1 **Oil Production from Mild Pyrolysis of Low-rank Coal in Molten**

2 **Salts Media**

3
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19 **Abstract**

20 The present study focused on the utilization of molten carbonate salts as a media for the
21 pyrolysis process to produce oil from low-rank coal. A ternary eutectic mix of alkali
22 carbonate salts (Li_2CO_3 , Na_2CO_3 , and K_2CO_3) was used to pyrolyze two kinds of
23 low-rank coals. The effect of molten salt to the reactivity of coal was investigated by
24 comparing the thermal decomposition profile of coal before and after it was mixed with
25 the molten salt. The oil yield and its composition were also investigated. The results
26 showed that the reactivity of the coal increased when the pyrolysis was performed in the
27 molten salt. The molten salt increased the pyrolysis conversion about 16.5 and 16.4%
28 for Loy yang and Xinghe coals, respectively, when they were pyrolyzed at 600 °C. The
29 use of molten salt increased the oil yield since it can rapidly heat the coal to make the
30 pyrolysis occur effectively. The total hydrocarbon content in the oil also increased about
31 13.6 and 11.0% for Loy yang and Xinghe coals, respectively. However, the molten
32 carbonate salts failed to retain the sulfuric compound during the pyrolysis period due to
33 the short residence time of oil in the molten salt phase.

34 **Keywords:** *Molten carbonate salts; Oil production; Low rank coal; Mild pyrolysis.*

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37 **1. Introduction**

38 Oil contributes about 33% of global energy consumption in 2013 [1]. Assuming
39 that the level of consumption remains constants over years and no more oil reserves are
40 found, it is believed that petroleum will deplete within a couple of decades. Based on
41 2013 data, the world oil reserves would only sufficient to meet 53.3 years of global
42 production [1]. Alternative sources must be found and coal is one of the attractive
43 option. Coal still has a longer depletion time compared with other fossil fuels such as
44 natural gas and crude oil. Furthermore, it is considered as a low-cost fuel. Coal
45 utilization process is a mature technology yet still attractive to be researched. The recent
46 researches on coal are focused on how to utilize low-rank coal effectively since about
47 half of the coal reserves are in the low-rank state (lignite and sub bituminous) [2, 3, 4, 5,
48 6, 7, 8, 9, 10].

49 Oil production from coal via thermal processing such as pyrolysis has been done
50 for years. In general, a relatively high temperature process is required to obtain oil from
51 the coal [11, 12, 13]. Some researchers try to mix the coal with biomass to decrease the
52 processing temperature [14, 15, 16, 17, 18, 19, 20]. However, other problems arise
53 when the coal is mixed with biomass. Biomass contains high amount of oxygen so that
54 the pyrolytic oil contains quite high amount of oxygenated compound with low oil

55 quality [21, 22, 23]. The use of the catalyst such as zeolite may improve the oil quality
56 by after upgrading process [24, 25, 26].

57 Pyrolysis in molten salt media can be considered as an attractive option to increase
58 the pyrolysis rate as well as the oil quality at relatively low temperature. Molten salt is
59 an ionic crystal which melts into ionic liquid at high temperature. Molten salt provides
60 several advantages, such as large heat capacity, good dissolution ability, good thermal
61 conductivity, and also it has a catalytic activity for certain reactions [27, 28]. Recently,
62 the molten salt has been exploited to assist many kinds of processes, such as for heat
63 transfer fluid in nuclear power plant [29], heat storage media for solar power plant [30,
64 31], electrolyte in the fuel cells system [32, 33], and catalyst for chemical reactions [34,
65 35].

66 Certain kinds of salts were also utilized to assist thermal conversion of organic
67 matters. Matsunami et al. [36] have successfully utilized the mix of K_2CO_3 and Na_2CO_3
68 to increase the gasification rate of coal. The similar result was also obtained by
69 utilization of binary and ternary mix of carbonate salts [37,38]. However, most of their
70 studies were focused on the gas production at high temperature. The use of molten salts
71 to produce oil was done by Jiang et al. [39] who utilized the mix of chloride salts and
72 nitrate salts, but they found that due to the strong oxidizing effect of the salts, some of

the obtained oil might undergo the secondary cracking reactions and thus increasing the gas yield [27, 39]. In the present study, the ternary eutectic mix of carbonate salts ($\text{Li}_2\text{CO}_3 - \text{Na}_2\text{CO}_3 - \text{K}_2\text{CO}_3$) was utilized as the media for pyrolyzing the low-rank coal to produce oil. The melting point of the salts mix is low enough so that it is possible to be utilized at low temperature. The effect of the adding salts was investigated by analyzing the product distribution and the chemical composition of the pyrolytic oil.

