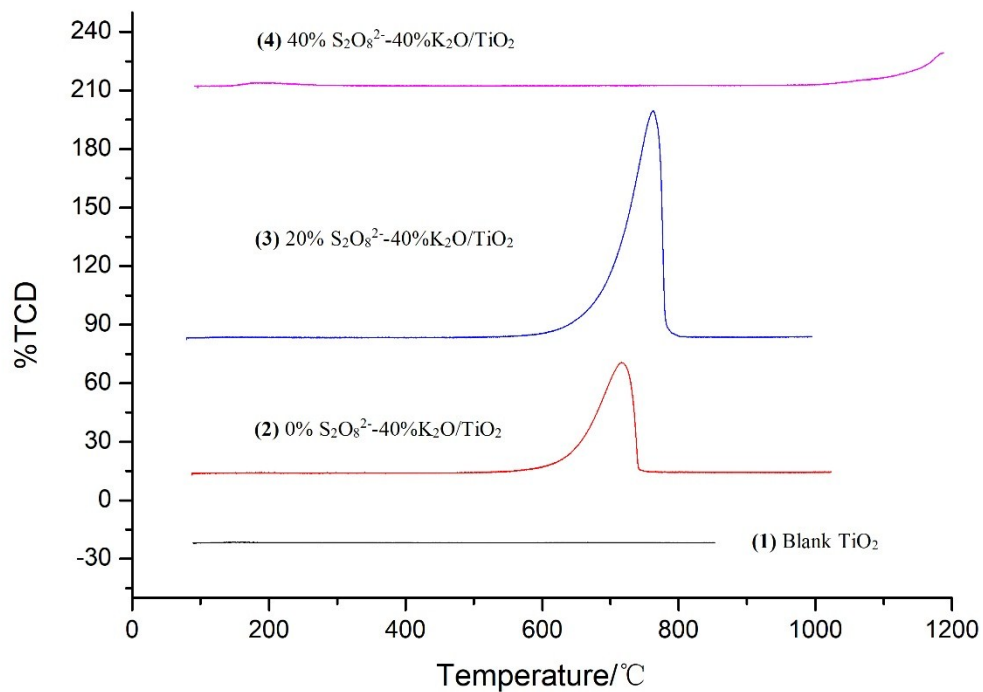
133 **Fig. S2** The adsorption of  $\text{NH}_3$ -TPD. **(a)** (1) Blank  $\text{TiO}_2$ . (2) 40%  $\text{S}_2\text{O}_8^{2-}$ -0% $\text{K}_2\text{O}/\text{TiO}_2$ .  
134 (3) 40%  $\text{S}_2\text{O}_8^{2-}$ -20% $\text{K}_2\text{O}/\text{TiO}_2$ . (4) 40%  $\text{S}_2\text{O}_8^{2-}$ -40% $\text{K}_2\text{O}/\text{TiO}_2$ . **(b)** (1) Blank  $\text{TiO}_2$ . (2)  
135 0%  $\text{S}_2\text{O}_8^{2-}$ -40% $\text{K}_2\text{O}/\text{TiO}_2$ . (3) 20%  $\text{S}_2\text{O}_8^{2-}$ -40% $\text{K}_2\text{O}/\text{TiO}_2$ . (4) 40%  $\text{S}_2\text{O}_8^{2-}$ -40% $\text{K}_2\text{O}/\text{TiO}_2$ .  
136 **(c)** 20%  $\text{S}_2\text{O}_8^{2-}$ -20% $\text{K}_2\text{O}/\text{TiO}_2$ .  
137 **(a)** (1) Blank  $\text{TiO}_2$ . (2) 40%  $\text{S}_2\text{O}_8^{2-}$ -0% $\text{K}_2\text{O}/\text{TiO}_2$ . (3) 40%  $\text{S}_2\text{O}_8^{2-}$ -20% $\text{K}_2\text{O}/\text{TiO}_2$ . (4) 40%  
138  $\text{S}_2\text{O}_8^{2-}$ -40% $\text{K}_2\text{O}/\text{TiO}_2$ .



