# REFERENCES


Anderson, R. B., Stein, K. C., Feenan, J. J., and Hofer, L. E. J. (1961) Catalytic combustion of methane. Industrial & Engineering Chemistry, 53, 809.

Ari, H. and Machida, M. (1991) Recent progress in high temperature catalytic combustion. Catalysis Today, 10, 81-94.

Baldwin, T. R. and Burch, R. (1990) Catalytic combustion of methane over supported palladium catalyst. Applied Catalysis, 66, 235-246.

Beebe, K.W., Cairns, K.D., Pareek, V.K., and Nickolas, S.G. (2000) Development of catalytic combustion technology for single-digit emissions from industrial gas turbines. Catalysis Today, 59, 95-115

Betta, R. A. D. (1997) Catalytic combustion gas turbine systems: the prefered technology for low emission electric power production and co-generation. Catalysis Today, 35, 129-135.

Briot, P. and Primet, M. (1991) Catalytic combustion of methane over palladium supported on alumina-effect of aging under reactants. Applied Catalysis, 69, 301-314.

Carroni, R., Schmidt, V., and Griffin., T. (2002) Catalytic combustion for power generation, Catalysis Today, 75, 287-295

Carstens, J. N., Su, S. C., and Bell, A. T. (1998) Factors affecting the catalytic activity of $Pd/ZrO_2$for the combustion of methane, Journal of Catalysis, 176, 136-142.

Chin, Y. H. and Resasco, D. (1999) Catalysis-Specialists Periodical Reports. In Spivey, J. J. (Eds.), Royal Society of Chemistry, New York: Cambridge.

Climino, S., Pirone, R., and Russo, G. (2001) Thermal stability of perovskite-based monolithic reactors in the catalytic combustion of methane. Industrial Chemical Research, 40(1), 80-58.

Dalla Betta, R.A. and Rostrup-Nielsen, T. (1999) Application of catalytic combustion to a 1.5 MW industrial gas turbine. Catalysis Today, 47, 369-375.

Datye, A. K., Bravoa, J., Nelson, T. R., Atanasova, P., Lyubovskyb, M., and Pfefferle, L. (2000) Catalyst microstructure and methane oxidation reactivity during the Pd↔PdO transformation on alumina supports. Applied Catalysis A: General, 198, 179-196

Eguchi, K., and Arai, H. (1996) Recent advances in high tenperature catalytic combustion. Catalysis Today, 29, 379-386.

Ersson, A. (2003) Material for High-Temperature Catalytic Combustion. Ph.D. Thesis in chemical engineering, Department of Chemical Engineering and Technology, Kingliga Tekniska Högskolan (Royal Institute of Technology).

Etemad, S., Karim, H., Smith, L. L., and Pfefferle. (1999) Advance technology catalytic combustior for high temperature ground power gas turbine applications. Catalysis Today, 47, 305-313.

Ferrauto, R. J., Hobson, M. C., Kennelly, T., and Waterman, E. M. (1992) Catalytic chemistry of supported palladium for combustion of methane. Applied Catalysis A: General, 81, 227-237.

Ferrauto, R. J., Lampert, J. K., Hobson, M. C., and Waterman, E. M. (1995) Thermal decomposition and reformation of PdO catalysts; support effect. Applied Catalysis B: Environmental, 6, 263-270.

Forzatti, P. (2000) Environmental catalysis for stationary applications. Catalysis Today, 62, 50-65

Gélin, P. and Primet, M. (2002) Complete oxidation of methane at low temperature over nobal metal based catalyst: a review. Applied Catalysis B: Environmental, 39, 1-37.

Geus, J. W. and Giez-en, J. C. (1999) Monoliths in catalytic oxidation. Catalysis Today, 47, 169-180.

Griffin, T., Weisenstein, W., and Fowles, M. (1995) Palladium-catalyzed combustion of methane: simulated gas turbine combustion at atmospheric pressure. Combustion and Flame, 101, 81-90.

Hicks, R. F., Qi, H., Young, M. L., and Lee, R. G. (1990) Structure sensitivity of methane oxidation over platinum and palladium. Journal of Catalysis, 122, 295-306.

Heck, R. M., Gulati, S., and Farrauto, R. J. (2001) The application of monoliths for gasphase catalytic reaction. Chemical Engineering Journal, 82, 149-156.

Holzwarth, A., Denton, P., Zanthoff, H., and Mirodatos, C. (2001) Combinatorial approaches to heterogeneous catalysts strategies and perspective for academic research. Catalysis Today, 67, 309-318.

Hoyos, L. J., Praliaud, H., and Primet, M. (1993) Catalytic combustion of methane over palladium supported on alumina and silica in presence of hydrogen sulfide. Applied Catalysis A: General, 98, 125-138.

IEA Greenhouse Gas R&D Programme June (1998) Abatement of methane emission.

Kapteijn, F. and Moulijn, J. A. (1996) Handbook of Heterogeneous Catalysis Vol. 3, In Ertl, G., Knözinger, H. and Weitkamp (Eds.), VCH: Weinheim.

Kennelly, J., Mead, B., and Freeauto, R. J. (1993) Catalytic combustion process using supported palladium oxide catalysts. US Patent 5,216,875.

Kennelly, J., Mead, B., Chou, T. C., Jose, S., and Freeauto, R. J. (1999) Combustion catalyst containing oxides and processes using the same. US Patent 5,863,851.

Kikuchi, R. Maeda, S., Sasaki, K., Wennerström, S., Ozawa, Y. and Eguchi, K. (2003) Catalytic activity of oxide-supported Pd catalysts on a honeycomb for low-temperature methane oxidation. Applied Catalysis A: General, 239, 169-179.

Ledwich, J. and Su, S. (2001) Catalytic combustion of coal mine ventilation air: literature review and experimental preparation. CSIRO Exploration and Mining, May 2001, Australia.

Lee, J. H. and Trimm, D. L. (1995) Catalytic combustion of methane. Fuel Processing Technology, 42, 339-359.

Lefebvre, A.H. (1983) Gas Turbine Combustion, Hemisphere Publishing Corp., Bristol.

Lopez, T., Asomoza, M., Bosch, P., Garcia-Fiueroa, E., and Gomez, R. (1992) Journal of Catalysis, 138, 463.

Lyubovsky, M., LaPierre, R., Smith, L., Castaldi, M., Nentwick, B., and Pefferle, W.C. (2002) Catalytic combustion of methane under fuel lean and fuel rich conditions over supported Pt, Pd and Rh catalysts. Book of abstracts - 5th International syumposium on catalytic combustion, Seoul.

McFarland, E.W. and Weinberg, W.H. (1999) Combinatorial approaches to materials discovery. Tibtech, 17, 107-115.

Méthivier, Ch., Beguin, B., Brun, M., Massardier, J., and Bertolini, J. C. (1998) Pd/SiC catalysts: characterization and catalytic activity for the methane total oxidation. Journal of Catalysis, 173, 374-382.

Méthivier, Ch., Massardier, J., and Bertolini, J. C. (1999) $Pd/Si_3N_4$ catalysts: preparation, characterization and catalytic activity for the methane total oxidation. Applied Catalysis A: General, 182, 337-344.

