REFERENCES

1. Bosch, H., and Janssen, F. *Catal. Today.* **2** (1988): 369.
2. Li, Y., and Armor, J.N. *Appl. Catal. B.* **1** (1992): L31-L40.
3. Li, Y., and Armor, J.N. *Appl. Catal. B.* **2** (1993): 239-256.
4. Bell, A.T. *Catal. Today.* **38** (1997): 151-156.
5. Hamada, H., Kintaichi, Y., Sasaki, M., Ito, T. and Tabata, M. *Appl. Catal.* **64** (1990): L1-L4.
6. Hamada, H., Kintaichi, Y., Sasaki, M., Ito, T. and Tabata, M. *Appl. Catal.* **70** (1991): L15-L20.
7. Sato, S.S., Hirabay, H., Yahiro, H., Mizuno, N., and Iwamoto, M. *Catal. Lett.* **12** (1992): 193-200.
8. Harrison, B.,Wyatt, M., and Gough, K.G. *Catalysis, Royal Society of Chemistry.* London, **5** (1982): 127-171.
9. Kharas, K.C.C., Robota, H.J., and Liu, D.J. *Appl. Catal. B.* **2** (1993): 225-238.
10. Tanabe, T., Iijima, T., Koiwai, A., Mizuno, J., Yokota, K., and Isogai, A. *Appl. Catal. B.* **6** (1995): 145.
11. Burch, R. *Abstracts of Second EU-Japan Workshop on Fundamental Aspects of Catalysts for Clean Combustion.* 30-31, October, 1995, Kyoto, Japan: p23.
12. Inui, T. *ACS Symp. Series.* **398** (1989): 479-492.
13. Li, Y., and Armor, J.N. *US Patent 5 149 512* (1992).
14. Li, Y., and Armor, J.N. *Appl. Catal. B.* **1** (1992): L21-L29.
15. Li, Y., and Armor, J.N. *Appl. Catal. B.* **3** (1993): L1-L11.
16. Li, Y., and Armor, J.N. *Appl. Catal. B.* **3** (1993): 55-60.

17. Li, Y., Battavio, P.J., and Armor, J.N. *J. Catal.* **142** (1993): 561-571.

18. Inui, T., Iwamoto, S., Kojo, S., Shimizu, S., and Hirabayashi, T. *Catal. Today.* **22** (1994): 41-57.

19. Inui, T., Iwamoto, S., Shimizu, S., and Hirabayashi, T. *Trans. Mat. Res. Soc. Jpn.* **18A** (1994): 397-400.

20. Inui, T., Iwamoto, S., and Hirabayashi, T. *Catal. Lett.* **27** (1994): 267-272.

21. Inui, T., Iwamoto, S., and Shimizu, S. *Stud. Surf. Sci. Catal.* **84** (1994): 1523-1530.

22. Witzel, F., Sill, G.A., and Hall, W.K. *Stud. Surf. Sci. Catal.* **84** (1994): 1531-1536.

23. Burch, R., and Scire, S. *Appl. Catal. B.* **3** (1994): 295-318.

24. Farris, Y., and Armor, J.N. *Appl. Catal. B.* **4** (1994): L11-L17.

25. Li, Y., and Armor, J.N. *Appl. Catal. B.* **5** (1995): L257-L270.

26. Petunchi, J., Vassallo, J., and Miro, E. *Appl. Catal. B.* **7** (1995): 65-78.

27. Cant, N.W., Cowan, A.D., and Dumpelmann, R. *J. Catal.* **151** (1995): 356-363.

28. Hall, W.K., d'Itri, J.L., Sill, G., and Lukyanov, D.B. *J. Catal.* **153** (1995): 265-274.

29. Kapteijn, F., Mul, G., Marban, G., Rodriguez-Mirasol, J., and Moulijn, J.A. *Stud. Surf. Sci. Catal.* **101** (1996): 641-650.

