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# APPENDICES

## Appendix A

### Pre Laboratory Test

**Stone testes**

**Test 1:** No washed in tap water and place in DI water.

Lime stone

| Sample no. | pH | Alk (mg/l as $CaCO_3$) |
|---|---|---|
| 1 | 7.30 | 40 |
| 2 | 7.24 | 40 |

Spinel mineral

| Sample no. | pH | Alk (mg/l as $CaCO_3$) |
|---|---|---|
| 1 | 7.25 | 30 |
| 2 | 7.23 | 30 |

**Test 2:** Washed in tap water before placed in DI water

Lime stone

| Sample no. | pH | Alk (mg/l as $CaCO_3$) |
|---|---|---|
| 1 | 7.51 | 60 |
| 2 | 7.46 | 60 |

Spinel mineral

| Sample no. | pH | Alk (mg/l as $CaCO_3$) |
|---|---|---|
| 1 | 7.34 | 30 |
| 2 | 7.28 | 30 |

**Test 3:** No washed in tap water and place in pH 5 solution.

Lime stone

| Sample no. | pH | Alk (mg/l as $CaCO_3$) | Wt Diff (g) |
|---|---|---|---|
| 1 | 5.49 | 11,800 | 2.05 |
| 2 | 5.44 | 12,000 | 1.71 |

Spinel mineral

| Sample no. | pH | Alk (mg/l as $CaCO_3$) | Wt Diff (g) |
|---|---|---|---|
| 1 | 5.07 | 4,740 | 0.3 |
| 2 | 5.06 | 4,680 | 0.35 |

**Test 4:** Washed in tap water before placed in pH 5 solution.

Lime stone

| Sample no. | pH | Alk (mg/l as $CaCO_3$) | Wt Diff (g) |
|---|---|---|---|
| 1 | 5.46 | 11,000 | 1.91 |
| 2 | 5.48 | 11,500 | 1.61 |

Spinel mineral

| Sample no. | pH | Alk (mg/l as $CaCO_3$) | Wt Diff (g) |
|---|---|---|---|
| 1 | 5.07 | 4,490 | 0.43 |
| 2 | 5.07 | 4,430 | 0.45 |

## Appendix B

### Qualities of Dewatered Sludge

| | |
|---|---|
| BOD | 8.7 mg/L |
| COD | 760,000 mg/L |
| Alkalinity | 2,060 mg/L as $CaCO_3$ |
| Moisture Content | 90% of sludge |
| Total Solid (TS) | 10% of sludge |
| Total Volatile Solid (TVS) | 20% of TS |
| Void Space (water/mixture) | 0.5 |
| Void Space (water/stone) | 0.3 |
| pH | 6.5 |

## Appendix C

The data of Experiment startup and operation

| Before added Zinc | ORP | | $SO_4^{2-}$ (ml/l) | | $S^{2-}$ (mg/l) | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| 1 | 35 | 10.1 | 20.74 | 19.29 | 0.37 | 0.12 |
| 2 | 20.1 | 7.3 | 18.89 | 19.01 | 0.88 | 0.57 |
| 3 | 18.2 | 5.1 | 17.67 | 18.94 | 0.97 | 0.71 |
| 4 | 13.9 | 1.7 | 15.21 | 18.73 | 1.13 | 0.87 |
| 5 | 2.9 | -5.3 | 12.29 | 17.54 | 1.16 | 0.93 |
| 6 | -2.6 | -8.5 | 11.98 | 17.32 | 1.98 | 3.12 |
| 7 | -5.9 | -20.9 | 11.59 | 16.97 | 2.21 | 4.69 |
| 8 | -20.5 | -30.2 | 11.38 | 15.58 | 3.17 | 5.94 |
| 9 | -25.2 | -34.1 | 11.11 | 15.28 | 3.49 | 6.45 |
| 10 | -35.8 | -40.4 | 10.86 | 14.89 | 4.68 | 7.14 |
| 11 | -40.2 | -44.7 | 10.38 | 14.31 | 5.01 | 8.89 |
| 12 | -48.1 | -53.4 | 10.15 | 13.75 | 4.89 | 10.89 |
| 13 | -52.9 | -60.3 | 9.92 | 12.89 | 6.97 | 10.93 |
| 14 | -56.2 | -63.2 | 9.91 | 12.85 | 7.05 | 11.98 |
| 15 | -59.6 | -69.4 | 9.52 | 12.19 | 7.11 | 12.21 |
| 16 | -64.1 | -77.9 | 9.21 | 11.87 | 7.69 | 12.89 |
| 17 | -66.8 | -79.2 | 8.75 | 11.07 | 7.54 | 13.37 |
| 18 | -68.4 | -80.2 | 8.39 | 10.39 | 8.15 | 13.54 |
| 19 | -87.1 | -90.3 | 8.32 | 10.08 | 9.02 | 15.76 |
| 20 | -89.1 | -94.7 | 7.68 | 8.17 | 9.45 | 16.45 |
| 21 | -89.3 | -100.7 | 6.87 | 7.69 | 10.77 | 21.71 |
| 22 | -91.2 | -100.9 | 6.55 | 7.44 | 10.87 | 22.43 |
| 23 | -94.3 | -109.7 | 6.49 | 6.87 | 10.94 | 22.56 |
| 24 | -95.5 | -114.8 | 5.89 | 6.12 | 12.83 | 24.21 |
| 25 | -100.8 | -122.8 | 4.32 | 5.78 | 12.98 | 24.12 |
| 26 | -100.1 | -122.9 | 4.19 | 5.12 | 12.68 | 27.43 |
| 27 | -100.5 | -125.7 | 4.18 | 4.99 | 12.75 | 27.63 |
| 28 | -99.2 | -124.7 | 4.11 | 4.78 | 12.71 | 27.58 |
| 29 | -99.9 | -122.9 | 4.12 | 4.83 | 12.68 | 27.65 |
| 30 | -100.8 | -123.4 | 4.21 | 4.73 | 12.76 | 27.61 |
| 31 | -100.2 | -124.9 | 4.18 | 4.85 | 12.72 | 27.59 |

The data of Experiment startup and operation (cont.)