139

140

141 (b) (1) Blank TiO<sub>2</sub>. (2) 0% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-40%K<sub>2</sub>O/TiO<sub>2</sub>. (3) 20% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-40%K<sub>2</sub>O/TiO<sub>2</sub>. (4)  
142 40% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-40%K<sub>2</sub>O/TiO<sub>2</sub>.

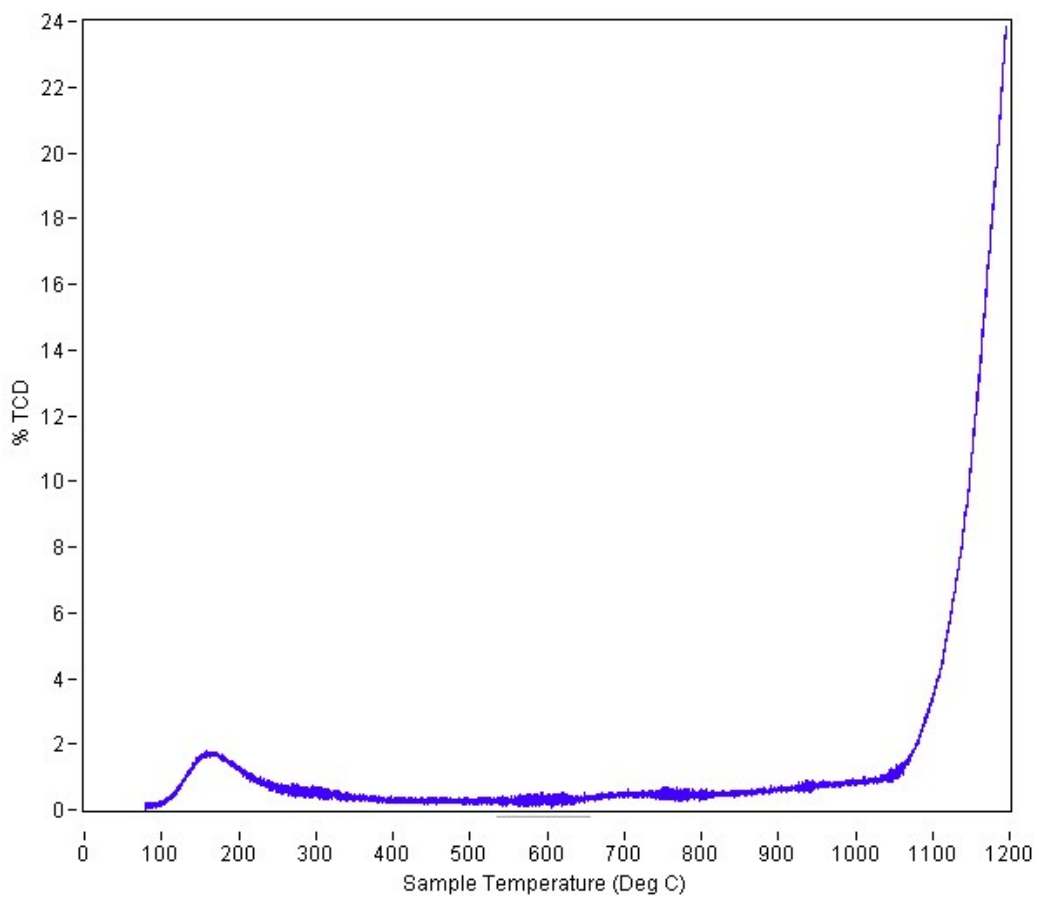


143

144



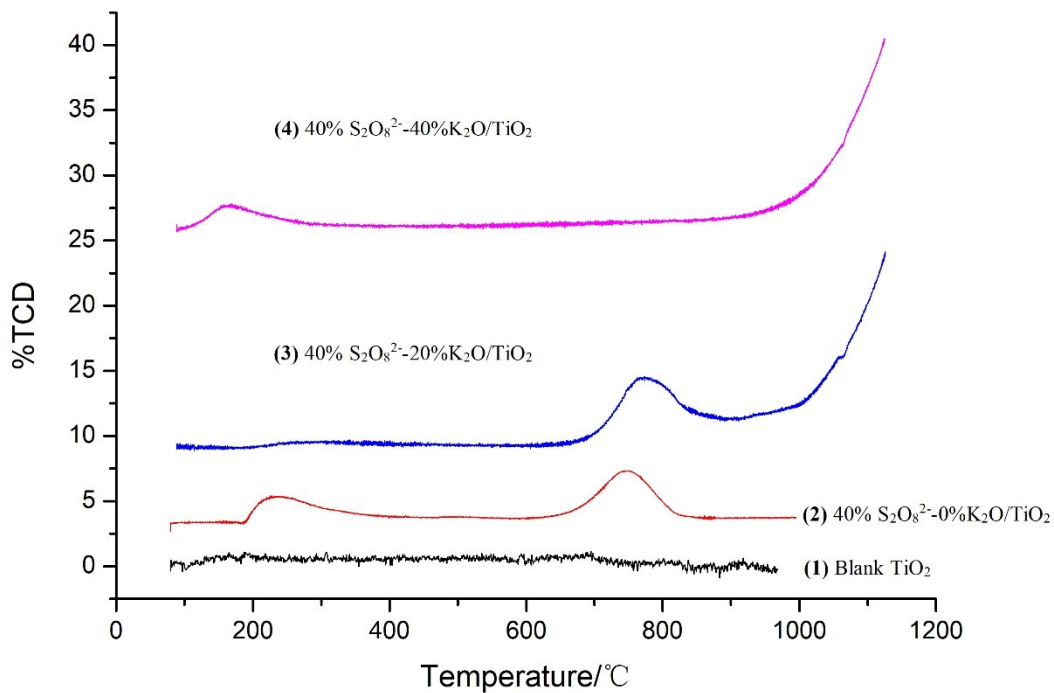
145 (c) 20% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-20%K<sub>2</sub>O/TiO<sub>2</sub>



146

147

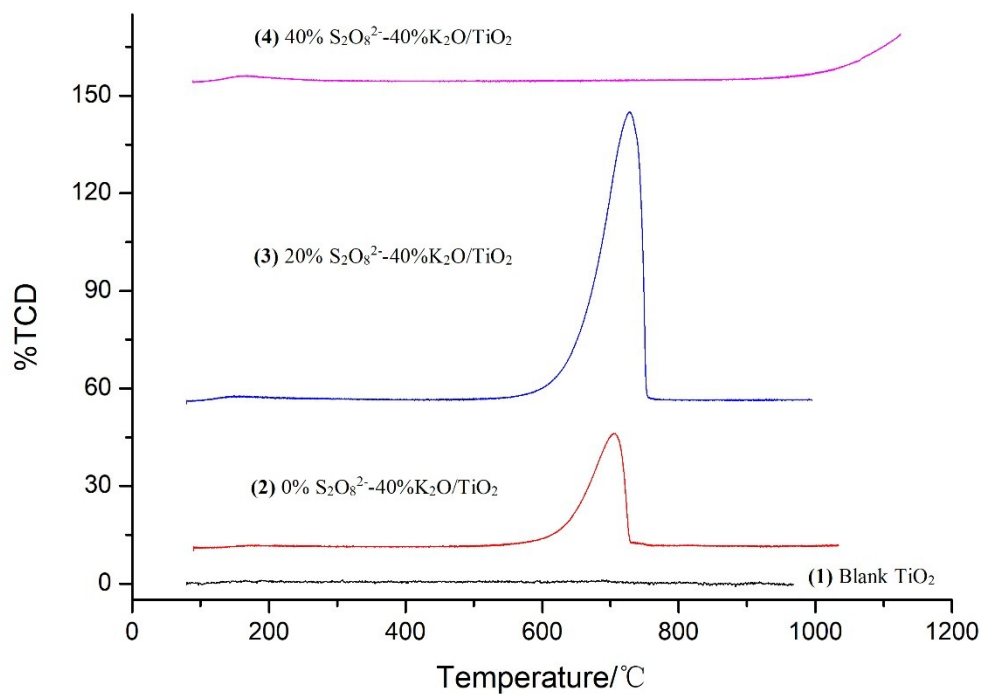
148 **Fig. S3** The adsorption of CO<sub>2</sub>-TPD. **(a)** (1) Blank TiO<sub>2</sub>. (2) 40% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-0%K<sub>2</sub>O/TiO<sub>2</sub>.  
149 (3) 40% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-20%K<sub>2</sub>O/TiO<sub>2</sub>. (4) 40% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-40%K<sub>2</sub>O/TiO<sub>2</sub>. **(b)** (1) Blank TiO<sub>2</sub>. (2)  
150 0% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-40%K<sub>2</sub>O/TiO<sub>2</sub>. (3) 20% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-40%K<sub>2</sub>O/TiO<sub>2</sub>. (4) 40% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-40%K<sub>2</sub>O/TiO<sub>2</sub>.  
151 **(c)** 20% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-20%K<sub>2</sub>O/TiO<sub>2</sub>.  
152 **(a)** (1) Blank TiO<sub>2</sub>. (2) 40% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-0%K<sub>2</sub>O/TiO<sub>2</sub>. (3) 40% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-20%K<sub>2</sub>O/TiO<sub>2</sub>. (4) 40%  
153 S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-40%K<sub>2</sub>O/TiO<sub>2</sub>.



