

## REFERENCES

- Chairat Katsuda. Oxidation reaction of alcohols over TS-1 catalyst. *Master's thesis*, Department of Chemical engineering, Graduated school, Chulalongkorn University, 2004.
- Guo, X., Wang, R., Wang, X., and Hao, J. Effects of preparation method and precipitator on the propylene epoxidation over Ag/TS-1 in the gas phase. *Catalysis Today* **93-95** (2004): 211-216.
- Huybrechts, D. R. C., Vaesen, I., Li, H. X. and Jacobs, P. A. Factors influencing the catalytic activity of titanium silicalites in selective oxidations. *Catal. Lett.* **8** (1991): 237-244.
- Julbe, A., Farrusseng, D., Jalibert J.C., Mirodatos, C. and Guizard, C. Characteristic and performance in the oxidative dehydrogenation of propane of MFI and V-MFI zeolite membranes. *Catalysis Today* **56** (2000): 199-209.
- Laufer, W., and Hoelderich, W. F. Direct oxidation of propylene and other olefins on precious metal containing Ti-catalysts. *Applied Catalysis* **213** (2001): 163-171.
- Li, L., Chen, J., Zhang, S., Guan, N., Wang, T., and Liu, S. Selective catalytic reduction of nitrogen oxides from exhaust of lean burn engine over in situ synthesized monolithic Cu-TS-1/cordierite. *Catalysis Today* **90** (2004): 207-213.
- Ma, X., Gong, J., Wang, S., He, F., Guo, H., Yang, X., and Xu, G. Characterization and reactivity of stannum modified titanium silicalite TS-1 catalysts for transesterification of dimethyl oxalate with phenol. *Journal of Molecular Catalysis* **237** (2005): 1-8.
- Matinez-Mendez, S., Henriquez, Y., Dominguez, O., D'Ornelas, L., and Krentzien, H. Catalytic properties of silica supported titanium, vanadium and niobium oxide nanoparticles towards the oxidation of saturated and unsaturated hydrocarbons. *Journal of Molecular Catalysis* **252** (2006): 226-234.
- Parvulescu, V., Anastasescu, C., and Su, B. L. Vanadium incorporated mesoporous silicates as catalysts for oxidation of alcohols and aromatics. *Journal of Molecular Catalysis* **198** (2003): 249-261.
- Perego, G., Bellussi, G., Corno, C., Taramasso, M., Buonomo, F. and Esposito, A. Titanium-silicalite: a novel derivative in the pentasil family. *Stud. Surf. Sci. Catal.* **28** (1986): 129-136.

- Pirutko, L. V., Uriarte, A. K., Chernyavsky, V. S., Kharitonov, A. S., and Panov, G. I. Preparation and catalytic study of metal modified TS-1 in the oxidation of benzene to phenol by  $N_2O$ . *Microporous and Mesoporous Materials* **48** (2001): 345-353.
- Schuster, W., Niederer, J. P. M., and Hoelderich, W. F. The gas phase oxidative dehydrogenation of propane over TS-1. *Applied Catalysis* **209** (2001): 131-143.
- Sooknoi, T., and Chitrannuwatkul, V. Ammoximation of cyclohexanone in acetic acid using titanium silicalite-1 catalyst: Activity and reaction pathway. *Journal of Molecular Catalysis* **236** (2005): 220-226.
- Sunphloi, R. Preparation of vanadium-titanium silicalite-1. *Master's thesis*, Department of Chemical engineering, Graduated school, Chulalongkorn University, 2005.
- Tavolaro, A., Tavolaro, P., and Drioli, E. Influence of synthesis parameters on vanadium-silicalite-1 crystal growth prepared with fluoride-containing media. *Journal of Crystal Growth* **289** (2006): 609-616.
- Taylor, B., Lauterbach, J., and Delgass, W. N. Gas-phase epoxidation of propylene over small gold ensembles on TS-1. *Applied Catalysis* **291** (2005): 188-198.
- Wang, Q., Mi, Z., Wang, Y., and Wang, L. Epoxidation of allyl chloride with molecular oxygen and 2-ethyl-anthrahydroquinone catalyzed by TS-1. *Journal of Molecular Catalysis* **229** (2005): 71-75.
- West, A. R., *Solid State Chemistry and its Applications*, New Delhi: Thomson Press (India), (1984): 41-42.
- Whittington, B.I. and Anderson, J.R. Vanadium-containing ZSM5 zeolite: Reaction between vanadyl trichloride and ZSM-5/silicate. *J. Phys. Chem.* **95** (1991): 3306-3310.
- Zhao, Q., Bao., X.H., Han, X.W., Liu, X.M., Tan, D.L., Lin, L.W., Guo, X.W., Li, G. and Wang, X.S. Studies on the crystallization process of titanium silicalite-1 (TS-1) synthesized using tetrapropylammonium bromide as a template. *Material Chemistry and Physics* **66** (2000): 41-50.
- Zhao, X., and Wang, X. Oxidative dehydrogenation of ethane to ethylene by carbon dioxide over Cr/TS-1 catalysts. *Catalysis Communication* **7** (2006): 633-638.

## APPENDICES

## APPENDIX A

### CALCULATION FOR CATALYST PREPARATION

#### 1. Mole of Si used for catalyst preparation

The calculations base on weight of sodium silicate ( $\text{Na}_2\text{O} \cdot \text{SiO}_2 \cdot \text{H}_2\text{O}$ ) in B1 and B2 solution.

Molecular weight of Si	=	28.0855
Molecular weight of $\text{SiO}_2$	=	60.0843
Weight percent of $\text{SiO}_2$ in sodium silicate	=	28.5
Molecular weight of $\text{Na}_2\text{O} \cdot \text{SiO}_2 \cdot \text{H}_2\text{O}$	=	202.04218

Using sodium silicate 69 g with 45 ml of water as B1 and B2 solution.

Find the amount of  $\text{SiO}_2$  in B1 and B2 solution

$$\begin{aligned} \text{Sodium silicate } 100 \text{ g contain } \text{SiO}_2 & 28.5 \text{ g} \\ \text{Sodium silicate } 69 \text{ g contain } \text{SiO}_2 & \frac{28.5}{100} \times 69 = 19.665 \text{ g} \end{aligned}$$

Find the amount of Si

$$\begin{aligned} \text{SiO}_2 \text{ } 60.0843 \text{ g contain Si } & 28.0855 \text{ g} \\ \text{SiO}_2 \text{ } 19.665 \text{ g contain Si } & 100 \text{ g } \frac{28.0855}{60.0843} \times 19.665 = 9.192 \text{ g} \\ & = \frac{9.192}{28.0855} = 0.3273 \text{ mole} \end{aligned}$$

#### 2. The amount of $\text{Ti}[\text{O}(\text{CH}_2)_3\text{CH}_3]_4$ used

Molecular weight of Ti	=	47.88
Molecular weight of $\text{Ti}[\text{O}(\text{CH}_2)_3\text{CH}_3]_4$	=	340.36
Weight % purity of $\text{Ti}[\text{O}(\text{CH}_2)_3\text{CH}_3]_4$	=	97

Set Si/Ti = 50

$$\text{Mole of Ti[O(CH}_2\text{)}_3\text{CH}_3\text{]}_4 \text{ required} = \frac{0.3273}{50} = 6.546 \times 10^{-3} \text{ mole}$$

$$\begin{aligned} \text{Amount of Ti[O(CH}_2\text{)}_3\text{CH}_3\text{]}_4 &= (6.546 \times 10^{-3}) \times (340.36) \times (100/97) \\ &= 2.2970 \text{ g} \end{aligned}$$

### 3. The amount of VCl<sub>3</sub> used

$$\text{Molecular weight of V} = 50.942$$

$$\text{Molecular weight of VCl}_3 = 340.36$$

$$\text{Weight \% purity of VCl}_3 = 96$$

Set Si/V = 100

$$\text{Mole of V required} = \frac{0.3273}{100} = 3.273 \times 10^{-3} \text{ mole}$$

$$\text{Mole of VCl}_3 \text{ required} = 3.273 \times 10^{-3} \text{ mole}$$

$$\begin{aligned} \text{Amount of VCl}_3 &= (3.273 \times 10^{-3}) \times (157.30) \times (100/96) \\ &= 0.5363 \text{ g} \end{aligned}$$

### 4. The amount of VO(acac)<sub>2</sub> used

$$\text{Molecular weight of V} = 50.942$$

$$\text{Molecular weight of VO(acac)}_2 = 265.16$$

$$\text{Weight \% purity of VO(acac)}_2 = 97$$

Set Si/V = 100

$$\text{Mole of V required} = \frac{0.3273}{100} = 3.273 \times 10^{-3} \text{ mole}$$

$$\text{Mole of VO(acac)}_2 \text{ required} = 3.273 \times 10^{-3} \text{ mole}$$

$$\begin{aligned} \text{Amount of VO(acac)}_2 &= (3.273 \times 10^{-3}) \times (265.16) \times (100/97) \\ &= 0.8947 \text{ g} \end{aligned}$$



### 5. The amount of $V_2O_5$ used

$$\text{Molecular weight of V} = 50.942$$

$$\text{Molecular weight of } V_2O_5 = 181.88$$

$$\text{Weight \% purity of } V_2O_5 = 99$$

Set Si/V = 100

$$\text{Mole of V required} = \frac{0.3273}{100} = 3.273 \times 10^{-3} \text{ mole}$$

There are V 2 moles in  $V_2O_5$  1 mole

$$\text{There are V } 3.273 \times 10^{-3} \text{ moles in } V_2O_5 \frac{3.273 \times 10^{-3}}{2} = 1.6365 \times 10^{-3} \text{ mole}$$

$$\text{Mole of } V_2O_5 \text{ required} = 3.273 \times 10^{-3} \text{ mole}$$

$$\text{Amount of } V_2O_5 = (3.273 \times 10^{-3}) \times (181.88) \times (100/97)$$

$$= 0.30065 \text{ g}$$

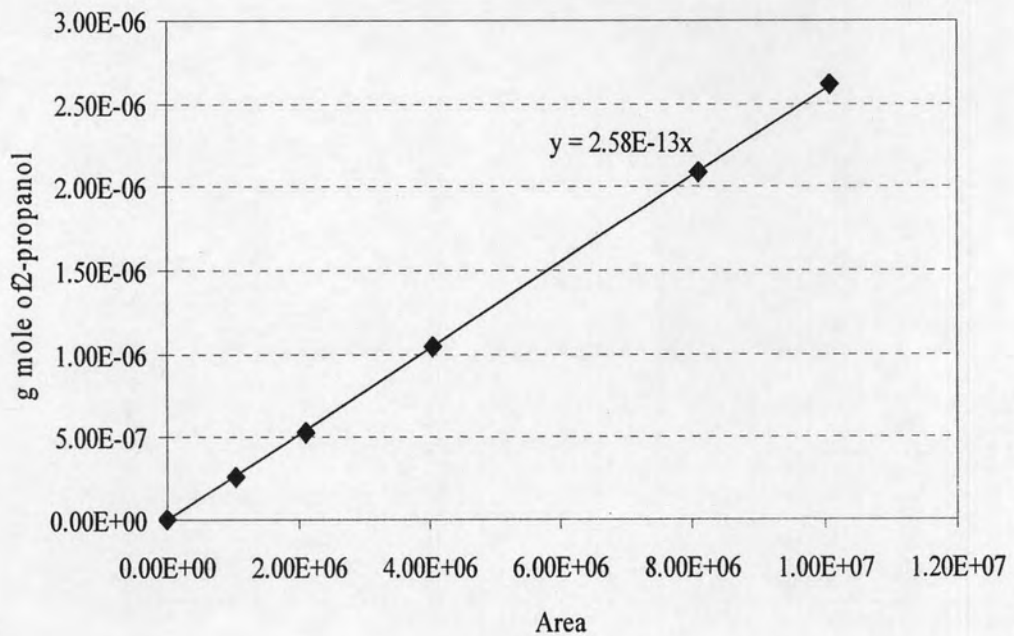
## APPENDIX B

### CALIBRATION CURVE

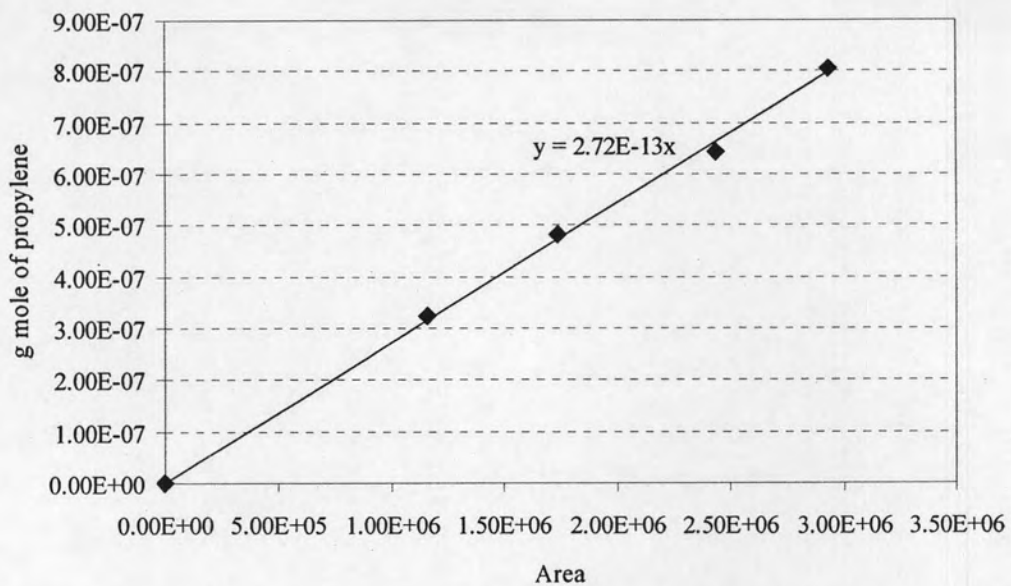
Flame ionization detector gas chromatograph, model 8A, was used to analyze the concentrations of oxygenated compounds. 2-propanol, propylene were analyzed by GC model 8A using Carbo-pack B/3% SP-1500.