2. Experimental

2.1 Feedstock and molten salt media

Two kinds of low rank coals (i.e. Australian Loy yang coal and Chinese Xinghe coal) were used as the feedstock samples. The proximate and ultimate analyses of the samples were presented in Table 1. Based on the preliminary experiment, to make sure that all coal particle can be smoothly dropped into the salt media for the fast pyrolysis, the samples were ground and sieved to particle size of 1-2.8 mm and then dried at 105 °C overnight in the oven to remove their moisture content. The remaining moisture was analyzed by using moisture content analyzer (MX50, AND, Japan).

Mixture of alkali carbonate salts (lithium carbonate, sodium carbonate, and potassium carbonate, Wako, Japan) was utilized as the pyrolysis media. The salts were

91 mixed in a ball mill at eutectic composition (29.8%-mol Na_2CO_3 + 44.1%-mol Li_2CO_3 +
92 26.1%-mol K_2CO_3). Eutectic composition was chosen since it has low melting
93 temperature and thus it can be utilized for low temperature pyrolysis. Thermal stability
94 of the salt mixture as well as its melting point were observed by using a
95 thermogravimetric/differential thermal analyzer/TGA-DTA (DTG-60H, Shimadzu,
96 Japan).

97

98 **Table 1** Proximate and ultimate analysis of the coal samples

99

100 The effect of molten carbonate salts on the reactivity of the coal was examined by
101 using a Thermogravimetric/Differential Thermal Analyzer/TGA-DTA (DTG-60H,
102 Shimadzu, Japan). The coal sample and the salt were homogeneously mixed at
103 coal-to-salt weight ratio of 1:0, 1:1, 1:5, 1:10, and 1:20 by mixing 1 mg of coal sample
104 with 1, 5, 10, and 20 mg of salt mixture, respectively. They were heated to a
105 temperature of 600 °C at a heating rate of 10 °C/min. The coal reactivity was examined
106 by comparing the TGA results before and after it was mixed with the salt.

107

108 *2.2 Pyrolysis setup*

109 Schematic diagram of the pyrolysis setup is presented in the Fig.1. A dropdown
110 batch reactor was used as the pyrolyzer. 1 gram of sample was put in the sample holder
111 while 10 g of salts were put in the main reactor. Based on the preliminary experiments,
112 it is found that 10 gram of salts is enough to immerse the inner tube to make sure that
113 coal sample can contact with the salts well during pyrolysis. The reactor was firstly
114 flushed by using argon gas to remove the air out of the system. Meanwhile, the electric
115 furnace was turned on to heat up the main reactor until it reached the desired pyrolysis
116 temperature, which was varied from 450-600 °C. The reactor was kept at the desired
117 temperature for 1 h to completely melt the salt and formed a eutectic liquid. Pyrolysis
118 process was started by opening the feeder valve to let the sample dropped down to the
119 molten salt media via the central tube inserted in the molten salt with carrier argon gas.
120 In order to let coal mix with molten salt well, the molten salt layer was continuously
121 bubbled with argon gas. The total reaction was fixed at 10 min. The volatile product
122 was carried out of the reactor by the argon gas with a total flow rate of 100 cm³/min
123 (STP), and then flowed to the condenser which consists of two series bottles placed in
124 the ice-water bath. The first bottle was used to collect the heavy tar while the second
125 condenser was filled by 20 ml of acetone to trap the light tar. Non condensable gas was
126 passed through the gas purifier and collected in the gas bag for further analysis using a

127 gas chromatograph (GC/TCD, Agilent 7890A, USA). The composition of the obtained
128 oil in the first and second condensers were analyzed by using a gas
129 chromatography/mass spectroscopy (GC/MS QP2010, Shimadzu, Japan) and their water
130 content were analyzed by using Karl-Fisher Titration method (MKS-500, KEM, Japan).
131 The remaining solid in the reactor was defined as salts and char.