| **Before added Zinc** | **Phosphate (mg/L)** | | **$NH_3$ (mh/L)** | | **COD (mg/L)** | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| 1 | | | | | 5460 | 6130 |
| 2 | 195.8 | 235.7 | 226.7 | 271.9 | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | 5410 | 6110 |
| 10 | | | | | | |
| 11 | | | | | | |
| 12 | | | | | | |
| 13 | | | | | | |
| 14 | | | | | | |
| 15 | | | | | | |
| 16 | | | | | | |
| 17 | | | | | | |
| 18 | | | | | | |
| 19 | | | | | 5420 | 6080 |
| 20 | | | | | | |
| 21 | | | | | | |
| 22 | | | | | | |
| 23 | | | | | | |
| 24 | | | | | | |
| 25 | | | | | 5430 | 6090 |
| 26 | | | | | | |
| 27 | 189.8 | 222.8 | 218.2 | 265.7 | | |
| 28 | | | | | | |
| 29 | | | | | | |
| 30 | 184.6 | 219.9 | 214.9 | 255.6 | | |
| 31 | | | | | 5400 | 6090 |

The data of Experiment startup and operation (cont.)

| Before added Zinc | pH | | Gas (mL) | | Alkalinity (mg/L) | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| 1 | 7.12 | 7.04 | | | 769.1 | 819.2 |
| 2 | 7.04 | 7.11 | | | | |
| 3 | 7.11 | 7.06 | | | | |
| 4 | 7.09 | 7.14 | | | | |
| 5 | 7.19 | 7.04 | | 10 | | |
| 6 | 7.15 | 7.09 | | | | |
| 7 | 7.17 | 7.18 | | | | |
| 8 | 7.04 | 7.13 | | | | |
| 9 | 7.08 | 7.02 | 5 | 10 | | |
| 10 | 7.11 | 7.06 | | | 761.3 | 809.1 |
| 11 | 7.06 | 7.11 | | | | |
| 12 | 7.13 | 7.02 | 10 | 10 | | |
| 13 | 7.05 | 7.08 | | | | |
| 14 | 7.12 | 7.11 | | | | |
| 15 | 7.09 | 7.06 | 10 | 10 | | |
| 16 | 7.12 | 7.03 | | | | |
| 17 | 7.07 | 7.09 | | | 758.8 | 805.3 |
| 18 | 7.02 | 7.11 | 10 | 10 | | |
| 19 | 7.09 | 7.05 | | | | |
| 20 | 7.12 | 7.02 | | | | |
| 21 | 7.02 | 7.06 | 10 | 10 | | |
| 22 | 7.08 | 7.12 | | | | |
| 23 | 7.03 | 7.03 | | | | |
| 24 | 7.12 | 7.09 | | | 755.3 | 801.4 |
| 25 | 7.06 | 7.02 | 10 | 10 | | |
| 26 | 7.09 | 7.11 | | | | |
| 27 | 7.12 | 7.14 | | | | |
| 28 | 7.09 | 7.02 | 10 | 10 | | |
| 29 | 7.15 | 7.07 | | | | |
| 30 | 7.07 | 7.13 | 10 | 10 | | |
| 31 | 7.06 | 7.07 | | | 751.2 | 793.1 |

## Appendix D

The data after the first addition of 10 mg/L of Zinc.

| Added Of Zinc 10ppm | pH | | ORP | | Conc. Of Zinc (mg/l) | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| Control | 7.06 | 7.11 | -101.2 | -122.9 | 0.81 | 0.97 |
| 10 min | 7.05 | 7.1 | -101.3 | -122.5 | 0.78 | 0.95 |
| 30 min | 7.09 | 7.12 | -100.1 | -121.3 | 0.81 | 0.99 |
| 1h | 7.01 | 7.05 | -99.5 | -121.3 | 0.81 | 1.04 |
| 1.5h | 6.95 | 7.08 | -99.3 | -121.5 | 0.83 | 1.08 |
| 2h | 7.03 | 6.99 | -98.1 | -120.1 | 0.82 | 1.07 |
| 3h | 6.98 | 7.07 | -97.3 | -117.3 | 0.85 | 1.11 |
| Day 2 | 7.07 | 7.04 | -98.8 | -115.2 | 0.91 | 1.04 |
| Day 3 | 7.02 | 7.11 | -100.1 | -112.8 | 0.92 | 0.99 |
| Day 4 | 7.1 | 7.05 | -101.5 | -118.5 | 0.86 | 1.02 |
| Day 5 | 7.05 | 7.04 | -100.1 | -120.9 | 0.89 | 0.97 |
| Day 6 | 7.09 | 7.09 | -100.5 | -119.5 | 0.92 | 1.04 |
| Day 7 | 7.01 | 7.11 | -99.8 | -119.1 | 0.87 | 1.01 |