Muller, M., Maciejewski, R. A., Koeppel, R., Tschan, A., and Baiker (1996) Role of lattice oxygen in the combustion of methane over $PdO/ZrO_2$: combined pulse TG/DTA and MS study with 18O-labelled catalyst. Journal of Physical Chemistry, 100, 20006-20014.

Müller, C. A., Maciejewski, M., Koeppel, R. A., and Baiker, A. (1997) Combustion of methane over palladium/zirconia derived from a glassy Pd-Zr alloy: effect of Pd particle size on catalytic behavior. Journal of Catalysis, 166, 36-43.

Narui, K., Yata, H., Furuta, K., Nishida, A., Kohtoku, Y. and Matsuzaki, T. (1999) Effects of adding of Pt to $PdO/Al_2O_3$ catalyst on catalytic activity for methane combustion and TEM observations of supported particles. Applied Catalysis A: General, 179, 165-173.

Neomangus, H. W. J. P., Saracco, G., Wessel, H. F. W., and Versteeg, G. F. (2000) The catalytic combustion of natural gas in a membrane reactor with separate feed of reactants. Chemical Engineering Journal, 77, 165-177.

Oh, S. H., Mitchell, P. J., and Siewert, R. M. (1991) Catalytic controll of air polution: mobile and stationary sources. In Silver, J. E. (Eds.), 202nd National Meeting of the American Chemical Society, 25-30 August 1991, ACS Series, Vol. 495.

Ozawa, Y., Fujii, T., Sato, M., Kanazawa, T., and Inoue, H. (1999) Development of a catalytically assisted combustor for a gas turbine. Catalysis Today, 47, 399-405.

Ozawa, Y., Tochihara, Y., Nagai, M., and Omi, S. (2003) Effect of addition of $Nd_2O_3$ and $La_2O_3$ to $PdO/Al_2O_3$ in catalytic combustion of methane. Catalysis Communications, 4, 87-90.

Ozawa, Y., Tochihara, Y., Watanabe, A., Nagai, M., and Omi, S. (2004) Deactivation of $Pt{\cdot}Pt/Al_2O_3$ in catalytic combustion of methane, Applied Catalysis A: General, 259, 1-7.

Papadias, D. (2001) Mathematical Modelling of Structured Reactors with Emphasis on Catalytic Combustion Reactions. Ph.D. Thesis in chemical engineering, Department of Chemical Engineering and Technology, Kingliga Tekniska Högskolan (Royal Institute of Technology).

Pitchon, V. and Fritz, A. (1997) The current state of research on automotive lean $NO_X$ catalysis, Applied. Catalysis B: Environmental, 13, 1-25.

Pérez-Ramírez, J., Berger, R., Mul, G., Kapteijn, F., and Moulijn, J. A. (2000) The six-flow reactor technology: a review on fast catalyst screening and kinetic studies. Catalysis Today, 60, 93-109.

Robeiro, F. H., Chow, M., and Dalla Betta, R. A. (1994) Kinetics of the complete oxidation of methane over supported palladium catalysts. Journal of Catalysis, 146, 537-544.

Ryu, C.K., Ryoo, M.W., Ryu, I. S., and Kang, S.K. (1999) Catalytic combustion of methane of methane over supported bimetallic Pd catalysts: Effects of Ru or Rh addition. Catalysis Today, 47, 141-147

Sadamori, H. (1999) Application concepts and evaluation of small-scale catalytic combustors for natural gas. Catalysis Today, 47, 325-338.

Sadamori, H., Tanioka, T., and Matsuhisa, T. (1995) Development of a high temperature combustion catalyst system and prototype catalytic combustor turbine test result. Catalysis Today, 26, 337-344.

Salomonsson, P., Johansson, S., and Kasermo, B. (1995) Catalysis Letters, 33, 1.

Sapoundjiew, H. (1999) High potential energy from dilute methane emission. Natural Resources Canada.

Sekizawa, K., Erguchu, K., Widjaja, H., and Machida, M. (1996) Property of Pd-supported catalysts for catalytic combustion. Catalysis Today, 28, 245-250.

Sekizawa, K., Widjaja, H., Maeda, S., Ozawa, Y., and Erguchu, K. (2000) Low temperature oxidation of methane supported on metal oxides. Catalysis Today, 59, 69-74.

Senken, S. (2001) Combinatorial heterogeneous catalysis-A new path in an old field. Angewandte Chemie International Edition, 40, 312-329.

Snapping Shoals EMC (2001) Electronic service–Green power (Landfill gas project).

Su, S.C., Carstens, J. N., and Bell, A. T. (1998) A study of the dynamics of Pd oxidation and PdO reduction by $H_2$ and $CH_4$, Journal of Catalysis, 176, 125-135.

Thevenin, P. (2002) Catalytic Combustion of Methane. Ph.D. Thesis in chemical engineering, Department of Chemical Engineering and Technology, Kingliga Tekniska Högskolan (Royal Institute of Technology).

Trimm, D. L. (1983) Catalytic combustion (review). Applied Catalysis, 7, 249-282.

Vatcha, S. R. (1997) Low emission gas turbine using catalytic combustion. Energy Conservation and Management, 38(10-B), 1327-1334.

Widjaja, H., Sekizawa, K., Erguchu, K., and Arai, H. (1999) Oxidation of methane over Pd/mixed oxide for catalytic combustion. Catalysis Today, 47, 95-101.

Wit, J. D., Johansen, K., Hansen, P. L., Rossen, H., and Rasmussen, N. B. (2000) Catalytic emission control with respect to $CH_4$ and CO for highly efficient gas fueled decentralized heat and power production. $5^{th}$ Internatinal Conference on Furnaces and Boilers (INFUB), April 2000, Portugal.

Yang, L. F., Shi, C. K., He, X., and Cai, J. X. (2002) Catalytic combustion of methane over PdO supported on Mg-modified alumina. Applied Catalysis B: Environmental, 38, 117-125.

