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Novel Input-Output Prediction Approach for Biomass Pyrolysis

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1. Abstract

Biomass pyrolysis to bio-oil is one of the promising sustainable fuels. In this work, relation between biomass feedstock element characteristic and pyrolysis process outputs was explored. The element characteristics considered in this study include moisture, ash, fix carbon, volatile matter, carbon, hydrogen, nitrogen, oxygen, and sulphur. A semi-batch fixed bed reactor was used for biomass pyrolysis with heating rate of 30 °C/min from room temperature to 600 °C and the reactor was held at 600 °C for 1 hour before cooling down. Constant nitrogen flow rate of 5 L/min was provided for anaerobic condition. Rice husk, Sago biomass and Napier grass were used in the study to form different element characteristic of feedstock by altering mixing ratio. Comparison between each element characteristic to total produced bio-oil yield, aqueous phase bio-oil yield, organic phase bio-oil yield, higher heating value of organic phase bio-oil, and organic bio-oil compounds was conducted. The results demonstrate that process performance is associated with feedstock properties, which can be used as a platform to access the process feedstock element acceptance range to estimate the process outputs. Ultimately, this work evaluated the element acceptance range for proposed biomass pyrolysis technology to integrate alternative biomass species feedstock based on element characteristic to enhance the flexibility of feedstock selection.

2. Keywords

Biomass element characteristic; element targeting; element acceptance range; fixed-bed pyrolysis

3. Introduction

Global warming and environmental issues are becoming the main concern of the world. Search for cleaner processes and sustainable resources are very critical in current stage of research and development to tackle the issue. Many leading researchers is targeting at the improvement of sustainable process integration (Klemeš et al., 2011). Among the renewable resources, biomass is one of the promising alternative sustainable resources. For example, palm biomass is one of the main-stream biomass developed to aim at the concept of Waste-to-Wealth (Ng et al., 2012). Conversion of biological waste into useful downstream product or energy further improves the quality of waste management (Klemeš and Varbanov, 2013). However, implementation of biomass in industry scale is yet to be feasible in many regions, especially on non-mainstream biomasses due to high transportation cost and unique properties of each biomass species. Distinctive properties of each biomass species further constraints biomass applicability, especially integration of underutilised biomass or non-mainstream biomass species into existing process technologies. The potential value of these underutilised biomasses is not being optimised and leading to potential environmental issue such as accumulative process waste. This is a very critical gap to achieve overall optimisation of system and at the same time increases waste management cost. On the other hand, supply chain management and logistic issue also contribute to the delay of biomass

49 implementation, such as in bio-energy production (Gold and Seuring, 2011). Lim and Lam (2016)
50 proposed element targeting approach to integrate alternative biomass into existing process technology to
51 enhance the flexibility of feedstock. Several researches have been conducted to relate performance of
52 biomass processes with respect to biomass element characteristics. For example, biomass combustion is
53 only feasible if the moisture content of biomass is less than 50 wt% (Mohammed et al., 2011). Lower
54 moisture content results higher energy output due to less energy used in vaporising water within the
55 feedstock. He et al. (2014) concluded that higher hydrolysis yield of corn stover and higher ethanol yield
56 was due to lower ash content of biomass feedstock. Utilising the pretreatment study proposed by Li et al.
57 (2009) research in simultaneous saccharification and fermentation on lignocellulosic biomass, Goh et al.,
58 (2010) proposed that bio-ethanol yield can be estimated based on cellulose and hemicellulose content of
59 the biomass feedstock. Kotarska et al. (2015) suggested that decomposition of lignocellulosic raw material
60 in biomass which consists of cellulose, hemicellulose and lignin increase production yield of ethanol from
61 corn straw in Simultaneous Saccharification and Fermentation (SSF) process.

62 Several studies on the impact of biomass feedstock element characteristic to pyrolysis process outcomes
63 were also conducted by researchers. For example, Azargohar et al. (2014) studied the chemical and
64 structural properties of biomass to the effect of fast pyrolysis to produce bio-char. The study proposed
65 activated carbon production favours biomass feedstock with lower H/C and O/C ratio, and ash content.
66 Rabacai et al. (2014) reported that production of light gas in pyrolysis is governed by cellulose content. In
67 addition, char and tar are governed by hemicellulose and lignin content. Giudicianni et al. (2014)
68 conducted research on the relation of cellulose, hemicellulose and lignin to *Arundo donax* steam assisted
69 pyrolysis. The study concluded that higher content of lignin in the feedstock increases yield of bio-oil and
70 reduce yield of char. Presence of steam promotes char gasification thus reducing char yield. Phan et al.
71 (2014) evaluated bio-oil production from Vietnamese biomasses via fast pyrolysis. The study shows that
72 bigger biomass feedstock size decreases bio-oil yield. Bagasse yielded highest bio-oil production of 67.22
73 % with lowest water content of 17 % in bio-oil. From element characteristic, bagasse has highest
74 combustible, cellulose, and lignin content, and lowest ash content. From the analysis above, it is clear that
75 biomass process technology outcomes are closely related to the feedstock element characteristic.
76 However, less effort has been focused on analysing the boundary of the element acceptance range of
77 pyrolysis. With a systematic knowledge of relation between feedstock element characteristic and process
78 outcomes, this information can be used as a platform to select optimum biomass for the system. Further
79 application into biomass supply chain management is possible as per the study by Lim and Lam (2014) to
80 consider underutilised biomass into the existing system.

81 The insight of this paper is an extension work to evaluate element targeting proposed by Lim and Lam
82 (2014) and Lim and Lam (2016) in laboratory scale. This work extends on analysis of the concept of
83 element targeting and feasibility of implementation in real life case scenario. In this work, impact of
84 biomass feedstock element characteristics to semi-batch fixed bed pyrolysis outputs is studied. The
85 process outputs to be considered in this paper includes total produced bio-oil yield, aqueous phase bio-oil
86 yield, organic phase bio-oil yield, higher heating value of organic phase bio-oil and several functional
87 groups of organic phase bio-oil compound. The objectives of this work is to analysis and constructs
88 relation between biomass feedstock element characteristics and pyrolysis output, and propose an
89 approach to estimate pyrolysis output based on feedstock element characteristic properties. This allows
90 integration of underutilised biomass into the existing biomass process technology, in this case, biomass
91 pyrolysis. The element characteristics to be considered include moisture content (MC), volatile matter
92 (VM), ash (AC), fixed carbon (FC), high heating value (HHV), carbon (C), hydrogen (H), nitrogen (N),
93 oxygen (O), and sulphur (S). Three biomass species are used in this study including rice husk, Napier
94 grass and sago biomass. Many developments have been conducted on rice husk process technologies,
95 however mass implementation is yet to be feasible due to general supply chain issues. Both Napier grass
96 and sago biomass are considered to be underutilised biomasses. Napier grass are generally available in
97 many regional area, but with limited availability and de-centralised accessibility. Nevertheless, Napier
98 grass has potential as raw material for downstream product, such as bio-fuel (Isah et al., 2015). On the
99 other hand, sago biomasses collected from process effluent from sago flour production consists of sago
100 fibre and starch normally treated as process waste. However, less research and development is conducted
101 in both biomass species thus resulting less implementation on biomass. In this paper, rice husk, Napier
102 grass and sago biomass are used as the feedstock for biomass pyrolysis. This provides opportunity to
103 evaluate application of underutilised biomasses into exiting process technology as alternative resources.
104 Mixing ratio of the biomasses is altered to create unique element characteristic of feedstock. The relations
105 is analysed to construct element acceptance range (EAR) of the process. EAR act as an estimation