Gas chromatograph with the thermal conductivity detector, model 8A, was used to analyze the concentration of CO<sub>2</sub> using molecular sieve 5A and porapak-Q columns respectively.

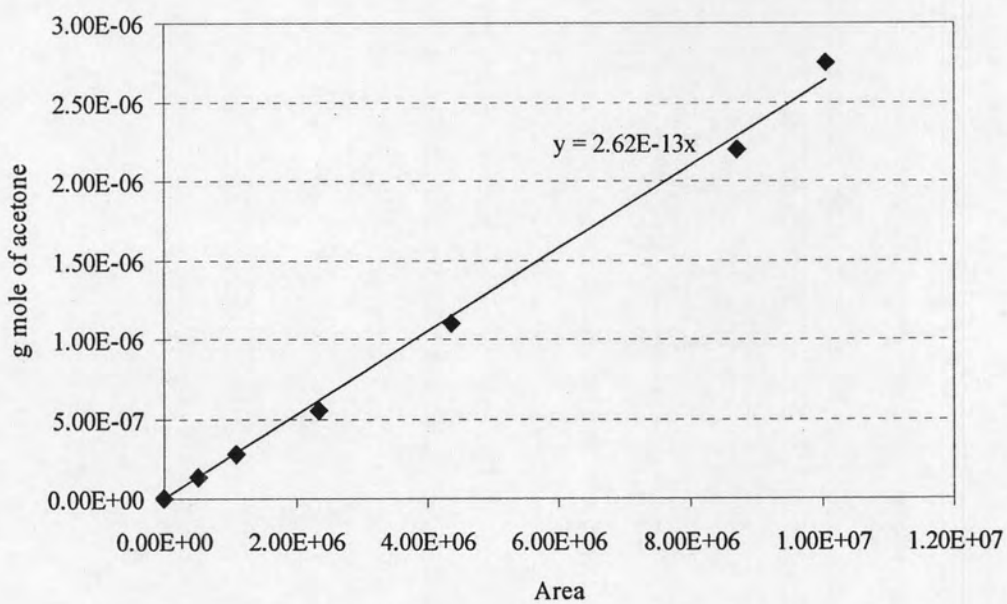
The calibration curves of 2-propanol, propylene, acetone and carbondioxide are illustrated in the following figures.



**Figure B1** The calibration curve of 2-propanol



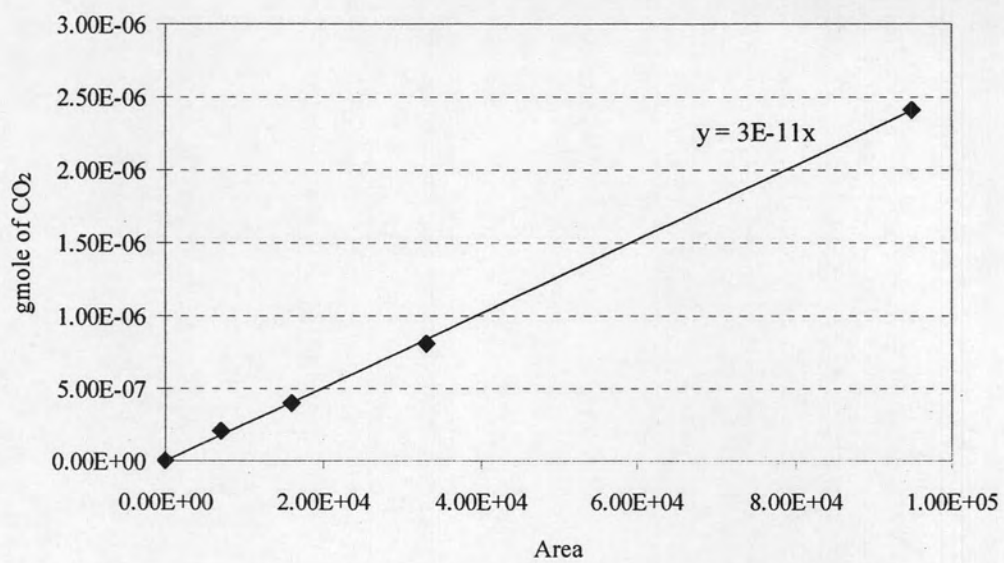
**Figure B2** The calibration curve of propylene



**Figure B3** The calibration curve of acetone







**Figure B4** The calibration curve of carbon dioxide

## APPENDIX C

### CALCULATION OF METAL QUANTITY

#### Example of the calculation of the metal quantity in $VCl_3\_A1$ catalyst

The XRF results were reported in the amount of metal oxide as shown in table C1

**Table C1** Data from XRF technique

Metal oxide	Concentration
$K_2O$	234 ppm
$CaO$	123 ppm
$TiO_2$	0.75 Wt%
$V_2O_5$	0.42 Wt%
$Fe_2O_3$	186 ppm
$Cu_2O$	83 ppm
$ZnO$	61 ppm
$ZrO_2$	33 ppm
$MoO_2$	2 ppm
$SiO_2$	98.75 Wt%
Br	45 ppm

Molecular weights of the metal oxides are shown as follow:

$K_2O$	94.196	$Fe_2O_3$	159.6922	$MoO_2$	127.9388
$CaO$	56.0794	$Cu_2O$	143.0914	$SiO_2$	60.0843
$TiO_2$	236.3818	$ZnO$	81.3894	Br	79.904
$V_2O_5$	181.88	$ZrO_2$	123.2228		

### 1. Convert concentration in unit ppm to weight%

For example, convert  $K_2O$  234 ppm to weight%

$$K_2O \text{ 234 ppm} = \frac{234}{1,000,000} \times 100 = 0.0234 \text{ wt\%}$$

### 2. Mole of metal oxides

$$\text{Mole of } K_2O = \frac{\text{weight of } K_2O}{\text{molecular weight of } K_2O}$$

$$\text{Mole of } K_2O = \frac{0.0234}{94.196} = 2.484 \times 10^{-4} \text{ mole}$$

### 3. Mole of cation (e.g. potassium: K)

Mole of cation = (number of cation atom)  $\times$  (mole of metal oxide)

$$\begin{aligned} \text{Mole of K} &= (2) \times (2.484 \times 10^{-4}) \\ &= 4.968 \times 10^{-4} \text{ mole} \end{aligned}$$

### 4. Mole percent of cation (e.g. potassium: K)

$$\text{Mole \% of K} = \frac{\text{mole of K}}{\text{total mole of cations}}$$

$$\text{Mole \% of K} = \frac{4.968 \times 10^{-4}}{1.650} = 0.0301 \text{ mole\%}$$

Calculated weight%, mole of metal oxide, mole of metal and mole% of cation are illustrated in table C2.

**Table C2** Calculated weight%, mole of metal oxide, mole of metal

Metal oxides	Concentration	weight%	mole of metal oxide	mole of metal	Mole% of cation
K <sub>2</sub> O	234 ppm	0.0234	$2.484 \times 10^{-4}$	$4.968 \times 10^{-4}$	0.0301
CaO	123 ppm	0.0123	$2.193 \times 10^{-4}$	$2.193 \times 10^{-4}$	0.0133
TiO <sub>2</sub>	0.75 Wt%	0.75	$3.173 \times 10^{-3}$	$3.173 \times 10^{-3}$	0.1920
V <sub>2</sub> O <sub>5</sub>	0.42 Wt%	0.42	$2.310 \times 10^{-3}$	$4.620 \times 10^{-4}$	0.2795
Fe <sub>2</sub> O <sub>3</sub>	186 ppm	0.0186	$1.165 \times 10^{-4}$	$2.329 \times 10^{-4}$	0.0141
Cu <sub>2</sub> O	83 ppm	0.0083	$5.800 \times 10^{-5}$	$1.160 \times 10^{-4}$	0.0070
ZnO	61 ppm	0.0061	$7.495 \times 10^{-5}$	$7.495 \times 10^{-5}$	0.0045
ZrO <sub>2</sub>	33 ppm	0.0033	$2.678 \times 10^{-5}$	$2.678 \times 10^{-5}$	0.0016
MoO <sub>2</sub>	2 ppm	0.0002	$1.563 \times 10^{-5}$	$1.563 \times 10^{-6}$	0.0000945
SiO <sub>2</sub>	98.75 Wt%	98.75	1.644	1.644	99.4544
Br	45 ppm	0.0045	$5.632 \times 10^{-5}$	$5.632 \times 10^{-5}$	0.0034
Total		99.9967	1.6498	1.650	100

Sample: Sample494068-No.6  
 Thu 12/07/2006 at 10:43:11 AM  
 Method Name: Method494068

V/TS-1 (VCl<sub>3</sub>-A1)

FCD Name  
 1 Liquids A (S,Cl)  
 2 Medium Elmts - Liquids  
 3 V. Heavy Elmts - Liquids  
 4 V. Light Elmts - Liquids

FCD	LT,s	Zero	FWHM	Gain
1	30	-0.1	89.2	100.01
2	30	-0.8	121.1	100.01
3	30	-1.9	122.5	100.01
4	30	-0.5	89.2	100.01

Total: 68.09% (Normalised to 100%)

El Line	Concentration	+/- Err	Fit	Intensity
K20 K	234 ppm	2.79E-3	1.5	18.7
Ca0 K	123 ppm	1.90E-3	1.6	13.7
Ti02K	0.75 wt %	3.66E-3	3370.8	4263.6
V205Kb	0.42 wt %	0.02	154.2	73.7
Fe203Ka	186 ppm	7.53E-4	2.1	73.8
Cu20Ka	83 ppm	7.21E-4	3.2	27.1
Zn0 Ka	61 ppm	5.53E-4	1.2	25.2
Br Ka	45 ppm	3.12E-4	0.6	78.2
Zr02Ka	33 ppm	2.57E-4	0.2	31.0
Mo02Ka	2 ppm	1.58E-4	0.5	2.4
Si02K	98.75 wt %	0.25	31.9	15480.1

Sample: Sample494068-No.3  
 Thu 12/07/2006 at 10:20:33 AM  
 Method Name: Method494068

V/TS-1 (VCl<sub>3</sub>-A2)

FCD Name  
 1 Liquids A (S,Cl)  
 2 Medium Elmts - Liquids  
 3 V. Heavy Elmts - Liquids  
 4 V. Light Elmts - Liquids

FCD	LT,s	Zero	FWHM	Gain
1	30	-0.1	89.1	100.01
2	30	-0.8	121.0	100.01
3	30	-1.9	122.4	100.01
4	30	-0.5	89.1	100.01

Total: 70.55% (Normalised to 100%)

El Line	Concentration	+/- Err	Fit	Intensity
K20 K	179 ppm	2.28E-3	0.6	16.7
Ca0 K	187 ppm	1.85E-3	1.8	24.2
Ti02K	0.84 wt %	3.61E-3	15.6	5540.7
V205Kb	200 ppm	0.01	12.3	3.6
Fe203Ka	131 ppm	6.52E-4	1.4	54.3
Cu20Ka	47 ppm	6.21E-4	2.2	16.1
Zn0 Ka	48 ppm	5.09E-4	0.5	20.9
Br Ka	12 ppm	2.51E-4	0.8	20.9
Zr02Ka	33 ppm	2.67E-4	0.4	32.9
Mo02Ka	0.00 wt %	0.00	0.8	-0.6
Si02K	99.08 wt %	0.24	41.1	16482.5