30. Hall, W.K., d'Itri, J.L., Sill, G., and Lukyanov, D.B. *Stud. Surf. Sci. Catal.* **101** (1996): 651-660.

31. Aylor, A.W., Lobree, L.J., Reimer, J.A., and Bell, A.T. *Stud. Surf. Sci. Catal.* **101** (1996): 661-670.

32. Campa, M.C., Rossi, S., Ferraris, G., and Indovina, V. *Appl. Catal. B.* **8** (1996): 315-331.

33. Stakheev, A.Y., Lee, C.W., Park, S.J., and Chong, P.J. *Appl. Catal. B.* **9** (1996): 65-76.

34. Sachtler, W.M.H., Adelman, B.J., Beutel, T., and Lei, G.D. *J. Catal.* **158** (1996): 327-335.

35. Halasz, I., Brenner, A., Ng, K.Y.S., and Hou, Y. *J. Catal.* **161** (1996): 359-372.

36. Lukyanov, D.B., Lombardo, E.A., Hall, W.K., Sill, G.A., and d'Itri, J.L. *J. Catal.* **163** (1996): 447-456.

37. Correa, C.M., Villa, A.L., and Zapata, M. *Catal. Lett.* **38** (1996): 27-32.

38. Stakheev, A.Y., Chong, P.J., Lee, C.W., and Park, S.J. *Catal. Lett.* **38** (1996): 271-278.

39. Jentys, A., Kleestorfer, K., and Vinek, H. *Catal. Lett.* **39** (1996): 119-123.

40. Tabata, T., Kokitsu, M., Ohtsuka, H., Okada, O., Sabatino, L.M.F., and Bellussi, G. *Catal. Today.* **27** (1996): 91-98.

41. Inui, T., Kim, J., and Takeguchi, T. *Zeolites.* **17** (1996): 354-360.

42. Jentys, A., Lugstein, A., and Vinek, H. *Zeolites.* **18** (1997): 391-397.

43. Woolery, G.L., Kuehl, G.H., Timken, H.C., Chester, A.W. and Vartuli, J.C. *Zeolites.* **19** (1997): 288-296.

44. Satsuma, A., Iwase, M., Shichi, T., Hattori, T., and Murakami, Y. *Stud. Surf. Sci. Catal.* **105** (1997): 1533-1540.