106 platform, such that as long as the biomass feedstock is within the proposed range, no significant
107 fluctuation in process outputs are expected.

108 4. Materials and procedures

109 Three species of biomasses are used in this work, Napier grass stem (NGS) and Rice Husk (RH) obtained
110 from Crop for the Future field research centre in Semenyih, Malaysia, and Sago biomass (Sago) consists
111 of fibre and starch collected from sago flour process plant effluent in Pusa, Sarawak, Malaysia. Due to high
112 moisture content of the as-received-biomass (range from 50 wt% to 80 wt% depending on the weather and
113 condition and collection period), all materials were oven dried upon received according to BS EN 14774-1
114 standard and element characteristic is conducted to preserve the biomass sample and shown in Table 1.
115 Noted that after exposed to atmosphere, air humidity in tropical country revert moisture content of pre-
116 dried biomasses back to approximately 10 wt%. A stainless steel fixed bed tubular reactor (115 cm length
117 and 5 cm inner diameter) was used for the pyrolysis process under inert atmosphere. Constant nitrogen
118 flow at 5L/min was provided to create inert environment. Approximate 100 g of biomass sample was
119 placed at center of the reactor and heated up at 30 °C/min to 600 °C and the temperature was held for 1
120 hour. Volatiles generated were cooled rapidly in a coil condenser connected to cooling water system at 3
121 °C and oil was collected in a container. Total produced bio-oil yield is calculated based on Eq(1). The
122 produced bio-oil is separated into aqueous phase and organic phase. The bio-oil is carefully decanted to
123 remove majority of the aqueous phase bio-oil from organic phase bio-oil. The remaining aqueous phase
124 bio-oil is then slowly removed using syringe to extract as much aqueous phase bio-oil from organic phase
125 bio-oil. Production yield of each phases are calculated based on the same formulation in Eq(1). HHV of
126 organic phase of produced bio-oil was determined via bomb calorimeter - series 6100 by Parr Instrument
127 Company. The compound of organic phase bio-oil is further analysed using a gas chromatograph-mass
128 spectrometer (GC-MS) system (PerkinElmer ClarusR SQ 8, USA) with a quadruple detector and
129 PerkinElmer-EliteTM-5ms column (30 m x 0.25 mm x 0.25 µm). The oven is programmed at an initial
130 temperature of 40 °C, ramp at 5 °C /min to 280 °C and held there for 20 min. The injection temperature,
131 volume, and split ratio were 250 °C, 1 µL, and 50:1 respectively. Helium was used as carrier gas at a flow
132 rate of 1 mL/min. The bio-oil samples in chloroform (10%, w/v) were prepared and used for the analysis.
133 MS ion source at 250 °C with 70 eV ionization energy was used. Peaks of the chromatogram were
134 identified by comparing with standard spectra of compounds in the National Institute of Standards and
135 Technology (NIST) library.

136 *Table 1: Element characteristic of Napier Grass Stem and Sago Biomass*

Biomass	MC (wt%)	AC (wt%)	VM (wt%)	FC (wt%)	HHV (MJ/kg)	C (wt%)	H (wt%)	N (wt%)	S (wt%)	O (wt%)
NGS	9.26	1.75	81.51	16.75	18.05	51.61	6.01	0.99	0.32	41.07
RH	11.71	13.16	72.27	14.57	16.56	40.67	6.79	0.44	0.87	51.23
Sago	9.19	11.63	73.97	5.21	19.07	39.66	6.61	0.19	0.00	53.54

137

$$137 \text{ bio_oil yield (wt\%)} = \frac{\text{bio_oil collected (g)}}{\text{total biomass feedstock (g)}} \times 100\% \quad (1)$$

138 Several cases of NGS, RH and sago mixtures are created to replicate unique element characteristic
139 properties of feedstock. Table 2 summaries the composition of biomass in each case of study and Table 3
140 presents the element characteristic for each case. The total produced bio-oil yield, aqueous bio-oil yield,
141 organic bio-oil yield, HHV of organic bio-oil, and bio-oil compound from each case are compared to
142 determine the relationship to biomass feedstock element characteristic to the pyrolysis process outputs.

143 *Table 2: Biomass composition in each case study*

Case	1	2	3	4	5	6	7
NGS (wt%)	100	0	0	50	0	50	30
RH (wt%)	0	100	0	50	50	0	40
Sago (wt%)	0	0	100	0	50	50	30

144 *Table 3: Element characteristic of biomass feedstock in each case study*

Case	MC (wt%)	AC (wt%)	VM (wt%)	FC (wt%)	HHV (MJ/kg)	C (wt%)	H (wt%)	N (wt%)	S (wt%)	O (wt%)
1	9.26	1.75	81.51	16.75	18.05	51.61	6.01	0.99	0.32	41.07

2	11.71	13.16	72.27	14.57	16.56	40.67	6.79	0.44	0.87	51.23
3	9.19	11.63	73.97	5.21	19.07	39.66	6.61	0.19	0.00	53.54
4	10.48	7.45	76.89	15.66	17.30	46.14	6.40	0.71	0.60	46.15
5	10.45	12.39	73.12	9.89	17.81	40.16	6.70	0.32	0.43	52.38
6	9.22	6.69	77.74	10.97	18.56	45.63	6.31	0.59	0.16	47.31
7	10.22	9.27	75.55	12.42	17.76	43.65	6.50	0.53	0.44	48.87

145 5. Results and discussions

146 Table 4 tabulated bio-oil production yield, aqueous phase bio-oil yield, organic phase bio-oil yield and HHV
 147 of organic phase bio-oil for each case. The relation between each feedstock element characteristic to
 148 produced bio-oil yields are presented in Figure 1. Similarly, the relations of feedstock elements with
 149 respect to HHV are presented in Figure 2. In general, a linear relation is observed in the relation between
 150 feedstock element characteristic with respect to the pyrolysis outputs. Besides, compound of organic
 151 phase bio-oil is analysed and the chromatogram is presented in Figure 3. More than 20 compounds are
 152 identified in each case. Table 5 presented the composition of the major functional groups identified within
 153 the organic phase bio-oil in each case.