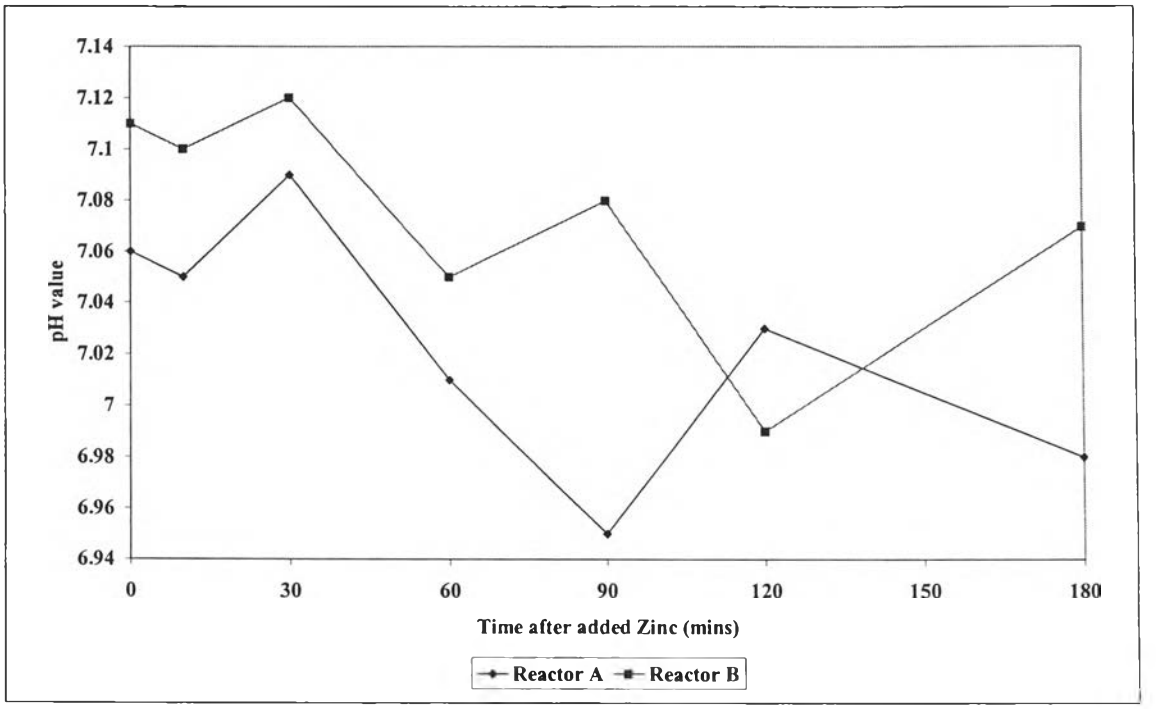
| Added Of Zinc 10ppm | $SO_4^{2-}$ (ml/l) | | $S^{2-}$ (mg/l) | |
|---|---|---|---|---|
| | A | B | A | B |
| Control | 4.22 | 4.71 | 12.73 | 27.58 |
| 10 min | 4.49 | 4.9 | 12.71 | 27.51 |
| 30 min | 4.66 | 5.32 | 12.34 | 26.72 |
| 1h | 5.23 | 5.71 | 12.01 | 26.17 |
| 1.5h | 5.84 | 6.52 | 11.83 | 25.80 |
| 2h | 6.51 | 7.12 | 11.28 | 25.11 |
| 3h | 7.23 | 8.20 | 10.55 | 24.31 |
| Day 2 | 6.38 | 8.09 | 10.76 | 24.12 |
| Day 3 | 6.12 | 8.28 | 11.11 | 24.69 |
| Day 4 | 6.34 | 8.11 | 11.02 | 24.11 |
| Day 5 | 6.55 | 8.28 | 11.05 | 23.89 |
| Day 6 | 6.21 | 8.31 | 10.91 | 24.43 |
| Day 7 | 6.49 | 8.01 | 11.56 | 24.09 |

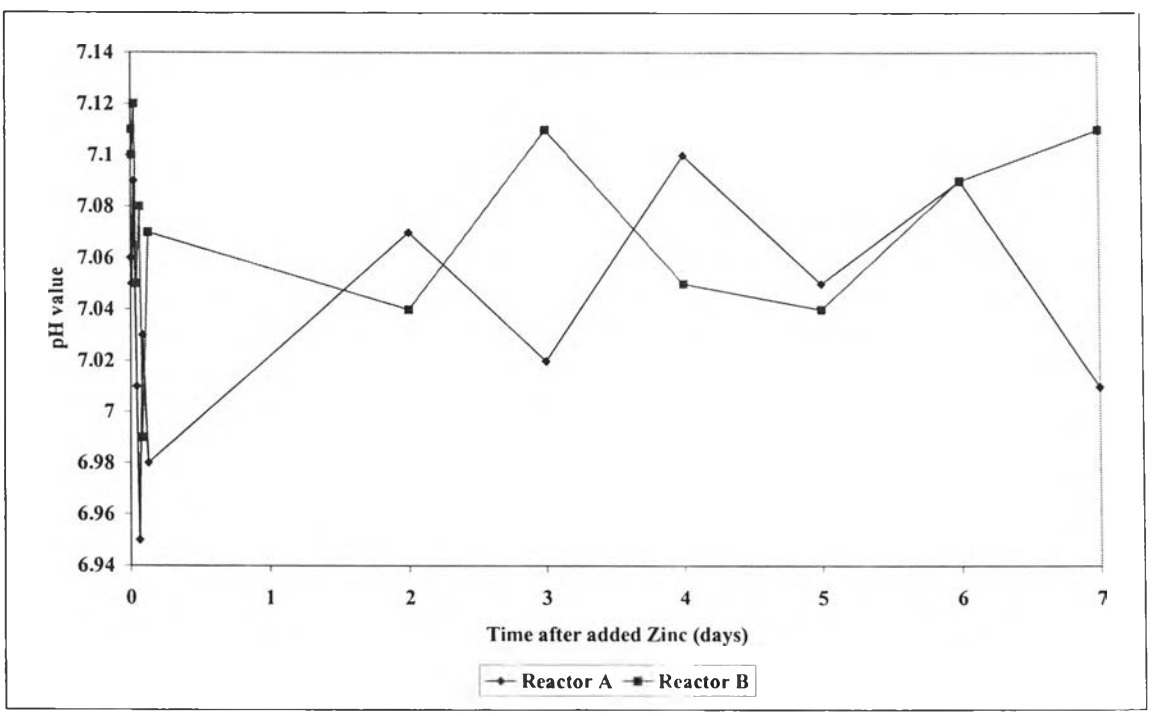
The data after the first addition of 10 mg/L of Zinc (Cont.).

| **Added Of Zinc 10ppm** | **PO4 (mg/L)** | | **$NH_{3\ (mg/L)}$** | | **COD (mg/L)** | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| Control | 184.5 | 219.7 | 214.9 | 255.6 | 5410 | 6110 |
| 10 min | | | | | | |
| 30 min | | | | | | |
| 1h | | | | | | |
| 1.5h | | | | | | |
| 2h | | | | | | |
| 3h | | | | | | |
| Day 2 | 183.9 | 219.2 | 214.6 | 254.7 | | |
| Day 3 | | | | | 5400 | 6100 |
| Day 4 | | | | | | |
| Day 5 | 184.5 | 218.6 | 213.8 | 254.8 | | |
| Day 6 | | | | | 5380 | 6080 |
| Day 7 | 183.5 | 218.2 | 213.1 | 254.1 | | |