Sample: Sample494279No.3  $YCl_3$  in  $Al_2$   
 wed 12/20/2006 at 2:01:02 PM  
 Method Name: Method494279-SetSTD

FCD Name  
 1 Liquids A (S,Cl)  
 2 Medium Elmts - Liquids  
 3 V. Heavy Elmts - Liquids  
 4 V. Light Elmts - Liquids

FCD	LT,s	Zero	FWHM	Gain
1	30	-0.1	89.1	100.01
2	30	-0.9	121.0	100.01
3	30	-1.8	122.3	100.01
4	30	-0.4	89.3	100.01

Total: 76.19% Factor: 1.312508

El Line	Concentration
SiO2K	75.16 wt %
CaO K	163 ppm
TiO2K	0.69 wt %
V2O5Ka	0.30 wt %
Fe2O3Ka	0.01 wt %
Cu2Oka	34 ppm
ZnO Ka	32 ppm
ZrO2Ka	37 ppm

Sample: Sample494068-No.4  $V/Ts-1 (VCl_3-Cl)$   
 Thu 12/07/2006 at 10:28:09 AM  
 Method Name: Method494068

FCD Name  
 1 Liquids A (S,Cl)  
 2 Medium Elmts - Liquids  
 3 V. Heavy Elmts - Liquids  
 4 V. Light Elmts - Liquids

FCD	LT,s	Zero	FWHM	Gain
1	30	-0.1	89.2	100.01
2	30	-0.9	121.2	100.01
3	30	-1.8	122.2	100.01
4	30	-0.4	89.2	100.01

Total: 64.31% (Normalised to 100%)

El Line	Concentration	+/- Err	Fit	Intensity
K2O K	164 ppm	2.58E-3	0.4	12.8
CaO K	122 ppm	2.09E-3	1.8	13.2
TiO2K	0.78 wt %	3.79E-3	3611.6	4320.9
V2O5Kb	0.44 wt %	0.02	177.5	75.8
Fe2O3Ka	113 ppm	6.27E-4	2.3	44.7
Cu2Oka	60 ppm	6.40E-4	1.0	19.6
ZnO Ka	36 ppm	5.25E-4	0.4	14.8
Br Ka	9 ppm	2.58E-4	0.2	15.5
ZrO2Ka	27 ppm	2.76E-4	0.1	23.1
MoO2Ka	8 ppm	1.73E-4	0.2	9.5
SiO2K	98.73 wt %	0.26	35.7	14197.6

Sample: Sample494279No.5 V4 in A1  
 wed 12/20/2006 at 2:16:00 PM  
 Method Name: Method494279-SetSTD

FCD Name  
 1 Liquids A (S,Cl)  
 2 Medium Elmts - Liquids  
 3 V. Heavy Elmts - Liquids  
 4 V. Light Elmts - Liquids

FCD	LT,s	Zero	FWHM	Gain
1	30	-0.1	89.1	100.01
2	30	-0.8	121.1	100.01
3	30	-1.8	122.1	100.01
4	30	-0.4	89.2	100.01

Total: 82.56% Factor: 1.211240

El Line	Concentration
SiO2K	81.10 wt %
CaO K	435 ppm
TiO2K	0.84 wt %
V2O5Ka	0.55 wt %
Fe2O3Ka	0.01 wt %
Cu2OKa	29 ppm
ZnO Ka	38 ppm
ZrO2Ka	48 ppm

Sample: Sample494279No.4 V4 in A1A2  
 wed 12/20/2006 at 2:08:27 PM  
 Method Name: Method494279-SetSTD

FCD Name  
 1 Liquids A (S,Cl)  
 2 Medium Elmts - Liquids  
 3 V. Heavy Elmts - Liquids  
 4 V. Light Elmts - Liquids

FCD	LT,s	Zero	FWHM	Gain
1	30	-0.1	89.1	100.01
2	30	-0.9	121.0	100.01
3	30	-1.9	122.3	100.01
4	30	-0.4	89.2	100.01

Total: 87.77% Factor: 1.139341

El Line	Concentration
SiO2K	86.74 wt %
CaO K	215 ppm
TiO2K	0.77 wt %
V2O5Ka	0.22 wt %
Fe2O3Ka	92 ppm
Cu2OKa	32 ppm
ZnO Ka	24 ppm
ZrO2Ka	37 ppm

Sample: Sample494068-No.2  
 Thu 12/07/2006 at 10:13:12 AM  
 Method Name: Method494068

V/TS-1 (V<sub>2</sub>O<sub>5</sub>-A1)

FCD Name  
 1 Liquids A (S,Cl)  
 2 Medium Elmts - Liquids  
 3 V. Heavy Elmts - Liquids  
 4 V. Light Elmts - Liquids

FCD	LT,s	Zero	FWHM	Gain
1	30	-0.1	89.0	100.01
2	30	-0.9	121.0	100.01
3	30	-1.6	121.9	100.01
4	30	-0.4	89.0	100.01

Total: 69.42% (Normalised to 100%)

El Line	Concentration	+/- Err	Fit	Intensity
K2O K	229 ppm	2.47E-3	5.6	20.5
CaO K	180 ppm	2.01E-3	2.2	22.4
TiO2K	0.94 wt %	3.89E-3	36.3	5940.3
V2O5Kb	205 ppm	0.01	22.0	4.4
Fe2O3Ka	129 ppm	5.79E-4	2.5	63.3
Cu2OKa	52 ppm	5.36E-4	1.9	21.4
ZnO Ka	52 ppm	4.89E-4	0.3	26.8
Br Ka	59 ppm	2.87E-4	0.7	125.9
ZrO2Ka	40 ppm	2.86E-4	3.2E-2	39.0

Sample: Sample494068-No.5  
 Thu 12/07/2006 at 10:35:43 AM  
 Method Name: Method494068

V/TS-1 (V<sub>2</sub>O<sub>5</sub>-A1A2)

FCD Name  
 1 Liquids A (S,Cl)  
 2 Medium Elmts - Liquids  
 3 V. Heavy Elmts - Liquids  
 4 V. Light Elmts - Liquids

FCD	LT,s	Zero	FWHM	Gain
1	30	-0.2	89.2	100.01
2	30	-0.9	121.1	100.01
3	30	-1.6	122.2	100.01
4	30	-0.5	89.3	100.01

Total: 70.82% (Normalised to 100%)

El Line	Concentration	+/- Err	Fit	Intensity
K2O K	218 ppm	2.38E-3	0.9	20.1
CaO K	233 ppm	2.03E-3	2.1	29.7
TiO2K	0.89 wt %	3.74E-3	26.8	5778.5
V2O5Kb	221 ppm	0.01	15.8	4.3
Fe2O3Ka	117 ppm	5.84E-4	1.6	52.7
Cu2OKa	44 ppm	5.44E-4	3.0	16.7
ZnO Ka	40 ppm	4.67E-4	1.2	18.8
Br Ka	39 ppm	2.76E-4	0.3	75.8
ZrO2Ka	51 ppm	2.87E-4	0.3	52.0
MoO2Ka	0.00 wt %	0.00	1.1	-3.0
SiO2K	99.02 wt %	0.24	43.6	16563.5

## EDX-Oxford Model 2000-Normalization

Sample: Sample494068-No.1  
 Thu 12/07/2006 at 10:04:26 AM V/TS-1 (V<sub>2</sub>O<sub>5</sub>-Cl)  
 Method Name: Method494068

FCD Name  
 1 Liquids A (S,Cl)  
 2 Medium Elmts - Liquids  
 3 V. Heavy Elmts - Liquids  
 4 V. Light Elmts - Liquids

FCD	LT, s	Zero	FWHM	Gain
1	30	-0.1	89.0	100.01
2	30	-0.9	120.9	100.01
3	30	-1.8	122.1	100.01
4	30	-0.4	89.1	100.01

Total: 68.84% (Normalised to 100%)

El Line	Concentration	+/- Err	Fit	Intensity
K2O K	200 ppm	2.44E-3	0.7	17.9
CaO K	231 ppm	2.11E-3	1.9	28.8
TiO2K	1.00 wt %	4.02E-3	18.5	6330.3
V2O5kb	142 ppm	0.01	17.7	2.7
Fe2O3Ka	77 ppm	5.59E-4	1.5	33.5
Cu2OKa	43 ppm	6.01E-4	1.0	15.5
ZnO Ka	69 ppm	5.63E-4	0.3	31.3
Br Ka	14 ppm	2.55E-4	0.6	25.7
ZrO2Ka	58 ppm	3.29E-4	0.3	55.7
MoO2Ka	0.00 wt %	0.00	1.2	-0.9
SiO2K	98.92 wt %	0.25	37.0	15817.6
MoO2Ka	0.00 wt %	0.00	0.7	-3.5
SiO2K	98.97 wt %	0.24	34.2	16033.8

## APPENDIX D

### DATA AND CALCULATION OF ACID SITE

**Table D1** Reported total peak area from Micromeritics Chemisorb 2750

Sample	Reported total peak
VCl <sub>3</sub> _A1	0.0565734
VCl <sub>3</sub> _A2	0.0360332
VCl <sub>3</sub> _A1A2	0.0369022
VCl <sub>3</sub> _C1	0.0236272
VO(acac) <sub>2</sub> _A1	0.0323645
VO(acac) <sub>2</sub> _A1A2	0.0204142
V <sub>2</sub> O <sub>5</sub> _A1	0.0342690
V <sub>2</sub> O <sub>5</sub> _A1A2	0.0390409
V <sub>2</sub> O <sub>5</sub> _C1	0.0225505

#### Calculation of total acid sites

For example, VCl<sub>3</sub>\_A1, total acid site is calculated from the following step.

##### 1. Conversion of total peak area to total peak volume

Conversion factor from Micromeritics Chemisorb 2750 is equal to 77.57016 ml/area unit. Therefore, total peak volume is derived from

$$\begin{aligned}\text{Total peak volume} &= 77.57016 \times \text{total peak area} \\ &= 77.57016 \times 0.0565734 \\ &= 4.388408 \text{ ml}\end{aligned}$$



2. Calculation for adsorbed volume of 15% NH<sub>3</sub>

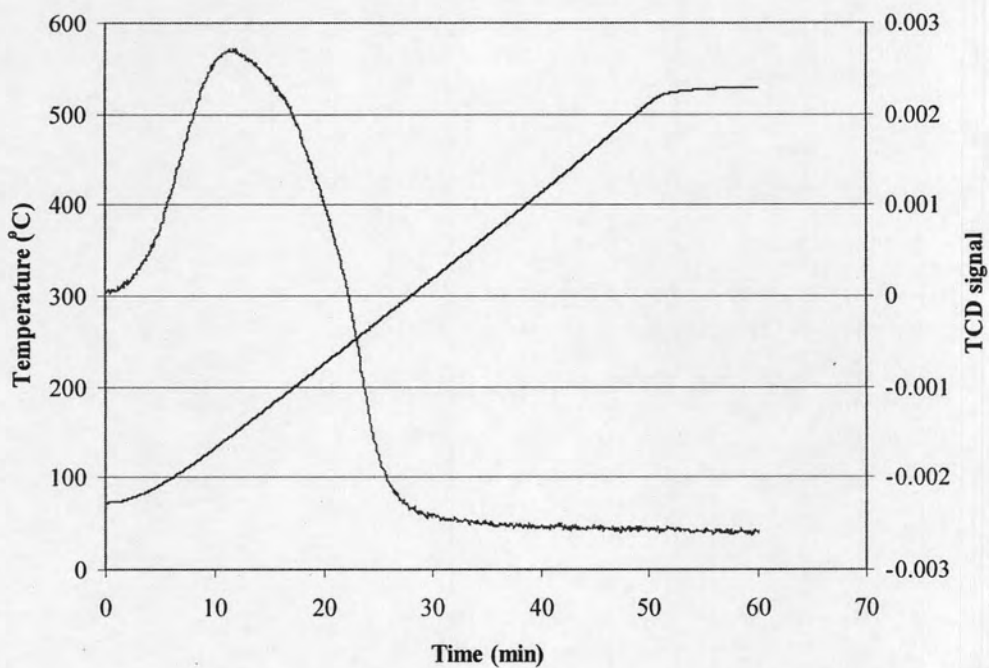
$$\begin{aligned}
 \text{Adsorbed volume of 15\% NH}_3 &= 0.15 \times \text{total peak volume} \\
 &= 0.15 \times 4.388408 \text{ ml} \\
 &= 0.65826 \text{ ml}
 \end{aligned}$$

