## REFERENCES


Arunsingkarat, K. (2012) Catalytic Partial Oxidation of Methane over NiO-MgO/$Ce_{0.75}Zr_{0.25}O_2$ Catalysts: Effects of Low Mg Conten and Incorporated Sequences. M.S. Thesis, The Petroleum and Petrochemical College, Chulalongkorn University, Bangkok, Thailand.

Bampenrat, A., Meeyoo, V., Kitiyanan, B., Rangsunvigit, P., and Rirksomboon, T. (2010) Naphthalene steam reforming over Mn-doped $CeO_2$-$ZrO_2$ supported nickel catalysts. Applied Catalysis A: General, 373, 154-159.

Bematollahi, B., Rezaei, M., and Khajenoori, M. (2011) Combined dry reforming and partial oxidation of methane to synthesis gas on noble metal catalysts. International Journal of Hydrogen energy, 36, 2969-2978.

Bartholomew, C.H. (2001) Mechanisms of catalyst deactivation. Applied Catalysis A: General, 212, 17-60.

Bradford, M.C.J. and Vannice, M.A. (1996) Catalytic reforming methane with carbon dioxide over nickel catalysts, I. Catalyst Characterization and activity. Applied Catalysis A: General, 142, 73-96.

Chen, J., Wu, Q., Zhang, J., and Zhang, J. (2008) Effect of preparation methods on structure and performance of Ni/$Ce_{0.75}Zr_{0.25}O_2$ catalysts for $CH_4$-$CO_2$ reforming. Fuel, 87, 2901-2907

Choque, V., Homs, N., Cicha-Szot, R., and Ramirez, P. (2009) Study of ruthenium supported no $Ta_2O_5$-$ZrO_2$ and $Nb_2$-$ZrO_2$ as catalysts for the partial oxidation of methane. Catalysis Today, 142, 308-313.

Choque, V., Ramirez, P., Molyneux, D., and Homs, Narcis. (2010) Ruthenium supported on new $TiO_2$-$ZrO_2$ systems as catalysts for the partial oxidation of methane. Catalysis Today, 149, 248-253.

Dong, W., Roh, H., Jun, K., Park, S., and Oh, Y. (2002) Methane reforming over Ni/Ce-$ZrO_2$ catalysts: effect of nickel content. Applied Catalysis A: General, 226, 63-72.

Enger, B.C., Lodeng, R., and Holmen, A. (2008) A review of catalytic partial oxidation of methane to synthesis gas with emphasis on reaction mechanisms over transition metal catalysts. Applied Catalysis A: General, 346, 1-27.

Khan, A., Sukonket, T., Saha, B., and Idem, R. (2012) Catalytic Activity of Various 5wt% $Ni/Ce_{0.5}Zr_{0.33}M_{0.17}O_{2-\delta}$ Catalysts for the $CO_2$ Reforming of $CH_4$ in the Presence and Absence of Steam. Energy & Fuels, 26, 365-379.

Li, Y., Guo, Y., and Xue, B. (2009) Catalytic combustion of methane over M (Ni, Co, Cu) supported on ceria-magnesia. Fuel Processing Technology, 90, 652-656.

Mateos-Pedrero, C., GonZalez-Carranzan, S.R., Soria, M.A., and Ruiz, P. (2007) Effect of the nature of $TiO_2$ support over the performances of $Rh/TiO_2$ catalyst in the partial oxidation of methane. Catalysis Today, 128, 216-222.

Miao, Q., Xiong, G., Sheng, S., Cui, W., Xu, L., and Guo, X. (1997) Partial oxidation of methane to syngas over nickel-based catalysts modified by alkali metal oxide and rare earth metal oxide. Applied Catalysis A, 154, 17-21.

Oemar, U., Hidajat, K., and Kawi, S. (2011) Role of catalyst support over PdO-NiO catalyst activity and stability for oxy-$co_2$ reforming of methane. Applied Catalysis A, 402, 176-187.

Otsuka, K., Wang, Y., and Nakamura, M. (1999) Direct conversion of methane to synthesis gas through gas-solid reaction using $CeO_2$-$ZrO_2$ solid solution at moderate temperature. Applied Catalysis A:General, 183, 317-324.

Pengpanich, S., Meeyoo, V., Rirksomboon, T., and Bunyakiat, K. (2002) Catalytic oxidation of methane over $CeO_2$-$ZrO_2$ mixed oxide solid solution catalysts prepared via urea hydrolysis. Applied Catalysis A: General, 234, 221-233.

Pengpanich, S., Meeyoo, V., and Rirksomboon, T. (2004) Methane partial oxidation over $Ni/CeO_2$-$ZrO_2$ mixed oxide solid solution catalysts. Catalysis Today, 93-95, 95-105.

Pengpanich, S., Meeyoo, V., Rirksomboon, T., and Schwank, J. (2007) The Effect of Nb Loading on Catalytic Properties of $Ni/Ce_{0.75}Zr_{0.25}O_2$ Catalyst for Methane Partial Oxidation. Journal of Natural Gas Chemistry, 16, 227-234.

Prieto, P.J.S., Ferreira, A.P., Haddad, P.S., Zanchet, D., and Bueno, J.M.C. (2009) Designing Pt nanoparticles supported on $CeO_2$-$Al_2O_3$: Synthesis characterization and catalytic properties in the steam reforming and partial oxidation of methane. Journal of Catalysis, 276, 351-359.

Pue-on, P. (2011) Methane Partial Oxidation over NiO-MgO/$Ce_{0.75}Zr_{0.25}O_2$ Mixed Oxide Catalysts. M.S. Thesis, The Petroleum and Petrochemical College, Chulalongkorn University, Bangkok, Thailand.

Qiu, M., Li, Y., Wang, T., Zhang, Q., Wang, C., and Zhang, X. (2012) Upgrading biomass fuel gas by reforming over Ni-MgO/$\gamma$-$Al_2O_3$ cordierite monolithic catalysts in the lab-scale reactor and pilot-scale multi-tube reformer. Applied Energy, 90, 3-10.