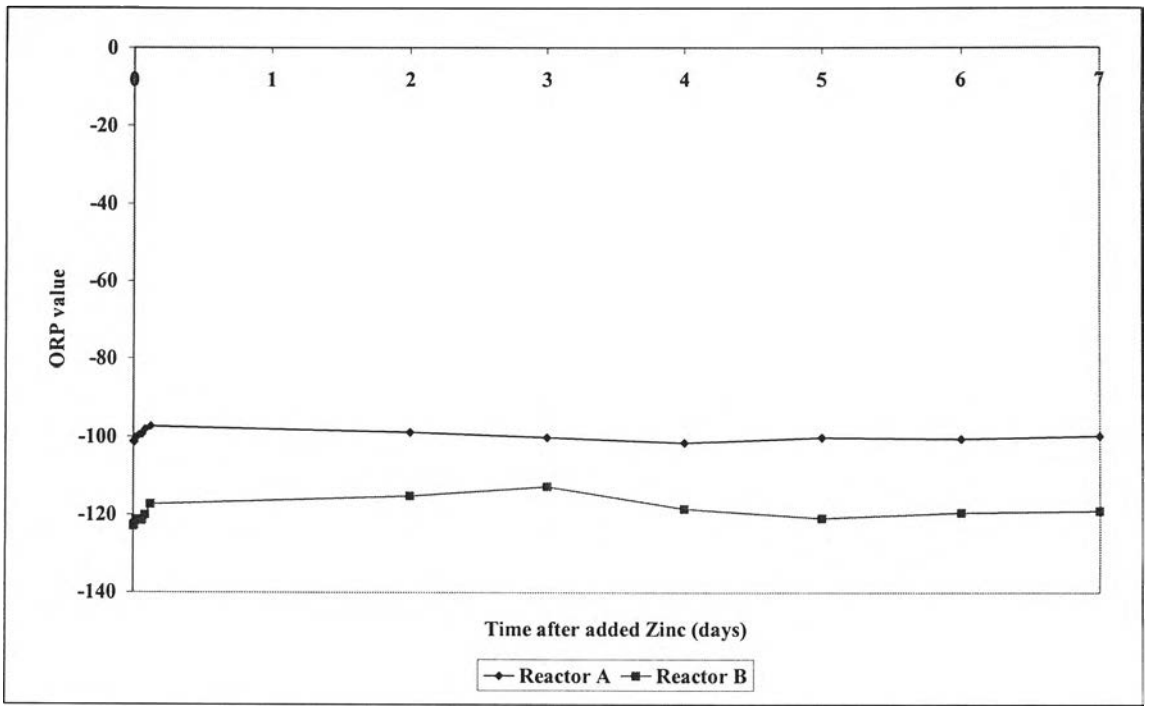
| **Added Of Zinc 10ppm** | **Gas (mL)** | | **Alkalinity (mg/L)** | |
|---|---|---|---|---|
| | A | B | A | B |
| Control | 10 | 5 | 750.8 | 792.9 |
| 10 min | | | | |
| 30 min | | | | |
| 1h | | | | |
| 1.5h | | | | |
| 2h | | | | |
| 3h | | | | |
| Day 2 | 5 | 5 | | |
| Day 3 | | | | |
| Day 4 | 10 | 10 | | |
| Day 5 | | | | |
| Day 6 | 5 | 10 | | |
| Day 7 | | | 748.3 | 792.1 |

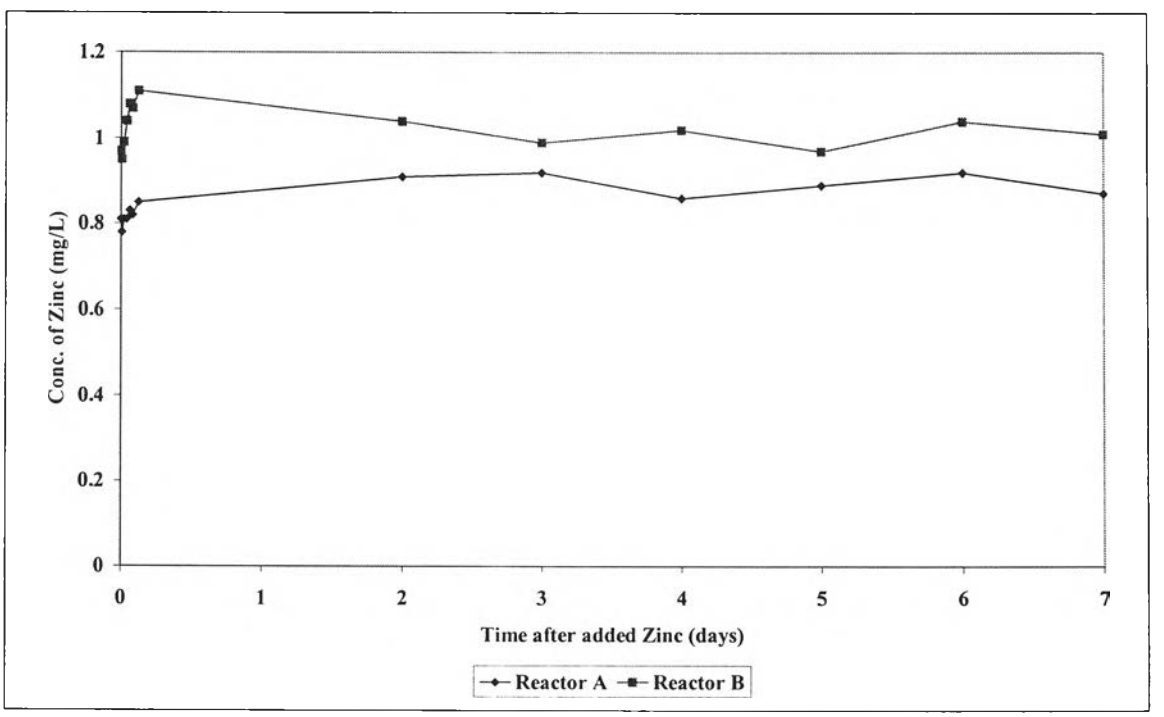
The result after the first addition of 10 mg/L of Zinc.