154

155

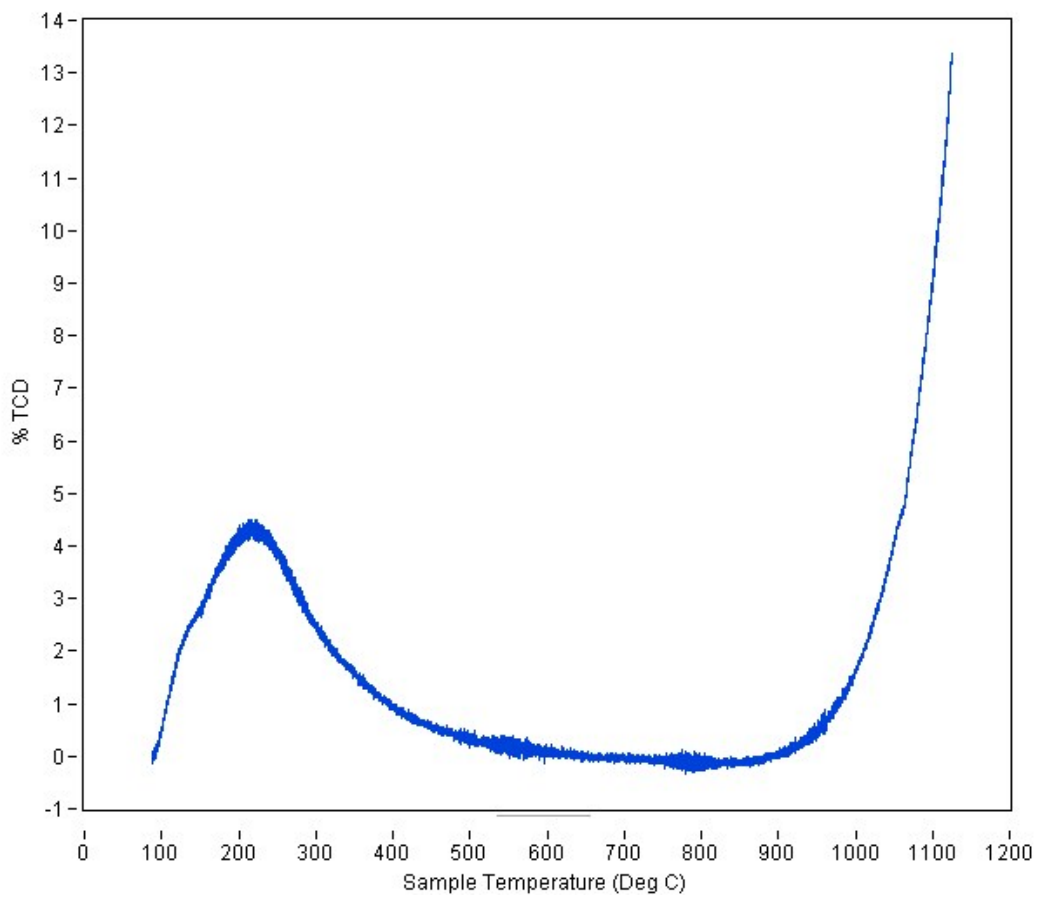
156 (b) (1) Blank TiO<sub>2</sub>. (2) 0% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-40%K<sub>2</sub>O/TiO<sub>2</sub>. (3) 20% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-40%K<sub>2</sub>O/TiO<sub>2</sub>. (4)  
157 40% S<sub>2</sub>O<sub>8</sub><sup>2-</sup>-40%K<sub>2</sub>O/TiO<sub>2</sub>.