Rathod, S., Arbad, B., and Lande, M. (2010) Preparation, characterization, and catalytic application of a nanosized $Ce_1Mg_xZr_{1-x}O_2$ solid heterogeneous catalyst for the synthesis of tetrahydrobenzo[b]pyran derivatives. Chinese Journal of Catalysis, 31, 631-636.

Rogatis, L.D., Montini, T., Cognigni, A., Olivi, L., and Fornasireo, P. (2009) Methane partial oxidation on NiCu-based catalysts. Catalysis Today, 145, 176-185.

Roh, H., Jun, K., Dong, W., Chang, J., Park, S., and Joe, Y. (2002) Highly active and stable Ni/Ce-$ZrO_2$ catalyst for $H_2$ production from methane. Journal of Molecular Catalysis A: Chemical, 181, 137-142.

Ruckenstein, E., and Hu, Y.H. (1999) Methane partial oxidation over NiO/MgO solid solution catalysts. Applied Catalysis A, 183, 85-92.

Ryu, J.H., Lee, K.Y., Kim, H.J., Yang, J., and Jung, H. (2008) Promotion of palladium-based catalysts on metal monolith for partial oxidation of methane to syngas. Applied Catalysis B, 80, 306-312.

Salazar-Villalpando, M.D., Berry, D.A., and Cugini, A. (2010) Role of lattice oxygen in the partial oxidation of methane over Rh/zirconia-doped ceria. Isotopic studies. International Jounal of Hydrogen Energy, 35, 1998-2003.

Salazar-Villalpando, M.D., and Miller, A.C. (2011) Hydrogen production by methane decomposition and catalytic partial oxidation of methane over Pt/$Ce_xGd_{1-x}O_2$ and Pt/$Ce_xZr_{1-x}O_2$. Chemical Enginerring Journal, 166, 738-743.

Sengupta, P., Khan, A., Zahid, Md. A., Ibrahim, H., and Idem, R. (2012) Evaluation of the Catalytic Activity of Various 5Ni/$Ce_{0.75}Zr_{0.33}M_{0.17}O_{2-\delta}$ Catalysts for Hydrogen Production by the Steam Reforming of a Mixture of Oxygenated Hydrocarbons. Energy Fuels, 26, 816-828.

Silva, F.A., Resende, K.A., Silva, A.M., Souza, K.R., Mattos, L.V., Montes, M., Souza-Aguiar, E.F., Noronha, F.B., and Hori, C.E. (2012) Syngas production by partial oxidation of methane over $Pt/CeZrO_2/Al_2O_3$ catalysts. Catalysis Today, 180, 111-116.

Slagtern, A., Swaan, H.M., Olsbye, U., Dahl, I.M., and Mirodatos, C. (1988) Catalytic partial oxidation of methane over Ni-, Co- and Fe-based catalysts. Catalysis Today, 46, 107-115.

Takeguchi, T., Furukawa, S., and Inoue, M. (2001) Hydrogen Spillover from NiO to the Large Surface Area $CeO_2$-$ZrO_2$ Solid Solutions and Activity of the $NiO/CeO_2$-$ZrO_2$ Catalysts for Partial Oxidation of Methane. Journal of Catalysis, 201, 14-24.

Tanaka, H., Kaino, R., Okumura, T., and Tomishige, K. (2009) Catalytic performance and characterization of $Rh\text{-}CeO_2/MgO$ catalysts for the catalytic partial oxidation of methane at short contact time. Journal of Catalysis, 268, 1-8.

Tang, S., Lin, J., and Tan, K.L. (1998) Partial oxidation of methane to syngas over Ni/MgO, Ni/CaO and $Ni/CeO_2$. Catalysis Letters, 51, 169-175.

Tsang, S.C., Claridge, J.B., and Green, M.L.H. (1995) Recent advances in the conversion of methane to synthesis gas. Catalysis Today, 23, 3-15.

Tsipouriari, V.A., Zhang, Z., and Verykios, X.E. (1997) Catalytic Partial Oxidation of Methane to Synthesis Gas over Ni-Based Catalysts: I. Catalyst Performance Characteristics. Journal of Catalysis, 179, 283-291.

Wu, T., Yan, Q., and Wan, H. (2005) Partial oxidation of methane to hydrogen and carbon monoxide over a $Ni/TiO_2$ catalyst. Journal of Molecular Catalysis A:Chemical, 226, 41-48.

Xu, S. and Wang, X. (2005) Highly active and coking resistant $Ni/CeO_2$-$ZrO_2$ catalyst for partial oxidation of methane. Fuel, 84, 563-567.

Yejun, Q., Jixiang, C., and Jiyan, Z. (2007) Effects of MgO promoter on properties of $Ni/Al_2O_3$ catalysts for partial oxidation of methane to syngas. Frontiers of Chemical Engineering in China, 1, 167-171.

York, A.P.E., Xiao, T., and Green, M.L.H. (2003) Brief overview of the partial oxidation of methane to synthesis gas. Topics in Catalysis, 22, 345-358.

Yu, C., Weng, W., Shu, Q., Meng, X., Zhang, B., Chen, X., and Zhou, X. (2011) Additive effects of alkaline-earth metals and nickel on the performance of $Co/\gamma\text{-}Al_2O_3$ in methane catalytic partial oxidation. Jounal of Natural Gas Chemistry, 20, 135-139.

Zanganeh, R., Rezaei, M., and Zamaniyan, A. (2013) Dry reforming of methane to synthesis gas on NiO-MgO nanocrystalline solid solution catalysts. International Journal of Hydrogen Energy, 38, 3012-3018.

Zhu, T., and Flytzani-Stephanopoulos, M. (2001) Catalytic partial oxidation of methane to synthesis gas over $Ni\text{-}CeO_2$. Applied Catalysis A:General, 208, 403-417.