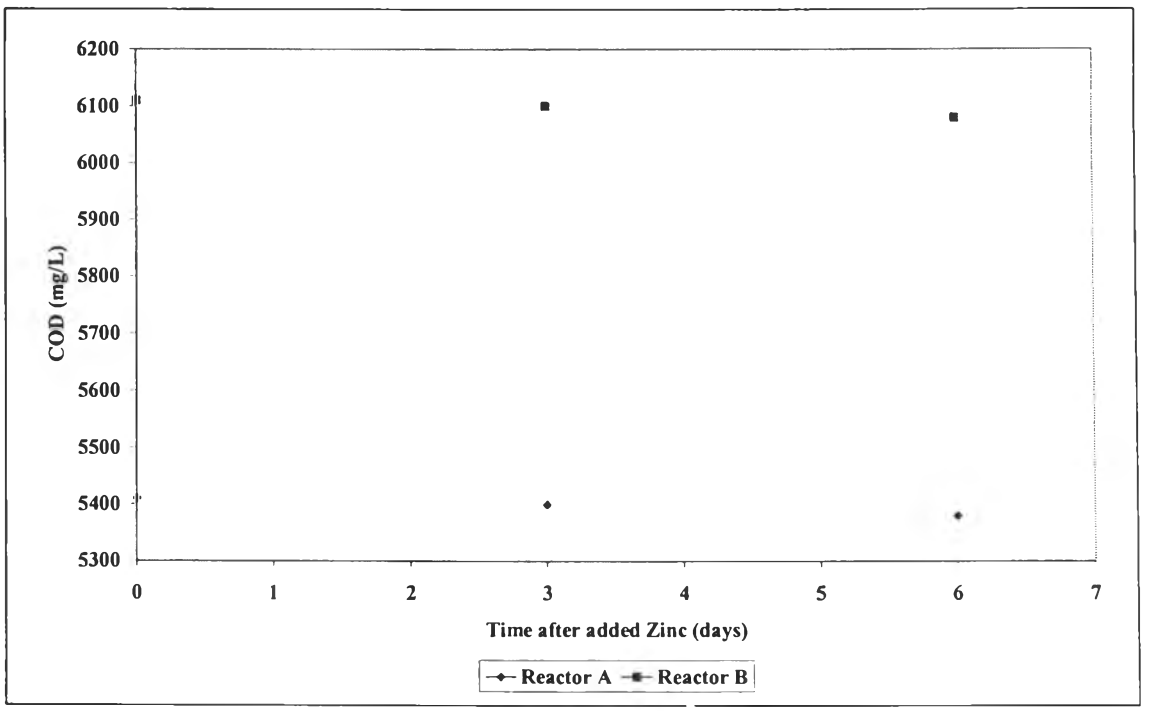



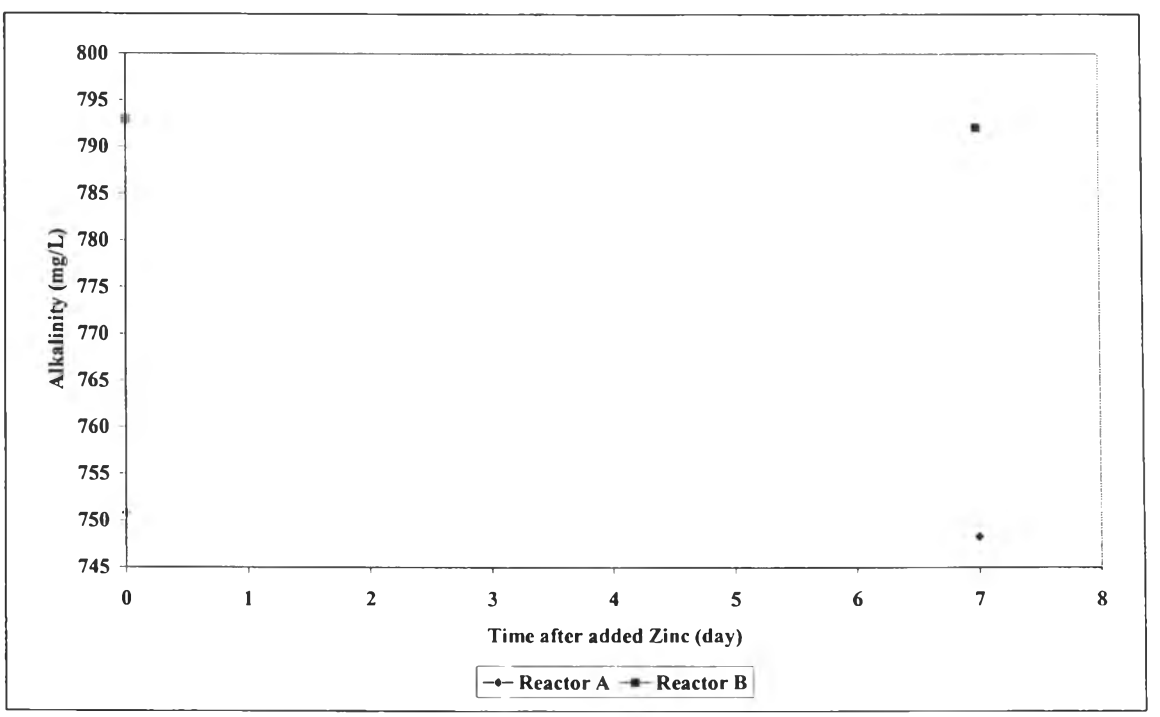
The result after the first addition of 10 mg/L of Zinc (Cont.).



