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# APPENDICES

## Appendix A X-ray Diffraction Patterns

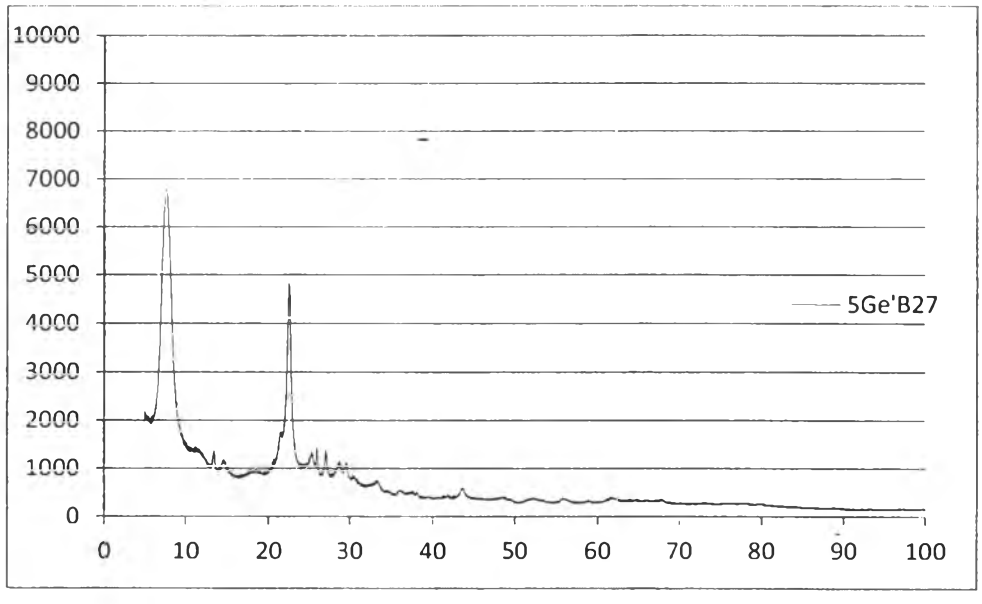


**Figure A1** XRD pattern of 5Ge'B27.

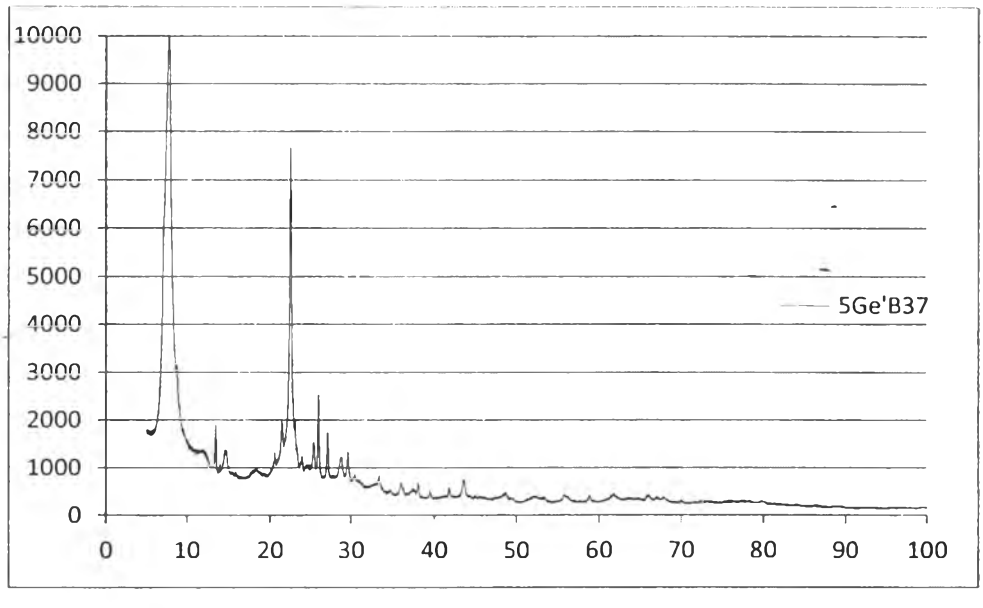


**Figure A2** XRD pattern of 5Ge'B37.

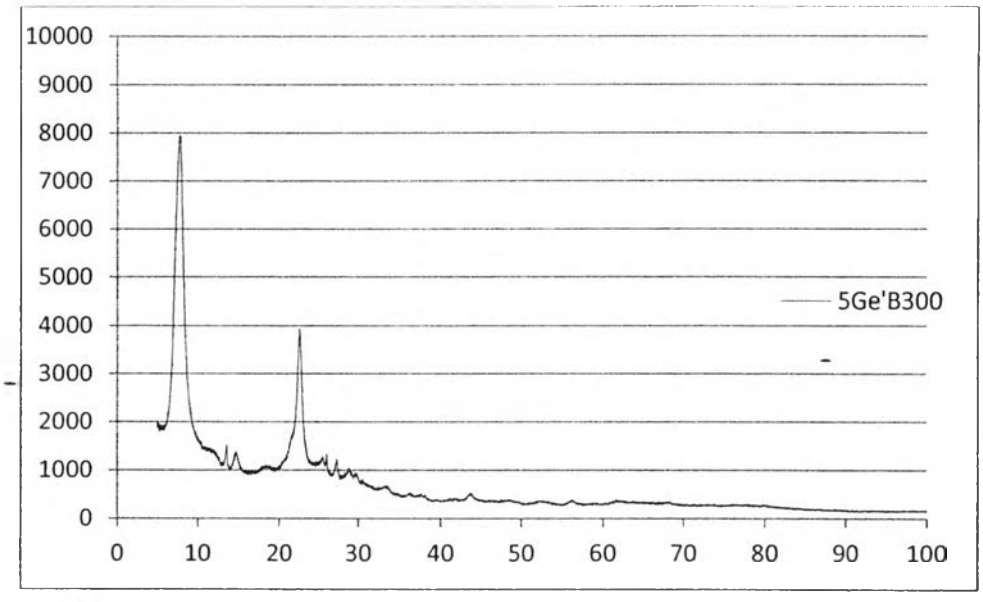


**Figure A3** XRD pattern of 5Ge'B300.

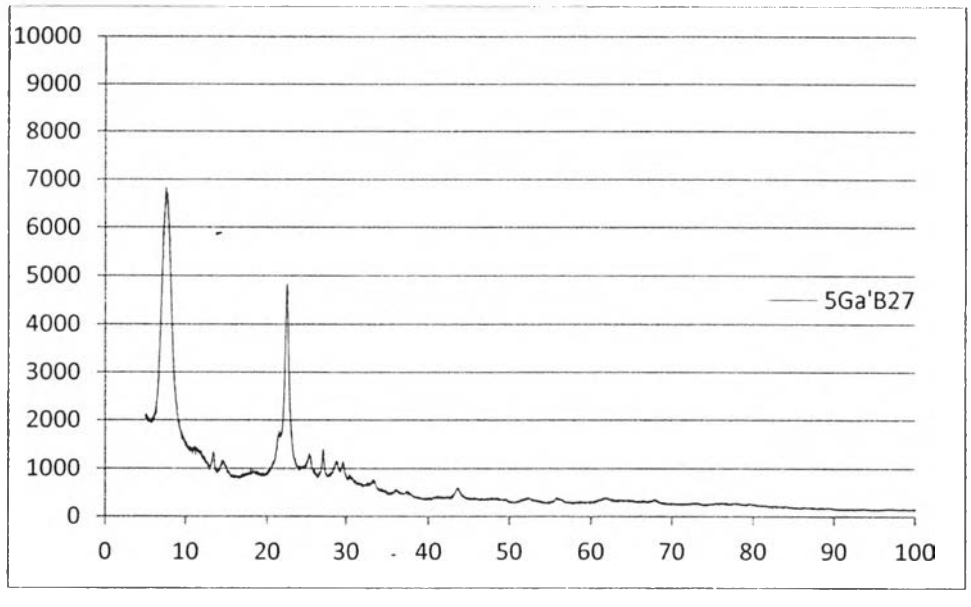


**Figure A4** XRD pattern of 5Ga'B27.

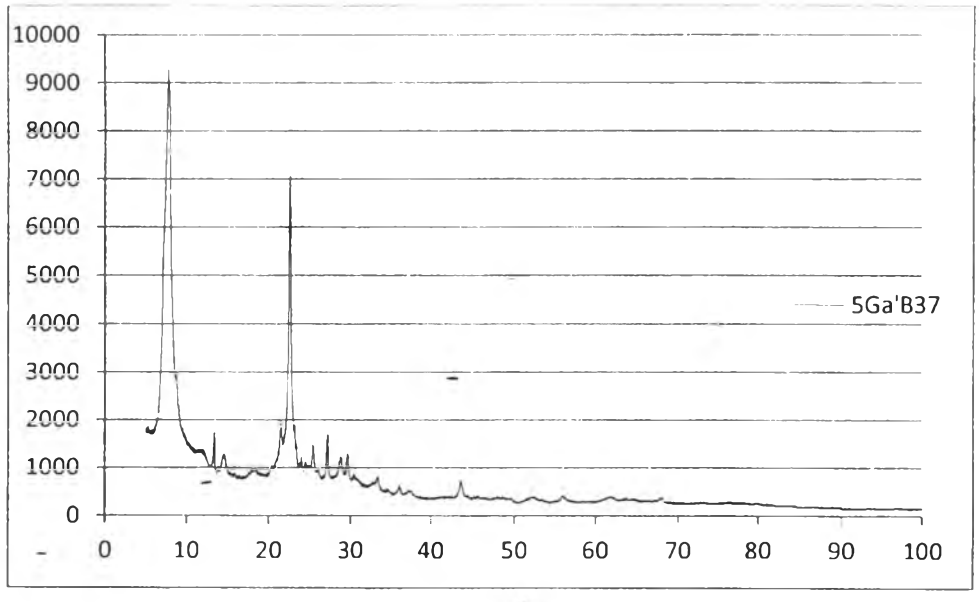


**Figure A5** XRD pattern of 5Ga'B37.

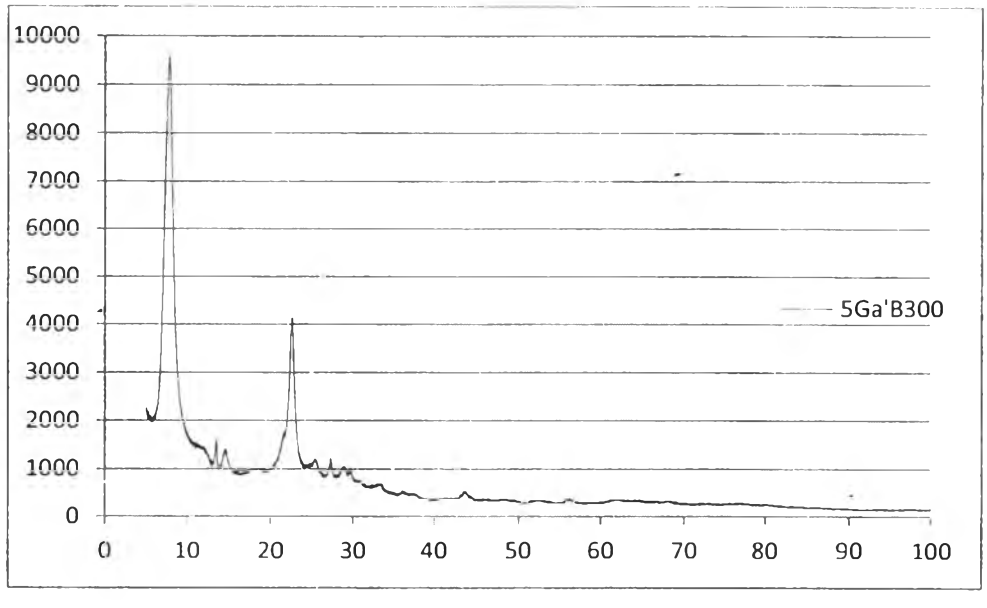


**Figure A6** XRD pattern of 5Ga'B300.

## Appendix B Product Distribution

**Table B1** Product distribution over B27, B37, and B300

| Catalyst | B 27 | B 37 | B 300 |
|---|---|---|---|