# APPENDICES

## Appendix A

**Table A1** Raw data obtained from the screening of catalysts in Library I using eight tubular flow reactors

| No | Catalyst | Relative ratio of elemental loading (%) | | | Remark | Screening results at 650°C | | |
|---|---|---|---|---|---|---|---|---|
| | | Pd | Pt | La | | Time (min) | %Conversion | %Selectivity |
| 1 | CM | - | - | - | Bare Monolith | 15 | 0.00 | 100 |
| | | | | | | 83 | 0.00 | 100 |
| | | | | | | 151 | 0.00 | 100 |
| | | | | | | 219 | 0.00 | 100 |
| | | | | | | 287 | 0.00 | 100 |
| | | | | | | 355 | 0.00 | 100 |
| 2 | C22 | - | - | - | Washcoated Monolith | 24 | 0.00 | 100 |
| | | | | | | 92 | 0.00 | 100 |
| | | | | | | 160 | 0.00 | 100 |
| | | | | | | 228 | 0.00 | 100 |
| | | | | | | 296 | 0.00 | 100 |
| | | | | | | 364 | 0.00 | 100 |
| 3 | C19A | 80 | 20 | - | Method A (Pd-based) | 32 | 99.5 | 100 |
| | | | | | | 100 | 99.0 | 100 |
| | | | | | | 168 | 98.7 | 100 |
| | | | | | | 236 | 99.7 | 100 |
| | | | | | | 304 | 98.0 | 100 |
| | | | | | | 372 | 96.81 | 100 |
| 4 | C19B | 80 | 20 | - | Method B (Pd-based) | 41 | 99.9 | 100 |
| | | | | | | 109 | 100 | 100 |
| | | | | | | 177 | 100 | 100 |
| | | | | | | 245 | 100 | 100 |
| | | | | | | 313 | 100 | 100 |
| | | | | | | 381 | 100 | 100 |
| 5 | C17A | 60 | 20 | 20 | Method A (Pd-based) | 49 | 97.7 | 100 |
| | | | | | | 117 | 97.4 | 100 |
| | | | | | | 185 | 97.0 | 100 |
| | | | | | | 253 | 96.3 | 100 |
| | | | | | | 321 | 95.9 | 100 |
| | | | | | | 389 | 95.9 | 100 |
| 6 | C17B | 60 | 20 | 20 | Method B (Pd-based) | 58 | 98.9 | 100 |
| | | | | | | 126 | 99.0 | 100 |
| | | | | | | 194 | 98.5 | 100 |
| | | | | | | 262 | 98.2 | 100 |
| | | | | | | 330 | 97.8 | 100 |
| | | | | | | 398 | 96.1 | 100 |

Note: Method A: washcoated monolith was calcined at 500°C and re-calcined at 900°C for 3 hrs after metal loading.

Method B: washcoated monolith was calcined at 900°C and re-calcined at 900°C for 3 hrs after metal loading.

**Table A1** continued

| No | Catalyst | Relative ratio of elemental loading (%) | | | Remark | Screening results at 650°C | | |
|---|---|---|---|---|---|---|---|---|
| | | Pd | Pt | La | | Time (min) | %Conversion | %Selectivity |
| 7 | C02A | - | 80 | 20 | Method A (Pt-based) | 66 | 44.2 | 100 |
| | | | | | | 134 | 44.9 | 100 |
| | | | | | | 202 | 44.5 | 100 |
| | | | | | | 270 | 43.6 | 100 |
| | | | | | | 338 | 43.3 | 100 |
| | | | | | | 406 | 30.2 | 100 |
| 8 | C02B | - | 80 | 20 | Method B (Pt-based) | 75 | 34.9 | 100 |
| | | | | | | 143 | 33.7 | 100 |
| | | | | | | 211 | 28.2 | 100 |
| | | | | | | 279 | 27.3 | 100 |
| | | | | | | 347 | 17.9 | 100 |
| | | | | | | 415 | 18.6 | 100 |

Note: Method A: washcoated monolith was calcined at 500°C and re-calcined at 900°C for 3 hrs after metal loading.
Method B: washcoated monolith was calcined at 900°C and re-calcined at 900°C for 3 hrs after metal loading.

**Table A2** Raw data obtained from the screening of catalysts in Library II using eight tubular flow reactors

| No | Catalyst | Pd loading (%wt) | Screening results at 350°C | | | Screening results at 400°C | | | Screening results at 4500°C | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Time (min) | %Conversion | %Selectivity | Time (min) | %Conversion | %Selectivity | Time (min) | %Conversion | %Selectivity |
| 1 | ML1 | 1% | 15 | 0.00 | 100 | 15 | 84.03 | 100 | 15 | 0.00 | 100 |
| | | | 83 | 0.00 | 100 | 83 | 1.50 | 100 | 83 | 0.00 | 100 |
| | | | 151 | 0.53 | 100 | 151 | 1.75 | 100 | | | |
| | | | 219 | 0.41 | 100 | 219 | 0.87 | 100 | | | |
| | | | | | | 287 | 1.02 | 100 | | | |
| 2 | ML2 | 2% | 24 | 0.00 | 100 | 24 | 0.00 | 100 | 24 | 0.00 | 100 |
| | | | 92 | 0.00 | 100 | 92 | 0.86 | 100 | 92 | 0.00 | 100 |
| | | | 160 | 0.43 | 100 | 160 | 1.31 | 100 | | | |
| | | | 228 | 0.30 | 100 | 228 | 1.07 | 100 | | | |
| | | | | | | 296 | 0.90 | 100 | | | |
| 3 | ML3 | 4% | 32 | 19.6 | 100 | 32 | 76.2 | 100 | 32 | 98.6 | 100 |
| | | | 100 | 16.9 | 100 | 100 | 43.1 | 100 | 100 | 93.0 | 100 |
| | | | 168 | 15.6 | 100 | 168 | 36.3 | 100 | | | |
| | | | 236 | 12.0 | 100 | 236 | 26.4 | 100 | | | |
| | | | | | | 304 | 27.1 | 100 | | | |
| 4 | ML4 | 5% | 41 | 22.5 | 100 | 41 | 78.8 | 100 | 41 | 99.3 | 100 |
| | | | 109 | 15.9 | 100 | 109 | 51.4 | 100 | 109 | 95.3 | 100 |
| | | | 177 | 12.6 | 100 | 177 | 25.7 | 100 | | | |
| | | | 245 | 10.5 | 100 | 245 | 20.0 | 100 | | | |
| | | | | | | 313 | 24.7 | 100 | | | |
| 5 | ML5 | 7% | 49 | 13.3 | 100 | 49 | 77.6 | 100 | 49 | 96.5 | 100 |
| | | | 117 | 10.5 | 100 | 117 | 57.9 | 100 | 117 | 93.4 | 100 |
| | | | 185 | 10.4 | 100 | 185 | 28.9 | 100 | | | |
| | | | 253 | 8.43 | 100 | 253 | 34.5 | 100 | | | |
| | | | | | | 321 | 28.2 | 100 | | | |

**Table A2** continued

| No | Catalyst | Pd loading (%wt) | Screening results at 350°C | | | Screening results at 400°C | | | Screening results at 4500°C | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Time (min) | %Conversion | %Selectivity | Time (min) | %Conversion | %Selectivity | Time (min) | %Conversion | %Selectivity |
| 6 | ML6 | 8% | 58 | 16.9 | 100 | 58 | 80.5 | 100 | 58 | 97.5 | 100 |
| | | | 126 | 12.3 | 100 | 126 | 50.9 | 100 | 126 | 92.5 | 100 |
| | | | 194 | 13.9 | 100 | 194 | 46.6 | 100 | | | |
| | | | 262 | 11.0 | 100 | 262 | 27.4 | 100 | | | |
| | | | | | | 330 | 23.9 | 100 | | | |
| 7 | ML7 | 10% | 66 | 37.0 | 100 | 66 | 93.2 | 100 | 66 | 99.0 | 100 |
| | | | 134 | 18.3 | 100 | 134 | 80.2 | 100 | 134 | 98.0 | 100 |
| | | | 202 | 17.1 | 100 | 202 | 61.4 | 100 | | | |
| | | | 270 | 13.5 | 100 | 270 | 42.6 | 100 | | | |
| | | | | | | 338 | 31.8 | 100 | | | |
| 8 | ML8 | 12% | 75 | 33.4 | 100 | 75 | 96.1 | 100 | 75 | 99.6 | 100 |
| | | | 143 | 18.1 | 100 | 143 | 90.8 | 100 | 143 | 98.5 | 100 |
| | | | 211 | 10.6 | 100 | 211 | 73.9 | 100 | | | |
| | | | 279 | 14.5 | 100 | 279 | 68.6 | 100 | | | |
| | | | | | | 347 | 52.9 | 100 | | | |