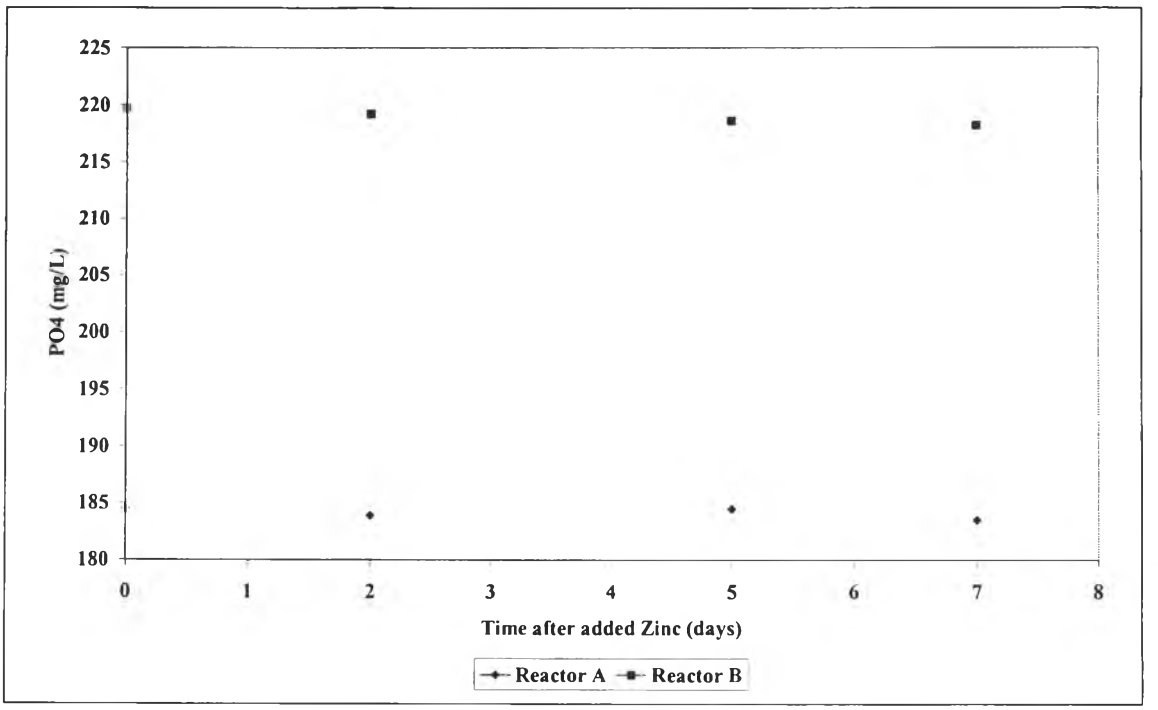



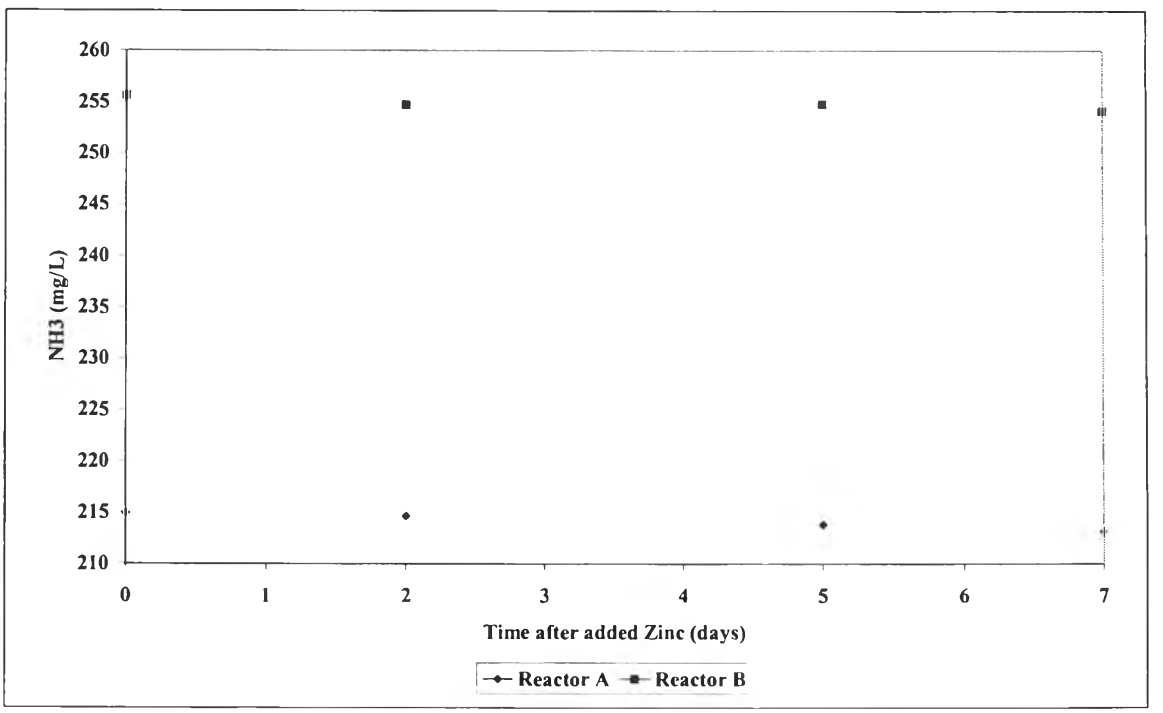
The result after the first addition of 10 mg/L of Zinc (Cont.).



The result after the first addition of 10 mg/L of Zinc (Cont.).



## Appendix E

The data after the second addition of 50 mg/L of Zinc.