| **Bio-ethanol conversion (%)** | 97.4 | 97.4 | 97.4 |
| **Product yield (wt %)** | | | |
| **Gas** | 75.8 | 63.0 | 81.5 |
| **Oil** | 5.05 | 7.27 | 5.43 |
| **Water** | 19.2 | 29.7 | 13.1 |
| **Gas composition (wt %)** | | | |
| **Methane** | 0.99 | 1.65 | 0.00 |
| **Ethylene** | 85. 9 | 80.4 | 94.6 |
| **Ethane** | 5.61 | 6.29 | 1.69 |
| **C3** | 5.85 | 8.88 | 2.82 |
| **C4** | 1.66 | 2.80 | 0.91 |
| **$CO_2$** | 0.00 | 0.00 | 0.00 |
| **Oil composition (wt %)** | | | |
| **Oxygenate compound** | 1.28 | 0.04 | 4.08 |
| **Non-aromatics** | 0.00 | 0.96 | 17.2 |
| **Benzene** | 11.3 | 0.67 | 36.2 |
| **Toluene** | 24.0 | 7.64 | 0.00 |
| **o-Xylene** | 12.0 | 8.02 | 7.13 |
| **m-Xylene** | 10.9 | 10.5 | 5.72 |
| **p-Xylene** | 21.3 | 7.81 | 12.6 |