154 *Table 4: Bio-oil production yield and HHV*

Case	1	2	3	4	5	6	7
Total produced bio-oil yield (wt%)	41.91	31.51	37.98	35.86	45.55	39.54	34.13
Aqueous phase bio-oil yield (wt%)	29.56	30.70	36.87	32.66	36.60	35.51	31.98
Organic phase bio-oil yield (wt%)	12.34	0.82	1.11	3.20	8.95	4.03	2.14
HHV of organic phase bio-oil (MJ/kg)	26.23	19.73	17.95	20.11	23.35	19.45	17.87

155 *Table 5: Main functional groups of organic phase bio-oil*

Case	1	2	3	4	5	6	7
Phenols (wt%)	51.60	58.20	64.26	72.38	70.88	71.43	67.89
Aldehydes (wt%)	16.14	2.64	13.11	16.81	9.13	3.20	3.20
Acids (wt%)	13.07	4.29	5.47	0.00	3.41	13.50	13.50
Ketones (wt%)	9.57	10.52	2.29	4.54	2.14	0.00	0.00
Hydrocarbon (wt%)	0.00	8.50	3.19	0.00	2.01	6.35	6.35
Alcohols (wt%)	2.52	8.99	2.06	0.00	9.02	0.00	0.00
Benzene derivatives (wt%)	2.17	2.60	2.26	2.08	1.47	0.00	0.00
Others (wt%)	4.66	4.26	7.36	4.19	1.95	0.00	9.06

156 5.1 Feedstock impacts to produced bio-oil yield

157 From the results, it is observed that more VM, HHV, C, and N, and; less MC, Ash, FC, H, S, and O in
 158 biomass feedstock resulting in higher yield of produced bio-oil production. However, noted that these
 159 relations are not all similar in the comparison cases of aqueous and organic phase bio-oil. The general
 160 linear relation of aqueous phase and organic phase is not parallel in comparisons of Ash, VM, FC, C, H, N,
 161 and O. Based on the trend of produced bio-oil yield with respect to the ash content in biomass feedstock,
 162 more ash content resulting in less bio-oil. This finding is comparable to the work by Choi et al., (2014) in
 163 pyrolysis of seaweed. Similar trend is found in VM analysis, where higher VM content resulting high yield in
 164 bio-oil. In pyrolysis, VM within biomass evaporated upon heating, heavier components at the produced gas
 165 condensed into bio-oil within the cooling system and remaining lighter gas is produced as syngas and light
 166 hydrocarbon gas. However, depending on the operating condition and thermal cracking of the biomass,
 167 possible lower bio-oil yield in high VM biomass feedstock due to more light gas is produced as syngas.
 168 Nevertheless, this is more likely to happen in the present of oxidation agent, such as in gasification
 169 process.

170 5.2 Feedstock impacts to produced organic phase bio-oil HHV

171 As the aqueous phase of bio-oil is generally consist of more acids and moisture, heating value is expected
 172 to be lower compared to organic phase of bio-oil. Thus, in this study, only the HHV of organic phase bio-oil
 173 is analysed for potential use as fuel. Based on the comparison, lower MC, Ash, HHV, H, and O, and;
 174 higher VM, FC, C, N, and S favours higher HHV value in the organic phase bio-oil. This analysis also
 175 highlights the key elements of the process. Key elements are the main element constraints that govern the

176 process output. Similarly, non-key elements are the feedstock elements characteristic that has less effect
177 to process output. For example, noted that MC, HHV and S content of the biomass feedstock has little
178 impact to the HHV of organic phase bio-oil, which a closed to horizontal line in this element analysis is
179 observed in Figure 2. Most of the moisture content within the produced bio-oil is presented in the aqueous
180 phase of bio-oil. This explains the minimum impact of biomass feedstock MC with respect to HHV of
181 organic phase bio-oil. The impact should be more significant if compared to HHV of aqueous phase bio-oil.
182 However, determination of HHV of aqueous phase bio-oil is very difficult due to the relatively high
183 concentration of moisture content which weakens its combustion property. On the other hand, as no
184 pretreatment conducted on the bio-oil, the moisture content may affect the bio-oil heating value analysis.
185 Part of the energy is used to evaporate moisture content within bio-oil. Thus, depending on the amount of
186 moisture content within the bio-oil, the HHV from the analysis will be affected. Therefore, comparison
187 between LHV of biomass feedstock and LHV of bio-oil will be more constructive and accurate. LHV of bio-
188 oil can be estimated provided that the moisture content in the bio-oil is determined. This will be verified in
189 future work.

190 **5.3 Feedstock impact to organic phase bio-oil compound**

191 From the analysis of organic phase bio-oil compounds, more than 20 compounds are identified including
192 different isomers. In order to simplify the comparisons, all identified compounds are classified into 8
193 functional groups as per Table 5. Similar to the study on bio-oil yield and HHV, the relation of biomass
194 feedstock element characteristics and organic phase bio-oil functional group compound is constructed as
195 shown in Figure 4(a) and 4(b). However from the analysis, no significant trend or relation is observed.
196 Quality of bio-oil in terms of chemical functional groups seems to be scatter around in the comparison to
197 element characteristics of the feedstock. One of the suggestions to this phenomenon is due to the present
198 of minerals within the ash content of biomass. Researches show that different mineral interacts differently
199 during thermochemical conversion (Ellis et al., 2015). Mineral within different biomass has the potential to
200 react with each other and interferes the overall process reaction. Specific mineral also can be used as
201 catalyst for pyrolysis to control and achieve particular bio-oil quality. However in this research, mineral
202 content is not considered as part of the feedstock properties. Thus, analysis and comparison to the
203 potential key element are unable to be conducted. This suggested that further improvement of current
204 element targeting approach is required, especially to integrate feedstock mineral content to process output
205 such as bio-oil compounds. Catalytic reaction might able to minimise the fluctuation in the relations, which
206 enable proximate estimation of bio-oil compound in the process output.