**Table A3** Raw data obtained from the screening of catalysts in Library III using eight tubular flow reactors

| No | Catalysts | Ratio of elements loading (%) | | | Screening Data | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | T = 400°C | | T = 450°C | | T = 500°C | | T = 550°C | | T = 600°C | | T = 800°C | |
| | | Pd | Pt | La | Time (min) | % Conv. | Time | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. |
| | | | | | 15 | 0.00 | 15 | 0.00 | 15 | 3.38 | 15 | 7.54 | 15 | 48.9 | 15 | 100 |
| | | | | | 83 | 0.00 | 83 | 0.00 | 83 | 3.54 | 83 | 8.12 | 83 | 55.0 | 83 | 100 |
| | | | | | 151 | 0.00 | 151 | 0.00 | 151 | 3.67 | 151 | 7.74 | 151 | 54.9 | 151 | 100 |
| 1 | C01 | 0.00 | 1.00 | 0.00 | 219 | 0.00 | 219 | 0.00 | 219 | 3.51 | 219 | 7.46 | 219 | 56.5 | 219 | 100 |
| | | | | | 287 | 0.00 | 287 | 0.00 | 287 | 3.28 | 287 | 7.33 | 287 | 53.3 | 287 | 100 |
| | | | | | 355 | 0.00 | 355 | 0.00 | 355 | 3.29 | 355 | 7.32 | 355 | 51.7 | 355 | 100 |
| | | | | | 423 | 0.00 | 423 | 0.00 | 423 | 3.29 | 423 | 6.43 | 423 | 49.8 | 423 | 100 |
| | | | | | 15 | 0.00 | 15 | 0.00 | 15 | 3.35 | 15 | 5.48 | 15 | 12.4 | 15 | 89.9 |
| | | | | | 83 | 0.00 | 83 | 0.00 | 83 | 0.00 | 83 | 4.88 | 83 | 11.7 | 83 | 89.9 |
| | | | | | 151 | 0.00 | 151 | 0.00 | 151 | 0.00 | 151 | 4.41 | 151 | 11.0 | 151 | 100 |
| 2 | C02 | 0.00 | 0.80 | 0.20 | 219 | 0.00 | 219 | 0.00 | 219 | 0.00 | 219 | 5.26 | 219 | 9.92 | 219 | 100 |
| | | | | | 287 | 0.00 | 287 | 0.00 | 287 | 0.00 | 287 | 4.82 | 287 | 10.3 | 287 | 100 |
| | | | | | 355 | 0.00 | 355 | 0.00 | 355 | 0.00 | 355 | 4.76 | 355 | 10.2 | 355 | 100 |
| | | | | | 423 | 0.00 | 423 | 0.00 | 423 | 0.00 | 423 | 3.60 | 423 | 10.4 | 423 | 100 |
| | | | | | 24 | 0.00 | 24 | 0.00 | 24 | 0.00 | 24 | 6.25 | 24 | 6.19 | 24 | 100 |
| | | | | | 92 | 0.00 | 92 | 0.00 | 92 | 0.00 | 92 | 6.32 | 92 | 6.94 | 92 | 100 |
| | | | | | 160 | 0.00 | 160 | 0.00 | 160 | 0.00 | 160 | 6.12 | 160 | 6.66 | 160 | 100 |
| 3 | C03 | 0.00 | 0.60 | 0.40 | 228 | 0.00 | 228 | 0.00 | 228 | 0.00 | 228 | 6.15 | 228 | 5.42 | 228 | 100 |
| | | | | | 296 | 0.00 | 296 | 0.00 | 296 | 0.00 | 296 | 5.78 | 296 | 4.55 | 296 | 100 |
| | | | | | 364 | 0.00 | 364 | 0.00 | 364 | 0.00 | 364 | 5.75 | 364 | 4.33 | 364 | 100 |
| | | | | | 432 | 0.00 | 432 | 0.00 | 432 | 0.00 | 432 | 5.58 | 432 | 3.81 | 432 | 100 |
| | | | | | 24 | 0.00 | 24 | 0.00 | 24 | 0.00 | 24 | 6.83 | 24 | 12.2 | 24 | 99.2 |
| | | | | | 92 | 0.00 | 92 | 0.00 | 92 | 0.00 | 92 | 5.80 | 92 | 12.4 | 92 | 99.4 |
| | | | | | 160 | 0.00 | 160 | 0.00 | 160 | 0.00 | 160 | 5.74 | 160 | 12.1 | 160 | 100 |
| 4 | C04 | 0.00 | 0.40 | 0.60 | 228 | 0.00 | 228 | 0.00 | 228 | 0.00 | 228 | 6.17 | 228 | 11.3 | 228 | 100 |
| | | | | | 296 | 0.00 | 296 | 0.00 | 296 | 0.00 | 296 | 5.59 | 296 | 10.7 | 296 | 100 |
| | | | | | 364 | 0.00 | 364 | 0.00 | 364 | 0.00 | 364 | 5.03 | 364 | 10.8 | 364 | 100 |
| | | | | | 432 | 0.00 | 432 | 0.00 | 432 | 0.00 | 432 | 4.13 | 432 | 10.5 | 432 | 100 |
| | | | | | 32 | 0.00 | 32 | 0.00 | 32 | 0.00 | 32 | 4.05 | 32 | 7.45 | 32 | 97.4 |
| | | | | | 100 | 0.00 | 100 | 0.00 | 100 | 0.00 | 100 | 0.00 | 100 | 6.80 | 100 | 98.2 |
| | | | | | 168 | 0.00 | 168 | 0.00 | 168 | 0.00 | 168 | 0.00 | 168 | 6.69 | 168 | 95.9 |
| 5 | C05 | 0.00 | 0.20 | 0.80 | 236 | 0.00 | 236 | 0.00 | 236 | 0.00 | 236 | 0.00 | 236 | 6.28 | 236 | 94.8 |
| | | | | | 304 | 0.00 | 304 | 0.00 | 304 | 0.00 | 304 | 0.00 | 304 | 6.61 | 304 | 93.0 |
| | | | | | 372 | 0.00 | 372 | 0.00 | 372 | 0.00 | 372 | 0.00 | 372 | 6.30 | 372 | 90.9 |
| | | | | | 440 | 0.00 | 440 | 0.00 | 440 | 0.00 | 440 | 0.00 | 440 | 6.26 | 440 | 89.4 |