# APPENDICES

## Appendix A Experimental Data of Gas Calibration of GC-8A

### 1. Methane

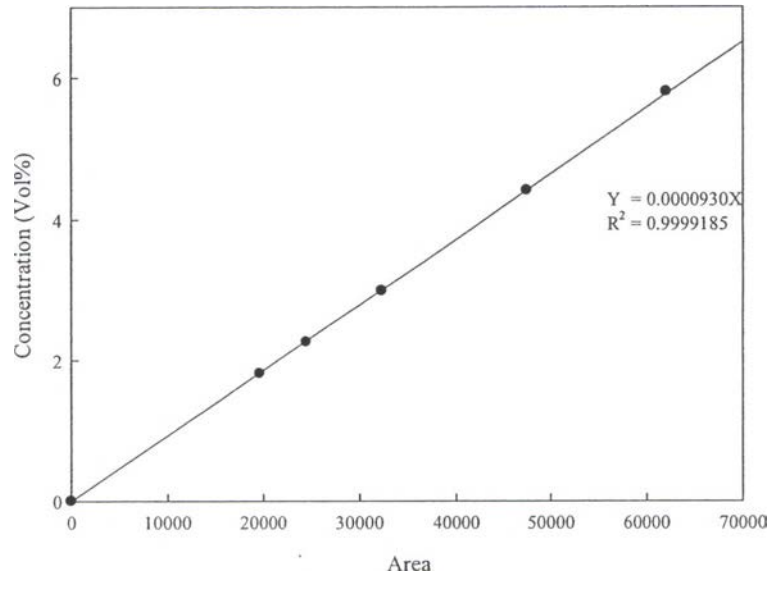


**Figure A1** Relationship between area and concentration of methane.

**2. Oxygen**

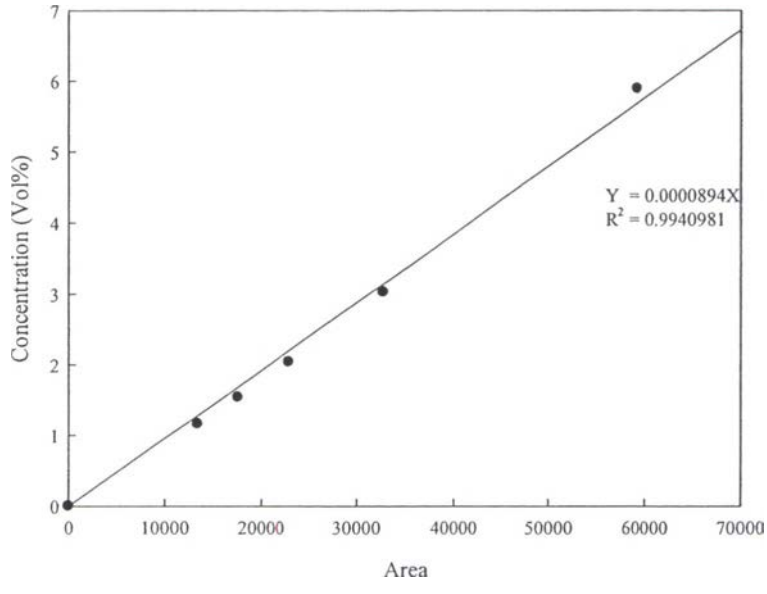


**Figure A2** Relationship between area and concentration of oxygen.

**3. Hydrogen**

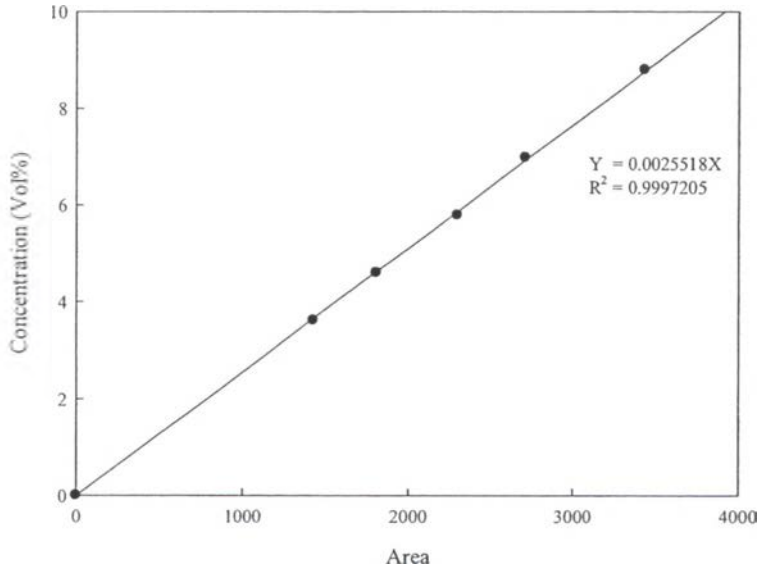


**Figure A3** Relationship between area and concentration of hydrogen.

**4. Carbon monoxide**

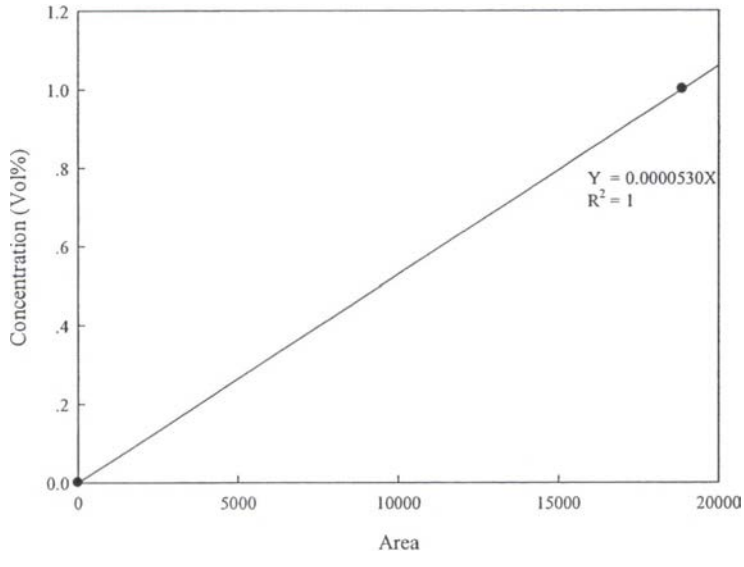


**Figure A4** Relationship between area and concentration of carbon monoxide.

**5. Carbon dioxide**

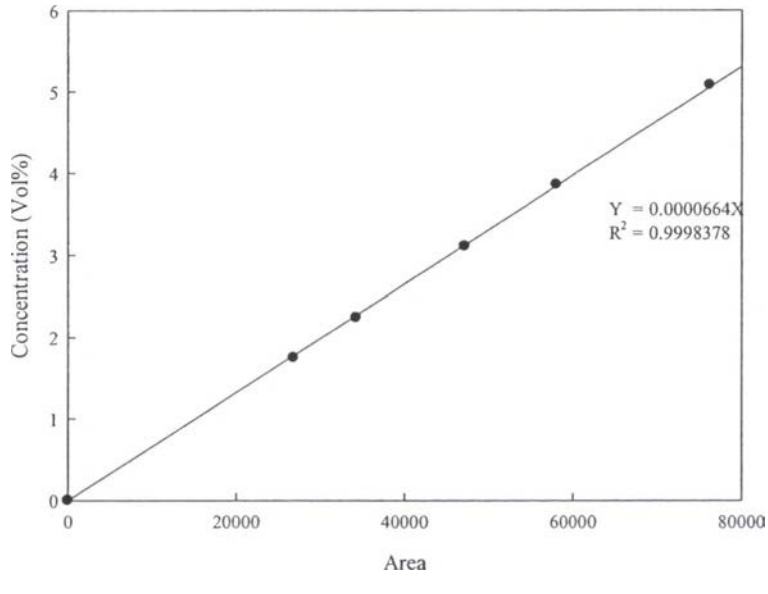


**Figure A5** Relationship between area and concentration of carbon dioxide.

**6. Nitrogen**

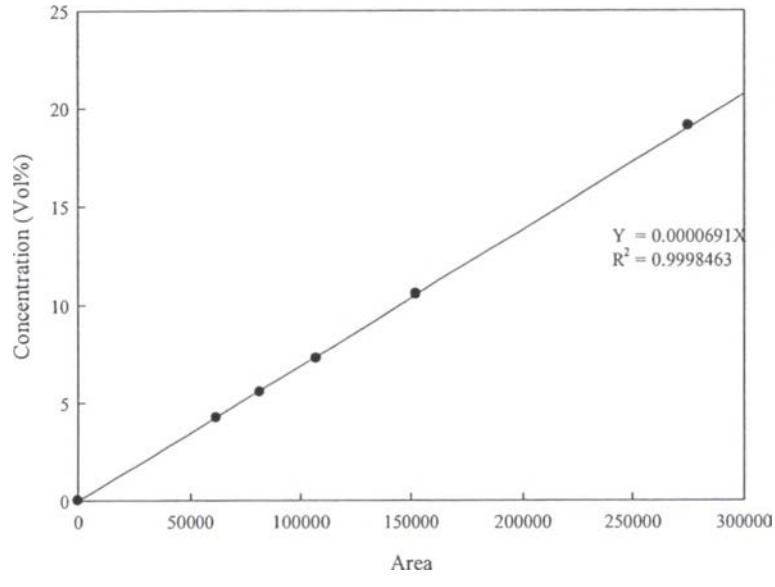


**Figure A6** Relationship between area and concentration of nitrogen.

## Appendix B Experimental Data of Flow Meter Gas Calibration of Brooks 5850E Mass Flow Controllers

### 1. Methane

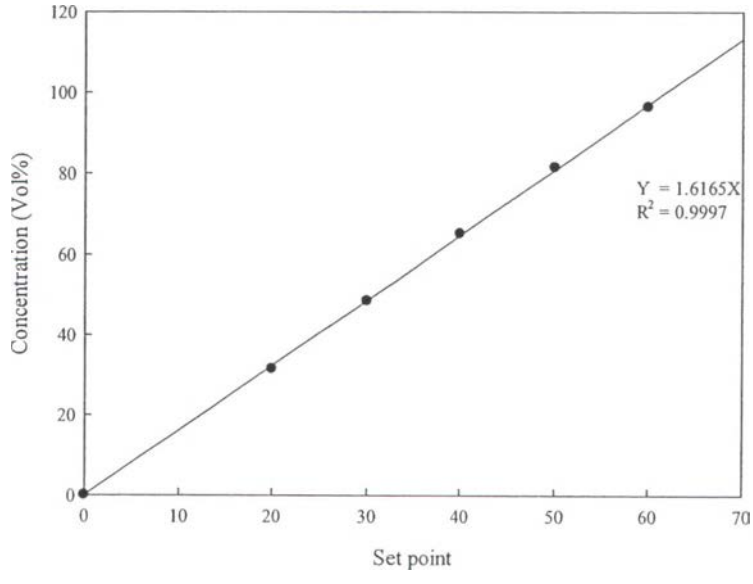


**Figure B1** Relationship between SP and flow rate of methane.

**2. Air Zero**

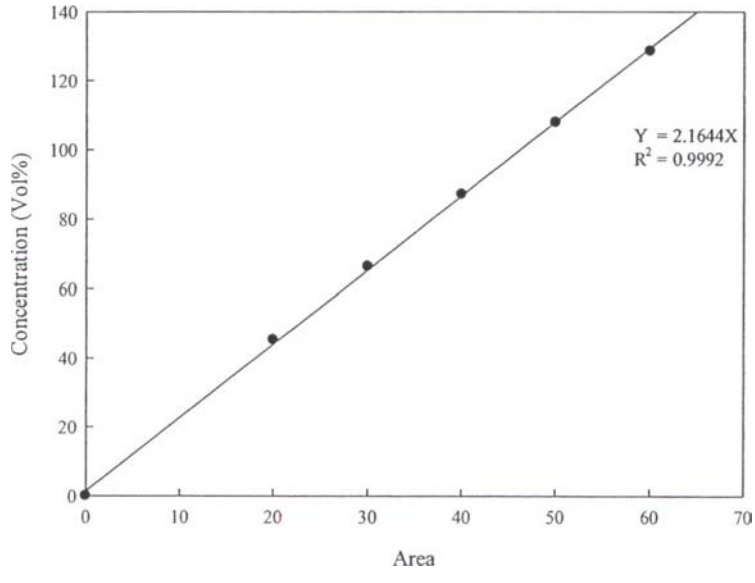


