Methanolyis of duckweed and azolla: A comparative analysis

R Rohim¹, K M Isa²,³*, T A T Abdullah⁴, R A Rashid⁵ and M A Aziz⁶

¹Faculty of Civil Engineering Technology, Universiti Malaysia Perlis, 02600, Jejawi Arau, Perlis, Malaysia
²Faculty of Chemical Engineering Technology, Universiti Malaysia Perlis, 02600, Jejawi Arau, Perlis, Malaysia
³Centre of Excellence for Biomass Utilization, School of Bioprocess Engineering, Universiti Malaysia Perlis, 02600, Arau, Perlis, Malaysia
⁴Centre of Hydrogen Energy, Institute of Future Energy, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia.
⁵Faculty of Languages and Communication, Universiti Sultan Zainal Abidin, 21300 Kuala Nerus, Terengganu, Malaysia.
⁶Faculty of Chemical and Natural Resources Engineering, Universiti Malaysia Pahang, Gambang Kuantan Pahang.

*E-mail: khairudin@unimap.edu.my

Abstract: This paper compares the bio-oil and chemical compositions produced from methanolysis of duckweed and Azolla. The methanolysis was carried out at 230°C, 250°C and 300°C for 30 minutes using the CJF-0.1L reactor. Oil yield produced from azolla was 34% and this is 3% higher as compared to the bio-oil yield produced by duckweed at 250°C. The Gas Chromatography Mass Spectrometry (GCMS) analysis showed that alcohol, ketone, amine, ether and ester compositions in the bio-oil produced from duckweed were slightly higher than azolla. However, carboxylic acids, amide and phenol compounds in the bio-oil produced from azolla are different and higher than duckweed. The results suggest that duckweed and azolla are the potential feedstocks from aquatic biomass to be further investigated for bio oil use.

1. Introduction
Biomass is devised as one of the most encouraging options to fossil fuels for the production of energy, bio-fuel, and chemical. The scientific community have received a challenge to find new techniques to accomplishment renewable energy in order to meet the world’s demand for energy as well as reducing greenhouse gases as the increasing of CO₂. Biomass is one of the largest sources of energy in the world. There is a developing consideration to the advancement of technologies to convert biomass into more valuable fuels in addition to the direct energy production. In this situation, liquefaction can be a fascinating technology to produce a biofuel from a wet feedstock without the need of energy engrossing drying process.

A conversion of aquatic biomass to liquid fuel by pyrolysis have been studied previously to produce bio-oil, gas, and bio-char [1]. The bio-oil from the aquatic biomass contained a huge fraction of aliphatic hydrocarbon likely from lipids, together with important proportions of aromatic nitrogen and oxygen compounds, likely derived from proteins [2]. The use of aquatic biomass to generate bio fuel gained
attention as it did not challenge with food for land usage, high photosynthetic efficiency, and fast growth rate.

Duckweed, which is an aquatic plant that floats on the surface of ponds, is the biomass selected for our study. This aquatic biomass has drawn enormous consideration from researchers due to its fascinating properties such as rapid multiplication, strong adaptability and low processing costs [3-6]. According to Catallo et al.[7], aquatic plants are considered as an ideal feedstock for production of biofuel due to its high photosynthetic efficiency, high area specific yield and fast growth rate. Recently, duckweed has gained many interest by researchers for conversion to biofuels. As it usually contains high moisture content after its harvesting, it can be considered for conversion of biofuel [7]. Duckweed can be recovered from the cultivation medium using simple mechanical separation, which is in sharp contrast to microalgae [4]. In addition, the ability to accumulate starch, which is required for creating biofuels, makes duckweed a promising candidate for biofuel feedstock [5-6].

