









Table 2 Composition of cellulose pyrolysis products without catalyst versus number of repeated catalyst experiments (peak area % of identified peaks, hydrocarbon (HC) compounds, unidentifiable compounds were classified as others)

sample	Acid%	Alcohol%	Esters%	Furans%	Ketone%	Phenols%	Sugar%	HC%	Others%
None	4.9±0.2	2.3±0.1	2.0±0.1	20.7±0.7	17.5±2.6	1.7±0.4	47.7±0.2	0	2.1±1.2
1st time	3.0±0.3	2.3±0.1	2.4±0.2	25.9±0.7	29.7±0.8	2.2±0.2	31.5±0.6	0.5±0.4	2.4±0.4
2nd time	2.1±0.2	2.5±0.3	3.4±0.9	25.4±1.1	29.9±1.1	2.1±0.6	30.0±0.3	1.1±0.8	3.5±0.4
3rd time	2.0±0.1	2.3±0.4	3.8±0.2	25.6±1.1	29.4±1.1	2.5±1.0	30.3±0.7	1.4±0.1	2.7±0.5
4th time	1.9±0.1	2.4±0.2	3.2±0.4	26.0±0.3	29.6±0.4	2.9±0.2	30.7±0.3	0.7±0.5	2.6±0.3
5th time	1.8±0.5	2.4±0.7	3.2±0.4	25.7±1.2	30.0±3.5	2.6±0.4	30.2±2.4	1.1±0.8	2.9±0.2

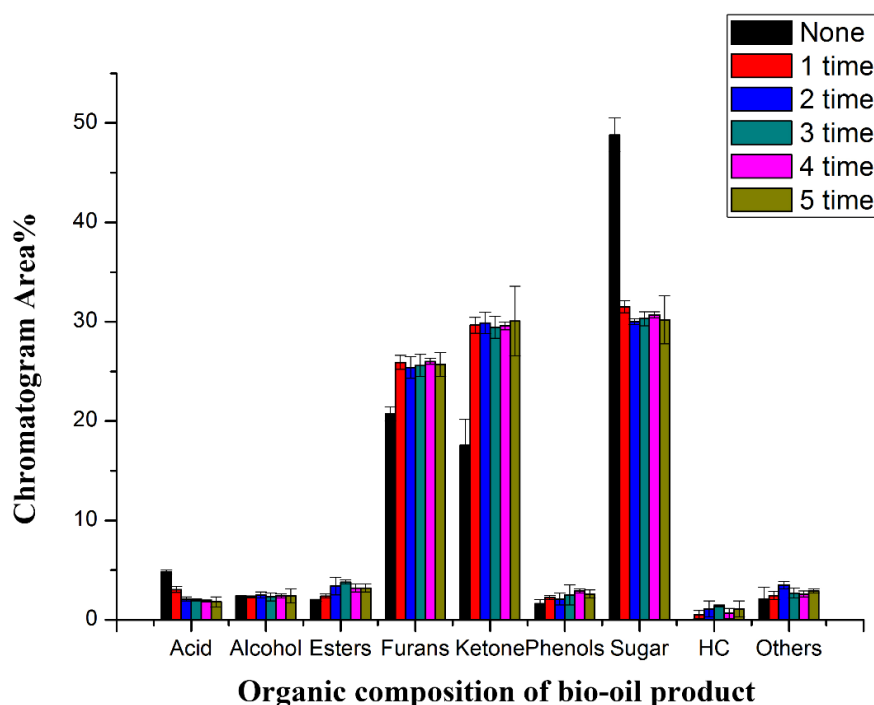


Figure 6. Chemical relative compositions of the organic phase of bio-oil without catalyst and after repeated catalyst use up to 5 times

Finally, the catalyst did not affect the phenol, alcohol, and ester amounts. The phenol compounds are usually formed from secondary reactions of the cellulose vapors (Stefanidis, Kalogiannis et al. 2014; Wang, Ma et al. 2016), which is why it did not change a lot in this study. Based on the above analysis, the following reaction pathway is proposed. The cellulose decomposed into sugar first, and then the sugar decomposed further into acid, furan, and ketone compounds. The same mechanism has been proposed in our previous study (Li, Cheng et al. 2020). We believe this reaction sequence can help explain the composition of the pyrolyzed bio-oil and catalyst interaction.

#### 4. Conclusion

The Ni<sub>2</sub>Fe<sub>3</sub> cluster catalysts were prepared by the sol-gel method successfully and the recyclable property was tested. The results indicated a new potential type of stable recyclable catalyst can be used for pyrolysis and the yield of bio-oil and composition was also stable after

repeated experiments. This Ni<sub>2</sub>Fe<sub>3</sub> cluster catalyst also showed a different reaction pathway when compared to other supported catalysts in the literature, directly transferring heat to the biomass while catalyzing the vapors. Furthermore, this cluster catalyst can reduce catalyst costs due to its recyclability since it is easy to separate from char.

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