207 **5.4 Estimation of pyrolysis output**

208 Upon the discussion on the analysis of relation between biomass feedstock element characteristic with
209 respect to pyrolysis outputs, this section discusses one of the potential application. Based on the
210 constructed relations, pyrolysis outputs can be estimated based on the feedstock element characteristic. In
211 cases of feedstock properties fluctuation or exploration of alternative feedstock, an early stage of process
212 outputs estimation is essential as decision making tool. Upon expansion of same approach in other
213 biomass technologies, it also can be used as a screening platform for research and development to
214 determine potential application of respective biomass species in each technology. However, as the
215 influence of each element characteristic to process outputs are varied, forward estimation might resulting
216 in multiple process outputs or a wide range of estimated which might not be feasible. For instance, a
217 biomass with 10 wt% MC and 72 wt% VM is estimated to generate produced bio-oil yield at 38.27 and
218 36.37 kg per kg feedstock respectively, which are not identical to each other. Thus, this approach is highly
219 dependence on the key element that governs the process conversion. In this example of bio-oil production
220 via pyrolysis, estimation based on VM is considered to be more accurate as VM are directly proportional to
221 the gaseous product generated in pyrolysis to produce bio-oil in the cooling system. Nevertheless, more
222 experiment and research need to be conducted to identify the impact factor of each element
223 characteristics and generalised a co-relation for process estimation.

224 **5.5 Construction and application of Element Acceptance Range (EAR)**

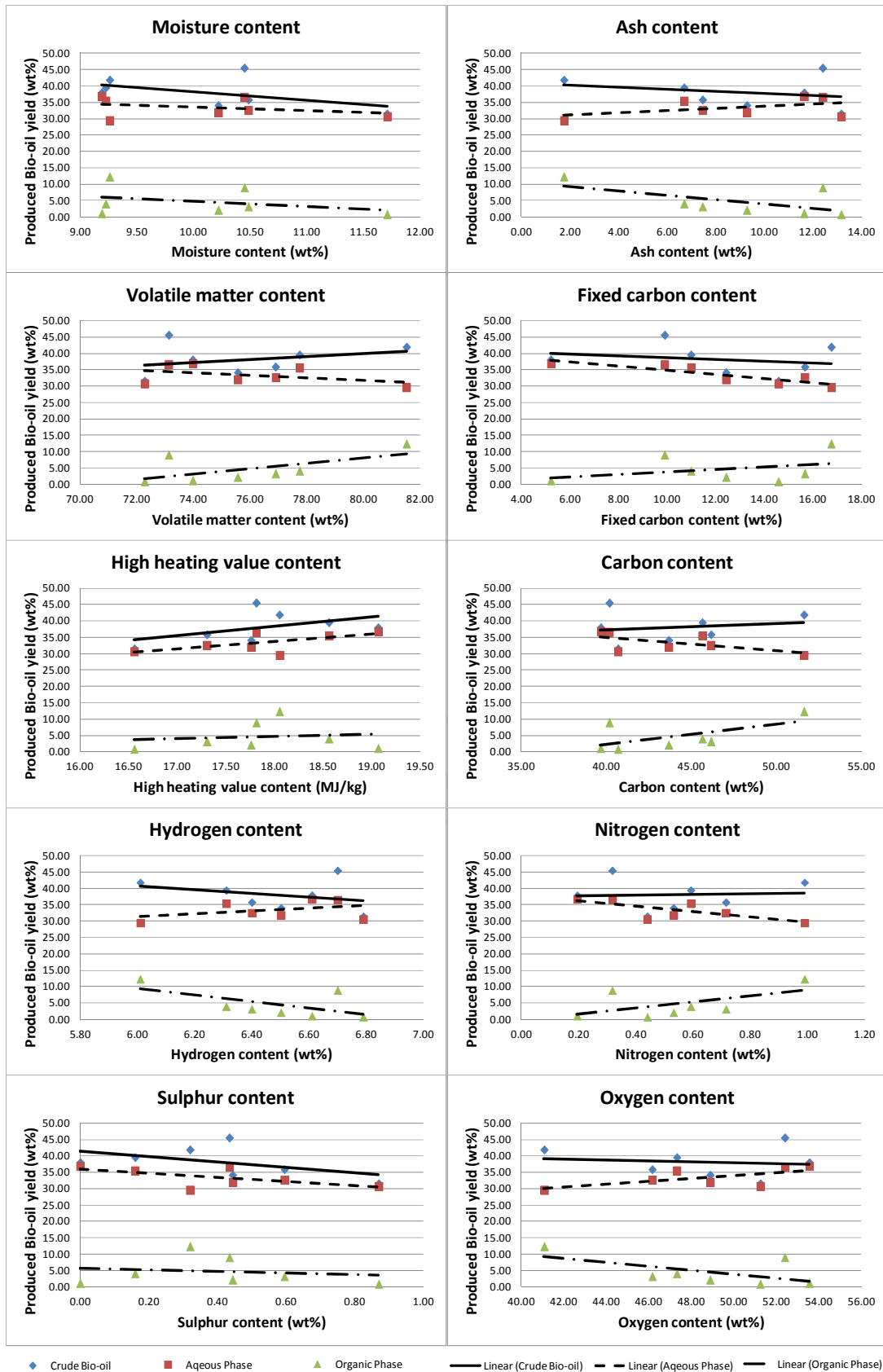
225 Another application of relation between biomass feedstock element characteristics and process outputs is
226 in the construction of EAR. EAR is the feedstock elemental boundary or limitation of respective process
227 technology in order to maintain operational and process consistency. In other words, as long as the
228 feedstock is within the proposed EAR, no significant process fluctuation is expected. EAR can be
229 constructed by backward estimation from targeted process output. For example in this case, assuming the
230 total produced bio-oil yield is targeted to be in the range of 35 wt% to 40 wt%. Based on the constructed
231 relations as shown in Figure 1 (between feedstock element characteristics and total produced bio-oil yield),

232 the element acceptance ranges of this pyrolysis technology are estimated as shown in Figure 5. Noted that
233 EAR of Figure 5 is only applicable to the proposed pyrolysis set up and operating conditions as per
234 described in Section 4. From the proposed element acceptance range, depending on the key elements of
235 the other process outputs, aqueous phase bio-oil yield, organic phase bio-oil yield, HHV of organic phase
236 bio-oil yield can be estimated. For instance, assuming VM to be the main key element in this process,
237 aqueous phase bio-oil yield, organic phase bio-oil yield, and HHV of organic phase bio-oil yield are
238 estimated to be in the range of 31.69 wt% to 36.15 wt%, 0 wt% to 8.31 wt%, and 17.14 MJ/kg to 22.89
239 MJ/kg. Thus, depending on the process output requirement, element targeting approach enables the
240 identification of element acceptance range of respective technology. The main advantage of the backward
241 estimation is to determine the feasibility of alternative biomass species as potential feedstock via the
242 constructed element acceptance range. The proposed range is also applicable to determine the optimum
243 composition of biomass mixture as feedstock to ensure consistency in process outputs as suggested by
244 Lim & Lam (2016).