Meanwhile, previous studies on Azolla showed that it is a useful feedstock for biofuel production. For example, Muradov et al.[8] investigated the possibility of Azolla plants for wastewater treatment and generation of renewable fuels. They found that Azolla contains several varieties of petrochemicals including straight chain C10-C21 alkanes, which can be an alternative for direct use of biodiesel fuel or component of bio-diesel [8]. Miranda et al. [9] investigated the capability of Azolla for production of hydrocarbons through liquefaction. They revealed that the amount of produced ethanol of Azolla was greater than woody plants and Miscanthus. Furthermore, the high C/N ratio content in the composition of Azolla can generate high amount of hydrogen gas, that makes it a capable feedstock for hydrogen generation [9]. In addition, previous studied by Biswas et al. [10] also found that high percentage of aliphatic functional groups in azolla bio-oil from the pyrolysis of azolla, sargassum tenerrimum and water hyacinth, making it an advantageous feedstock to generate bio-fuel and bio-chemicals [10].

The most promising thermochemical conversion for aquatic biomass is through liquefaction. Liquefaction can be conducted at low temperature and high pressure using wet/dry samples in which the biomass is converted into three products; bio-oil fraction, a gas fraction and a solid residue fraction, in water or another suitable solvent [11]. There are many aquatic liquefaction studies from previous researchers, however, none of the studies focuses on the comparison of bio-fuel production from several types of aquatic biomass. In this study, the bio-oil from different aquatic biomass were compared for its yield and chemical compositions. To date, there is no study comparing the products from liquefaction of Azolla and Duckweed, and hopefully this study will give a quick insight on the potential of azolla and duckweed.

2. Research Methodology

2.1 Materials
Azolla and duckweed were collected from the Normala Kamis Herbs nursery in Panggau, Perlis (Malaysia) and air-dried for 24 hours. Samples were dried in an oven at temperature of 105°C for 24 hours. The samples were grounded into small particles size (<0.06mm) by mortar and pestle and then kept in the air-tight container for further use.

2.2 Proximate analysis
Proximate analysis was performed using the thermogravimetric analysis (TGA) DTA/DSC TA Model SDT Q600 according to ASTM D2974. The proximate analysis was performed in order to determine the moisture, volatile matter, fixed carbon and ash in biomass. It was performed under inert nitrogen gas and purified air with a constant flow rate of 100 ml/min and heating rate of 20 °C/min.6mg of sample was weighed and put into the alumina crucible and the temperature was kept isothermal for 0.5 min until a steady condition was obtained before ramping to the desired temperature [12-13].
2.3 Methanolsysis
For liquefaction process, a 5g of Azolla was loaded into the stainless steel reactor model CJF-0.1L, and followed by 40 ml of methanol. The temperatures were set at 230°C, 250°C and 300°C for 30 min with stirring at 680 rpm to investigate the effect of temperature. Then, reactor was cooled down to ambient temperature. The reacted products, which were solid and liquid were washed with approximately 150 ml DCM and transferred into the conical flask. Heavy oil can be described as the oil product from liquefaction process which has a density of greater than one, while light oil has a density less than one. The solid residue was separated from the liquid product by filtration with filter paper. The filtered liquid product was left dried in the fume cupboard. The obtained crude oil was measured and recorded. The bio-oil yield consists of heavy oil and light oil. Experiments were repeated 4 times for its reproducibility. The yield of each product was calculated as follows [14]:

\[
\text{Residue yield} = \frac{\text{mass char (g)}}{\text{initial sample loaded (g)}} \times 100
\]

\[
\text{Conversion} = 100 - \text{residue yield}
\]

\[
\text{Total oil and water yield} = 100 - (\text{residue yield} + \text{gas yield})
\]

\[
\text{Heavy oil yield} = \frac{\text{mass heavy oil (g)}}{\text{initial sample load (g)}} \times 100
\]

\[
\text{Product loss} = \text{Gas yield} + \text{light oil yield}
\]

2.4 GCMS analysis
Gas chromatography–mass spectrometry (GC MS – QP2010 Ultra Shimadzu) analyses of the oils (1 μL in DCM) were performed (source temperature 280 °C). Separation was performed on a fused silica capillary column (30 m × 0.25 mm i.d) coated with BPX5 phase (0.25 μm thickness). Helium was used as the carrier gas, with a temperature programme of 35 °C (2 min) to 250 °C at 20 °C/min and hold for 20 min. Injections were performed in full scan mode with split ratio 1:30. Experiments were repeated 3 times for its reproducibility.