132 **Fig.1** Schematic diagram of the pyrolysis setup

133

134 **3. Results and discussion**

135 *3.1 Characterization of molten salts*

136 Thermal characterization of the molten salt was done by using the TGA/DTA and
137 the results are presented in Fig.2. The salt obtained from ball-milling process was
138 heated until 600 °C at a heating rate of 10 °C/min and the TGA/DTA results are shown
139 in the Fig.2a. Once it was cooled down, the salt was reheated at the same heating
140 condition (10 °C/min until it reached 600 °C) and the TGA/DTA results are shown in
141 the Fig.2b. TGA result (residual weight profile) of the salts after ball-milled process in
142 Fig.2a shows that the sample weight decreased about 3.6% after the salts was heated
143 until 110 °C due to the evaporation of the moisture contained in the salt. After all the
144 water was evaporated, no weight decreasing was observed even until the temperature of
145 salts reached 600 °C indicating that the molten carbonate salts is thermally stable. As for

146 the reheated salt (Fig.2b), no weight loss was observed since no more moisture was
147 contained in the salt

148

149 **Fig.2** TGA/ DTA profile of the salts after (a) ball-milled and (b) re-melted.

150

151 so that the weight remained constant until the end of heating. DTA result in Fig.2a
152 shows that two peaks were observed for the after-ball-milled salt. The first appeared at
153 the temperature of about 100 °C, which correlated with the evaporation of the moisture
154 in the salt while the second peak appeared at the temperature of about 430 °C, which
155 correlated with the salt melting. For the reheated salt (Fig.2b), only one peak was
156 observed at about 400 °C which correlated with the salt melting. The onset temperature
157 analysis showed that the melting temperature for the salt after ball-milling process was
158 429 °C while for the reheated salt was 395 °C. The melting point results indicate that
159 mixing the salts in a ball mill cannot completely homogenize the mixture. The eutectic
160 mix of the salts can be obtained after the mixture was melted. However, since the
161 melting point was still lower than the desired pyrolysis temperature, salt mixture from
162 the ball-mill mixing process can be utilized as the mild pyrolysis media.

163

164 3.2 *The effect of adding molten salt on the coal reactivity*

165 A thermogravimetric analyzer was utilized to investigate the effect of molten salt
166 addition on the reactivity of the coal. The change of the coal reactivity in the presence
167 of molten salts was determined by comparing the thermal decomposition profile of the
168 coal before and after mixed with the molten salts. Fig.3 shows the residual weight of
169 Loy yang coal as the function of the temperature before and after mixed with the
170 carbonate molten salts at various ratio (1 mg of coal mixed with 1, 5, 10, and 20 mg of
171 salts). The samples were heated until 600 °C at a heating rate of 10 °C/min in the
172 atmosphere of nitrogen. Herein, it should be noted that the moisture content of the salt
173 (as seen in the Fig.2) has been calculated and subtracted proportionally from each of the
174 thermal decomposition profile. From Fig.3, it can be seen that the addition of the molten
175 salt can increase the thermal conversion of the coal quite significantly. The conversion
176 of the coal increased from 46.8 to 52.1% at 600 °C when 1 mg of the salt was added and
177 further increased to 58.5%, 61.6%, and 63.8% when the salt amount was increased to 5,
178 10, and 20 mg, respectively.

179

180 **Fig.3** Thermal decomposition profile of Loy yang coal before and after mixed with the
181 various amount of molten salts.

182

183 The increase of the coal conversion is strongly due to the catalytic activity of the
184 alkali species in the salt. Alkali metal species are known to have a good catalytic effect
185 on the pyrolysis and gasification [40, 41, 42, 43, 44]. Alkali metal species such as
186 potassium could interact with the carbon and form active carbon/potassium complex
187 which is easier to be decomposed [42]. Xu et al. [45] also found that the use of alkali
188 carbonate salts can promote the thermal decomposition of the organic matter and as
189 such, the conversion rate was increased and the pyrolysis time was shortened.