245 Analysis on the relation between feedstock element characteristic and process outputs enables a
246 systematic platform to determine main process constraints. This breakthrough the limitation in
247 conventional technologies, where developed technology only applicable to the respective biomass
248 feedstock or selected few biomass species. Integration and estimation of process outputs based on
249 element characteristic instead of biomass species offer higher flexibility in feedstock selection without
250 compromise the process and operation. With the proposed EAR approach, all biomass technology has the
251 potential to be implemented in any region with diverse biomass resources. Non-main stream biomass
252 species or underutilised biomasses are able to be considered into the system as potential resources as
253 long as the overall element characteristic of biomass feedstock mixture is within EAR of the technology.
254 Another advantage of element targeting is to tackle uncertainties in biomass resources. Uncertainty of
255 biomass availability and quality due to seasonal fluctuation and weather condition can be minimized based
256 on EAR, such that alternative biomass species or mixtures are exploited as temporary solution. No doubt
257 that more research and experimental works are required to construct a systematic co-relation between
258 feedstock element characteristic and process outputs, however, the advantages of element targeting are
259 able to tackle the limitation in biomass technology and supply chain management.

260 **5.6 Limitation of the proposed element targeting approach**

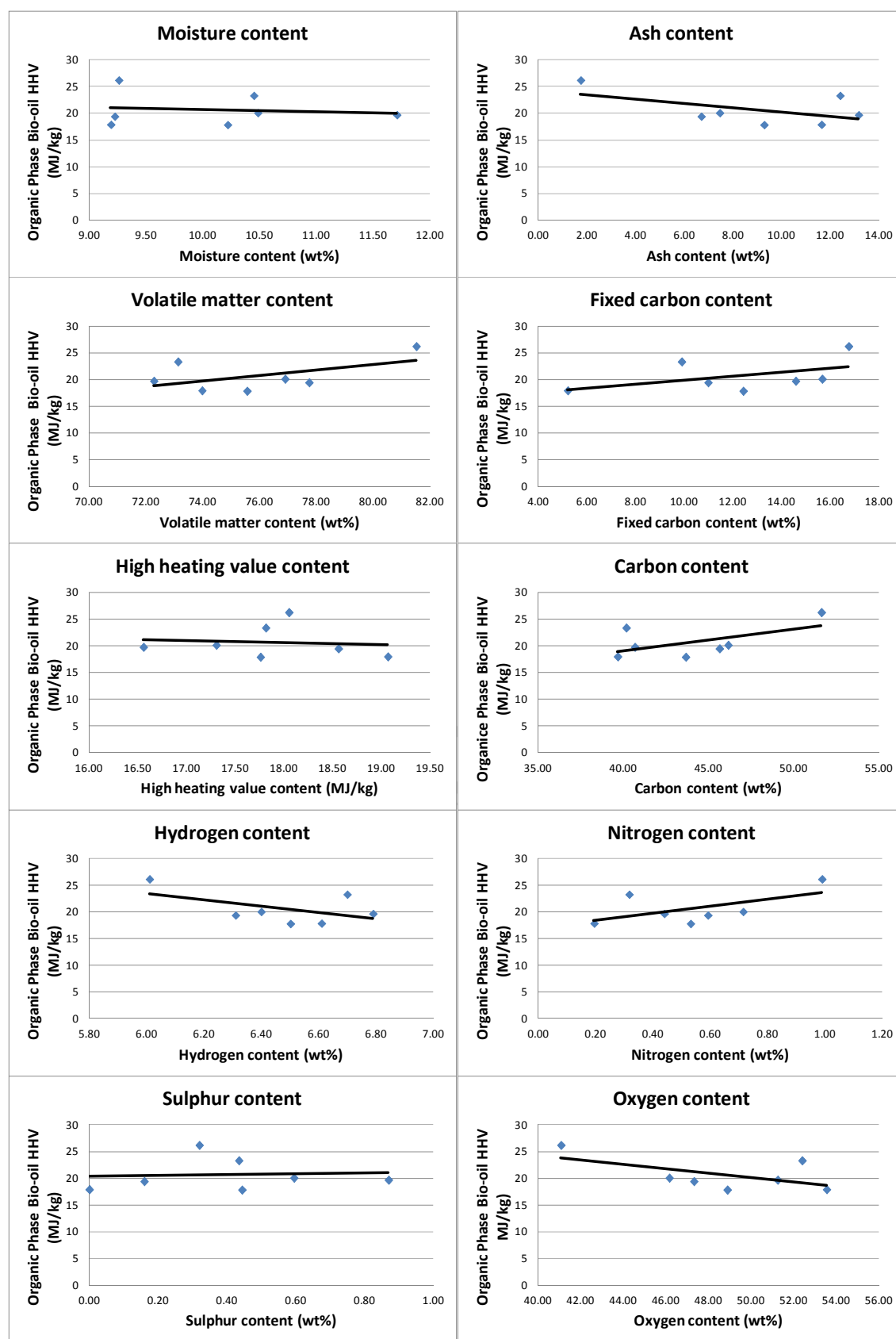
261 Previous discussion has shown promising advantages and application of element targeting approach in
262 biomass processes, especially focused in pyrolysis. However, due to limited biomass feedstock variety in
263 the experiment, the similar boundaries are also reflected in the construction of element acceptance range.
264 Based on the feedstock element characteristics reported in Table 3, overall biomass feedstock properties
265 are limited in this experimental work. Thus, the proposed relations between biomass feedstock element
266 characteristics and process outputs proposed are only applicable to biomass feedstock within the range of
267 element characteristics as presented in Figure 6. Alternative biomass feedstock with element
268 characteristics out of the boundary might result error in the outputs estimation. This study also unable to
269 clearly point out the key elements of the process, but a general acceptance range is proposed instead.
270 Nevertheless, these issue can be easily rectified by including more biomass species into the experimental
271 study. Diversify biomass species as feedstock for the experiment enables the analysis to cover wider
272 feedstock element acceptance range. Study wider range of feedstock element characteristic further
273 enhance the analysis of the impact of each biomass properties to the process output which are essential to
274 determine the key element and construction of general co-relation of pyrolysis process. These extension
275 works could potentially identify and prioritise the impact of each element characteristics to the process
276 performance,