**Table A3** continued

| No | Catalysts | Ratio of elements loading (%) | | | Screening Data | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | T = 400°C | | T = 450°C | | T = 500°C | | T = 550°C | | T = 600°C | | T = 800°C | |
| | | Pd | Pt | La | Time (min) | % Conv. | Time | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. |
| 6 | C06 | 0.00 | 0.00 | 1.00 | 32 | 0.00 | 32 | 0.00 | 32 | 0.00 | 32 | 0.00 | 32 | 9.92 | 32 | 63.1 |
| | | | | | 100 | 0.00 | 100 | 0.00 | 100 | 0.00 | 100 | 0.00 | 100 | 7.43 | 100 | 62.3 |
| | | | | | 168 | 0.00 | 168 | 0.00 | 168 | 0.00 | 168 | 0.00 | 168 | 7.32 | 168 | 60.1 |
| | | | | | 236 | 0.00 | 236 | 0.00 | 236 | 0.00 | 236 | 0.00 | 236 | 5.73 | 236 | 64.2 |
| | | | | | 304 | 0.00 | 304 | 0.00 | 304 | 0.00 | 304 | 0.00 | 304 | 5.60 | 304 | 59.5 |
| | | | | | 372 | 0.00 | 372 | 0.60 | 372 | 0.00 | 372 | 0.00 | 372 | 4.75 | 372 | 65.1 |
| | | | | | 440 | 0.00 | 440 | 0.00 | 440 | 0.00 | 440 | 0.00 | 440 | 3.31 | 440 | 63.0 |
| 7 | C07 | 0.20 | 0.80 | 0.00 | 15 | 6.08 | 15 | 38.2 | 15 | 67.3 | 15 | 87.7 | 15 | 29.1 | 15 | 100 |
| | | | | | 83 | 9.58 | 83 | 44.8 | 83 | 82.5 | 83 | 94.8 | 83 | 93.0 | 83 | 100 |
| | | | | | 151 | 9.94 | 151 | 49.2 | 151 | 89.2 | 151 | 96.2 | 151 | 92.1 | 151 | 100 |
| | | | | | 219 | 10.5 | 219 | 54.0 | 219 | 91.1 | 219 | 98.0 | 219 | 91.2 | 219 | 100 |
| | | | | | 287 | 10.8 | 287 | 56.4 | 287 | 91.6 | 287 | 98.4 | 287 | 90.6 | 287 | 100 |
| | | | | | 355 | 11.5 | 355 | 54.7 | 355 | 91.4 | 355 | 98.0 | 355 | 90.2 | 355 | 100 |
| | | | | | 423 | 12.1 | 423 | 56.6 | 423 | 91.6 | 423 | 97.7 | 423 | 89.9 | 423 | 100 |
| 8 | C08 | 0.20 | 0.60 | 0.20 | 24 | 8.04 | 24 | 37.2 | 24 | 64.8 | 24 | 87.1 | 24 | 82.2 | 24 | 100 |
| | | | | | 92 | 9.55 | 92 | 43.5 | 92 | 79.9 | 92 | 89.7 | 92 | 88.7 | 92 | 100 |
| | | | | | 160 | 9.94 | 160 | 46.7 | 160 | 87.1 | 160 | 89.4 | 160 | 90.2 | 160 | 100 |
| | | | | | 228 | 10.2 | 228 | 50.2 | 228 | 89.3 | 228 | 88.6 | 228 | 91.0 | 228 | 100 |
| | | | | | 296 | 10.0 | 296 | 52.2 | 296 | 90.1 | 296 | 88.9 | 296 | 90.3 | 296 | 100 |
| | | | | | 364 | 10.8 | 364 | 51.6 | 364 | 89.8 | 364 | 87.7 | 364 | 89.1 | 364 | 100 |
| | | | | | 432 | 11.2 | 432 | 53.3 | 432 | 89.9 | 432 | 87.4 | 432 | 89.6 | 432 | 100 |
| 9 | C09 | 0.20 | 0.40 | 0.40 | 41 | 6.46 | 41 | 23.2 | 41 | 51.1 | 41 | 72.5 | 41 | 69.9 | 41 | 98.3 |
| | | | | | 109 | 6.03 | 109 | 27.6 | 109 | 58.6 | 109 | 75.4 | 109 | 78.9 | 109 | 98.2 |
| | | | | | 177 | 6.96 | 177 | 30.3 | 177 | 65.2 | 177 | 74.9 | 177 | 84.4 | 177 | 98.3 |
| | | | | | 245 | 6.71 | 245 | 30.6 | 245 | 70.0 | 245 | 74.1 | 245 | 83.8 | 245 | 98.0 |
| | | | | | 313 | 5.94 | 313 | 31.7 | 313 | 72.6 | 313 | 73.1 | 313 | 89.7 | 313 | 97.1 |
| | | | | | 381 | 6.77 | 381 | 33.1 | 381 | 74.2 | 381 | 72.6 | 381 | 89.3 | 381 | 96.7 |
| | | | | | 449 | 6.87 | 449 | 35.5 | 449 | 75.2 | 449 | 72.6 | 449 | 88.9 | 449 | 96.2 |
| 10 | C10 | 0.20 | 0.20 | 0.60 | 41 | 12.5 | 41 | 48.3 | 41 | 72.4 | 41 | 89.3 | 41 | 67.6 | 41 | 95.1 |
| | | | | | 109 | 9.09 | 109 | 51.0 | 109 | 79.4 | 109 | 88.7 | 109 | 71.5 | 109 | 94.4 |
| | | | | | 177 | 8.48 | 177 | 54.1 | 177 | 84.6 | 177 | 89.0 | 177 | 73.6 | 177 | 92.0 |
| | | | | | 245 | 8.31 | 245 | 56.6 | 245 | 79.4 | 245 | 92.5 | 245 | 74.7 | 245 | 85.7 |
| | | | | | 313 | 7.14 | 313 | 59.3 | 313 | 77.8 | 313 | 92.5 | 313 | 75.7 | 313 | 89.9 |
| | | | | | 381 | 7.84 | 381 | 61.9 | 381 | 79.9 | 381 | 90.8 | 381 | 76.4 | 381 | 88.6 |
| | | | | | 449 | 11.6 | 449 | 64.5 | 449 | 86.3 | 449 | 89.9 | 449 | 76.8 | 449 | 87.5 |