190 Furthermore, as seen in Fig.3, at the low salt amount (1 or 5 mg) addition, the coal
191 conversion increased after the temperature reached 400 °C, but the conversion remained
192 almost the same as that without molten salt at the temperature lower than 400 °C. At
193 low salt amount addition, only some parts of the coal can be contacted with the salt.
194 When the temperature reached 400 °C, the salt started to melt to fluid phase and flow
195 into the coal samples. As a result, more coal can contact with the salt and result in the
196 increasing of the conversion. In contrast, at higher salt content (10 mg), the amount of
197 salt was high enough to make an effective contact with the coal samples so that the
198 conversion increased even before the salt melted. Further increasing of the salt content
199 to 20 mg did not increase the conversion obviously since the effective contact could
200 already reach the maximum at the salt amount of 10 mg. As seen in Fig.3, there is no

201 significant difference on the thermal decomposition profile of the coal when the salt
202 amount was increased from 10 to 20 mg. Similar result was observed by Jin et al. [46]
203 who found that catalytic effect of the molten salt achieved an optimum when the
204 biomass to catalyst weight ratio exceeded 1:10. The pyrolysis conversion should relate
205 with the coal distributed in the molten salt. When the sample is evenly distributed,
206 adding more salts will not give any significant effect on the coal pyrolysis.

207

208 3.3 *Product distribution*

209 Flash pyrolysis was performed in the dropdown batch reactor as seen in Fig.1. For
210 each run, 10 gram of salts were used to pyrolyze 1 gram of coal sample. 10 gram of
211 salts is considered to be appropriate amount of salts to catalyze 1 gram of coal since it is
212 enough to distribute in coal sample and make a good contact with each other. 10 gram
213 of salts was also enough to immerse the inner tube of the reactor to ensure the contact
214 between coal sample and the molten salts. Fig.4 compares the product distributions
215 from the pyrolysis of Loy yang coal (Fig.4a) and Xinghe coal (Fig.4b) without (shaded
216 graph) and with molten salt media (solid graph). Gas yield was obtained from GC/TCD
217 analysis result and the char yield was obtained from the remaining solid in the reactor
218 assuming that the amount of salt remained stable. The detail of gas yield calculation

219 based on GC/TCD analysis is presented in the supplementary data. For the oil yield, it is
220 practically difficult to collect all the oil product from the reactor completely. Therefore,
221 oil yield was directly calculated from mass balance after subtracted by its water content
222 which was analyzed by using Karl-Fisher titration (KFT) method. The results in Fig.4
223 showed that the char yield decreased significantly when the coal samples were
224 pyrolyzed in the molten salts for Loy yang as well as Xinghe coals. The use of molten
225 carbonate salts as the pyrolysis media decreased the char yield from 55.3 to 38.8% for
226 Loy yang coal and from 61.3 to 49.5% for Xinghe coal at 600 °C. The char yield
227 decreasing was still observed even at lower temperature. As stated above, alkali metal
228 species in the salt could increase the reactivity of the coal and thus the coal is easier to
229 be pyrolyzed. Furthermore, in the liquid phase, molten salt can transfer the heat more
230 effectively since generally they have higher thermal conductivity. Once contacted with
231 the molten salt, the coal would be rapidly heated and thus the pyrolysis happens
232 effectively in a very short time. Here, it should be noted that since Loy yang coal has
233 more volatile matter than Xinghe coal, its reactivity was also higher [47] and thus less
234 char was produced from Loy yang coal than that from Xinghe coal during the pyrolysis
235 process.
236

Fig.4 Product yield distribution from pyrolysis of coal with molten salts media (solid area) and without molten salts media (Shaded area) for (a) Loy yang coal and (b) Xinghe coal.

It is observed that the use of molten salts slightly increased the gas yield at low temperature but the increase became more significant when the temperature was increased up to 600 °C. As seen in Fig.5, significant increases were observed for CO₂ and H₂. At 600 °C, the use of molten salts increased hydrogen production for about 70.3% and CO₂ production for about 66.6%. In the presence of CO₂ or H₂O, alkali carbonate salt could catalyze the gasification of coal based on following reactions [48]:

In the presence of H₂O

In the presence of CO₂

256 where M is an alkali metal. Based on above mechanism, the use of alkali carbonate
257 might increase the yield of hydrogen gas. The CO amount in the obtained gas product
258 did not increase since it might be converted into CO₂ via water gas shift reaction. As a
259 result, the CO₂ increased. The increasing yield of CO₂ might also come from the
260 decomposition of the carbonate salt due to the presence of steam as follow [38]:

262 where M is an alkali metal. However, in the present study, the salt decomposition is
263 negligible since the amount of steam is very limited so that it cannot interact intensively
264 with the salts. Therefore, the increasing amount of CO₂ should be mainly due to CO
265 conversion.