3. Total acid sites are calculated from the following equation

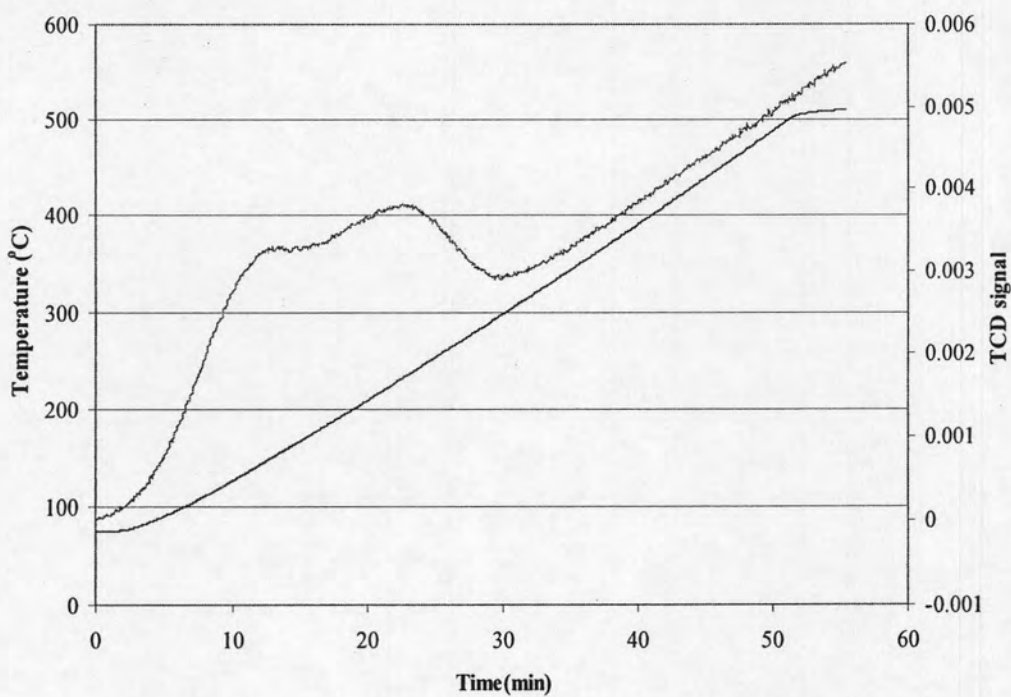
$$\text{Total acid sites} = \frac{(\text{Adsorbed volume, ml}) \times 101.325 \text{ Pa}}{\left(8.314 \times 10^{-3} \frac{\text{Pa} \cdot \text{ml}}{\text{K} \cdot \mu\text{mol}}\right) \times 298 \text{ K} \times (\text{weight of catalyst, g})}$$

For TS-1 sample, 0.1006 g of this one was measured, therefore

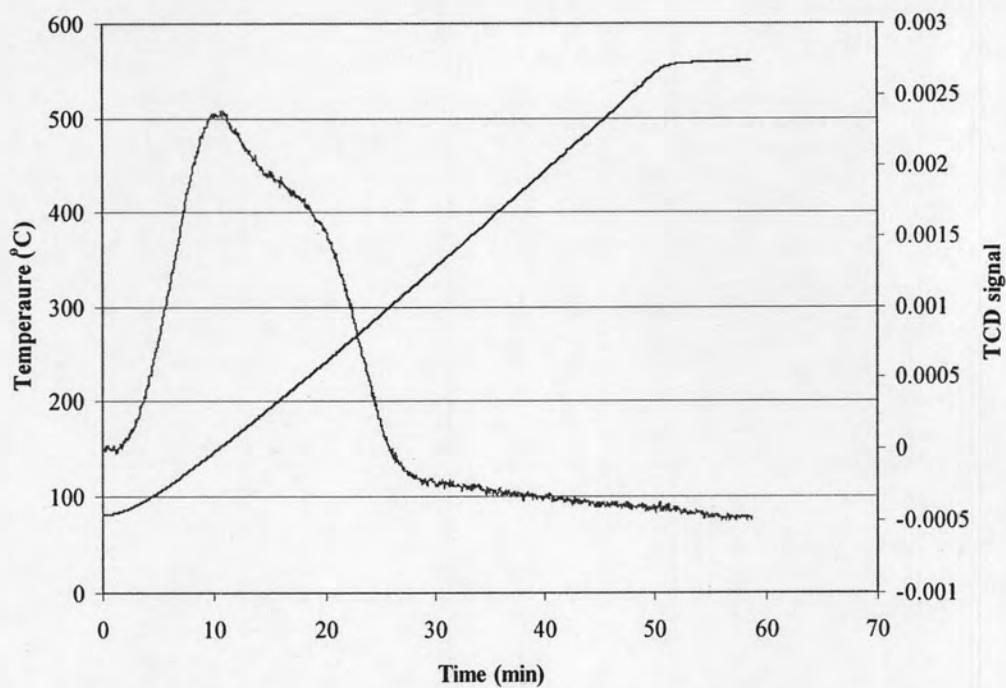
$$\begin{aligned}
 \text{Total acid sites} &= \frac{0.65826 \text{ ml} \times 101.325 \text{ Pa}}{\left(8.314 \times 10^{-3} \frac{\text{Pa} \cdot \text{ml}}{\text{K} \cdot \mu\text{mol}}\right) \times 298 \text{ K} \times (0.1031 \text{ g})} \\
 &= 261 \mu\text{mol H}^+/\text{g}
 \end{aligned}$$



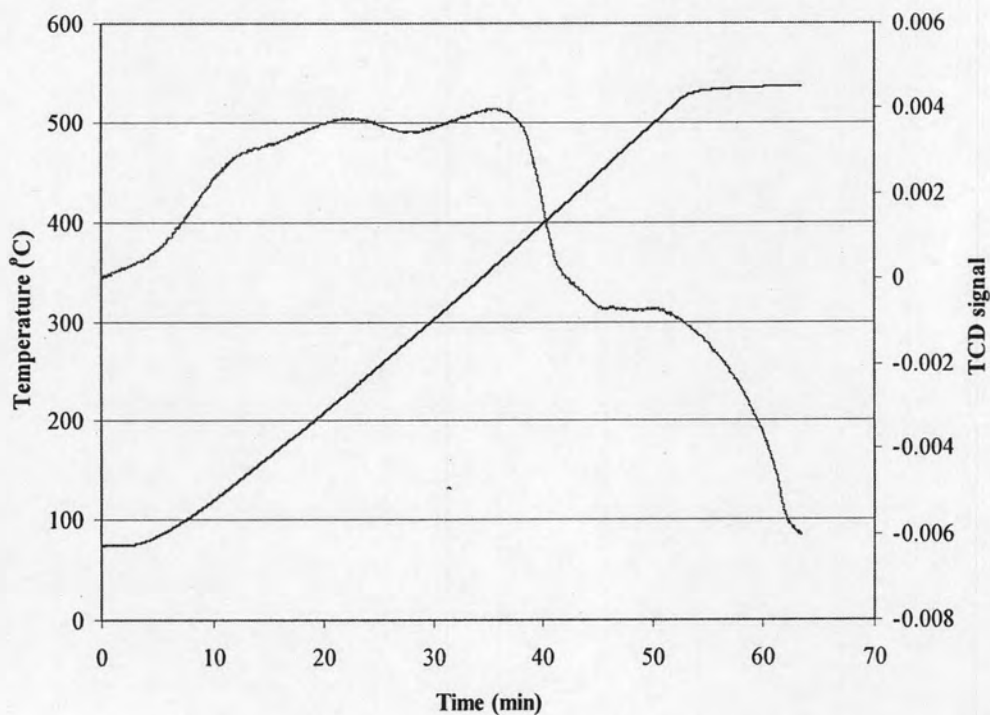
**Figure D1** TCD signal and temperature versus time data of  $VCl_3\_A1$  from Micromeritics Chemisorb 2750



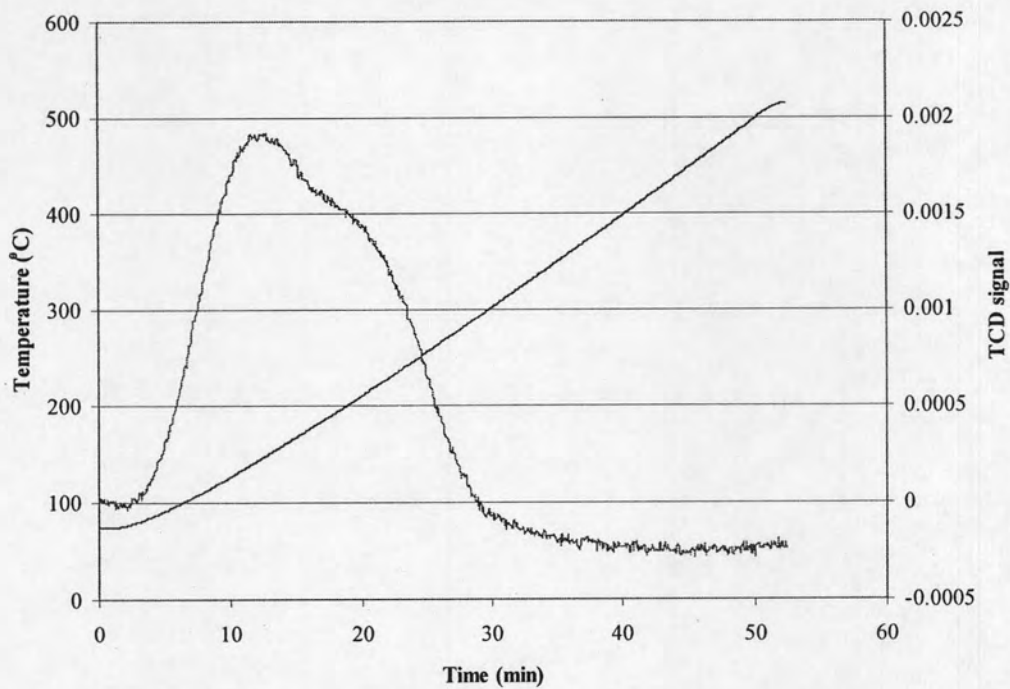
**Figure D2** TCD signal and temperature versus time data of  $VCl_3\_A2$  from Micromeritics Chemisorb 2750



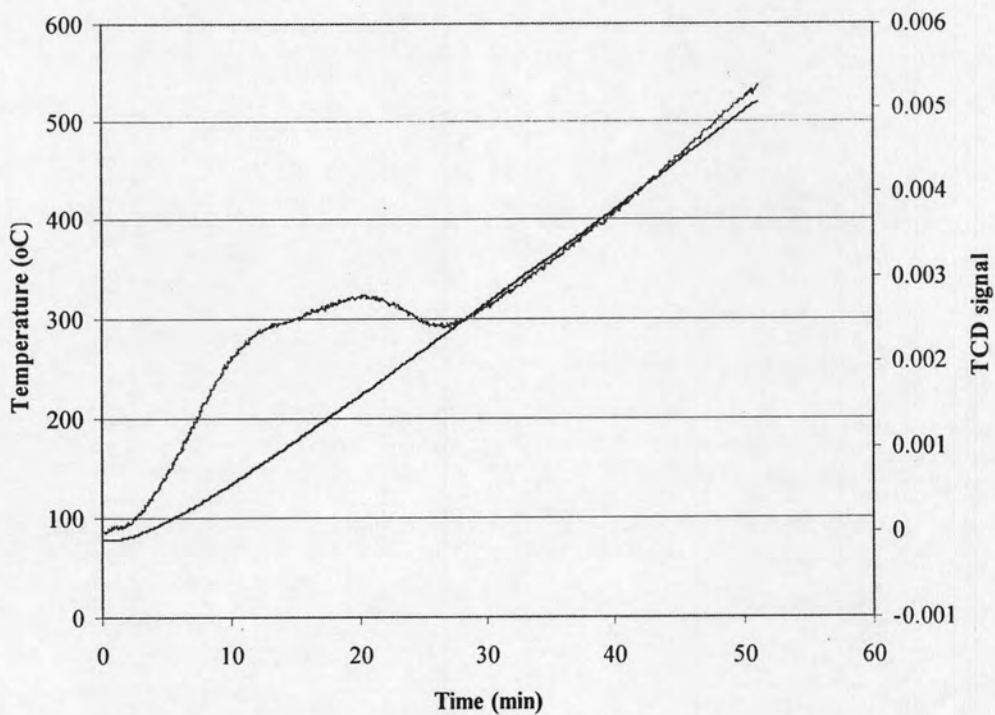
**Figure D3** TCD signal and temperature versus time data of VCl<sub>3</sub>\_A1A2 from Micromeritics Chemisorb 2750