3. Results and discussion
3.1 Proximate analysis of Azolla and duckweed
The properties of Azolla and duckweed are presented in Table 1. The proximate analysis showed that the volatile matter yield for Azolla was higher than the duckweed. A higher yield of volatile matter is expected to produce more liquid product during liquefaction. The high ash content is noteworthy as it leads to reduce liquid yields [15]. Based on the result obtained, azolla contains less ash content than the duckweed and this leads to the production of higher liquid yield as can be seen in Table 2. Previous studies also obtained approximately the same results with this study. For example, Pirbazari et al. [16] reported that the moisture content for Azolla was 6.8%, volatile matter was 75.1% the fixed carbon was 5.7%, and the ash content was 12.4%. The proximate analysis for duckweed obtained from Wang et al. [17] was 13.2% for moisture content, 58.7% of volatile matter, 9.8% of fixed carbon and 18.3% of ash content.
Table 1. Proximate analysis of duckweed and azolla

| Proximate Analysis     | Mass fraction (%) |
|------------------------|-------------------|
|                        | Duckweed | Azolla |
| Moisture content       | 13       | 7      |
| Volatile matter        | 60       | 77     |
| Fixed carbon content   | 10       | 5      |
| Ash content            | 17       | 11     |

3.2 Yield of Bio-oil
The percentages of oil yield from duckweed and azolla liquefaction were produced at 230°C, 250°C and 300°C with a reaction time of 30 min. Azolla had the highest bio-oil yield of 35% and it was recorded at 250°C, in agreement with the proximate analysis reported above. Duckweed had the lowest bio-oil yield of 26% and recorded at 230°C. A previous study showed 21.1% of oil yield was obtained from liquefaction of duckweed with temperature of 350°C for 30 min[17].

Table 2 Oil yield (%) from duckweed and Azolla.

| Types of biomass | Oil yield (%) |
|------------------|---------------|
|                  | 230°C | 250°C | 300°C |
| Duckweed         | 26    | 32    | 30    |
| Azolla           | 28    | 35    | 33    |

3.3 Analysis of Bio-Oil
The GCMS was conducted for the samples of bio-oil from methanolysis of azolla and duckweed using 40 ml of methanol solvent at temperature of 250°C for 30 minutes. Those tested parameters were similar as reported by Wang et al.[17]. The GCMS results were shown in Table 3. The major compounds that were found in the bio-oil products were esters, phenols derivatives, ketone, alcohols, and aromatic. Based on the result below, oil yield from duckweed contains a higher ester yield than oil yield from azolla. The comparison of azolla and duckweed bio-oil can be seen in Figure 1. A lower yield of acidic content for sample of duckweed (i.e 2%) was seen as compared to azolla (i.e 15%). The composition of oil produced from duckweed is explained in previous research by Peigao Duan et al.[18]. The high-yield compounds that were presented in the bio-oil at a reaction temperature of 350°C, with reaction time of 30 min and 2.5 g duckweed were ketones and acids, while in this study ester was the highest yield found. Methanolysis had increased the ester content in the produced bio-oil. The high content of carboxylic acids in azolla is likely due to the decomposition of protein [19]. Although acid content in azolla’s bio-oil was higher than duckweed’s bio-oil, the percentage of acid content from liquefaction of azolla were lower than the one from pyrolysis process. Acid compound yield from pyrolysis of Azolla by Pirbazari et al. [16] was about 25%, as compared to only 15% of acid content obtained in this study. The results of liquefaction of Azolla have not been reported in any other studies yet. The hydrocarbons in the liquefaction products may be generated through different pathways, which are dehydration of alcohols, feedstock hydrocarbons breaking down, decarboxylation of fatty acids, and recombination of the resultant radical fragment [20]. The alcohols present from both bio-oil may be derived from the reduction of the acids [20].
Table 3 GCMS result for bio-oil produced from Azolla and duckweed