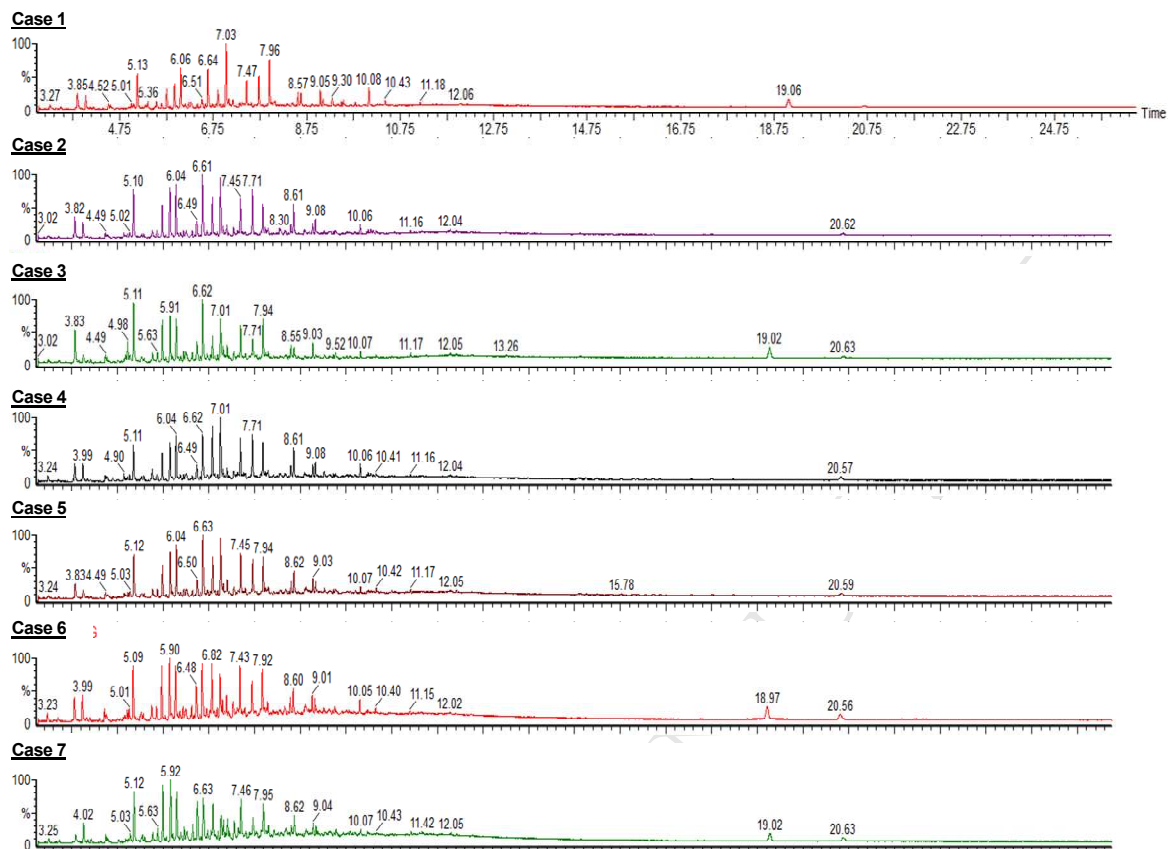


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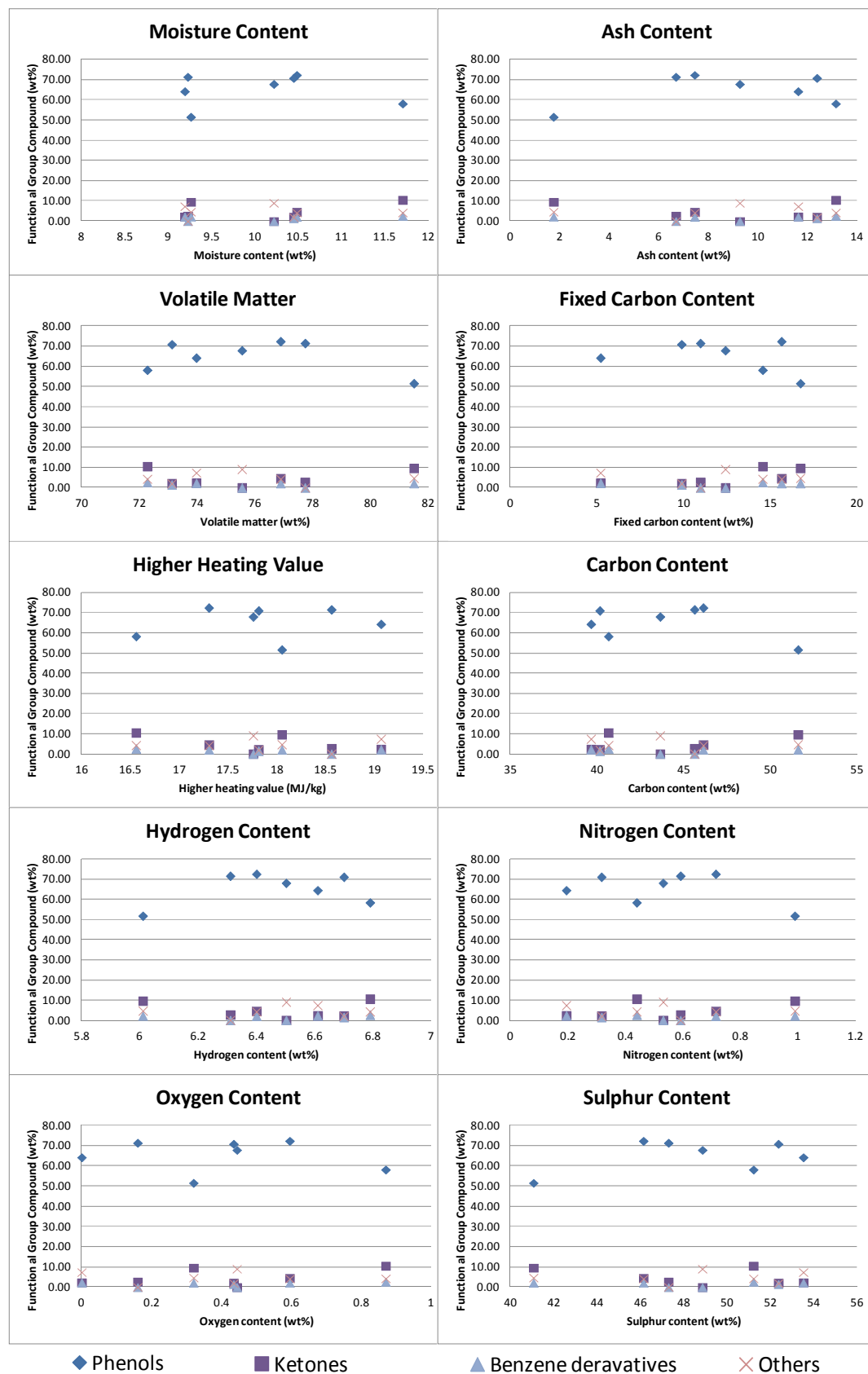
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Figure 1: Relation of feedstock element characteristic to bio-oil yields