158

159

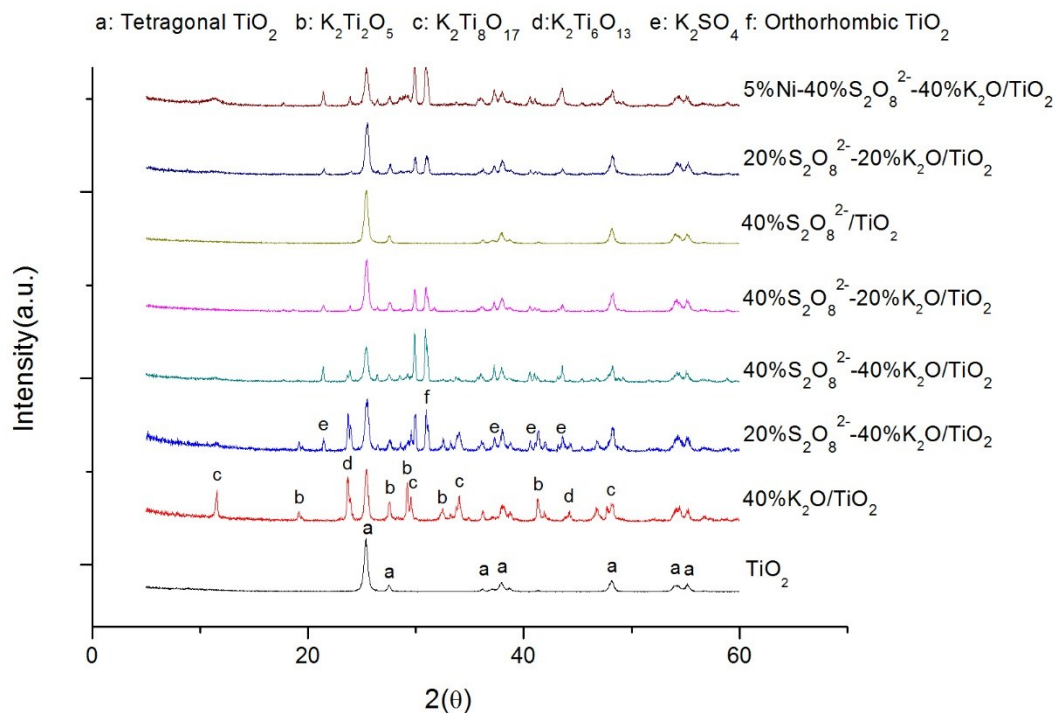
160 (c) 20%  $S_2O_8^{2-}$ -20% $K_2O$ / $TiO_2$