| NAME                                                   | RETENTION TIME | AREA (AZOLLA) | AREA (DUCKWEED) |
|--------------------------------------------------------|----------------|---------------|-----------------|
| Succinic anhydride                                     | 2.52           | 52703         | N/A             |
| Trimethylene oxide                                     | 2.53           | N/A           | 28056           |
| 2-Propanamine                                          | 2.55           | N/A           | 35101           |
| Formic acid, ethenyl ester                            | 2.60           | 11202         | N/A             |
| Acetic acid, 1-methylethyl ester                       | 2.81           | 68461         | 51846           |
| Butane, 2-chloro-2-methyl-                             | 2.85           | 44342         | 37917           |
| 2-Propanone, 1-chloro-                                 | 3.06           | 10267         | 6581            |
| Methanamine, N-methoxy-N-nitroso-                      | 3.23           | N/A           | 1320            |
| Serine                                                 | 3.24           | N/A           | 1320            |
| Propane, 1,2-dichloro-                                 | 3.27           | N/A           | 1009            |
| 2-Butanone, 3-chloro-                                  | 3.48           | 6135          | 5459            |
| Acetic acid, [aminocarbonyl]amino]oxo-2-Propanone, 1,1-dichloro- | 3.68           | 22639         | 20486           |
| Propane, 1,1'-sulfonylbis-                             | 3.88           | 77117         | N/A             |
| Trimethylene oxide                                     | 3.99           | 5363          | 4913            |
| Propanoic acid, 2,2-dimethyl-                          | 4.45           | 3232          | N/A             |
| Propanoic acid, 2-hydroxy-2-methyl-, methyl e          | 4.50           | 301           | 315             |
| Hydrazinecarboxylic acid, 1,1-dimethylthyl e           | 4.55           | N/A           | 464             |
| 2-Hexanol                                              | 4.67           | 92701         | 76433           |
| Butane, 2,3-dichloro-2-methyl-                         | 4.86           | 16699         | 15467           |
| Succinic anhydride                                     | 4.90           | 1771          | N/A             |
| Heptane, 1-chloro-                                     | 5.17           | N/A           | 2619            |
| Hexane, 1-chloro-                                      | 5.18           | 2662          | N/A             |
| d-Alanine                                              | 5.22           | N/A           | 1218            |
| 3-Nitropropanoic acid                                  | 5.28           | 1199          | N/A             |
| 2-Propanone, 1,3-dichloro-                             | 5.54           | 1953          | 2137            |
| 2-Propenoic acid, ethenyl ester                        | 5.70           | 4847          | N/A             |
| Pentane, 3-bromo-                                      | 5.91           | 1050          | N/A             |
| 3-Hexanol, 2-methyl-                                   | 5.69           | 1301          | N/A             |
| 4-Heptanol                                             | 5.69           | N/A           | 1791            |
| Diisopropyl sulfide                                    | 5.85           | N/A           | 676             |
| Methyl 3-hydroxytetradecanoate                         | 5.86           | 843           | N/A             |
| Cyclopentane, 1,2-dichloro-, trans-1-Butene, 2-chloro-3-methyl- | 5.89           | N/A           | 4819            |
| Ethane, 1,1,2,2-tetrachloro-                            | 5.98           | 2269          | 1824            |
| Chemical Name / Structure | T-O1 | T-O2 | T-O3 |
|---------------------------|------|------|------|
| 1,3,7-Octatriene           | 6.11 | 1564 | 1857 |
| Propanoic acid, 2,3-      | 6.16 | N/A  | 963  |
|    dichloro-, methyl ester|      |      |      |
| Carbamic acid, diethyl-,  | 6.23 | N/A  | 2122 |