45. Budi, P., Curry-Hyde, E., and Howe, R.F. *Stud. Surf. Sci. Catal.* **105** (1997): 1549-1556.

46. Stakheev, A.Y., Lee, C.W, Park, S.J., and Chong, P.J. *Stud. Surf. Sci. Catal.* **105** (1997): 1579-1586.

47. Inui, T., Iwamoto, S., Kon, S., and Yoshida, S. *Stud. Surf. Sci. Catal.* **105** (1997): 1587-1592.

48. Chang, Y., and McCarty, J.G. *J. Catal.* **165** (1997): 1-11.

49. Lobree, L.J., Aylor, A.W., Reimer, J.A., and Bell, A.T. *J. Catal.* **169** (1997): 188-193.

50. Ying, J.Y., Sun, T., and Fokema, M.D. *Catal. Today.* **33** (1997): 251-261.

51. Inui, T., Iwamoto, S., Saigo, K., and Yoshida, S. *Catal. Today.* **35** (1997): 171-175.

52. Inui, T., Iwamoto, S., Kon, S., Sakimon, T., and Kagawa, K. *Catal. Today.* **38** (1997): 169-174.

53. Howe, R.F., and Budi, P. *Catal. Today.* **38** (1997): 175-179.

54. Miller, J.T., Glusker, E., Peddi, R., Zheng, T., and Regalbuto, J.R. *Catal. Lett.* **51** (1998): 15-22.

55. Inui, T., Kagawa, K., Kon, S., and Iwamoto, S. *Catal. Lett.* **52** (1998): 139-144.

56. Inui, T., Kagawa, K., Ichikawa, Y., and Iwamoto, S. *Catal. Lett.* **52** (1998): 145-149.

57. Lombardo, E.A., Hall, W.K., Sill, G.A., and d'Itri, J.L. *J. Catal.* **173** (1998): 440-449.

58. Cant, N.W., Cowan, A.D., Haynes, B.S., and Nelson, P.F. *J. Catal.* **176** (1998): 329-343.

59. Ying, J.Y., Sun, T., and Trudean, M.L. *J. Phys. Chem.* **100** (1996): 13662-13666.

60. Amiridis, M.D., Zhang, T., and Farrauto, R.J. *Appl. Catal. B.* **10** (1996): 203-227.

61. Inui, T., Kojo, S., Shibata, M., Yoshida, T., and Iwamoto, S. *Stud. Surf. Sci. Catal.* **69** (1991): 355.

62. Iwamoto, M., Yahiro, H., Yoshioka, T., and Mizuno, N. *Catal. Lett.* (1990): 1967.

63. Inui, T., Iwamoto, S., Kojo, S., Shimizu, S., and Hirabayashi, T. *Catal. Today.* **22** (1994): 41.

64. Inui, T. *Stud. Surf. Sci. Catal.* **105** (1997): 1441-1468.

65. Derouane, E, Topsøe, N., and Pedersen, K. *J. Catal.* **70** (1981): 41-52.

66. Connerton, J., Joyner, R.W., and Padley, M.B. *J. Chem. Soc. Faraday Trans.* **91** (1995): 1841-1844.

67. Koningsveld, H., JAnsen, J.C., and Bekkum, H. *Zeolites.* **10** (1990): 235-242.

68. Treacy, M.M.J., Higgins, J.B., and Ballmoos, R. *Zeolites.* **16** (1996): 525.

69. Rosynek, M.P., and Polansky, C.A. *Appl. Catal.* **73** (1991): 97-112.

70. Lapidus, A.,Krylova, A., Kazanskii, V., Borovkov, V., Zaitsev, A., Rathousky, J., Zukal, A.,and Jancalkava, M. *Appl. Catal.* **73** (1991): 65-82.

APPENDIX

APPENDIX A

SAMPLE OF CALCULATIONS

A-1 Calculation of Si/Metal Atomic Ratio for ZSM-5 and Co.Al-silicate

The calculation is based on weight of sodium silicate ($Na_2O.SiO_2.H_2O$) in B1 and B2 solutions.

M.W. of Si	= 28
M.W. of SiO_2	= 60
Weight percent of SiO_2 in Sodium Silicate	= 28.5
M.W. of Al	= 27
M.W. of $AlCl_3$	= 133
Weight percent purity of $AlCl_3$	= 97
M.W. of Co	= 59
M.W. of $Co(CH_3COO)_2.4H_2O$	= 249
Weight percent purity of $Cu(NO_3)_2.3H_2O$	= 99.5

For example, to prepare ZSM-5 at Si/Al atomic ratio of 50. Using Sodium Silicate 69 g with 45 g of water in B1 and B2 solution.

Mole of Si used

$$= \frac{\text{wt. (\% purity)}}{100} \times \frac{\text{(M.W. of Si)}}{\text{(M.W. of } SiO_2)} \qquad \text{(A-1.1)}$$

$$= 69 \times (28.5/100) \times (28/60)$$

$= 0.3273$

Si/Al atomic ratio = 50

mole of Al required $= 0.3273/50 = 6.5458 \times 10^{-3}$ mole

amount of $AlCl_3$ $= 6.5458 \times 10^{-3} \times 133 \times (100/97)$

$= 0.8998$ g

This is the amount of $AlCl_3$ used in A1 and A2 solutions

A-2 Calculation of Metal Ion-exchanged ZSM-5 and Bimetallosilicate

Co ion-exchange

Determine the amount of Co into catalyst = 0.5 wt.%

The catalyst use = x g

So that: from the equation

$$Co/(x + Co) = 0.5/100$$

$$100 \times Co = 0.5 \times (x + Co)$$

$$(100 - 0.5) \times Co = 0.5 \times x$$

thus $Co = 0.5 \times x / (100 - 0.5)$ g

use $Co(CH_3COO)_2.4H_2O$ (M.W. 249, purity 99.5%)

weight of $Co(CH_3COO)_2.4H_2O$ $= [0.5 \times x /(100 - 0.5)] \times [(249/59) \times (99.5/100)]$

A-3 Calculation of Reaction Flow Rate

The catalyst used = 0.50 g

Packed catalyst into quartz reactor (diameter = 0.6 cm)

Determine the average high of catalyst bed = x cm

So that, volume of catalyst bed = $\pi \times (0.3)^2 \times x$ ml-catalyst

Used GHSV (Gas Hourly Space Velocity) = 4,000 h^{-1}

$$GHSV = \frac{\text{Volumetric flow rate}}{\text{Volume of Catalyst}} = 4{,}000\ h^{-1}$$

Volumetirc flow rate^t = 4,000 × Volume of Catalyst

= $4{,}000 \times \pi (0.3)^2 \times x$ ml/h

= $4{,}000 \times \pi (0.3)^2 \times x/60$ ml/min

at STP : Volumetric flow rate = volume flow rate^t × (273.15/273.25+t)

where : t = room temperature, °C

A-4 Calculation of NO and CH_4 conversion

The effluent gas was analyzed by gas chromatography, the NO reduction activity was evaluated in terms of the conversion of NO into N_2.

$$\text{NO conversion (\%)} = (2[N_2]_{out}/[NO]_{in}) \times 100$$

The CH_4 oxidation activity was evaluated in terms of the conversion of CH_4 into CO and CO_2.