**Figure B2** Relationship between SP and flow rate of air zero.

**3. Helium**

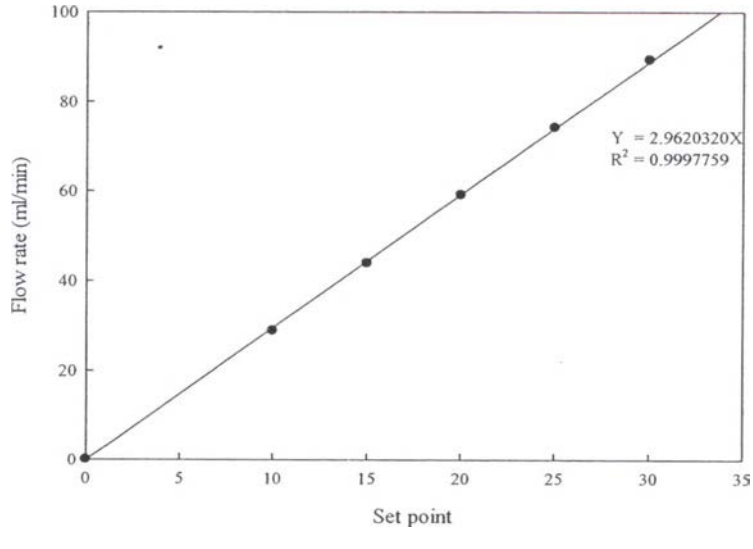


**Figure B3** Relationship between SP and flow rate of helium.

## Appendix C Experimental Data of Catalytic Activity Tests for MPO

**Table C1** Catalytic activity test of CZO catalyst

| Temperature | $X_{CH_4}$ | $X_{O_2}$ | $S_{H_2O}$ | $S_{CO}$ | $Y_{H_2O}$ | $Y_{CO_2}$ |
|---|---|---|---|---|---|---|
| ( °C ) | (%) | (%) | (%) | (%) | (%) | (%) |
| 400 | 0.05 | 0.00 | 100.00 | 100.00 | 0.32 | 0.32 |
| 450 | 0.07 | 0.88 | 100.00 | 100.00 | 0.70 | 0.70 |
| 500 | 1.67 | 6.67 | 100.00 | 100.00 | 1.91 | 1.91 |
| 550 | 3.81 | 19.56 | 100.00 | 100.00 | 4.41 | 4.41 |
| 600 | 7.36 | 39.07 | 100.00 | 100.00 | 8.18 | 8.18 |
| 650 | 13.00 | 64.26 | 100.00 | 100.00 | 13.03 | 13.03 |
| 700 | 18.60 | 93.70 | 100.00 | 100.00 | 18.65 | 18.65 |
| 750 | 20.25 | 100.00 | 100.00 | 100.00 | 19.73 | 19.73 |
| 800 | 19.74 | 100.00 | 100.00 | 100.00 | 18.91 | 18.91 |

**Table C2** Catalytic activity test of CZM1O catalyst

| Temperature | $X_{CH_4}$ | $X_{O_2}$ | $S_{H_2O}$ | $S_{CO}$ | $Y_{H_2O}$ | $Y_{CO_2}$ |
|---|---|---|---|---|---|---|
| ( °C ) | (%) | (%) | (%) | (%) | (%) | (%) |
| 400 | 0.05 | 0.12 | 100.00 | 100.00 | 0.23 | 0.23 |