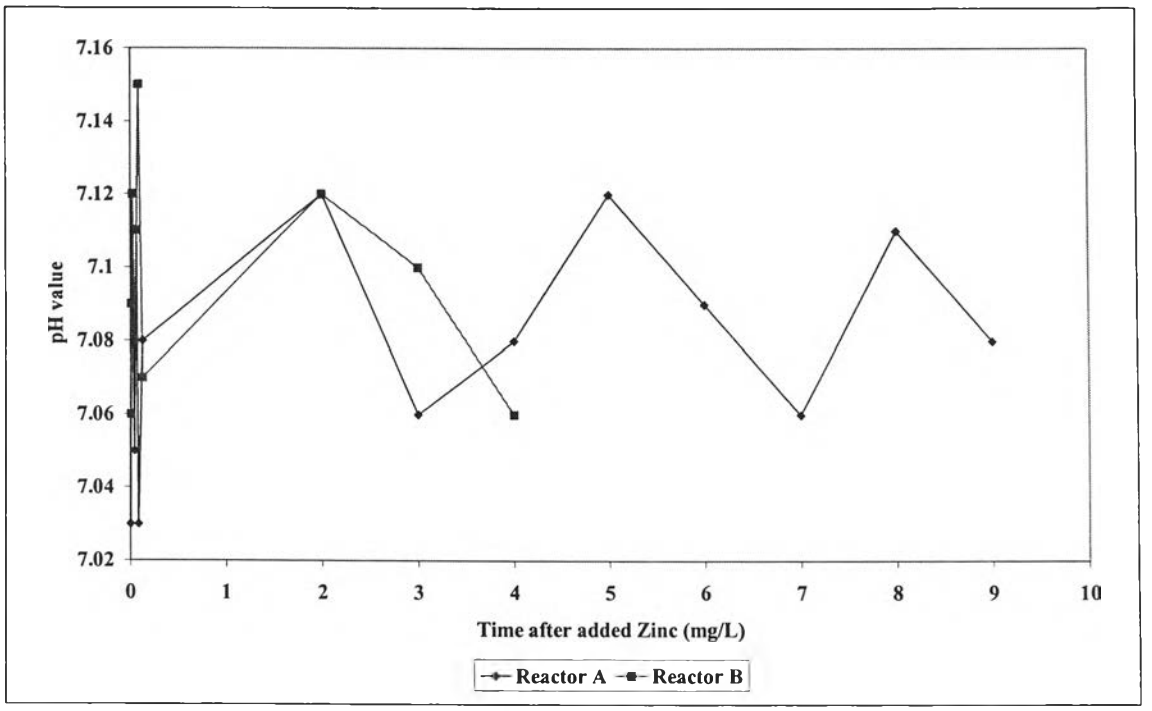
| 50ppm 1st | pH | | ORP | | $SO_4^{2-}$ (ml/l) | | $S^{2-}$ (mg/l) | |
|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B |
| Control | 7.03 | 7.09 | -100.2 | -119.9 | 6.45 | 7.98 | 11.49 | 24.12 |
| 10 min | 7.09 | 7.06 | -99.9 | -119.1 | 6.4 | 7.91 | 11.44 | 24.08 |
| 30 min | 7.12 | 7.12 | -98.8 | -118.7 | 6.49 | 7.97 | 11.31 | 24.16 |
| 1h | 7.05 | 7.08 | -99.3 | -119.4 | 6.43 | 7.93 | 11.39 | 24.02 |
| 1.5h | 7.11 | 7.11 | -98.8 | -120.1 | 6.36 | 7.86 | 11.14 | 24.08 |
| 2h | 7.03 | 7.15 | -99.1 | -118.6 | 6.42 | 7.91 | 11.2 | 23.97 |
| 3h | 7.08 | 7.07 | -99 | -118.2 | 6.39 | 7.88 | 11.13 | 24.01 |
| Day 2 | 7.12 | 7.12 | -98.6 | -119.4 | 6.33 | 7.81 | 11.25 | 24.09 |
| Day 3 | 7.06 | 7.1 | -99.1 | -119.8 | 6.29 | 7.76 | 11.19 | 24.02 |
| Day 4 | 7.08 | 7.06 | -99.5 | -120.4 | 6.31 | 7.81 | 11.16 | 24.29 |
| Day 5 | 7.12 | | -98.9 | | 6.37 | | 11.14 | |
| Day 6 | 7.09 | | -99.2 | | 6.32 | | 11.09 | |
| Day 7 | 7.06 | | -99.1 | | 6.29 | | 11.01 | |
| Day 8 | 7.11 | | -98.8 | | 6.28 | | 10.97 | |
| Day 9 | 7.08 | | -98.7 | | 6.25 | | 11.07 | |

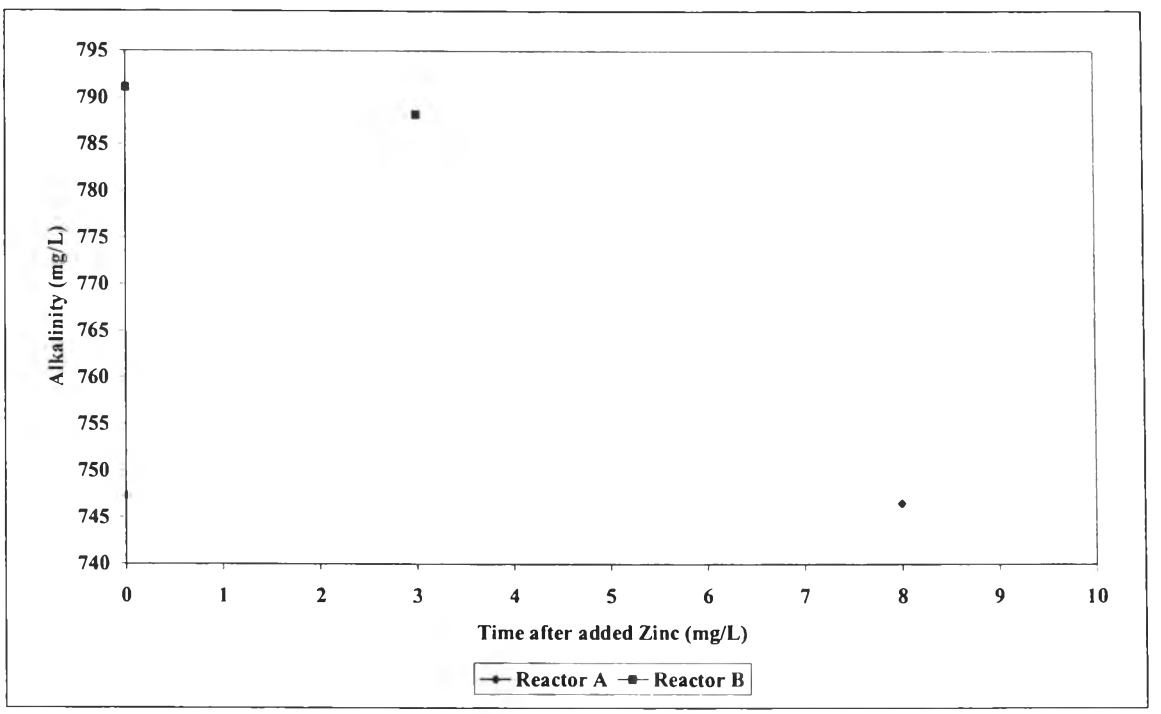
| 50ppm 1st | Conc. Of Zinc (mg/l) | | PO4 | | $NH_3$ | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| Control | 0.85 | 1.03 | 183.5 | 218.1 | 213.1 | 254.0 |
| 10 min | 0.87 | 1.07 | | | | |
| 30 min | 0.92 | 1.09 | | | | |
| 1h | 10.43 | 13.12 | | | | |
| 1.5h | 19.12 | 14.89 | | | | |
| 2h | 22.76 | 14.02 | | | | |
| 3h | 23.12 | 13.89 | | | | |
| Day 2 | 24.12 | 8.12 | | | | |
| Day 3 | 24.17 | 5.59 | | | | |
| Day 4 | 24.13 | 5.02 | | 215.8 | | 253.8 |
| Day 5 | 24.16 | | 179.9 | | | |
| Day 6 | 24.10 | | | | 211.2 | |
| Day 7 | 24.24 | | | | | |
| Day 8 | 24.19 | | | | | |
| Day 9 | 24.15 | | 176.4 | | 212.3 | |

The data after the second addition of 50 mg/L of Zinc (Cont.).