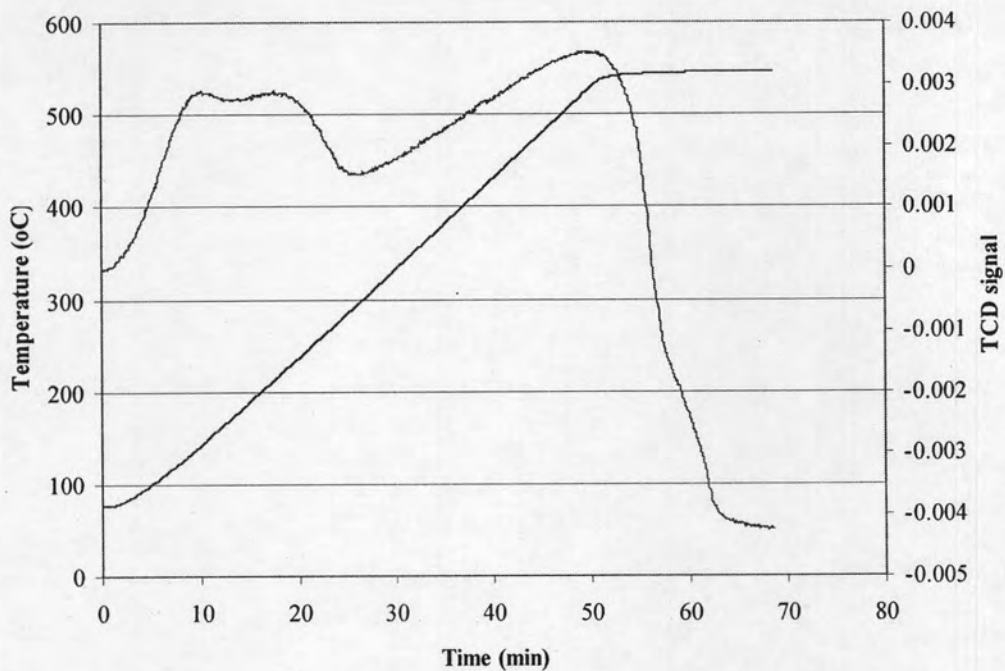
**Figure D4** TCD signal and temperature versus time data of VCl<sub>3</sub>\_C1 from Micromeritics Chemisorb 2750



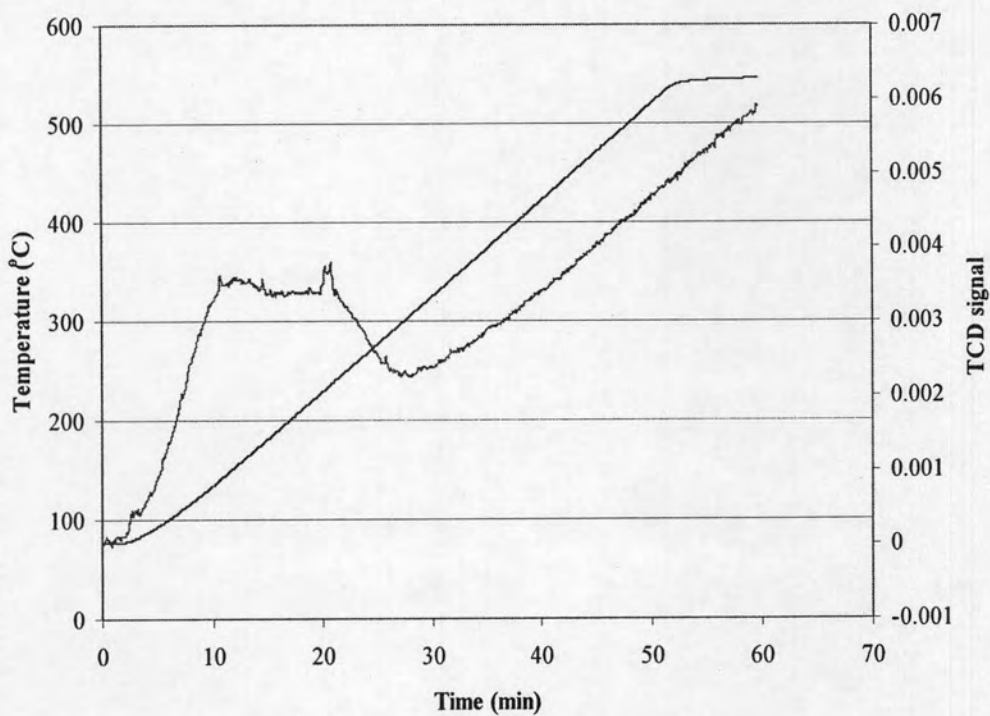
**Figure D5** TCD signal and temperature versus time data of VO(acac)<sub>2</sub>\_A1 from Micromeritics Chemisorb 2750



**Figure D6** TCD signal and temperature versus time data of VO(acac)<sub>2</sub>\_A1A2 from Micromeritics Chemisorb 2750

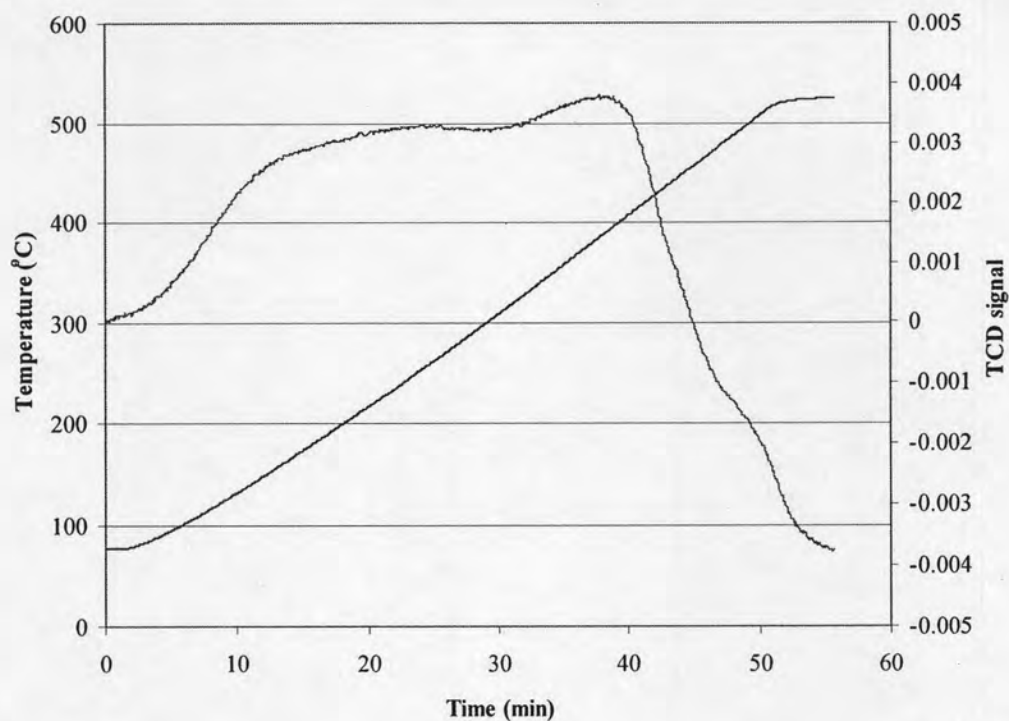


**Figure D7** TCD signal and temperature versus time data of  $V_2O_5\_A1$  from Micromeritics Chemisorb 2750

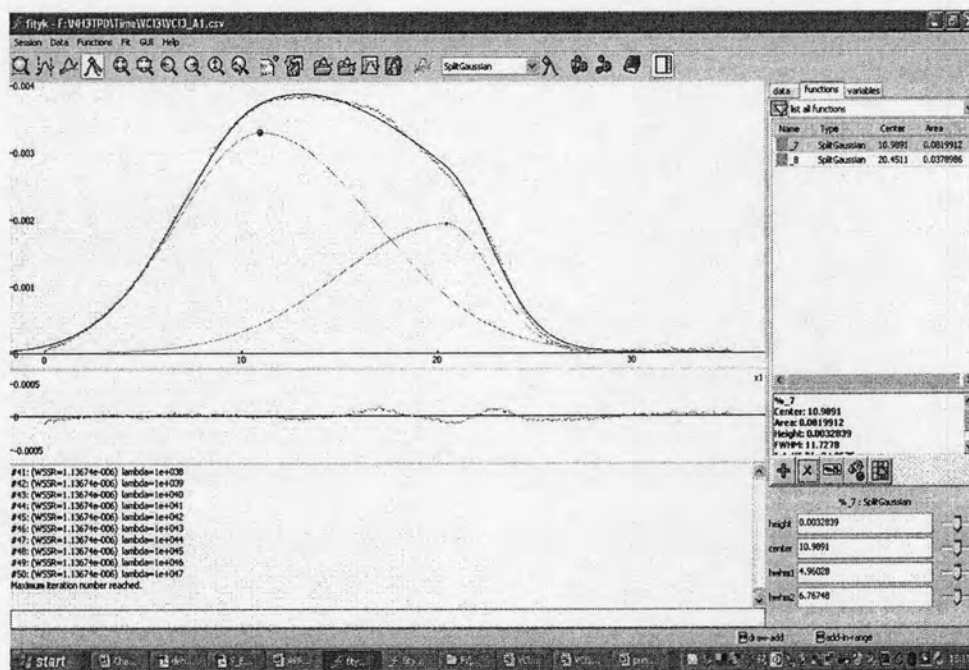


**Figure D8** TCD signal and temperature versus time data of  $V_2O_5\_A1A2$  from Micromeritics Chemisorb 2750





**Figure D9** TCD signal and temperature versus time data of  $V_2O_5\_C1$  from Micromeritics Chemisorb 2750



**Figure D10** Data for calculating of acid site ratio of  $VCl_3\_A1$  from peak fitting program

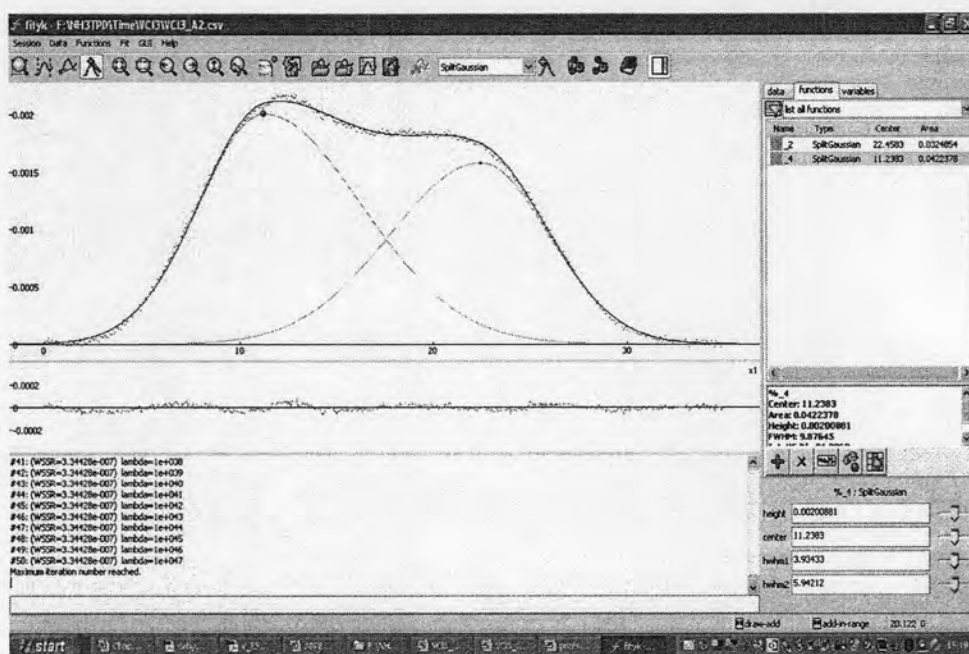


Figure D11 Data for calculating of acid site ratio of  $\text{VCl}_3\_A2$  from peak fitting program