| 450 | 0.07 | 1.34 | 100.00 | 100.00 | 0.74 | 0.74 |
| 500 | 0.39 | 7.88 | 100.00 | 100.00 | 2.19 | 2.19 |
| 550 | 2.85 | 22.81 | 100.00 | 100.00 | 5.31 | 5.31 |
| 600 | 8.55 | 47.06 | 100.00 | 100.00 | 10.31 | 10.31 |
| 650 | 11.36 | 64.33 | 100.00 | 100.00 | 13.34 | 13.34 |
| 700 | 16.31 | 88.77 | 100.00 | 100.00 | 18.02 | 18.02 |
| 750 | 17.86 | 100.00 | 100.00 | 100.00 | 19.78 | 19.78 |
| 800 | 17.92 | 100.00 | 100.00 | 100.00 | 19.35 | 19.35 |

**Table C3** Catalytic activity test of CZM3O catalyst

| Temperature | $X_{CH_4}$ | $X_{O_2}$ | $S_{H_2O}$ | $S_{CO}$ | $Y_{H_2O}$ | $Y_{CO_2}$ |
|---|---|---|---|---|---|---|
| ( °C ) | (%) | (%) | (%) | (%) | (%) | (%) |
| 400 | 0.05 | 0.13 | 100.00 | 100.00 | 0.36 | 0.36 |
| 450 | 0.07 | 2.16 | 100.00 | 100.00 | 0.77 | 0.77 |
| 500 | 1.78 | 9.67 | 100.00 | 100.00 | 2.50 | 2.50 |
| 550 | 5.27 | 28.66 | 100.00 | 100.00 | 6.46 | 6.46 |
| 600 | 12.98 | 60.60 | 100.00 | 100.00 | 12.82 | 12.82 |
| 650 | 17.42 | 82.19 | 100.00 | 100.00 | 16.78 | 16.78 |
| 700 | 19.62 | 96.01 | 100.00 | 100.00 | 19.12 | 19.12 |
| 750 | 21.44 | 100.00 | 100.00 | 100.00 | 19.94 | 19.94 |
| 800 | 21.73 | 100.00 | 100.00 | 100.00 | 19.31 | 19.31 |