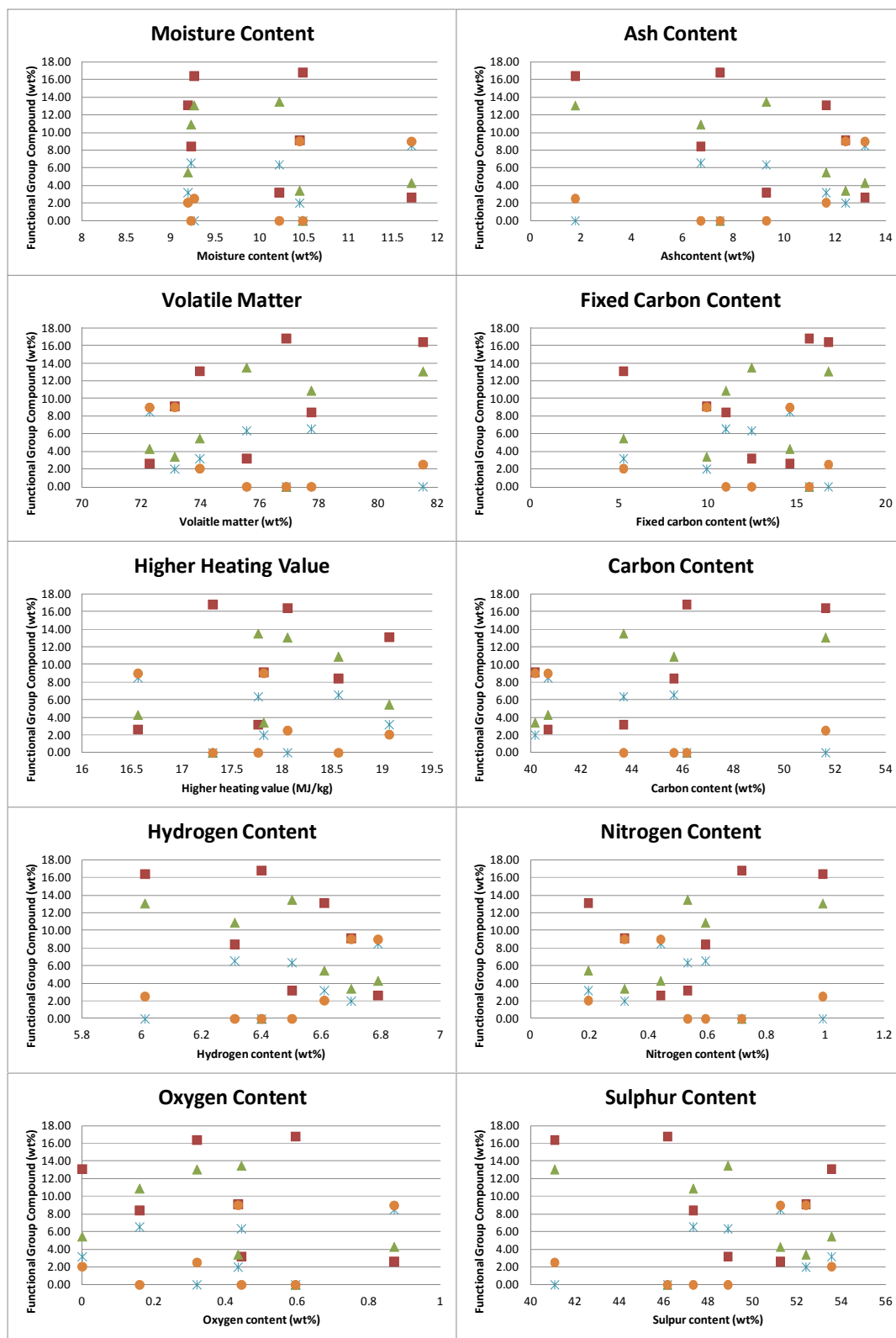


283 *Figure 3: Chromatogram for bio-oil compound analysis*



284

285 *Figure 4(a): Relation of feedstock element characteristic to organic phase bio-oil functional compounds*