$$CH_4 \text{ conversion (\%)} = \frac{([CH_4]_{in} - [CH_4]_{out}}{[CH_4]_{in}} \times 100$$

A-5 Calculation of Active Sites

Calculation of active sites of the catalyst by CO adsorption at room temperature has the procedure as follow :

Let the weight of catalyst used = W g

Height of CO peak after adsorption = A unit

Height of 40 μl standard CO peak = B unit

Amount of CO adsorbed on catalyst = B - A unit

Volume of CO adsorbed on catalyst = $40[(B - A)/B]$ μl

Volume of gas 1 mole at 30 °C = 24.86×10^6 μl

Mole of CO adsorbed on catalyst = $40[(B - A)/B]/(24.86 \times 10^6)$ μl

Molecules of CO adsorbed on catalyst

= $40(6.02 \times 10^{23})[(B - A)/B]/(24.86 \times 10^6)$ molecules

= $9.68 \times 10^{17}[(B - A)/B]$ molecules

Active sites = $9.68 \times 10^{17}[(B - A)/B]/W$ molecules of CO/g

APPENDIX B

AIR QUALITY STANDARDS

1) Emission Standards

(A) Industrial Emission Standards

No.	Substance	Sources	Standard Values
1	Particulate	Boiler	
		- Heavy oil as fuel	300 mg/Nm^3
		- Coal as Fuel	400 mg/Nm^3
		- Other fuel	400 mg/Nm^3
		Steel / Aluminum manufacturing	300 mg/Nm^3
		Other source	400 mg/Nm^3
2.	Antimony	Any source	20 mg/Nm^3
3.	Arsenic	Any source	20 mg/Nm^3
4.	Copper	Furnace or smelter	30 mg/Nm^3
5.	Lead	Any source	30 mg/Nm^3
6.	Chlorine	Any source	30 mg/Nm^3
7.	Hydrogen chloride	Any source	200 mg/Nm^3
8.	Mercury	Any source	3 mg/Nm^3
9.	Carbon monoxide	Any source	1,000 mg/Nm^3 or 870 ppm
10.	Sulfuric acid	Any source	100 mg/Nm^3 or 25 ppm
11.	Hydrogen sulphide	Any source	140 mg/Nm^3 or 100 ppm
12.	Sulfur dioxide	H_2SO_4 production	1,300 mg/Nm^3 or 500 ppm
13.	Oxides of nitrogen	Boiler	
	(as Nitrogen dioxide)	- Coal as fuel	940 mg/Nm^3 or 500 ppm
		- Other fuel	470 mg/Nm^3 or 250 ppm
14.	Xylene	Any source	870 mg/Nm^3 or 200 ppm
15.	Cresol	Any source	22 mg/Nm^3 or 5 ppm
16.	Sulfur dioxide	-Heavy oil as fuel	1,250 ppm

Source : 1-14 : Notification of the Ministry of Industry No. 2, B.E. 2536 (1993) , issued under Factory Act B.E. 2535 (1992) dated July 20 , B.E. 2536 (1993) published in the Royal Government Gazette. Vol. 109 . Part 108 , dated October 16 , B.E. 2536 (1993)

15 : Notification of the Ministry of Industry No. 2, B.E. 2536 (1993) , issued under Factory Act B.E. 2535 (1992) dated September 6 , B.E. 2538 (1995)

16 : Notification of the Ministry of Industry No. 2, B.E. 2536 (1993), issued under Factory Act B.E. 253 (1992) dated September 3 , B.E. 2539 (1996)

(B) Emission Standard for New Power Plants

No.	Pollutants	Type of Fuel		
		Coal	Oil	Gas
1.	Sulfur dioxide (SO_2) (ppm)			
	Power Plant Size > 500 MW	320	320	20
	300 - 500 MW	450	450	20
	< 300 MW	640	640	20
2.	Oxides of nitrogen (as NO_2) (ppm)	350	180	120
3.	Particulate (mg/m^3)	120	120	60

Remark : Reference Condition are 25 degree Celsius at 1 atm or 760 mm.Hg , excess air at 50 % or excess O_2 at 7%

Source : (1) Notification of the Ministry of Science , Technology and Environment ,dated December 25 , B.E. 2538 (1995)

(2) Notification of the Ministry of Industry No.2 , B.E. 2536 (1993) , issued under Factory Act B.E. 2535 (1992) , dated January 11 , B. E .2540 (1997) published in the Royal Government Gazette , Vol . 144 , Part 108 , dated January 21 , B.E. 2540 (1997)