266 Compared with the decreasing yield of char, the gas yield increasing was not
267 significant as seen in Fig.4. It indicates that the use of molten carbonate salts could
268 improve the liquid yield. Since the temperature was quite low and the residence time
269 was also short, the secondary reaction, which possibly converts volatiles to produce
270 more gas, could be avoided and thus the pyrolysis process tends to produce more liquid
271 than gas. However, the oil yield was slightly decreased when the temperature was
272 increased from 550 to 600 °C. Herein, the oil yield decreased from 33.9 to 30.9% for the
273 Loy yang coal and from 31.1 to 27.7% for the Xinghe coal. The slight decreasing of the

oil yield is probably caused by the thermal cracking some parts of oil and production of water as the byproduct. As seen in the figure, the yield of water was also increased from 21.2 to 24.8% for the Loy yang coal, indicating that those water could probably be produced from the cracking of the oil.

Fig.5 Gas composition obtained from pyrolysis of Xinghe coal without molten salt media (shaded area) and with molten salt media (solid area)

3.4 *The effect of the molten salt on oil composition*

Fig.6 shows the composition of the obtained oil from the pyrolysis process with and without molten salt media at 600 °C. For the Loy yang coal (Fig.6a), the original pyrolytic oil contained about 50.9% hydrocarbon compounds. Most oxygenated compounds appeared in the form of phenols, followed by alcohols, ketones, and small amount of carboxylates. When the sample was pyrolyzed in the molten salt media, hydrocarbon content increased significantly to 64.5% while the oxygenated compounds such as phenol and alcohol decreased about 11.5% and 9.0%, respectively. The increase of hydrocarbon content was due to the higher conversion of the coal which characterized by less char production. Less char production implies that the coal sample tends to produce more volatiles rather than remains as char. In the volatiles, more

hydrocarbons were formed than the oxygenated compounds since coal has a very low content of oxygen. Furthermore, at high temperature, some parts of the oil were cracked. It is possible that some of the

Fig.6 Composition of the oil from pyrolysis of (a) Loy yang coal and (b) Xinghe coal with and without salt molten media at 600 °C

oxygenated compounds were cracked to hydrocarbons, and water was also produced as the byproduct. As a result, water content in the oil was increased as seen in Fig.4. Moreover, alkali and alkaline earth metal species were found to be able to decrease the amount of oxygenated compound to form less oxygenated ones [49, 50]. Similar results were obtained for the Xinghe coal (Fig.6b). The original pyrolytic oil was shown to have a very high content of phenols (about 63.2%). After it was pyrolyzed in the molten salt media, the phenol content decreased and the hydrocarbons increased from 15.5 to 26.5%.

It should be noted from Fig.6b that sulfuric compounds in the oil increased from 3.5 to 6.5% when the molten salt media was used. The increase of sulfuric compounds was caused by the increase of pyrolysis conversion. When the pyrolysis conversion increased, more sulfuric elements was also released from the char matrix. Theoretically,

311 carbonate salts have an ability to capture sulfuric compounds according to the following
312 reaction:

313 In the form of organic compound [51]

315 In the form of H_2S [52]

317 If assume that the sulfur behaves as elemental sulfur [53]

319 The most possible reaction to be happened is the reaction (10) if it is assumed that the
320 sulfur behaves as elemental sulfur. However, reaction (10) is a highly endothermic
321 reaction [53] so that it needs high temperature to occur effectively. In the present study,
322 pyrolysis was done at relatively low temperature and low reaction time and thus
323 reaction (10) could not occur effectively. Coal has a higher specific gravity than the
324 salts, but after volatile matter released, the remaining char became lighter. Sugiura et al.
325 [52] reported that the samples floated on the surface of the molten salts once it entered
326 the salt media. The short contact time causes the sulfur cannot be captured effectively
327 since the reaction rate is low [52]. In addition, the oxygen was absent in the reaction
328 system and thus reaction (8) could not happen. The sulfuric elements were possibly

329 released either in the form of gas (SO_2 and H_2S) or organic sulfur, such as thiophene
330 and thiol. The organic sulfur were easily mixed with the oil. Therefore, more sulfuric
331 components were detected in the obtained oil.