286

■ Aldehydes

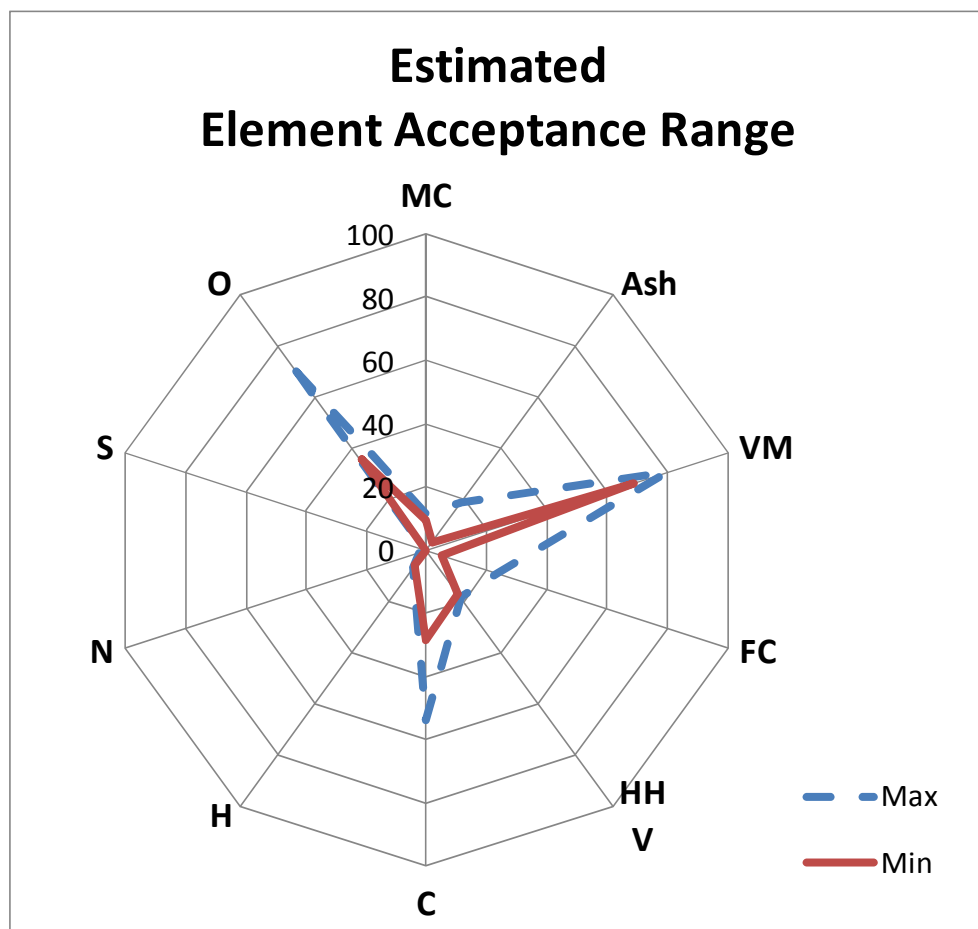
▲ Acids

× Hydrocarbons

● Alcohols

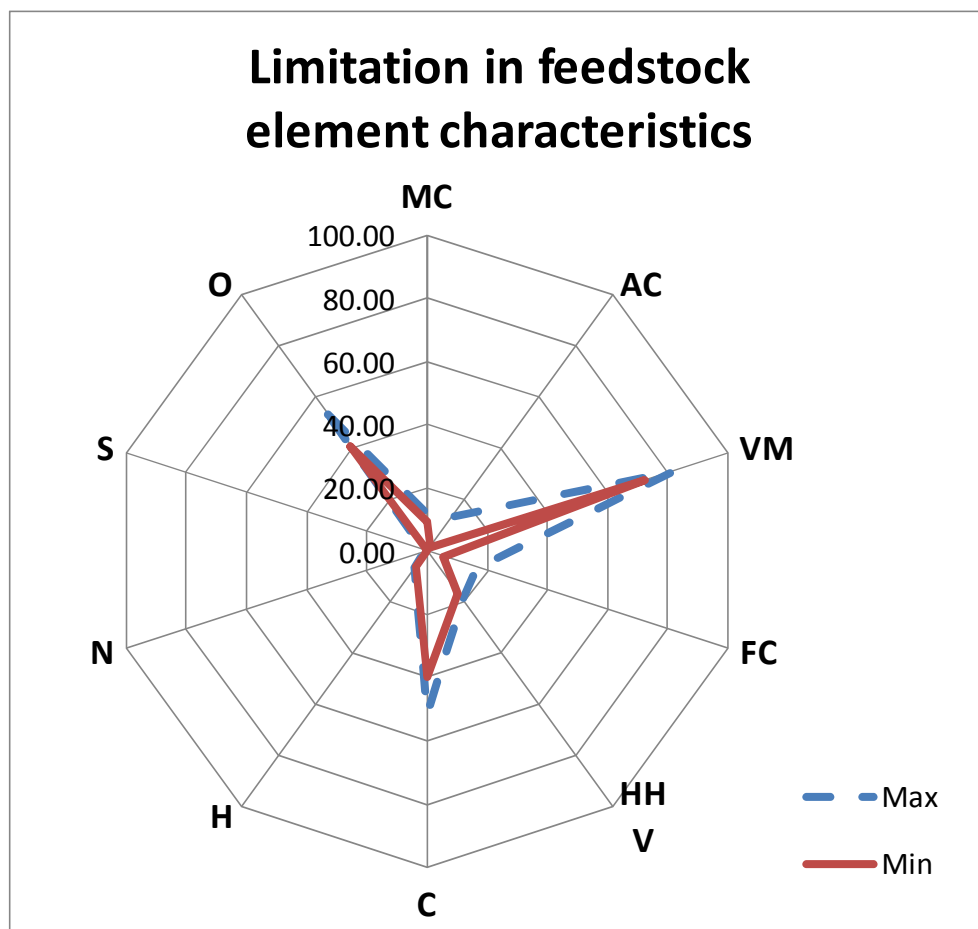
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Figure 4(b): Relation of feedstock element characteristic to organic phase bio-oil functional compounds



288

289 *Figure 5: Estimated element acceptance range to generate 35wt% to 40wt% of produced bio-oil*



290

291 *Figure 6: Research limitation for biomass feedstock element characteristic*292 **6. Conclusions**

293 Three biomass species are used as biomass feedstock for pyrolysis for bio-oil production including Napier
 294 grass stem, rice husk and sago biomass. Mixing ratio of the biomasses is altered to create unique element
 295 characteristic of biomass feedstock. The impact of varies biomass feedstock element characteristics to
 296 process outputs, including overall produced bio-oil yield, aqueous phase bio-oil yield, organic phase bio-oil
 297 yield, and HHV of organic phase bio-oil are analysed. Based on the relations, systematic process output
 298 estimation is proposed using element targeting approach. This approach enables construction of element
 299 acceptance range for respective technology, in this case fixed bed pyrolysis, to integrate alternative
 300 biomass into existing process without major modification. The analysis shows that total produced bio-oil
 301 yield, aqueous phase bio-oil yield, organic phase bio-oil yield and organic phase bio-oil higher heating
 302 value generally has linear relations with feedstock element characteristics. Nevertheless, no significant
 303 relation is observed in the comparison of organic phase bio-oil compounds with respect to feedstock
 304 properties. Several advantages of element targeting approach are discussed such as integration of
 305 underutilised biomass into existing process. This enhances feedstock flexibility of process technology and
 306 at the same time reduces waste management for cleaner production. However, the proposed results are
 307 limited to the biomass element characteristics range based on the three biomass species. More
 308 experimental work on various biomass species are required to widen the range of element characteristic
 309 study in biomass pyrolysis.

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1. Highlights

- To study impact of feedstock element characteristics to pyrolysis process outputs
- Construction of element acceptance range for fixed bed pyrolysis
- Integrate alternative biomass as feedstock without major process modification
- Estimation of process outputs in the event of feedstock properties uncertainty

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