|    methyl ester           |      |      |      |
| Isopropylsulfonyl chloride| 6.27 | 6258 | 5090 |
| 1-Propene, 1,2,3-trichloro-,| 6.31 | 5437 | 4770 |
|   (Z)-                    |      |      |      |
|    Propane, 1,2-dichloro-  | 6.47 | 9606 | 11812|
|    2-methyl-              |      |      |      |
| Chlorodimethylethylsilane | 6.66 | 7876 | 7186 |
| 1-Octanamine, N-methyl-   | 6.70 | N/A  | 1801 |
|   Pentanal, 2,3-dimethyl- | 6.77 | 1064 | N/A  |
| 2-Nonanone                | 6.78 | N/A  | 922  |
| Octane, 2-bromo-          | 6.85 | N/A  | 5467 |
| Bis(2-chloroethyl) ether  | 6.86 | 6267 | 4265 |
| Diethyl Phthalate         | 6.89 | 2534 | N/A  |
| Benzenepropanenitrile,    | 7.04 | 4977 | 4265 |
|    beta.-hydroxy-         |      |      |      |
|   Thiourea                | 7.07 | N/A  | 2089 |
| 1-Propanethiol            | 7.08 | 2309 | N/A  |
| 2,2-Bis(chloromethyl)-1   | 7.20 | 4819 | 4503 |
|    propanol               |      |      |      |
|   Propane, 1,3-dichloro-  | 7.27 | 7881 | 7857 |
|   Propane, 1,3-dichloro-  | 7.34 | 6539 | 6768 |
|   Butane, 1-chloro-3-methyl-| 7.52 | 1923 | N/A  |
|   2,2-Bis(chloromethyl)-1-| 7.53 | N/A  | 1737 |
|    propanol               |      |      |      |
|   Benzene, 1-chloro-2-propyl-| 7.56 | N/A  | 1502 |
|    1,3-Dichloro-2-butene  | 7.57 | 1476 | N/A  |
|   Oxirane, 2,3-dimethyl-  | 7.95 | N/A  | 725  |
|   Succinic anhydride      | 8.07 | 3703 | N/A  |
|   N-Acetylmethionine      | 8.25 | 963  | N/A  |
|   Propane, 1,3-dichloro-  | 8.46 | N/A  | 910  |
|   n-Heptadecylbenzene    | 8.58 | 2135 | 2105 |
|   2-(N                   | 8.59 | N/A  | 494  |
|   Morpholino)ethanesulfonic acid |
|   Cyclopropanecarboxylic acid, 3-(2,2-dichloro) | 8.65 | N/A  | 1043 |
|   Nithiamide              | 8.71 | 584  | N/A  |
|   Propane, 2-bromo-1-chloro- | 8.76 | 2312 | 2492 |
|   Carboxylic dihydrozide  | 8.79 | N/A  | 705  |
|   1,4-Dioxane             | 8.88 | N/A  | 1793 |
|   Benzaldehyde, 2,5-dimethyl- | 8.93 | 5819 | N/A  |
|   1,3-Bis-(methylthio)-2- | 8.99 | 493  | N/A  |
|    methoxypropane         |      |      |      |
|   2-Butanone, 3-chloro-   | 9.10 | 6089 | 4859 |
|   Butane, 1-chloro-3,3-   | 9.33 | N/A  | 989  |
|    dimethyl-              |      |      |      |
|   Diethyl Phthalate       | 9.50 | 72181| N/A  |
| Compound                                      | Rf  | Rt   | N/A |
|-----------------------------------------------|-----|------|-----|
| Diethyl Phthalate                             | 9.58| 31075| N/A |
| Diethyl Phthalate                             | 9.62| 27260| N/A |
| Diallylethylamine                             | 9.66| N/A  | 2881|
| Diethyl Phthalate                             | 9.58| 31075| N/A |
| Phthalic acid, monoethyl ester                | 9.71| 3253 | N/A |
| 1,4-Dioxane, 2,3-dichloro-                     | 9.77| N/A  | 1747|
| Diethyl Phthalate                             | 9.54| 16047| N/A |
| Decane, 1-chloro-                             | 10.21| N/A  | 586 |
| Benzonatate                                   | 10.22| 1353 | N/A |
| Propane, 1,2-dichloro-2-methyl-                | 10.41| 6647 | 5450|
| Diethyl Phthalate                             | 10.50| 4503 | N/A |
| Propane, 2-bromo-1-chloro-1-Dodecanol          | 10.56| N/A  | 3006|
| Cyclooctasiloxane, hexadecamethyl-             | 10.92| 3174 | N/A |
| Dodecanoic acid, methyl ester                 | 11.13| N/A  | 18720|
| Hexadecane                                    | 11.22| N/A  | 716 |
| Hexatriacontane                               | 11.29| N/A  | 892 |
| Dodecanoic acid                               | 11.34| N/A  | 1744|
| Aziridine, 2-methyl-                           | 11.37| 2986 | N/A |
| 2-Acetylbenzoic acid                          | 11.56| 5830 | N/A |
| 1,4-Dioxane                                   | 11.73| 5445 | N/A |
| n-Pentadecanol                                | 12.16| N/A  | 609 |
| Decane, 1-iodo-                               | 12.32| N/A  | 808 |
| Phenol, 4-(aminomethyl)-2-methoxy-             | 12.39| 2140 | N/A |
| Methyl tetradecanoate                          | 12.43| N/A  | 11182|
| 1,6-Hexanediame, N,N'-dimethyl-                | 12.44| N/A  | 1493|