**Table C4** Catalytic activity test of 15Ni/CZO catalyst

| Temperature | $X_{CH4}$ | $X_{O2}$ | $S_{H2}$ | $S_{CO}$ | $Y_{H2}$ | $Y_{CO}$ |
|---|---|---|---|---|---|---|
| ( °C ) | (%) | (%) | (%) | (%) | (%) | (%) |
| 400 | 1.08 | 5.29 | 0.00 | 0.00 | 0.00 | 0.00 |
| 450 | 2.92 | 16.41 | 0.00 | 0.00 | 0.00 | 0.00 |
| 500 | 8.47 | 44.76 | 0.00 | 0.00 | 0.00 | 0.00 |
| 550 | 70.76 | 100.00 | 85.02 | 86.32 | 52.66 | 58.53 |
| 600 | 77.71 | 100.00 | 92.17 | 93.27 | 59.12 | 69.58 |
| 650 | 81.81 | 100.00 | 96.11 | 96.71 | 64.26 | 76.42 |
| 700 | 83.75 | 100.00 | 98.12 | 98.43 | 66.78 | 80.09 |
| 750 | 84.44 | 100.00 | 99.06 | 99.23 | 67.60 | 82.10 |
| 800 | 84.11 | 100.00 | 99.36 | 99.48 | 67.70 | 83.27 |

**Table C5** Catalytic activity test of 15Ni/CZM1O catalyst

| Temperature | $X_{CH4}$ | $X_{O2}$ | $S_{H2}$ | $S_{CO}$ | $Y_{H2}$ | $Y_{CO}$ |
|---|---|---|---|---|---|---|
| ( °C ) | (%) | (%) | (%) | (%) | (%) | (%) |
| 400 | 0.05 | 3.88 | 0.00 | 0.00 | 0.00 | 0.00 |
| 450 | 1.12 | 14.77 | 0.00 | 0.00 | 0.00 | 0.00 |
| 500 | 6.20 | 41.59 | 0.00 | 0.00 | 0.00 | 0.00 |
| 550 | 14.55 | 80.76 | 0.00 | 0.00 | 0.00 | 0.00 |
| 600 | 77.48 | 100.00 | 91.68 | 92.68 | 61.03 | 70.16 |
| 650 | 78.29 | 100.00 | 94.50 | 95.53 | 61.40 | 76.36 |
| 700 | 82.24 | 100.00 | 97.76 | 98.17 | 66.51 | 81.77 |
| 750 | 83.93 | 100.00 | 99.02 | 99.20 | 68.87 | 85.46 |
| 800 | 84.13 | 100.00 | 99.39 | 99.51 | 69.99 | 87.12 |

**Table C6** Catalytic activity test of 15Ni/CZM3O catalyst

| Temperature | $X_{CH4}$ | $X_{O2}$ | $S_{H2}$ | $S_{CO}$ | $Y_{H2}$ | $Y_{CO}$ |
|---|---|---|---|---|---|---|
| ( °C ) | (%) | (%) | (%) | (%) | (%) | (%) |
| 400 | 0.31 | 5.90 | 0.00 | 0.00 | 0.00 | 0.00 |
| 450 | 3.38 | 22.90 | 0.00 | 0.00 | 0.00 | 0.00 |
| 500 | 9.71 | 55.79 | 0.00 | 0.00 | 0.00 | 0.00 |
| 550 | 12.99 | 91.28 | 0.00 | 0.00 | 0.00 | 0.00 |
| 600 | 83.59 | 100.00 | 93.51 | 94.02 | 66.01 | 72.05 |
| 650 | 87.96 | 100.00 | 96.90 | 97.20 | 70.80 | 78.64 |
| 700 | 88.56 | 100.00 | 98.61 | 98.78 | 72.32 | 82.95 |
| 750 | 88.68 | 100.00 | 99.31 | 99.43 | 70.61 | 85.57 |
| 800 | 85.17 | 100.00 | 99.42 | 99.52 | 70.44 | 86.16 |

## Appendix D Experimental Data of Stability Tests for MPO

**Table D1** Stability test of Ni/CZO catalyst

| Time (hr) | $X_{CH4}$ (%) | $X_{O2}$ (%) | $S_{H2}$ (%) | $S_{CO}$ (%) | $Y_{H2}$ (%) | $Y_{CO}$ (%) |
|---|---|---|---|---|---|---|
| 5 | 69.09 | 100.00 | 98.26 | 98.52 | 65.97 | 78.05 |
| 10 | 69.31 | 100.00 | 97.38 | 97.78 | 62.94 | 74.62 |
| 15 | 69.96 | 100.00 | 97.10 | 97.58 | 61.26 | 73.89 |
| 20 | 69.51 | 100.00 | 96.87 | 97.24 | 62.15 | 70.73 |
| 25 | 67.64 | 100.00 | 96.84 | 96.99 | 62.17 | 75.79 |
| 30 | 63.84 | 100.00 | 96.08 | 96.65 | 61.57 | 72.64 |
| 35 | 63.34 | 100.00 | 95.12 | 95.65 | 60.89 | 68.73 |
| 40 | 66.62 | 100.00 | 94.63 | 95.25 | 59.3 | 67.50 |
| 45 | 65.04 | 100.00 | 93.99 | 94.75 | 57.22 | 66.04 |
| 50 | 63.84 | 100.00 | 94.39 | 95.11 | 59.69 | 68.95 |

**Table D2** Stability test of Ni/CZM1O catalyst

| Time (hr) | $X_{CH4}$ (%) | $X_{O2}$ (%) | $S_{H2}$ (%) | $S_{CO}$ (%) | $Y_{H2}$ (%) | $Y_{CO}$ (%) |
|---|---|---|---|---|---|---|
| 5 | 73.20 | 100.00 | 97.90 | 98.23 | 62.09 | 73.92 |
| 10 | 72.63 | 100.00 | 97.54 | 97.86 | 61.93 | 71.48 |
| 15 | 72.54 | 100.00 | 97.32 | 97.69 | 61.92 | 72.20 |
| 20 | 72.26 | 100.00 | 97.03 | 97.48 | 60.33 | 71.46 |
| 25 | 72.51 | 100.00 | 96.70 | 97.21 | 59.89 | 71.21 |
| 30 | 72.15 | 100.00 | 96.65 | 97.10 | 61.80 | 71.69 |
| 35 | 73.14 | 100.00 | 97.61 | 97.93 | 63.29 | 73.42 |
| 40 | 71.42 | 100.00 | 96.08 | 96.64 | 60.06 | 70.46 |
| 45 | 70.72 | 100.00 | 95.58 | 96.00 | 61.27 | 68.02 |
| 50 | 70.11 | 100.00 | 95.32 | 95.94 | 58.80 | 68.26 |