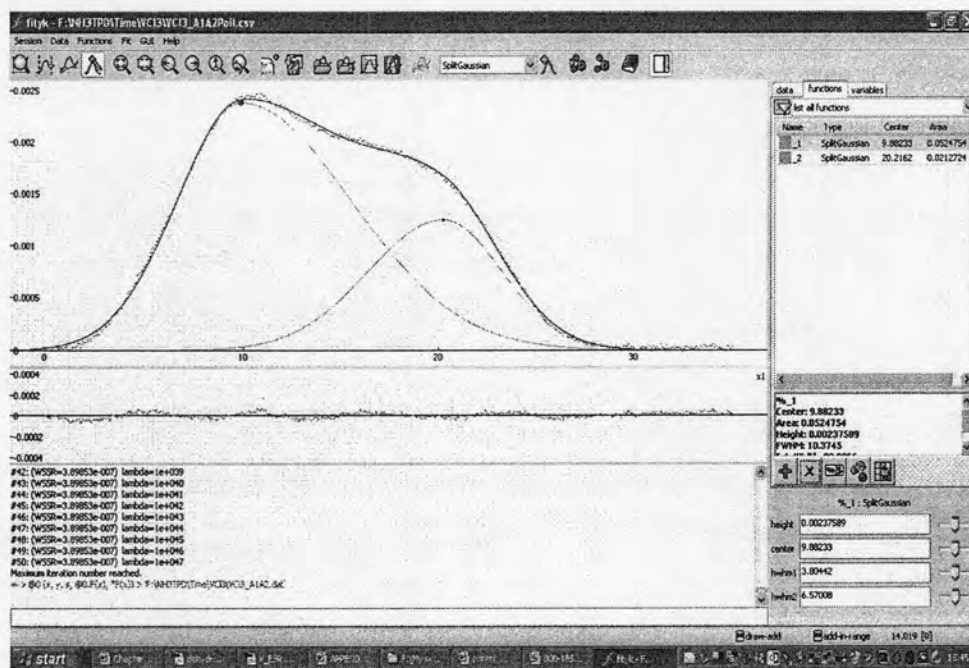


Figure D12 Data for calculating of acid site ratio of  $\text{VCl}_3\_A1A2$  from peak fitting program



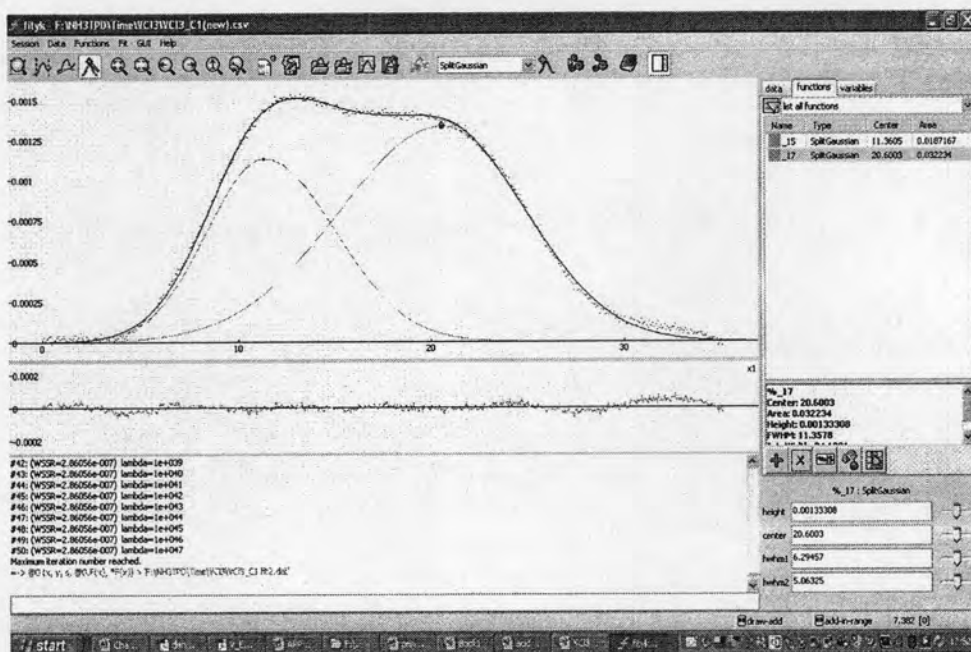


Figure D13 Data for calculating of acid site ratio of  $VCl_3\_C1$  from peak fitting program

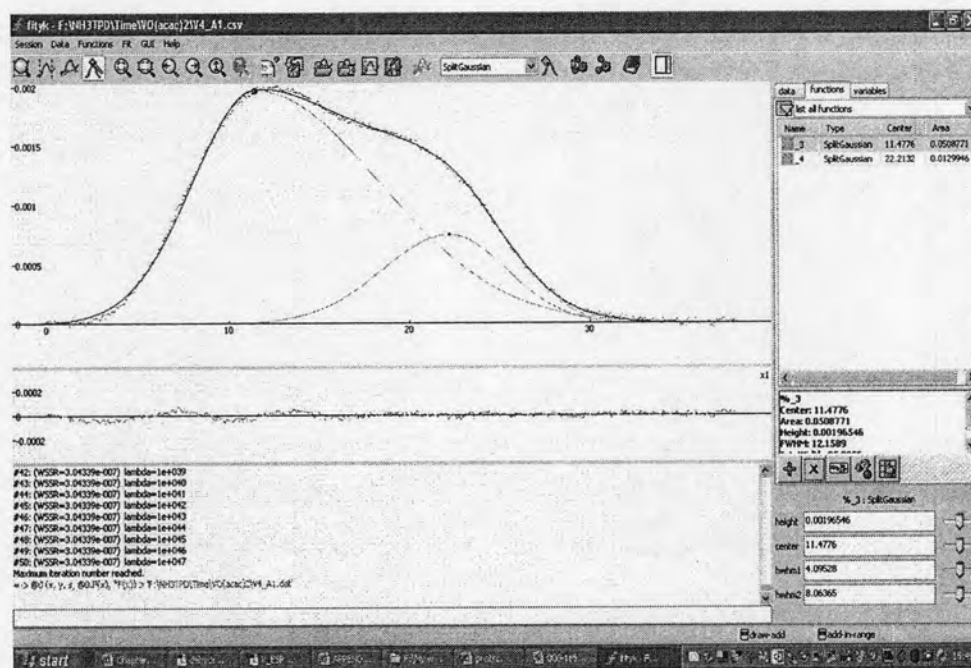


Figure D14 Data for calculating of acid site ratio of  $VO(acac)_2\_A1$  from peak fitting program

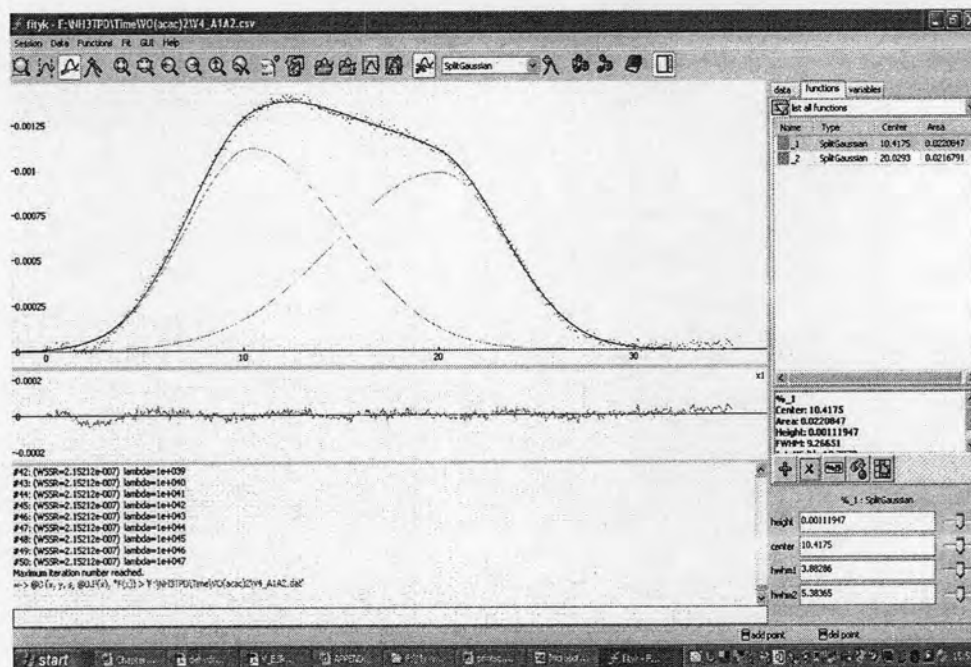


Figure D15 Data for calculating of acid site ratio of  $\text{VO}(\text{acac})_2\text{-A1A2}$  from peak fitting program

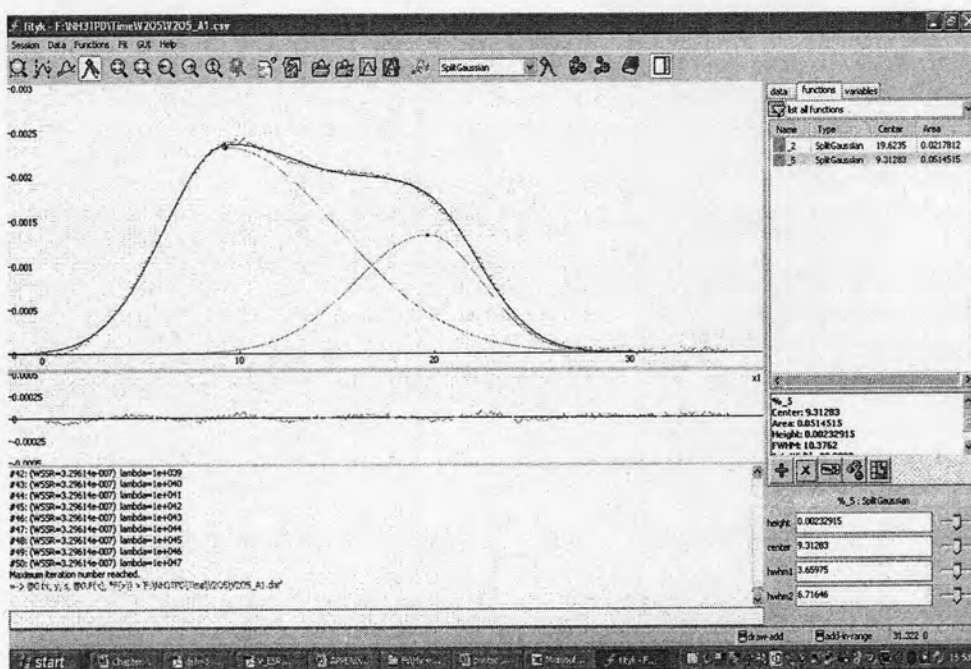


Figure D16 Data for calculating of acid site ratio of  $\text{V}_2\text{O}_5\text{-A1}$  from peak fitting program

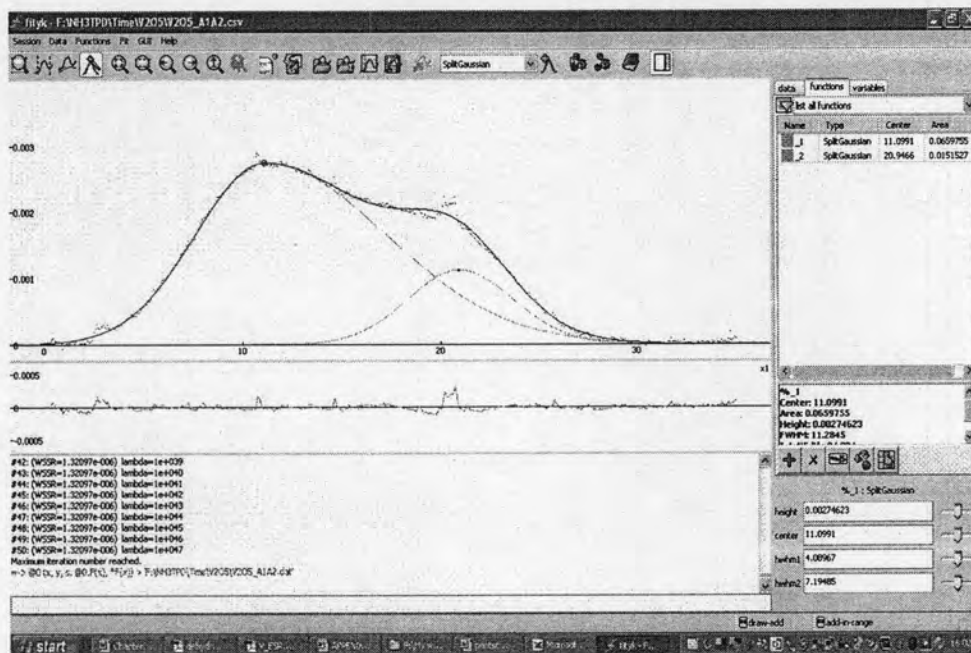


Figure D17 Data for calculating of acid site ratio of  $V_2O_5\_A1A2$  from peak fitting program