| Heptadecane, 3-methyl-                         | 12.58| N/A  | 1203|
| Heptasiloxane, hexadecamethyl-                 | 12.69| 26554| N/A |
| Hexadecane, 1-iodo-                            | 12.70| N/A  | 791 |
| n-Heptadecanol-1                              | 12.86| 1057 | N/A |
| Octadecanoic acid, 2-oxo-, methyl ester       | 12.90| N/A  | 632 |
| Formic acid, ethenyl ester                    | 13.20| 3113 | N/A |
| 1,4-Dioxane                                   | 13.18| 2096 | N/A |
| d-Alanine                                     | 13.19| 1074 | N/A |
| Formic acid, ethenyl ester                    | 13.23| 1074 | N/A |
| Heptasiloxane, hexadecamethyl-                 | 13.61| 40663| N/A |
| Hexadecanoic acid, methyl ester               | 13.68| 31986| N/A |
| Hexadecanoic acid, methyl ester               | 13.75| N/A  | 101155|
| Pentadecanoic acid                            | 13.89| N/A  | 4018|
| Azeleonitrile                                 | 14.10| 435  | N/A |
| Compound                                      | Retention Time | Peak Area | comment |
|-----------------------------------------------|----------------|-----------|---------|
| Tridecanoic acid                              | 13.91          | 22710     | N/A     |
| Ethanol, 2-bromo-                             | 14.09          | 1526      | N/A     |
| Octadecanal                                   | 14.37          | 15889     | N/A     |
| Dehydroabietylamine                           | 14.23          | N/A       | 1444    |
| Heptadecanoic acid, methyl ester              | 14.36          | N/A       | 1358    |
| Benzoic acid, 2,6-bis[(trimethylsilyl)oxy]-, triphenol, 4-(aminomethyl)-2-methoxy-n-Nonadecanol-1 | 14.61          | 35226     | N/A     |
| 1,2-Ethanedi amine, N-(2-aminoethyl)-4-Decenoic acid, methyl ester, Z-Octadecanoic acid, methyl ester | 14.70          | 5497      | N/A     |
| Cyclohexanone, 4-(methylthio)-Formic acid, ethenyl ester | 15.38          | 2158      | N/A     |
| Semioxamazide                                 | 15.50          | N/A       | 2563    |
| 1(2H)-Naphthalenone, octahydro-4-hydroxy-,1-Heptadecanol, acetate | 15.58          | N/A       | 2106    |
| 3,4-Methylenedioxy-beta-nitrostyrene          | 16.10          | 1661      | N/A     |
| Hexasiloxane, tetradecamethyl-Trimethylene oxide | 15.80          | 33979     | N/A     |
| Formic acid, ethenyl ester                   | 16.10          | 1661      | N/A     |
| 4-Penten-1-ol, 3-methyl-Trimethylene oxide    | 16.69          | N/A       | 1056    |
| Succinic anhydride                            | 17.05          | N/A       | 3084    |
| 1,2-Oxathiolane, 2,2-dioxide                 | 17.06          | 2999      | N/A     |
| Hexasiloxane, tetradecamethyl-Formic acid, ethenyl ester | 17.08          | 3706      | N/A     |
| 2(R),3(S)-1,2,3,4-Butanetetrol                | 17.36          | 22083     | N/A     |
| Trimethylene oxide                            | 17.48          | 4555      | N/A     |
| Acetic acid, hydrazide                        | 17.56          | N/A       | 3168    |
| 1,3,6-Trioxocane                              | 18.42          | 5887      | N/A     |
| Acetic acid, hydrazide                        | 18.46          | N/A       | 938     |
| 1,2-Ethanedi amine, N-(2-aminoethyl)-2-Octanamine | 19.32          | 979       | N/A     |
| Stearic acid hydrazide                        | 18.53          | 5073      | N/A     |
| 1,2-Ethanedi amine, N-(2-aminoethyl)-2-Octanamine | 19.40          | N/A       | 414     |
| 1,2-Oxathiolane, 2,2-dioxide                  | 18.56          | N/A       | 2412    |
| Semioxamazide                                 | 19.62          | N/A       | 1661    |
Heptasiloxane, hexadecamethyl- 19.70 13825 N/A
Methionine 19.89 2205 N/A
d-Alanine 20.19 1620 N/A
Formic acid, ethenyl ester 20.20 3794 N/A
9-Octadecenoic acid, 12- (acetyloxy) -, methyl e 20.31 N/A 9759
Hydrazinecarboxylic acid, ethyl ester 20.42 N/A 1371
Succinic anhydride 20.67 N/A 2815
Formic acid, ethenyl ester 20.72 3918 1334
3,6-Dimethylpiperazine-2,5-dione 20.72 3918 N/A
Propanamide 20.77 787 N/A
Formic acid, ethenyl ester 21.88 5555 N/A