**Table A3** continued

| No | Catalysts | Ratio of elements loading (%) | | | Screening Data | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | T = 400°C | | T = 450°C | | T = 500°C | | T = 550°C | | T = 600°C | | T = 800°C | |
| | | Pd | Pt | La | Time (min) | % Conv. | Time | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. |
| 11 | C11 | 0.20 | 0.00 | 0.80 | 49 | 11.7 | 66 | 9.69 | 66 | 28.2 | 66 | 47.0 | 49 | 96.9 | 49 | 88.4 |
| | | | | | 117 | 13.1 | 134 | 9.15 | 134 | 26.2 | 134 | 43.9 | 117 | 96.9 | 117 | 90.6 |
| | | | | | 185 | 12.9 | 202 | 9.23 | 202 | 25.5 | 202 | 42.6 | 185 | 96.7 | 185 | 90.0 |
| | | | | | 253 | 13.1 | 270 | 8.96 | 270 | 24.8 | 270 | 41.4 | 253 | 96.5 | 253 | 88.1 |
| | | | | | 321 | 12.9 | 338 | 14.4 | 338 | 30.0 | 338 | 40.4 | 321 | 96.4 | 321 | 88.6 |
| | | | | | 389 | 11.4 | 406 | 16.0 | 406 | 31.4 | 406 | 39.9 | 389 | 96.2 | 389 | 88.0 |
| | | | | | 457 | 10.3 | 474 | 22.7 | 474 | 30.0 | 474 | 39.8 | 457 | 96.0 | 457 | 87.3 |
| 12 | C12 | 0.40 | 0.60 | 0.00 | 49 | 9.44 | 58 | 30.2 | 49 | 67.4 | 49 | 84.9 | 49 | 81.1 | 49 | 100 |
| | | | | | 117 | 9.87 | 126 | 38.5 | 117 | 75.9 | 117 | 87.3 | 117 | 87.7 | 117 | 100 |
| | | | | | 185 | 9.71 | 194 | 42.0 | 185 | 81.0 | 185 | 87.3 | 185 | 89.9 | 185 | 100 |
| | | | | | 253 | 10.2 | 262 | 44.5 | 253 | 83.1 | 253 | 87.1 | 253 | 88.0 | 253 | 100 |
| | | | | | 321 | 9.97 | 330 | 50.5 | 321 | 83.9 | 321 | 87.0 | 321 | 88.7 | 321 | 100 |
| | | | | | 389 | 11.1 | 398 | 55.2 | 389 | 84.2 | 389 | 86.9 | 389 | 86.7 | 389 | 100 |
| | | | | | 457 | 11.5 | 466 | 58.8 | 457 | 84.7 | 457 | 87.0 | 457 | 86.0 | 457 | 100 |
| 13 | C13 | 0.40 | 0.40 | 0.20 | 32 | 6.47 | 32 | 35.6 | 32 | 59.2 | 32 | 75.6 | 32 | 95.2 | 32 | 100 |
| | | | | | 100 | 6.71 | 100 | 39.0 | 100 | 68.3 | 100 | 77.9 | 100 | 94.1 | 100 | 100 |
| | | | | | 168 | 6.98 | 168 | 42.1 | 168 | 74.7 | 168 | 78.4 | 168 | 93.5 | 168 | 100 |
| | | | | | 236 | 7.61 | 236 | 45.0 | 236 | 77.8 | 236 | 77.7 | 236 | 93.1 | 236 | 100 |
| | | | | | 304 | 7.49 | 304 | 45.7 | 304 | 79.6 | 304 | 77.1 | 304 | 92.6 | 304 | 100 |
| | | | | | 372 | 7.91 | 372 | 43.1 | 372 | 79.2 | 372 | 76.5 | 372 | 92.2 | 372 | 100 |
| | | | | | 440 | 8.10 | 440 | 44.2 | 440 | 80.6 | 440 | 76.3 | 440 | 92.0 | 440 | 100 |
| 14 | C14 | 0.40 | 0.20 | 0.40 | 58 | 14.8 | 58 | 35.0 | 58 | 67.9 | 58 | 75.2 | 58 | 93.2 | 58 | 89.3 |
| | | | | | 126 | 14.9 | 126 | 37.8 | 126 | 73.7 | 126 | 75.7 | 126 | 93.8 | 126 | 90.9 |
| | | | | | 194 | 14.0 | 194 | 39.6 | 194 | 75.8 | 194 | 74.1 | 194 | 93.8 | 194 | 93.1 |
| | | | | | 262 | 13.5 | 262 | 42.5 | 262 | 76.5 | 262 | 72.9 | 262 | 92.1 | 262 | 87.2 |
| | | | | | 330 | 14.4 | 330 | 43.6 | 330 | 76.4 | 330 | 71.6 | 330 | 93.1 | 330 | 82.8 |
| | | | | | 398 | 13.6 | 398 | 45.9 | 398 | 76.2 | 398 | 71.6 | 398 | 90.9 | 398 | 79.7 |
| | | | | | 466 | 13.9 | 466 | 45.0 | 466 | 75.9 | 466 | 71.4 | 466 | 90.4 | 466 | 77.2 |
| 15 | C15 | 0.40 | 0.00 | 0.60 | 58 | 15.7 | 58 | 50.5 | 58 | 83.3 | 58 | 96.7 | 58 | 97.9 | 58 | 96.8 |
| | | | | | 126 | 10.5 | 126 | 45.6 | 126 | 76.8 | 126 | 95.0 | 126 | 96.2 | 126 | 98.5 |
| | | | | | 194 | 10.7 | 194 | 45.0 | 194 | 72.3 | 194 | 95.0 | 194 | 95.1 | 194 | 98.2 |
| | | | | | 262 | 13.2 | 262 | 43.5 | 262 | 74.2 | 262 | 92.6 | 262 | 93.7 | 262 | 98.5 |
| | | | | | 330 | 13.1 | 330 | 43.0 | 330 | 74.4 | 330 | 90.9 | 330 | 92.8 | 330 | 95.8 |
| | | | | | 398 | 13.8 | 398 | 42.2 | 398 | 73.3 | 398 | 90.4 | 398 | 91.5 | 398 | 93.2 |
| | | | | | 466 | 11.6 | 466 | 41.7 | 466 | 75.2 | 466 | 91.9 | 466 | 90.6 | 466 | 91.5 |