**Table D3** Stability test of Ni/CZM3O catalyst

| Time (hr) | $X_{CH4}$ (%) | $X_{O2}$ (%) | $S_{H2}$ (%) | $S_{CO}$ (%) | $Y_{H2}$ (%) | $Y_{CO}$ (%) |
|---|---|---|---|---|---|---|
| 5 | 74.92 | 100.00 | 99.19 | 99.30 | 66.86 | 77.12 |
| 10 | 74.14 | 100.00 | 99.15 | 99.28 | 64.72 | 76.88 |
| 15 | 74.38 | 100.00 | 99.16 | 99.28 | 66.31 | 77.36 |
| 20 | 75.28 | 100.00 | 99.09 | 99.18 | 67.38 | 75.44 |
| 25 | 74.09 | 100.00 | 98.98 | 99.14 | 64.17 | 76.16 |
| 30 | 73.35 | 100.00 | 99.10 | 99.23 | 65.48 | 76.40 |
| 35 | 73.02 | 100.00 | 98.98 | 99.14 | 64.69 | 76.63 |
| 40 | 73.75 | 100.00 | 98.99 | 99.12 | 66.03 | 75.68 |
| 45 | 73.59 | 100.00 | 98.95 | 99.09 | 65.23 | 75.44 |
| 50 | 74.14 | 100.00 | 99.05 | 99.20 | 65.36 | 77.83 |

**Table D4** Stability test of Ni/CZO catalyst cycle 1

| Time (hr) | $X_{CH4}$ (%) | $X_{O2}$ (%) | $S_{H2}$ (%) | $S_{CO}$ (%) | $Y_{H2}$ (%) | $Y_{CO}$ (%) |
|---|---|---|---|---|---|---|
| 1 | 73.69 | 100.00 | 98.90 | 99.05 | 66.92 | 77.11 |
| 2 | 71.12 | 100.00 | 98.49 | 98.69 | 66.9 | 77.57 |
| 3 | 69.77 | 100.00 | 97.98 | 98.06 | 66.36 | 77.07 |
| 4 | 69.35 | 100.00 | 98.01 | 98.27 | 67.44 | 77.79 |
| 5 | 69.09 | 100.00 | 98.26 | 98.52 | 65.97 | 78.05 |
| 6 | 68.25 | 100.00 | 97.83 | 98.10 | 66.32 | 75.85 |
| 7 | 69.22 | 100.00 | 97.64 | 97.88 | 67.70 | 75.84 |
| 8 | 68.53 | 100.00 | 97.98 | 98.20 | 66.11 | 74.40 |
| 9 | 69.22 | 100.00 | 97.53 | 97.83 | 64.83 | 74.14 |
| 10 | 69.31 | 100.00 | 97.38 | 97.78 | 62.94 | 74.62 |

**Table D5** Stability test of Ni/CZO catalyst cycle 2

| Time (hr) | $X_{CH4}$ (%) | $X_{O2}$ (%) | $S_{H2}$ (%) | $S_{CO}$ (%) | $Y_{H2}$ (%) | $Y_{CO}$ (%) |
|---|---|---|---|---|---|---|
| 1 | 72.34 | 100.00 | 96.70 | 97.00 | 64.86 | 71.44 |
| 2 | 72.47 | 100.00 | 96.54 | 96.98 | 63.37 | 72.89 |
| 3 | 72.26 | 100.00 | 96.66 | 97.00 | 62.98 | 70.48 |
| 4 | 70.34 | 100.00 | 95.77 | 96.28 | 60.73 | 69.48 |
| 5 | 69.82 | 100.00 | 95.27 | 95.68 | 60.55 | 66.56 |
| 6 | 70.47 | 100.00 | 94.55 | 94.87 | 61.05 | 65.08 |
| 7 | 70.85 | 100.00 | 94.77 | 95.43 | 57.77 | 66.55 |
| 8 | 69.23 | 100.00 | 94.15 | 94.76 | 57.87 | 65.07 |
| 9 | 71.00 | 100.00 | 95.49 | 96.00 | 58.99 | 66.81 |
| 10 | 70.14 | 100.00 | 94.57 | 95.19 | 57.73 | 65.57 |

**Table D6** Stability test of Ni/CZM1O catalyst cycle 1

| Time (hr) | $X_{CH4}$ (%) | $X_{O2}$ (%) | $S_{H2}$ (%) | $S_{CO}$ (%) | $Y_{H2}$ (%) | $Y_{CO}$ (%) |
|---|---|---|---|---|---|---|
| 1 | 75.59 | 100.00 | 98.25 | 98.47 | 63.43 | 72.72 |
| 2 | 74.70 | 100.00 | 98.19 | 98.48 | 63.15 | 75.38 |
| 3 | 74.22 | 100.00 | 98.21 | 98.45 | 64.64 | 74.66 |
| 4 | 74.18 | 100.00 | 98.02 | 98.30 | 64.38 | 74.89 |
| 5 | 73.20 | 100.00 | 97.90 | 98.23 | 62.09 | 73.92 |
| 6 | 72.67 | 100.00 | 98.03 | 98.23 | 64.72 | 72.47 |
| 7 | 73.52 | 100.00 | 97.89 | 98.21 | 63.45 | 74.89 |
| 8 | 73.05 | 100.00 | 97.73 | 97.98 | 64.71 | 72.94 |
| 9 | 73.22 | 100.00 | 97.70 | 97.98 | 64.06 | 73.18 |
| 10 | 72.63 | 100.00 | 97.54 | 97.86 | 61.93 | 71.48 |