332 Major compounds detected in the oil obtained from pyrolysis of Loy yang coal in
333 the molten carbonate salts media at various temperatures are presented in Table 2. As
334 seen in Fig.6a, the pyrolytic oil was dominated by hydrocarbon components. Table 2
335 shows that more than half of the hydrocarbons were in the form of aromatics (benzene,
336 toluene, and their derivatives). Most of the oxygenated components were found in the
337 form of phenolic compounds, such as phenol and cresol. Other oxygenated components
338 were also found in the form of ketones and alcohols. As shown in Table 2, the amount
339 of hydrocarbons was decreased with the decreasing of temperature. The amount of
340 hydrocarbons may increase along with the increasing of coal conversion. It can be seen
341 in Fig.4 that the char yield was continuously decreased along with the increasing of
342 pyrolysis temperature from 450 to 600 °C. It indicates that further conversion of coal
343 could increase the content of hydrocarbons.

344

345 **Table 2** Main chemical compositions of the obtained oil from the pyrolysis of Loy yang
346 coal.

347

348 **4. Conclusions**

349 Eutectic mix of alkali carbonate salts was employed to assist pyrolysis of the low
350 rank coals for oil production. Some properties of the molten salt, such as good catalytic
351 activity and high thermal conductivity were exploited to increase the performance of the
352 pyrolysis process for oil production at mild temperature. The results showed that the use
353 of molten carbonate salts significantly enhanced the liquid production yield by
354 increasing the reactivity of the coal. The molten salt was also able to transfer the heat
355 rapidly so that the pyrolysis could occur in a very short time and thus the further
356 decomposition of liquid to produce gas could be avoided. The use of molten carbonate
357 salt also showed a good activity to increase the oil quality by increasing the
358 hydrocarbon content in the oil. Although molten carbonate salt has a potential to retain
359 the unwanted component such as sulfur, it would not occur if the temperature is too low
360 while the contact time is too short. Extending contact time is necessary if molten
361 carbonate salt is expected to separate the sulfur with the pyrolysis product.

362

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FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

Table 1

	Xinghe coal	Loy yang coal
Proximate analysis (%-d*):		
Ash	11.9	1.6
Volatile matter***	41.0	51.5
Fixed carbon	47.1	46.9
Ultimate analysis (mass%-d.a.f**)		
C	69.1	67.3
H	4.6	4.9
O***	20.6	26.9
N	1.0	0.9
S	4.7	-

*dry base; **dry ash-free base; ***by difference

Table 2

Ret. time (min)	Chemical name	% -area			
		450 °C	500 °C	550 °C	600 °C
1.569	2-Butanone	2.46		2.9	3.14
1.834	Benzene	10.59	12.41	13.08	14.19
1.96	Cyclopentane, 1,2-dimethyl-, cis-	1.87	2.2	1.82	1.97
2.541	Toluene	8.46	9.93	7.2	7.81
2.73	1-Octene	1.79	2.1	1.62	1.76
2.815	Hexane, 2,4-dimethyl-	1.35	1.52	2.01	2.11
3.265	2-Pentanone, 4-hydroxy-4-methyl-	7.59	8.91	7.12	7.67
3.65	o-Xylene	5.58	6.55	5.58	6.05
3.895	1-Nonanol	1.96	2.3	1.7	1.85
3.964	o-Xylene	3.02	3.55	3.05	3.31
4.01	4,4-Dimethyl octane	1.25	1.47	1.81	1.97
5.135	Phenol	7.37	8.65	4.97	5.39
5.338	Cyclopropane, nonyl-	1.81	2.12	1.2	1.29
5.422	Benzene, 1,2,3-trimethyl-	2.82	3.31	2.85	3.07
5.47	Undecane	2.06	2.42	2.31	2.48
5.878	Benzene, 1,2,3-trimethyl-	1.48	1.73	2.11	1.98
6.231	Phenol, 2-methyl-	0.82		3.47	3.76
6.288	Phenol, 2-methyl-	3.51	4.13		
6.6	p-Cresol	9.28	10.9	7.04	7.63
6.898	1-Tridecene	2.05	2.31	2.3	
7.028	Pentadecane	0.96		1.47	1.59
7.771	Phenol, 3,5-dimethyl-	2.85	3.29		2.53
8.455	Cyclobutane, 3-hexyl-1,1,2-trimethyl-	2.73	2.8	3.28	3.5
8.581	Tetradecane	1.45		1.37	1.49
11.503	Heneicosane	1.02			2.25
12.854	Heptadecane	1.53	1.78	1.18	
14.13	Heneicosane	1.07		2.07	
14.18	Naphthalene, 1,4,6-trimethyl-	1.46	1.36	1.64