**Table A3** continued

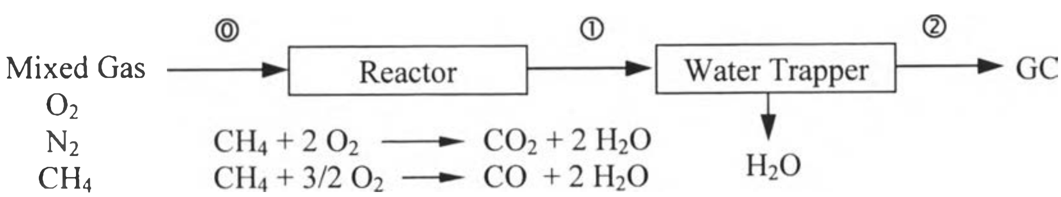
| No | Catalysts | Ratio of elements loading (%) | | | Screening Data | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | T = 400°C | | T = 450°C | | T = 500°C | | T = 550°C | | T = 600°C | | T = 800°C | |
| | | Pd | Pt | La | Time (min) | % Conv. | Time | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. |
| 16 | C16 | 0.60 | 0.40 | 0.00 | 66 | 5.46 | 66 | 40.5 | 66 | 82.3 | 66 | 95.7 | 66 | 93.9 | 66 | 96.8 |
| | | | | | 134 | 11.1 | 134 | 41.8 | 134 | 84.6 | 134 | 96.1 | 134 | 94.3 | 134 | 89.2 |
| | | | | | 202 | 11.0 | 202 | 47.8 | 202 | 89.2 | 202 | 96.4 | 202 | 93.9 | 202 | 88.1 |
| | | | | | 270 | 12.3 | 270 | 46.3 | 270 | 90.8 | 270 | 94.6 | 270 | 93.8 | 270 | 87.7 |
| | | | | | 338 | 12.3 | 338 | 48.5 | 338 | 90.4 | 338 | 94.4 | 338 | 93.8 | 338 | 87.1 |
| | | | | | 406 | 13.6 | 406 | 49.2 | 406 | 85.6 | 406 | 96.0 | 406 | 94.0 | 406 | 87.9 |
| | | | | | 474 | 10.5 | 474 | 52.1 | 474 | 82.2 | 474 | 96.8 | 474 | 93.4 | 474 | 85.5 |
| 17 | C17 | 0.60 | 0.20 | 0.20 | 66 | 23.2 | 66 | 43.3 | 66 | 73.5 | 66 | 77.4 | 66 | 96.9 | 66 | 96.0 |
| | | | | | 134 | 23.0 | 134 | 45.7 | 134 | 76.4 | 134 | 78.2 | 134 | 97.0 | 134 | 96.1 |
| | | | | | 202 | 21.8 | 202 | 47.6 | 202 | 77.7 | 202 | 76.9 | 202 | 96.9 | 202 | 94.6 |
| | | | | | 270 | 22.0 | 270 | 49.5 | 270 | 78.2 | 270 | 74.8 | 270 | 96.0 | 270 | 91.7 |
| | | | | | 338 | 23.4 | 338 | 48.9 | 338 | 77.7 | 338 | 74.4 | 338 | 96.7 | 338 | 89.3 |
| | | | | | 406 | 23.6 | 406 | 49.4 | 406 | 78.5 | 406 | 74.1 | 406 | 90.7 | 406 | 88.3 |
| | | | | | 474 | 23.9 | 474 | 49.1 | 474 | 78.4 | 474 | 74.1 | 474 | 90.0 | 474 | 86.9 |
| 18 | C18 | 0.60 | 0.00 | 0.40 | 41 | 17.4 | 41 | 40.8 | 41 | 61.0 | 41 | 88.0 | 41 | 99.6 | 41 | 100 |
| | | | | | 109 | 15.5 | 109 | 38.5 | 109 | 55.9 | 109 | 85.0 | 109 | 98.2 | 109 | 100 |
| | | | | | 177 | 21.6 | 177 | 36.8 | 177 | 53.8 | 177 | 84.1 | 177 | 98.2 | 177 | 100 |
| | | | | | 245 | 15.4 | 245 | 35.7 | 245 | 50.4 | 245 | 82.8 | 245 | 97.6 | 245 | 95.4 |
| | | | | | 313 | 14.4 | 313 | 30.7 | 313 | 50.1 | 313 | 81.8 | 313 | 97.3 | 313 | 96.4 |
| | | | | | 381 | 14.5 | 381 | 25.9 | 381 | 46.0 | 381 | 81.1 | 381 | 96.8 | 381 | 98.7 |
| | | | | | 449 | 15.3 | 449 | 25.7 | 449 | 47.3 | 449 | 80.5 | 449 | 96.3 | 449 | 100 |
| 19 | C19 | 0.80 | 0.20 | 0.00 | 75 | 26.6 | 75 | 56.0 | 75 | 84.1 | 75 | 89.9 | 75 | 98.2 | 75 | 90.0 |
| | | | | | 143 | 26.0 | 143 | 54.6 | 143 | 83.5 | 143 | 89.7 | 143 | 97.7 | 143 | 91.8 |
| | | | | | 211 | 24.3 | 211 | 56.9 | 211 | 82.3 | 211 | 89.1 | 211 | 97.3 | 211 | 90.4 |
| | | | | | 279 | 24.8 | 279 | 57.9 | 279 | 81.7 | 279 | 88.4 | 279 | 97.2 | 279 | 93.4 |
| | | | | | 347 | 25.6 | 347 | 58.0 | 347 | 81.7 | 347 | 87.0 | 347 | 96.7 | 347 | 90.3 |
| | | | | | 415 | 26.6 | 415 | 58.4 | 415 | 80.1 | 415 | 86.6 | 415 | 96.3 | 415 | 88.0 |
| | | | | | 483 | 26.3 | 483 | 58.0 | 483 | 79.9 | 483 | 86.0 | 483 | 96.3 | 483 | 87.5 |
| 20 | C20 | 0.80 | 0.00 | 0.20 | 49 | 27.8 | 49 | 52.2 | 49 | 76.4 | 49 | 97.0 | 49 | 97.8 | 49 | 80.5 |
| | | | | | 117 | 25.3 | 117 | 48.9 | 117 | 69.8 | 117 | 95.3 | 117 | 96.2 | 117 | 80.9 |
| | | | | | 185 | 23.4 | 185 | 46.1 | 185 | 65.5 | 185 | 94.3 | 185 | 94.6 | 185 | 80.6 |
| | | | | | 253 | 23.2 | 253 | 45.7 | 253 | 62.3 | 253 | 92.5 | 253 | 93.7 | 253 | 77.0 |
| | | | | | 321 | 22.4 | 321 | 43.6 | 321 | 57.3 | 321 | 91.2 | 321 | 92.6 | 321 | 75.8 |
| | | | | | 389 | 22.5 | 389 | 48.6 | 389 | 50.3 | 389 | 90.3 | 389 | 91.5 | 389 | 77.2 |
| | | | | | 457 | 20.9 | 457 | 49.0 | 457 | 53.7 | 457 | 89.4 | 457 | 90.8 | 457 | 76.6 |

**Table A3** continued

| No | Catalysts | Ratio of elements loading (%) | | | Screening Data | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | T = 400°C | | T = 450°C | | T = 500°C | | T = 550°C | | T = 600°C | | T = 800°C | |
| | | Pd | Pt | La | Time (min) | % Conv. | Time | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. | Time (min) | % Conv. |
| 21 | C21 | 1.00 | 0.00 | 0.00 | 58 | 42.1 | 75 | 38.6 | 75 | 70.0 | 75 | 95.7 | 58 | 100 | 58 | 100 |
| | | | | | 126 | 37.9 | 143 | 34.1 | 143 | 63.5 | 143 | 94.3 | 126 | 99.4 | 126 | 100 |
| | | | | | 194 | 36.2 | 211 | 32.3 | 211 | 59.6 | 211 | 92.4 | 194 | 98.7 | 194 | 100 |
| | | | | | 262 | 35.1 | 279 | 32.2 | 279 | 56.1 | 279 | 91.7 | 262 | 98.3 | 262 | 99.1 |
| | | | | | 330 | 33.7 | 347 | 49.9 | 347 | 59.0 | 347 | 90.0 | 330 | 97.8 | 330 | 99.0 |
| | | | | | 398 | 33.0 | 415 | 60.5 | 415 | 58.8 | 415 | 88.9 | 398 | 97.6 | 398 | 100 |
| | | | | | 466 | 32.3 | 483 | 60.7 | 483 | 56.8 | 483 | 88.7 | 466 | 97.0 | 466 | 100 |
| 22 | C22 | Washcoated Monolith | | | 66 | 0.00 | 75 | 0.00 | 75 | 0.00 | 75 | 0.00 | 66 | 0.00 | 66 | 97.9 |
| | | | | | 134 | 0.00 | 143 | 0.00 | 143 | 0.00 | 143 | 0.00 | 134 | 0.00 | 134 | 98.1 |
| | | | | | 202 | 0.00 | 211 | 0.00 | 211 | 0.00 | 211 | 0.00 | 202 | 0.00 | 202 | 98.7 |
| | | | | | 270 | 0.00 | 279 | 0.00 | 279 | 0.00 | 279 | 0.00 | 270 | 0.00 | 270 | 99.2 |
| | | | | | 338 | 0.00 | 347 | 0.00 | 347 | 0.00 | 347 | 0.00 | 338 | 0.00 | 338 | 98.9 |
| | | | | | 406 | 0.00 | 415 | 0.00 | 415 | 0.00 | 415 | 0.00 | 406 | 0.00 | 406 | 98.5 |
| | | | | | 474 | 0.00 | 483 | 0.00 | 483 | 0.00 | 483 | 0.00 | 474 | 0.00 | 474 | 98.9 |
| 23 | C23 | Only quartz wool | | | 75 | 0.00 | 75 | 0.00 | 75 | 0.00 | 75 | 0.00 | 75 | 0.00 | 75 | 22.6 |
| | | | | | 143 | 0.00 | 143 | 0.00 | 143 | 0.00 | 143 | 0.00 | 143 | 0.00 | 143 | 28.9 |
| | | | | | 211 | 0.00 | 211 | 0.00 | 211 | 0.00 | 211 | 0.00 | 211 | 0.00 | 211 | 21.1 |
| | | | | | 279 | 0.00 | 279 | 0.00 | 279 | 0.00 | 279 | 0.00 | 279 | 0.00 | 279 | 19.0 |
| | | | | | 347 | 0.00 | 347 | 0.00 | 347 | 0.00 | 347 | 0.00 | 347 | 0.00 | 347 | 18.1 |
| | | | | | 415 | 0.00 | 415 | 0.00 | 415 | 0.00 | 415 | 0.00 | 415 | 0.00 | 415 | 20.4 |
| | | | | | 483 | 0.00 | 483 | 0.00 | 483 | 0.00 | 483 | 0.00 | 483 | 0.00 | 483 | 12.3 |