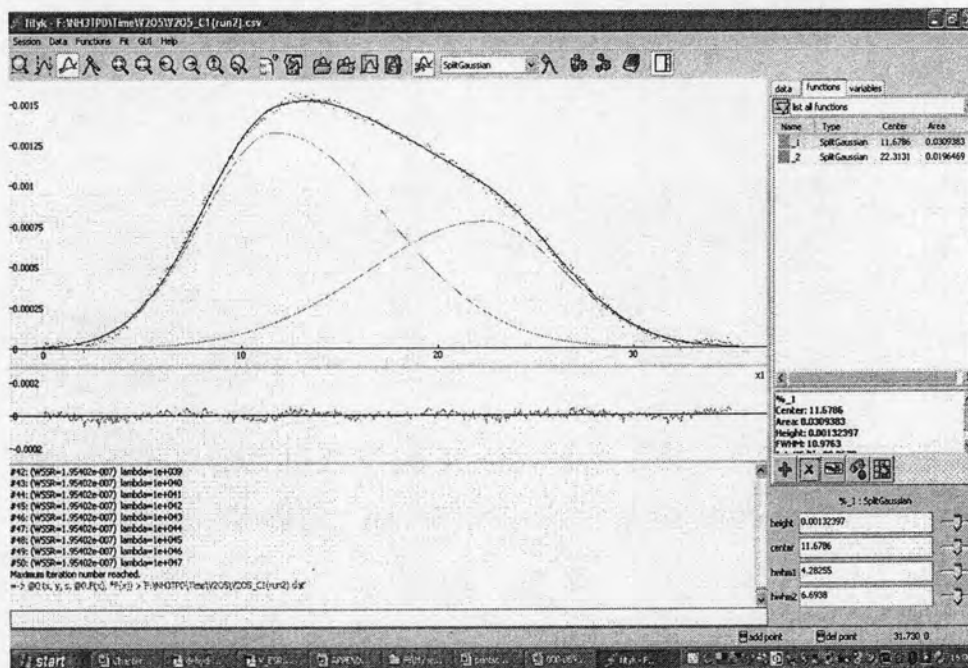


Figure D18 Data for calculating of acid site ratio of  $V_2O_5\_C1$  from peak fitting program



### Calculation of acid site ratio

To calculate acid site ratio, experiment data from Micromeritics Chemisorb 2750 are transferred to peak fitting program to separate peak. As known, the first peak of desorption process is indicated as weak acid, relative with another peak, and the second one is strong acid. Ratio of each acid site on the catalyst surface is calculated from peak areas reported by peak fitting program as shown above.

For example,  $VCl_3\_A1$ , the ratio of each acid site on catalyst surface is calculated from the following equation.

$$\text{The ratio of weak acid} = \frac{\text{1}^{\text{st}} \text{ peak area}}{\text{summation of both peak areas}} \times 100 \%$$

From figure D10, 1<sup>st</sup> peak area and 2<sup>nd</sup> peak area are equal to 0.0819912 and 0.0378986, respectively.

$$\begin{aligned} \text{The ratio of weak acid} &= \frac{0.0819912}{0.0819912 + 0.0378986} \times 100 \% \\ &= 68.39 \% \end{aligned}$$

$$\begin{aligned} \text{Therefore, the ratio of strong acid} &= 100 - 68.39 \% \\ &= 31.61 \% \end{aligned}$$

Note. Reported center values of both peaks from peak fitting program reveal times at the maximum of both peaks occur. Since, we know the relationship between time and temperature during desorption process from Micromeritics Chemisorb 2750, hence, the temperature at the maximum of both peaks as we state as desorption temperature of both acid sites can be located.

## APPENDIX E

### DATA OF CATALYTIC EXPERIMENTS

**Table E1** Catalytic data of VCl<sub>3</sub>\_A1

Reaction temperature (°C)	% conversion 2-propanol	Mole of reactant used/products formed			
		2-propanol	Propylene	Acetone	CO <sub>2</sub> /3
100	1.39	3.43E-06	1.29E-08	3.36E-08	0.00E+00
150	1.94	3.07E-06	1.28E-08	5.10E-08	0.00E+00
200	9.36	3.02E-06	1.62E-08	3.05E-07	0.00E+00
250	12.80	2.79E-06	4.47E-08	3.94E-07	0.00E+00
300	35.62	2.08E-06	2.96E-07	9.08E-07	0.00E+00
350	74.89	6.95E-07	6.69E-07	1.62E-06	2.47E-07
400	70.61	2.14E-07	4.81E-07	1.40E-06	4.71E-07
450	84.94	2.28E-07	5.95E-07	2.06E-06	2.51E-07
500	93.47	8.32E-08	6.23E-07	1.80E-06	7.04E-07

**Table E2** Catalytic data of VCl<sub>3</sub>\_A2

Reaction temperature (°C)	% conversion 2-propanol	Mole of reactant used/products formed			
		2-propanol	Propylene	Acetone	CO <sub>2</sub> /3
100	0.01	2.99E-06	0.00E+00	3.16E-10	0.00E+00
150	0.17	3.51E-06	1.41E-09	4.34E-09	0.00E+00
200	8.14	2.92E-06	2.78E-08	2.31E-07	0.00E+00
250	13.70	2.78E-06	2.63E-07	1.83E-07	3.94E-09
300	53.05	2.02E-06	1.26E-06	4.28E-07	4.17E-08
350	89.59	8.88E-07	1.69E-06	1.00E-06	2.42E-07
400	103.70	1.86E-07	1.31E-06	1.33E-06	7.85E-07
450	101.65	3.58E-08	9.28E-07	1.49E-06	9.07E-07
500	100.46	3.14E-08	7.80E-07	1.66E-06	9.15E-07

**Table E3** Catalytic data of VCl<sub>3</sub>\_A1A2

Reaction temperature (°C)	% conversion 2-propanol	Mole of reactant used/products formed			
		2-propanol	Propylene	Acetone	CO <sub>2</sub> /3
100	2.39	3.53E-06	2.76E-08	5.36E-08	0.00E+00
150	2.61	3.09E-06	2.89E-08	5.69E-08	0.00E+00
200	4.84	3.02E-06	3.21E-08	1.29E-07	0.00E+00
250	13.29	2.64E-06	7.47E-08	3.65E-07	0.00E+00
300	43.81	1.49E-06	3.58E-07	1.03E-06	4.05E-08
350	71.75	4.06E-07	5.80E-07	1.52E-06	2.99E-07
400	75.11	2.19E-07	4.96E-07	1.45E-06	4.96E-07
450	85.09	5.53E-08	5.88E-07	1.87E-06	3.43E-07
500	107.41	1.18E-08	6.41E-07	2.06E-06	7.19E-07

**Table E4** Catalytic data of VCl<sub>3</sub>\_C1

Reaction temperature (°C)	% conversion 2-propanol	Mole of reactant used/products formed			
		2-propanol	Propylene	Acetone	CO <sub>2</sub> /3
100	0.00	3.47E-06	0.00E+00	1.07E-10	0.00E+00
150	0.04	3.17E-06	6.94E-11	1.06E-09	0.00E+00
200	1.14	2.88E-06	2.04E-09	3.56E-08	0.00E+00
250	5.88	3.13E-06	3.21E-08	1.54E-07	0.00E+00
300	36.80	2.24E-06	3.48E-07	8.05E-07	1.41E-08
350	76.57	1.04E-06	8.38E-07	1.44E-06	1.21E-07
400	87.78	2.25E-07	9.25E-07	1.21E-06	8.35E-08
450	94.73	1.03E-07	7.58E-07	1.43E-06	2.99E-07
500	97.70	6.57E-09	5.48E-07	1.66E-06	4.45E-07

**Table E5** Catalytic data of VO(acac)<sub>2</sub>\_A1

Reaction temperature (°C)	% conversion 2-propanol	Mole of reactant used/products formed			
		2-propanol	Propylene	Acetone	CO <sub>2</sub> /3
100	0.00	3.41E-06	0.00E+00	5.72E-11	0.00E+00
150	0.12	3.50E-06	6.89E-11	4.07E-09	0.00E+00
200	2.77	3.23E-06	4.35E-09	8.66E-08	0.00E+00
250	6.89	3.15E-06	4.88E-08	1.76E-07	0.00E+00
300	37.18	1.98E-06	4.36E-07	8.13E-07	1.44E-08
350	81.50	6.09E-07	9.89E-07	1.69E-06	5.73E-08
400	74.67	1.34E-07	8.83E-07	1.49E-06	1.10E-07
450	85.72	1.01E-07	1.01E-06	1.48E-06	2.78E-07
500	89.47	2.49E-08	1.16E-06	1.52E-06	2.75E-07

**Table E6** Catalytic data of VO(acac)<sub>2</sub>\_A1A2

Reaction temperature (°C)	% conversion 2-propanol	Mole of reactant used/products formed			
		2-propanol	Propylene	Acetone	CO <sub>2</sub> /3
100	0.28	3.09E-06	1.49E-09	7.72E-09	0.00E+00
150	2.92	3.17E-06	2.68E-09	9.53E-08	0.00E+00
200	5.36	3.36E-06	5.70E-09	1.73E-07	0.00E+00
250	15.37	2.34E-06	7.92E-08	4.09E-07	6.84E-09
300	47.17	1.39E-06	4.34E-07	1.04E-06	7.92E-08
350	74.25	2.98E-07	5.45E-07	1.30E-06	5.87E-07
400	86.18	1.33E-07	4.79E-07	1.57E-06	7.37E-07
450	88.19	7.20E-08	6.15E-07	1.63E-06	6.10E-07
500	84.48	4.37E-08	6.45E-07	1.61E-06	5.61E-07

**Table E7** Catalytic data of V<sub>2</sub>O<sub>5</sub>\_A1

Reaction temperature (°C)	% conversion 2-propanol	Mole of reactant used/products formed			
		2-propanol	Propylene	Acetone	CO <sub>2</sub> /3
100	0.12	3.29E-06	2.21E-10	3.96E-09	0.00E+00
150	0.05	3.37E-06	1.36E-09	2.45E-10	0.00E+00
200	0.06	3.57E-06	1.56E-09	3.31E-10	0.00E+00
250	3.98	3.23E-06	1.87E-08	1.10E-07	0.00E+00
300	26.65	2.34E-06	1.99E-07	6.94E-07	1.67E-08
350	57.53	1.31E-06	4.77E-07	1.31E-06	1.10E-07
400	73.67	4.17E-07	4.52E-07	1.56E-06	3.73E-07
450	73.14	3.27E-07	4.50E-07	1.62E-06	3.65E-07
500	72.70	2.35E-07	5.18E-07	1.57E-06	3.32E-07

**Table E8** Catalytic data of V<sub>2</sub>O<sub>5</sub>\_A1A2

Reaction temperature (°C)	% conversion 2-propanol	Mole of reactant used/products formed			
		2-propanol	Propylene	Acetone	CO <sub>2</sub> /3
100	0.29	3.33E-06	3.24E-09	6.38E-09	0.00E+00
150	1.87	3.10E-06	2.04E-08	4.03E-08	0.00E+00
200	4.94	2.98E-06	1.60E-08	1.50E-07	0.00E+00
250	13.82	2.65E-06	7.88E-08	3.90E-07	0.00E+00
300	49.10	1.71E-06	4.40E-07	1.17E-06	5.22E-08
350	88.95	4.75E-07	6.77E-07	1.74E-06	5.42E-07
400	84.36	2.27E-07	6.48E-07	1.56E-06	6.16E-07
450	100.07	2.17E-07	7.98E-07	1.84E-06	6.47E-07
500	83.52	1.30E-07	6.41E-07	1.57E-06	5.71E-07



**Table E9** Catalytic data of V<sub>2</sub>O<sub>5</sub>\_C1

Reaction temperature (°C)	% conversion 2-propanol	Mole of reactant used/products formed			
		2-propanol	Propylene	Acetone	CO <sub>2</sub> /3
100	0.02	3.26E-06	1.58E-10	6.07E-10	0.00E+00
150	0.13	3.17E-06	5.06E-10	3.76E-09	0.00E+00
200	5.52	3.15E-06	3.08E-09	1.80E-07	0.00E+00
250	14.31	2.85E-06	5.87E-08	4.32E-07	0.00E+00
300	36.44	2.21E-06	4.34E-07	7.74E-07	2.21E-08
350	76.04	8.97E-07	9.24E-07	1.56E-06	1.24E-07
400	92.99	2.68E-07	7.97E-07	1.46E-06	7.41E-07
450	93.73	2.77E-07	7.00E-07	1.71E-06	7.53E-07
500	91.21	5.83E-08	6.82E-07	1.62E-06	7.87E-07

## APPENDIX F

### MATERIAL SAFETY DATA SHEET

#### Vanadium (III) chloride

##### General

Synonyms: Vanadium (III) chloride

Molecular formula:  $\text{VCl}_3$

Chemical formula :  $\text{VCl}_3$

##### Stability

Conditions to be avoided: Strong heating.