| **Ethylbenzene** | 2.93 | 5.53 | 2.05 |
| **C9 Aromatics** | 14.4 | 34.0 | 12.3 |
| **C10+ Aromatics** | 1.98 | 24.9 | 2.72 |
| **Petroleum fraction in oil (wt %)** | | | |
| **Gasoline** | 70.0 | 65.5 | 94.7 |
| **Kerosene** | 18.1 | 31.0 | 3.28 |
| **Gas oil** | 11.9 | 3.50 | 2.02 |

**Data were taken at the eighth hour of time-on-stream**

**Table B2** Product distribution over all $Ga_2O_3$–modified catalysts

| Catalyst | 5Ga'B27 | 5Ga'B37 | 5Ga'B 300 |
|---|---|---|---|
| **Bio-ethanol conversion (%)** | 97.4 | 97.4 | 97.4 |
| **Product yield (wt %)** | | | |
| **Gas** | 83.7 | 75.4 | 78.6 |
| **Oil** | 3.92 | 6.48 | 3.11 |
| **Water** | 12.4 | 18.1 | 18.3 |
| **Gas composition (wt %)** | | | |
| **Methane** | 1.34 | 1.28 | 0.00 |
| **Ethylene** | 87.1 | 73.8 | 95.5 |
| **Ethane** | 5.27 | 6.16 | 1.53 |
| **C3** | 5.10 | 13.4 | 2.27 |
| **C4** | 1.22 | 5.40 | 0.41 |
| **$CO_2$** | 0.00 | 0.00 | 0.99 |
| **Oil composition (wt %)** | | | |
| **Oxygenate compound** | 0.43 | 4.71 | 45.1 |
| **Non-aromatics** | 0.17 | 18.8 | 0.00 |
| **Benzene** | 4.12 | 1.05 | 9.34 |
| **Toluene** | 12.8 | 0.92 | 7.39 |
| **o-Xylene** | 11.9 | 2.92 | 4.90 |
| **m-Xylene** | 11.5 | 2.46 | 4.25 |
| **p-Xylene** | 23.4 | 4.35 | 8.84 |
| **Ethylbenzene** | 2.68 | 10.3 | 1.18 |
| **C9 Aromatics** | 26.9 | 15.6 | 14.4 |
| **C10+ Aromatics** | 6.02 | 39.0 | 4.57 |
| **Petroleum fraction in oil (wt %)** | | | |
| **Gasoline** | 63.8 | 62.2 | 87.7 |
| **Kerosene** | 25.2 | 33.1 | 8.06 |
| **Gas oil** | 11.0 | 4.74 | 4.25 |