# Appendix B

**System schematic:**




**Streams details:**

| | | | | |
|---|---|---|---|---|
| ♦ Stream #0: | Volumetric flow rate: | | $F_0$ | $cm^3$/min |
| | Compositions: | - Methane fraction: | $y_{Me,0}$ | |
| | | - Oxygen fraction: | $y_{O2,0}$ | |
| | | - Nitrogen fraction: | $y_{N2,0}$ | |
| ♦ Stream #1: | Volumetric flow rate: | | $F_1$ | $cm^3$/min |
| | Compositions: | - Methane fraction: | $y_{Me,1}$ | |
| | | - Oxygen fraction: | $y_{O2,1}$ | |
| | | - Nitrogen fraction: | $y_{N2,1}$ | |
| | | - Carbon dioxide: | $y_{CO2,1}$ | |
| | | - Carbon monoxide: | $y_{CO,1}$ | |
| | | - Water: | $y_{H2O,1}$ | |
| ♦ Stream #2: | Volumetric flow rate: | | $F_2$ | $cm^3$/min |
| | Compositions: | - Methane fraction: | $y_{Me,2}$ | |
| | | - Oxygen fraction: | $y_{O2,2}$ | |
| | | - Nitrogen fraction: | $y_{N2,2}$ | |
| | | - Carbon dioxide: | $y_{CO2,2}$ | |
| | | - Carbon monoxide: | $y_{CO,2}$ | |

**Assumptions:**

- no $NO_X$ formation during the combustion since the combustion is occurred below 1500°C

- the analyzed compositions received from GC are the compositions of the stream #2

**Conversion:**

$$\text{Conversion} = \frac{\text{Initial methane fed} - \text{Residual methane}}{\text{Initial methane fed}} \times 100\%$$

$$= \frac{\frac{P_0F_0}{RT_0}\cdot y_{Me,0} - \frac{P_1F_1}{RT_1}\cdot y_{Me,1}}{\frac{P_0F_0}{RT_0}\cdot y_{Me,0}} \times 100\%$$

**Assume**: Pressure remains constant along the combustion reaction, thus

$$\text{Conversion} = \frac{\frac{F_0}{T_0}\cdot y_{Me,0} - \frac{F_1}{T_1}\cdot y_{Me,1}}{\frac{F_0}{T_0}\cdot y_{Me,0}} \times 100\%$$

Carbon balanced around the reactor

$$\frac{P_0F_0}{RT_0}\cdot y_{Me,0} = \frac{P_1F_1}{RT_1}(y_{Me,1} + y_{CO2,1} + y_{CO,1})$$

**Assume**: Pressure remains constant along the combustion reaction, so

$$\frac{F_0}{T_0}\cdot y_{Me,0} = \frac{F_1}{T_1}(y_{Me,1} + y_{CO2,1} + y_{CO,1})$$

Therefore, the conversion can be written in the new form of evaluated data as below,

$$\text{Conversion} = \frac{\frac{F_1}{T_1}(y_{Me,1} + y_{CO2,1} + y_{CO,1}) - \frac{F_1}{T_1} \cdot y_{Me,1}}{\frac{F_1}{T_1}(y_{Me,1} + y_{CO2,1} + y_{CO,1})} \times 100\%$$

But, the evaluated compositions from GC are the compositions of stream #2. Therefore, carbon and methane balances are needed in order to convert these compositions to the flue composition from the reactor.

Carbon balanced around the water trapper

$$\frac{F_2}{T_2}(y_{Me,2} + y_{CO2,2} + y_{CO,2}) = \frac{F_1}{T_1}(y_{Me,1} + y_{CO2,1} + y_{CO,1})$$

Methane Balanced around Water Trapper:

$$\frac{F_2}{T_2} \cdot y_{Me,2} = \frac{F_1}{T_1} \cdot y_{Me,1}$$

Thus,

$$\text{Conversion} = \frac{\frac{F_2}{T_2}(y_{Me,2} + y_{CO2,2} + y_{CO,2}) - \frac{F_2}{T_2} \cdot y_{Me,2}}{\frac{F_2}{T_2}(y_{Me,2} + y_{CO2,2} + y_{CO,2})} \times 100\%$$

$$= \frac{y_{CO2,2} + y_{CO,2}}{y_{Me,2} + y_{CO2,2} + y_{CO,2}} \times 100\%$$

**Selectivity:**

$$\text{Selectivity}_{CO_2} = \frac{\text{Mole of } CO_2 \text{ generated}}{\text{Mole of } CH_4 \text{ consumed}}$$

$$= \frac{\frac{P_1F_1}{RT_1}\cdot y_{CO2,1}}{\frac{P_0F_0}{RT_0}\cdot y_{Me,0} - \frac{P_1F_1}{RT_1}\cdot y_{Me,1}}$$ , and

$$\text{Selectivity}_{CO} = \frac{\frac{P_1F_1}{RT_1}\cdot y_{CO,1}}{\frac{P_0F_0}{RT_0}\cdot y_{Me,0} - \frac{P_1F_1}{RT_1}\cdot y_{Me,1}}$$

Thus,

$$\%\text{Selectivity}_{CO_2/CO} = \frac{\text{Selectivity to } CO_2}{\text{Selectivity to CO} + \text{Selectivity to } CO_2}\times 100\%$$

$$= \frac{y_{CO2,1}}{y_{CO,1} + y_{CO2,1}}\times 100\%$$

From CO and $CO_2$ balanced around the water trapper, we can rewrite the above equation as,

$$\text{Selectivity} = \frac{y_{CO2,2}}{y_{CO,2} + y_{CO2,2}}\times 100\%$$

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