Substances to be avoided: alkali metals, alkaline earth metals, aluminium in powder form, oxidizing agent, organic nitro compounds, aldehydes, amines, fuming sulfuric acid, phosgene.

Hazardous decomposition products: no information available.

Further information: highly inflammable; hygroscopic, explosive with air in a vapor/gas state.

##### Toxicology

Harmful if swallowed

Causes burn

##### Personal protection

Avoid contact with eyes.

Wear suitable protective clothing, gloves and eye/face protection

In case of accident or if you feel unwell, seek medical advice diately (show the label where possible)

## Vanadyl acetylacetonate

### General

Synonym: Vanadium(IV)-oxy acetylacetonate VO(acac)<sub>2</sub>

Molecular Formula: C<sub>10</sub>H<sub>14</sub>O<sub>5</sub>V

### Stability

Chemical Stability: Stable at room temperature in closed containers under normal storage and handling conditions. May discolor on exposure to air.

Conditions to Avoid: Incompatible materials, dust generation, excess heat, strong oxidants.

### Physical and chemical properties

Physical State : Crystals

Appearance : blue-green

Freezing/Melting Point : 256.00 - 259.00°C

Molecular Weight : 265.15

### Toxicology

Causes respiratory tract irritation. Irritant. Causes eye and skin irritation. May cause digestive tract irritation. Air sensitive.

### Personal Protection

Eyes: Wear appropriate protective eyeglasses or chemical safety goggles

Skin: Wear appropriate protective gloves to prevent skin exposure.

Clothing: Wear appropriate protective clothing to minimize contact with skin.

## Vanadium (V) oxide

### General

Synonyms: Vanadium pentoxide, vanadic anhydride, divanadium pentoxide

Molecular formula:  $V_2O_5$

Chemical formula :  $V_2O_5$

### Physical data

Appearance : yellow to rust-brown or orange crystals or powder

Melting point : 690 °C

Boiling point : 1750 °C

Vapour density : 6.3

Vapour pressure: effectively nil at 20 °C

Density ( $g\ cm^{-3}$ ): 3.36

Water solubility : slight

### Stability

Stable. Incompatible with chlorine, chlorates, acids, alkali metals, interhalogens.

### Toxicology

Extremely toxic. May be fatal if swallowed, inhaled or absorbed through skin. Note low LD50s below. May cause reproductive defects. May cause severe irritation or burns on contact. Typical TLV/TWA 0.05  $mg/m^3$ .

### Environmental information

Hazardous in the environment.

### Personal protection

Safety glasses, gloves, good ventilation.

## Titanium (IV) n-butoxide

### General

Synonyms: Tetra-n-butyl titanate; TNBT; Titanium(IV) n-butoxide (TYZOR TNBT); Tetra-n-butyl orthotitanate for synthesis; titanium tetrabutanolate; Titanium(IV)n-butoxide (TYZOR TBT); Butyl Titanate; Titaniumbutoxidecolorlessliq; Titanium n-butoxide; Titanium(IV)n-butoxide,99+%Tetra-n-utoxytitanium(IV)~Tetra-n-butylorthotitanate; Titanium tetrabutoxide; Triethoxy Methane; Titanium tetrabutylate; Orthotitanic acid tetrabutyl ester

Molecular formula:  $C_{16}H_{36}O_4Ti$

Chemical formula:  $Ti[O(CH_2)_3CH_3]_4$

### Physical data

Boiling point: 310-314 °C

Flash point : 78°C

Density : 1.486 g/cm<sup>3</sup>

### Toxicology

Irritating to eyes, respiratory system and skin.

### Personal protection

Avoid contact with skin and eyes.



## Tetrapropylammonium bromide

### General

Synonyms: 1-Propanaminium, N, N, N-tripropyl, bromide or Tetra-n-propylammonium bromide or TPBr or TPABr

Molecular formula:  $C_{12}H_{28}N.Br$

Chemical formula :  $(C_3H_7)_4NBr$

### Physical data

Solubility in Water: 60% (20 °C)

pH : 5 - 10 for solution

Melting Point : 275-278 °C (decomposes)

### Stability and reactivity

Stable at ambient temperatures. Do not expose to high temperatures.  
Oxidizers should be tested for compatibility before use.

### Hazardous decomposition

In fire conditions: Carbon monoxide, Hydrobromic acid and Nitrogen oxides.  
If heated to decomposition, tripropylamine may be released.

### Potential health effect

Inhalation : May cause irritation.

Eye Contact : May cause irritation.

Skin Contact : May cause irritation.

Ingestion : No toxicity or other health effects information available.

Chronic : May cause irritation. No additional information available.

**First aid measure**

Inhalation: Remove to fresh air. If breathing has stopped, give artificial respiration. Consult a physician.

Eye Contact: Immediately flush with water until no evidence of chemical remains (at least 15-20 minutes) and consult a physician.

Skin Contact: Immediately flush with water with sufficient volume until there is no evidence of the chemical on the affected area.

Ingestion: If person is conscious and able to swallow, have them drink a large volume of water and milk and induce vomiting. Contact a physician.

**Fire fighting measures**

Wear S.C.B.A. May use water spray, carbon dioxide, dry chemical or chemical foam to fight fire.

**Hazardous product combustion**

May emit Nitrogen oxides, Hydrobromic acid and Carbon monoxide.

## Sodium chloride

### General

Synonyms: extra fine 200 salt, extra fine 325 salt, H.G. blending, salt, sea salt, table salt, common salt, dendritis, rock salt, top flake, white crystal, saline, halite, purex, USP sodium chloride

Molecular formula: NaCl

### Physical data

Appearance : colorless crystals or white powder

Melting point : 804 °C

Boiling point : 1413 °C

Vapor pressure : 1 mm Hg at 865°C

Specific gravity : 2.16 g cm<sup>-3</sup>

Solubility in water : 35.7 g/100g at °C

### Stability

Stable. Incompatible with strong oxidizing agents.

### Toxicology

May cause skin, eye or respiratory irritation.

### Personal protection

Not believed to present a significant hazard to health.

## Sodium hydroxide

### General

Synonyms: caustic soda, soda lye, lye, white caustic, aetznatron, ascarite, Collo-Grillrein, Collo-Tapetta, sodium hydrate, fotofoil etchant, NAOH, STCC 4935235, sodium hydroxide pellets, Lewis red devil lye

Molecular formula: NaOH

### Physical data

Appearance : colorless white solid (often sold as pellets)

Melting point : 318 °C

Boiling point : 1390 °C

Vapor pressure : 1 mm Hg at 739 °C

Specific gravity : 2.12 g cm<sup>-3</sup>

Water solubility : high (Note: dissolution in water is highly exothermic)

### Stability

Stable. Incompatible with a wide variety of materials including many metals, ammonium compounds, cyanides, acids, nitro compounds, phenols, combustible organics. Hygroscopic. Heat of solution is very high and may lead to a dangerously hot solution if small amounts of water are used. Absorbs carbon dioxide from the air.

### Toxicology

Very corrosive. Causes severe burns. May cause serious permanent eye damage. Very harmful by ingestion. Harmful by skin contact or by inhalation of dust.

### Personal protection

Safety glasses, adequate ventilation, Neoprene or PVC gloves.

## Sodium silicate

### General

Synonyms: silicic acid sodium salt, water glass, sodium water glass, soluble glass, silicate of soda, silicon sodium oxide, sodium orthosilicate, sodium sesquisilicate, sodium silicate glass, agrosil S, barasil S, britesil, carsil 2000, chemfin 60, chemsilicate, crystal 79, crystal 96, ineos 140, inosil Na 4237, portil A, pyramid 8, vitrosol N40, ZhS 3, very large number of further trade names

Molecular formula:  $\text{Na}_4\text{O}_4\text{Si}$

### Physical data

Appearance : colourless liquid as usually supplied (solution)

Boiling point : ca. 102 °C for a 40% aqueous solution

Specific gravity: approximately 1.3 for a ca. 40% solution

### Stability

Stable. Incompatible with acids, most metals, many organic materials.

### Toxicology

Harmful by ingestion. Corrosive - may cause burns through skin or eye contact. Very destructive of mucous membranes.

### Personal protection

Safety glasses, gloves.



## 2-Propanol

### General

Synonyms: Isopropanol, Isopropyl alcohol

Molecular formula: C<sub>3</sub>H<sub>8</sub>O

Chemical formula: CH<sub>3</sub>CH(OH)CH<sub>3</sub>

### Physical data

Melting point	: -89.5°C
Boiling point	: 82.4 °C
Ignition temperature	: 425°C
Flash point	: 12°C
Explosion limits	: 2 % - 12.7 %
Vapor pressure	: 31.68 mm (14.7°C)
Relative vapor density	: 2.07
Density	: 0.786 g/ml (20°C)
Solubility in water	: soluble (20°C)

### Stability

Conditions to be avoided: Strong heating.

Substances to be avoided: alkali metals, alkaline earth metals, aluminium in powder form, oxidizing agent, organic nitro compounds, aldehydes, amines, fuming sulfuric acid, phosgene.

Hazardous decomposition products: no information available.

Further information: highly inflammable; hygroscopic, explosive with air in a vapor/gas state.

### Toxicology

Further toxicological information

After inhalation: Irritation symptoms in the respiratory tract Drowsiness

After skin contact: degreasing effect on the skin possibly followed by secondary inflammation.

After eye contact: Irritations.

After swallowing: after accidental swallowing the substance may pose a risk of aspiration. Passage into the lung can result in a condition resembling pneumonia

After absorption: headache, dizziness, inebriation

After uptake of large quantities: respiratory paralysis, coma.

### **Personal protection**

Personal protective equipment: Protective clothing should be selected specifically for the working place, depending on concentration and quantity of the hazardous substances handled. The resistance of the protective clothing to chemicals should be ascertained with the respective supplier.

Industrial hygiene: Change contaminated clothing. Application of Skin-protective barrier cream recommended. Should be wash hands after working with substance.



## Sulfuric acid

### General

Synonyms: oil of vitriol, mattling acid, vitriol, battery acid, dipping acid, electrolyte acid, vitriol brown oil, sulphuric acid

Molecular formula:  $\text{H}_2\text{SO}_4$

### Physical data

Appearance : colorless oily liquid

Melting point :  $-2\text{ }^\circ\text{C}$

Boiling point :  $327\text{ }^\circ\text{C}$

Specific gravity :  $1.84\text{ g cm}^{-3}$

Vapor pressure :  $<0.3\text{ mm Hg at }20\text{ }^\circ\text{C}$  (vapor density 3.4)

Water solubility: miscible in all proportions

### Stability

Stable, but reacts with moisture very exothermically, which may enhance its ability to act as an oxidizing agent. Substances to be avoided include water, most common metals, organic materials, strong reducing agents, combustible materials, bases, oxidising agents. Reacts violently with water - when diluting concentrated acid, carefully and slowly add acid to water, not the reverse. Reaction with many metals is rapid or violent, and generates hydrogen (flammable, explosion hazard).

### Toxicology

Extremely corrosive, causes serious burns. Highly toxic. Harmful by inhalation, ingestion and through skin contact. Ingestion may be fatal. Skin contact can lead to extensive and severe burns. Chronic exposure may result in lung damage and possibly cancer.

**Personal protection**

Safety glasses or face mask; acid-resistant gloves. Suitable ventilation. In the UK use of this material must be assessed under the COSHH regulations.

## APPENDIX G

### LIST OF PUBLICATION

Karittha Im-orb, Rattanawalee Sunphloi, and Tharathon Mongkhonsi  
“Preparation of vanadium titanium silicalite-1”, Proceedings of Thai Institute of  
Chemical Engineering and Applied Chemical Conference 16<sup>th</sup>, Bangkok, Thailand, Oct,  
2006, Ref. No.CRE-008.

Karittha Im-orb and Tharathon Mongkhonsi “Synthesis methodology affecting  
the vanadium titanium silicalite-1”, 7<sup>th</sup> National Graduate Research Conference: GRAD-  
RESEARCH 2007, Surat Thani, Thailand, April, 4-5, 2007, Ref. No.O-30-Phys.



## VITA

Miss Karittha Im-orb was born on December 16<sup>th</sup>, 1982 in Loei, Thailand. She finished high school from Loeipittayakom School in 2001, and received the bachelor's degree of Chemical Engineering from Faculty of Engineer, King Mongkut's Institute of Technology Ladkrabang in 2005. She continued her master's study at Department of Chemical Engineering, Faculty of Engineering, Chulalongkorn University in June, 2005.