**Data were taken at the eighth hour of time-on-stream**

**Table B3** Product distribution over all $GeO_2$–modified catalysts

| Catalyst | 5Ge'B27 | 5Ge'B37 | 5Ge'B 300 |
|---|---|---|---|
| **Bio-ethanol conversion (%)** | 97.4 | 97.4 | 97.4 |
| **Product yield (wt %)** | | | |
| **Gas** | 80.9 | 68.5 | 70.2 |
| **Oil** | 5.04 | 4.62 | 4.81 |
| **Water** | 14.1 | 26.8 | 25.0 |
| **Gas composition (wt %)** | | | |
| **Methane** | 5.57 | 1.44 | 0.16 |
| **Ethylene** | 77.4 | 85.7 | 79.6 |
| **Ethane** | 7.16 | 4.62 | 14.7 |
| **C3** | 7.72 | 6.70 | 3.61 |
| **C4** | 2.19 | 2.55 | 1.58 |
| **$CO_2$** | 0.00 | 0.00 | 0.30 |
| **Oil composition (wt %)** | | | |
| **Oxygenate compound** | 0.74 | 0.20 | 10.5 |
| **Non-aromatics** | 0.00 | 1.04 | 1.18 |
| **Benzene** | 6.24 | 0.55 | 24.1 |
| **Toluene** | 14.1 | 6.11 | 22.8 |
| **o-Xylene** | 11.7 | 6.58 | 9.28 |
| **m-Xylene** | 10.5 | 6.70 | 6.67 |
| **p-Xylene** | 21.6 | 7.43 | 13.1 |
| **Ethylbenzene** | 2.64 | 4.93 | 3.38 |
| **C9 Aromatics** | 27.0 | 25.5 | 8.27 |
| **C10+ Aromatics** | 5.45 | 41.0 | 0.63 |
| **Petroleum fraction in oil (wt %)** | | | |
| **Gasoline** | 59.9 | 58.4 | 69.8 |
| **Kerosene** | 25.1 | 36.7 | 24.3 |
| **Gas oil** | 15.0 | 4.91 | 5.85 |

**Data were taken at the eighth hour of time-on-stream**

**Table B4** Product distribution over $Ga_2O_3$–and $GeO_2$ modified MSU catalysts

| Catalyst | MSU | 5GaMSU | 5GeMSU |
|---|---|---|---|
| **Bio-ethanol conversion (%)** | 97.3 | 97.3 | 97.3 |
| **Product yield (wt %)** | | | |
| **Gas** | 77.4 | 79.6 | 75.3 |
| **Oil** | 4.47 | 5.17 | 6.95 |
| **Water** | 18.2 | 15.2 | 17.7 |
| **Gas composition (wt %)** | | | |
| **Methane** | 0.44 | 0.65 | 0.25 |
| **Ethylene** | 93.6 | 92.8 | 94.4 |
| **Ethane** | 1.38 | 1.36 | 1.52 |
| **C3** | 2.66 | 2.23 | 1.91 |
| **C4** | 1.71 | 1.67 | 1.62 |
| **$CO_2$** | | | |
| **Oil composition (wt %)** | | | |
| **Oxygenate compound** | 4.32 | 92.4 | 9.54 |
| **Non-aromatics** | 2.05 | 1.63 | 3.89 |
| **Benzene** | 2.35 | 5.94 | 2.02 |
| **Toluene** | 4.33 | 0.00 | 0.00 |
| **o-Xylene** | 9.61 | 0.00 | 9.39 |
| **m-Xylene** | 8.69 | 0.00 | 7.65 |
| **p-Xylene** | 18.5 | 0.00 | 13.6 |
| **Ethylbenzene** | 1.8 | 0.00 | 1.66 |
| **C9 Aromatics** | 28.0 | 0.00 | 22.2 |
| **C10+ Aromatics** | 20.4 | 0.00 | 30.1 |
| **Petroleum fraction in oil (wt %)** | | | |
| **Gasoline** | 48.5 | 81.7 | 51.5 |
| **Kerosene** | 47.2 | 14.4 | 44.5 |
| **Gas oil** | 4.28 | 3.85 | 3.99 |