(C) Emission Standards for Existing Power Plant

No.	Pollutants	Type of Fuel		
		Coal	Oil	Gas
1	Sulfur dioxide (SO_2) (ppm)	1,000	1,000	20
2	Oxides of nitrogen (as NO_2) (ppm)	400	200	200
3	Particulate (mg/m^3)	320	240	60

Remark : Reference Condition are 25 degree Celsius at 1 atm or 760 mm. Hg , excess air at 50 % or excess O_2 at 7%

Source : Notification of the Ministry of Industry No.2 , B.E. 2536 (1993) , issued under Factory Act B.E. 2535 (1992) , dated January 11 , B. E . 2540 (1997) published in the Royal Government Gazette , Vol . 114 , Part 108 , dated January 21 , B.E. 2540 (1997)

Standard Analytical Methods

1. Sulfur dioxide (SO_2)	Use U.S.EPA Method 6 U.S.EPA Method 8 or other methods approved by the pollution Control Department (PCD)
2. Oxides of nitrogen (as NO_2)	Use U.S.EPA Method 7 or other methods approved by the PCD
3. Particulate (mg/m^3)	Use U.S.EPA Method 5 or other methods approved by the PCD

Emission Standards for power Plants with Mixed Fuel

In case of a power plant utilizing mixed fuel (mixture of various types of fuels) in each generation unit , emission standard values must be calculated based upon the ration of each type of fuel as follows :

Emission Standards = AX + BY + CZ

When
A = Emission Standards for utilizing only coal as fuel
B = Emission Standards for utilizing only oil as fuel
C = Emission Standards for utilizing only gas as fuel
X = Ration of Heat Input from utilizing only coal as fuel
Y = Ration of Heat Input from utilizing only oil as fuel
Z = Ration of Heat Input from utilizing only gas as fuel

(D) Motor Vehicle Emission Standards

No.	Parameters	Emission Standards		Measurement Methods
		Measurement System	Maximum Permissible Limit	
1	Black Smoke (Diesel Vehicle)	Bosch	50 %	1.At rapid acceleration under no-load condition to maximum rotating speed. Use maximum value of the two measurements.
		Hartridge Bosch	52 % 40 %	2.On test bench , running with full-load at 60 % of the maximum rotating speed. Use average value of the two measurements.
2	CO (Gasoline Vehicle)	Non-Dispersive infrared Detection	6 %	1. Idling 2. Average value of the two measurements.
3	HC (Motorcycle)	Non-Dispersive infrared Detection	10,000 ppm	1. Idling 2. Average value of the two measurements.

Source : 1) Standards for Diesel and Gasoline Vehicles : Notification of Ministry of Science , Technology and Environment, dated August 28, B.E. 2535 (1992) , published in the Royal Government Gazette . Vol. 109 , Part 119 , dated September 17 , B.E. 2535 (1992)

2) Standards for Motorcycle : Notification of Ministry of Science , Technology and Environment , dated March 17 , B.E. 2536 (1993) , published in the Royal Government Gazette . Vol. 110 Part 38 , date March 31, B.E. 2536 (1993)

2) Ambient Air Quality Standards

Pollutants	1-hr average value		8-hr average value		24-hr average value		1-month average value		1-yr. Average value		Measurement Mothods
	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	
Carbon Monoxide (CO)	34.2	30	10.26	9	-	-	-	-	-	-	Non-Dispersive Infrared Detection
Nitrogen Dioxide (NO_2)	0.32	0.17	-	-	-	-	-	-	-	-	Chemilumi-nescence
Sulfur Dioxide (SO_2)	0.78	0.30	-	-	0.30	0.12	-	-	0.10*	0.04	Pararosaniline
Suspended Particulate Matter (SPM)	-	-	-	-	0.33	-	-	-	0.10*	-	Gravimetric - High Volume
Particulate Matter < 10 microns (PM - 10)	-	-	-	-	0.12	-	-	-	0.05*	-	Gravimetric - High Volume
Photochemica l Oxidant (O_3)	0.20	0.10	-	-	-	-	-	-	-	-	Chemilumi-nescence
Lead (Pb)	-	-	-	-	-	-	1.5*	-	-	-	Atomic Absorption Spectrometer

Remark : 1) * : Geometric mean value
2) Concentration of each gas in ambient is based on 1 atm. And 25 C
Source : Notification of the National Environment Board , No. 10 , B.E. 2538 (1995) , dated April 17 , B.E. 2538 (1995)

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