| Compound                                      | azolla  | duckweed | N/A |
|-----------------------------------------------|---------|----------|-----|
| acids                                         | 45.00   | 20.00    |     |
| ester                                         | 35.00   | 10.00    |     |
| ether                                         | 25.00   | 30.00    |     |
| amine                                         | 20.00   | 40.00    |     |
| amide                                         | 15.00   | 15.00    |     |
| ketone                                        | 15.00   | 15.00    |     |
| alcohol                                       | 10.00   | 10.00    |     |
| phenol                                        | 5.00    | 5.00     |     |
| hydrocarbon                                   | 5.00    | 5.00     |     |

Figure 1. Chemical composition (%) for bio-oils produced from duckweed and azolla

4. Conclusion
A thorough comparison of the oil yield and chemical compositions from methanolsysis of duckweed and azolla had been carried out. A higher oil yield was produced from the liquefaction of azolla than that of duckweed. Azolla produced 35% oil yield which is 3% higher than the duckweed’s. However, the hydrocarbon, alcohol, ester amine, ketone and ether compounds of duckweed were higher than the compounds in the bio-oil produced from azolla. The duckweed is a potential feedstock for bio-oil with a reduced content of acids. Both aquatic biomasses showed high ester content with comparable compounds of ketones, phenol and hydrocarbon. The obtained results showed that duckweed and azolla are the potential feedstocks from aquatic biomass to be further investigated for bio-oil use.

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