**Data were taken at the eighth hour of time-on-stream**

## Appendix C Transmission Electron Microscopy

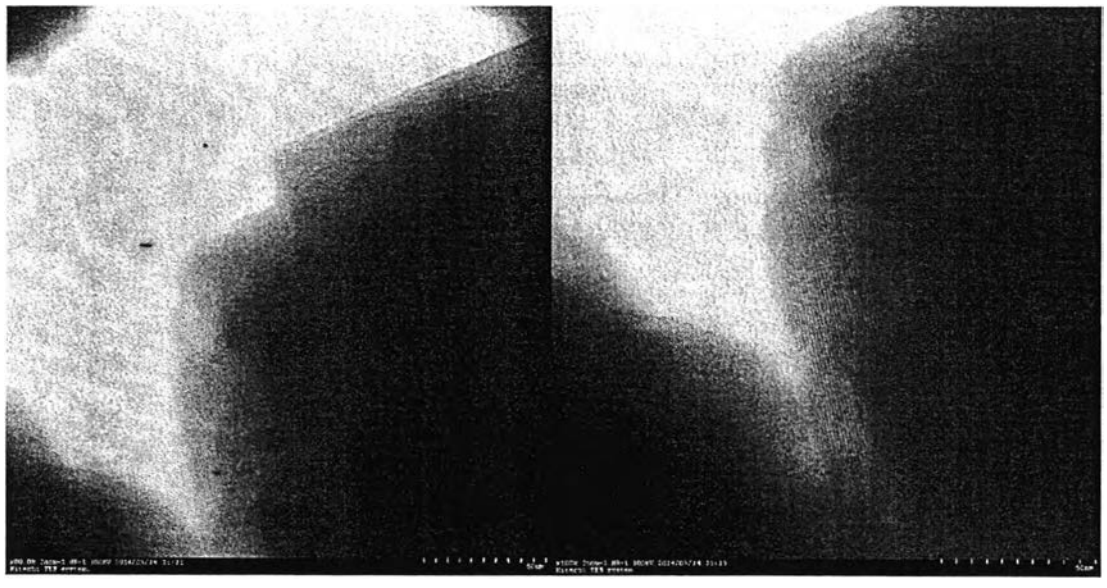

**Figure C1** TEM image of B37 (×100k 100kV).

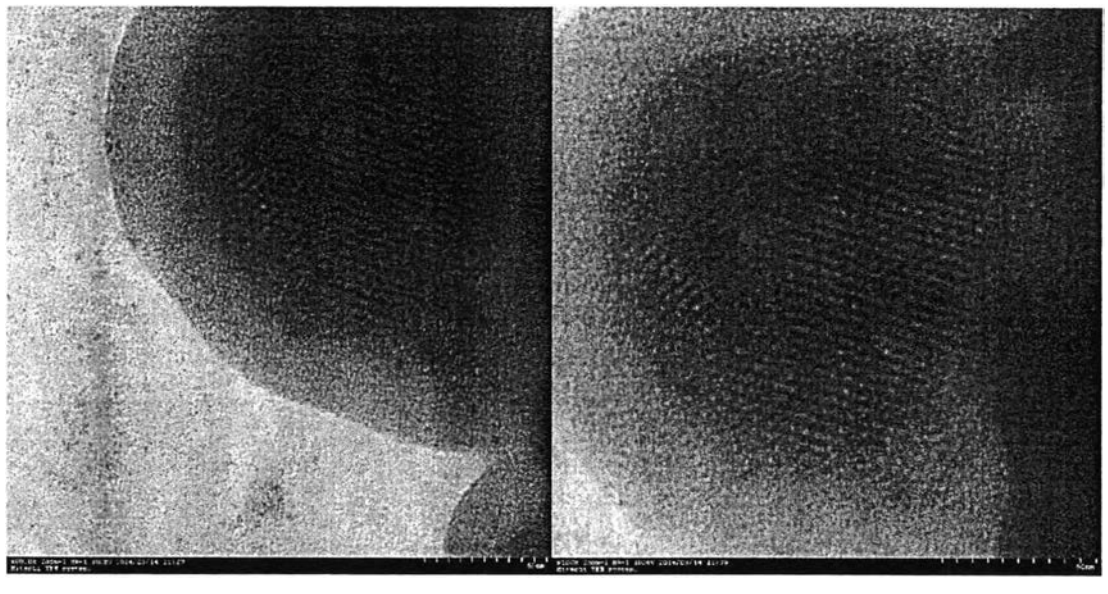

**Figure C2** TEM image of MSU (×100k 100kV).

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1. Sujeerakulkai, S. and Jitkarnka, S. (2014) Bio-ethanol Dehydration to Hydrocarbons Using $Ga_2O_3$/Beta Zeolites with Various $Si/Al_2$ Ratios Proceeding of The 17th Conference Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, Prague, Czech Republic.
2. Sujeerakulkai, S. and Jitkarnka, S. (2014) Oxygenate production from bio-ethanol dehydration using gallium oxide promoted H-Beta ($Si/Al_2$ = 300) Proceedings of The 5th Research Symposium on Petrochemical and Materials Technology and The 20th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.