**Table D7** Stability test of Ni/CZM1O catalyst cycle 2

| Time (hr) | $X_{CH4}$ (%) | $X_{O2}$ (%) | $S_{H2}$ (%) | $S_{CO}$ (%) | $Y_{H2}$ (%) | $Y_{CO}$ (%) |
|---|---|---|---|---|---|---|
| 1 | 72.73 | 100.00 | 97.28 | 97.63 | 63.40 | 72.92 |
| 2 | 71.68 | 100.00 | 97.26 | 97.58 | 64.51 | 73.16 |
| 3 | 72.13 | 100.00 | 97.19 | 97.54 | 63.86 | 73.16 |
| 4 | 71.91 | 100.00 | 97.05 | 97.44 | 63.17 | 73.16 |
| 5 | 72.35 | 100.00 | 97.04 | 97.42 | 63.17 | 72.67 |
| 6 | 72.23 | 100.00 | 96.85 | 97.26 | 63.17 | 72.91 |
| 7 | 71.95 | 100.00 | 96.80 | 97.20 | 62.89 | 72.18 |
| 8 | 71.49 | 100.00 | 96.66 | 97.09 | 61.77 | 71.21 |
| 9 | 71.18 | 100.00 | 96.59 | 97.02 | 61.86 | 71.20 |
| 10 | 71.58 | 100.00 | 96.60 | 97.06 | 62.26 | 72.41 |

**Table D8** Stability test of Ni/CZM3O catalyst cycle 1

| Time (hr) | $X_{CH4}$ (%) | $X_{O2}$ (%) | $S_{H2}$ (%) | $S_{CO}$ (%) | $Y_{H2}$ (%) | $Y_{CO}$ (%) |
|---|---|---|---|---|---|---|
| 1 | 82.10 | 100.00 | 99.32 | 99.36 | 71.79 | 76.89 |
| 2 | 80.40 | 100.00 | 99.26 | 99.31 | 71.39 | 77.12 |
| 3 | 77.89 | 100.00 | 99.24 | 99.32 | 69.37 | 77.36 |
| 4 | 75.42 | 100.00 | 99.23 | 99.33 | 66.99 | 76.40 |
| 5 | 74.92 | 100.00 | 99.19 | 99.30 | 66.86 | 77.12 |
| 6 | 74.52 | 100.00 | 99.16 | 99.28 | 66.22 | 77.36 |
| 7 | 73.72 | 100.00 | 99.14 | 99.26 | 66.16 | 77.36 |
| 8 | 73.76 | 100.00 | 99.12 | 99.23 | 67.13 | 77.12 |
| 9 | 73.53 | 100.00 | 99.15 | 99.27 | 66.37 | 76.88 |
| 10 | 74.14 | 100.00 | 99.15 | 99.28 | 64.72 | 76.88 |

**Table D9** Stability test of Ni/CZM3O catalyst cycle 2

| Time (hr) | $X_{CH4}$ (%) | $X_{O2}$ (%) | $S_{H2}$ (%) | $S_{CO}$ (%) | $Y_{H2}$ (%) | $Y_{CO}$ (%) |
|---|---|---|---|---|---|---|
| 1 | 72.34 | 100.00 | 96.70 | 97.00 | 64.86 | 71.44 |
| 2 | 72.47 | 100.00 | 96.54 | 96.98 | 63.37 | 72.89 |
| 3 | 72.26 | 100.00 | 96.66 | 97.00 | 62.98 | 70.48 |
| 4 | 70.34 | 100.00 | 95.77 | 96.28 | 60.73 | 69.48 |
| 5 | 69.82 | 100.00 | 95.27 | 95.68 | 60.55 | 66.56 |
| 6 | 70.47 | 100.00 | 94.55 | 94.87 | 61.05 | 65.08 |
| 7 | 70.85 | 100.00 | 94.77 | 95.43 | 57.77 | 66.55 |
| 8 | 69.23 | 100.00 | 94.15 | 94.76 | 57.87 | 65.07 |
| 9 | 71.00 | 100.00 | 95.49 | 96.00 | 58.99 | 66.81 |
| 10 | 70.14 | 100.00 | 94.57 | 95.19 | 57.73 | 65.57 |

## Appendix E Temperature programmed oxidation of spent Ni-doped catalyst

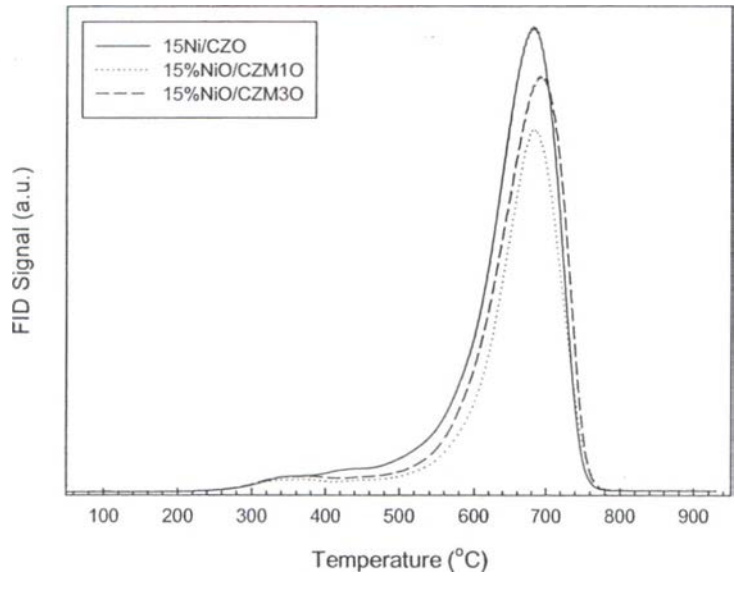


**Figure E1** The TPO profiles of spent Ni-doped catalysts.

# CURRICULUM VITAE

Name: Mr.Ratchaphon Sukkaeo

Date of Birth: August 6, 1988

Nationality: Thai

University Education:

2007-2011 Bachelor Degree of Engineering in major of Petrochemicals and Polymeric materials , Faculty of Engineering and Industrial technology, Silpakorn University, Nakorn Pathom, Thaland.

2011-2012 Master Degree of Science in Petrochemical technology, The Petroleum and Petrochemical College, Chulalongkorn University, Thailand.

Working Experience:

2010 Position: Trainee (1 month)

Company name: TOC Glycol Co., Ltd.

Proceedings:

1. Sukkaeo, R.; Rirksomboon, T.; and Meeyoo, V. (2013, April 23) Catalytic Partial Oxidation of Methane Over $NiO/Ce_{0.75}Zr_{0.25-x}Mg_{2x}O_2$-Based Catalysts. Proceedings of The 19th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.