161

162

163 **Fig. S4** XRD patterns of the catalysts



164

165 The JCPDS file number for the peaks are as below.

166 Anatase tetragonal  $\text{TiO}_2$  <sup>(a)</sup> JCPDS File No.21-1272

167  $\text{K}_2\text{Ti}_2\text{O}_5$  <sup>(b)</sup> JCPDS File No.13-0448

168  $\text{K}_2\text{Ti}_8\text{O}_{17}$  <sup>(c)</sup> JCPDS File No.41-1100

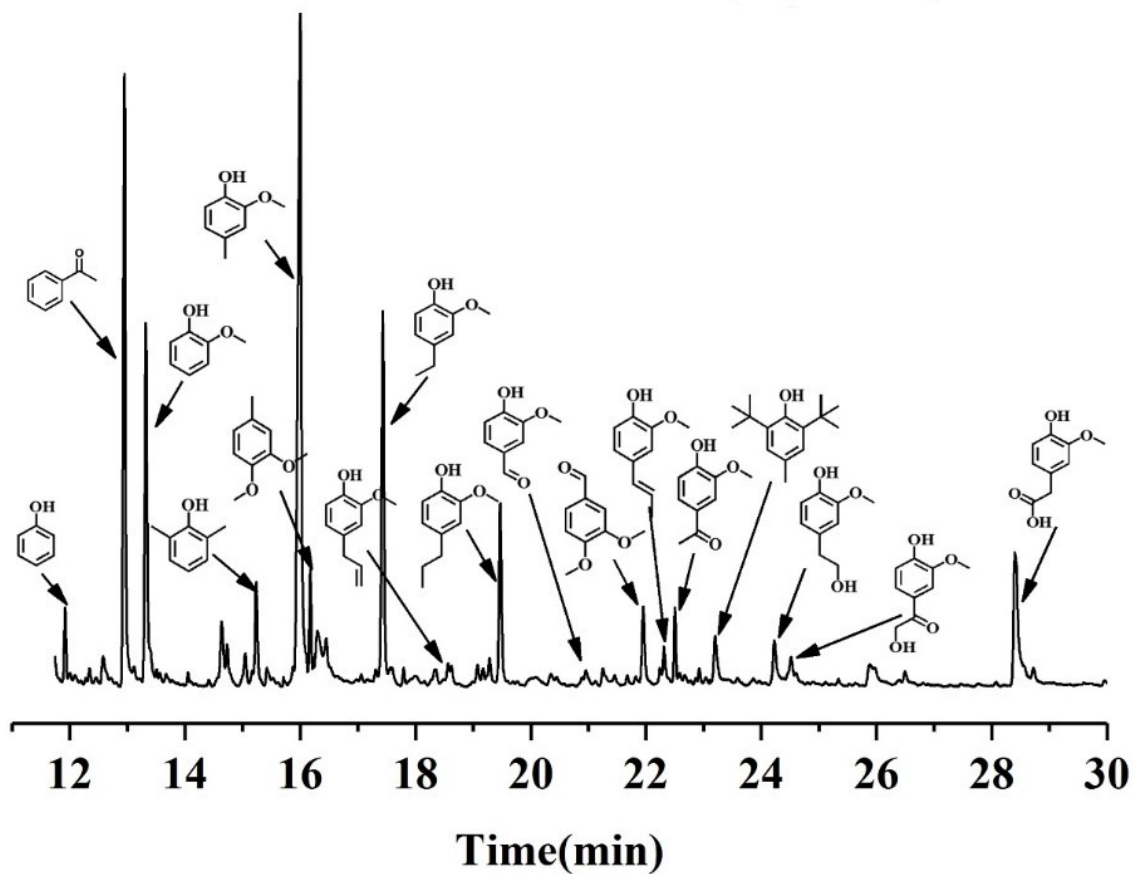
169  $\text{K}_2\text{Ti}_6\text{O}_{13}$  <sup>(d)</sup> JCPDS File No.40-0403

170  $\text{K}_2\text{SO}_4$  <sup>(e)</sup> JCPDS File No.05-0613

171 Brookite orthorhombic  $\text{TiO}_2$  <sup>(f)</sup> JCPDS File No.29-1360

172

173 **Fig. S5** The result of GC-MS Reaction conditions: 0.5 g lignin, 0.2 g 40%  $S_2O_8^{2-}$ -  
174 40% $K_2O/TiO_2$ , 4 MPa  $H_2$ , 320 °C, 12 h, 900 rpm.



## 176 References

- 177 [1] Hu, Z., Du, X., Liu, J., Chang, H. M., Jameel, H. Structural characterization of pine kraft lignin: BioChoice  
178 lignin vs Indulin AT. *J Wood Chem Technol*, 36(6), (2016), 432-446.
- 179 [2] Wang, J., Li, W., Wang, H., Ma, Q., Li, S., Chang, H. M., & Jameel, H. Liquefaction of kraft lignin by  
180 hydrocracking with simultaneous use of a novel dual acid-base catalyst and a hydrogenation  
181 catalyst. *Bioresource Technol*, 243, (2017), 100-106.

182