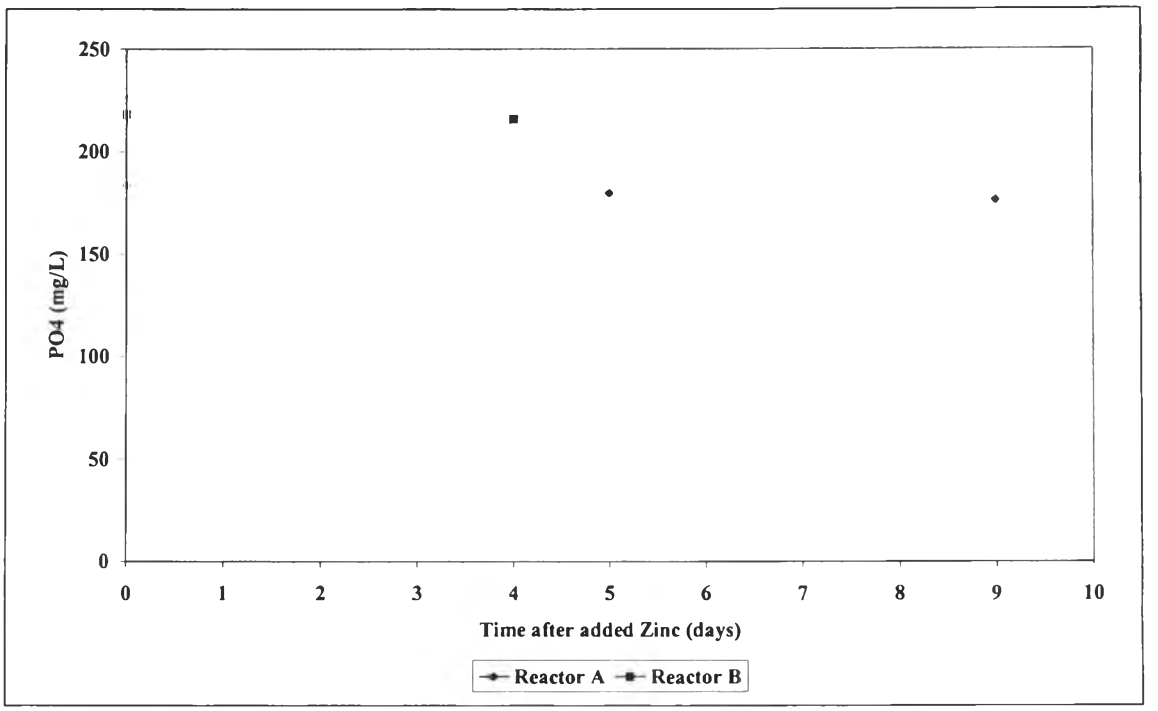
| **50ppm 1st** | **Gas (mL)** | | **COD** | | **Alkalinity** | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| Control | 5 | 10 | 5370 | 6060 | 747.3 | 791.1 |
| 10 min | | | | | | |
| 30 min | | | | | | |
| 1h | | | | | | |
| 1.5h | | | | | | |
| 2h | | | | | | |
| 3h | | | | | | |
| Day 2 | 5 | 5 | | | | |
| Day 3 | | | | | | 788.2 |
| Day 4 | 10 | 5 | | 6040 | | |
| Day 5 | | | | | | |
| Day 6 | 10 | | 5350 | | | |
| Day 7 | | | | | | |
| Day 8 | 5 | | | | 746.5 | |
| Day 9 | 5 | | 5310 | | | |

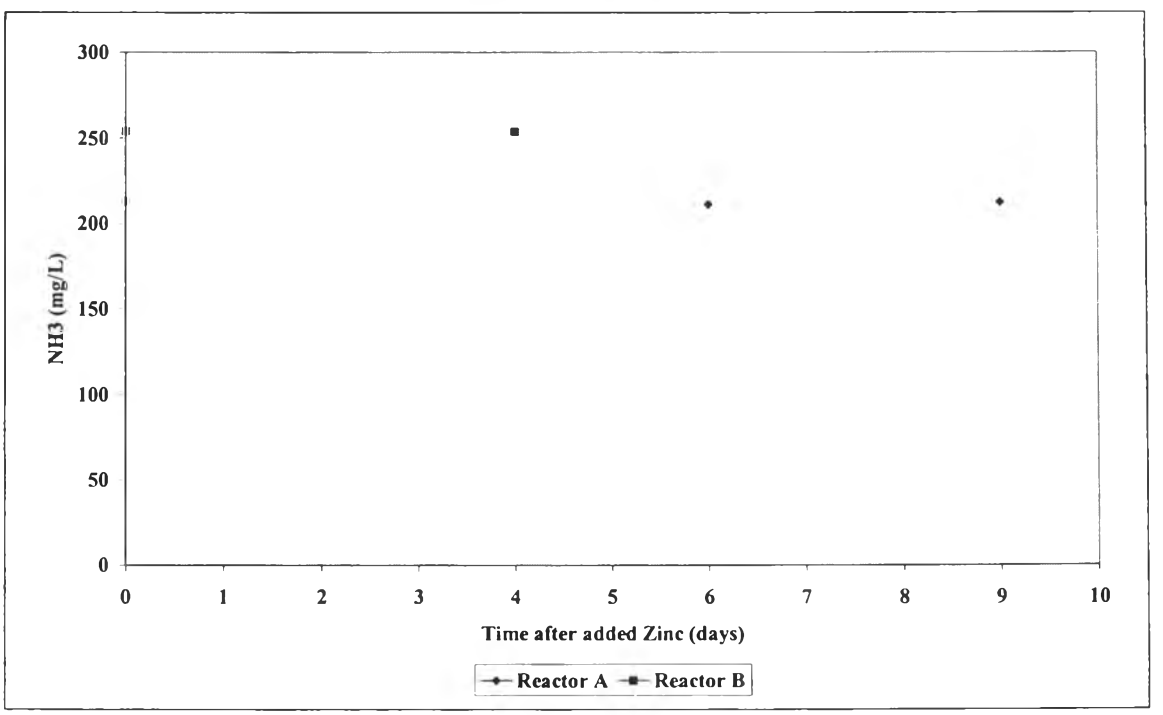
The result after the second addition of 50 mg/L of Zinc.



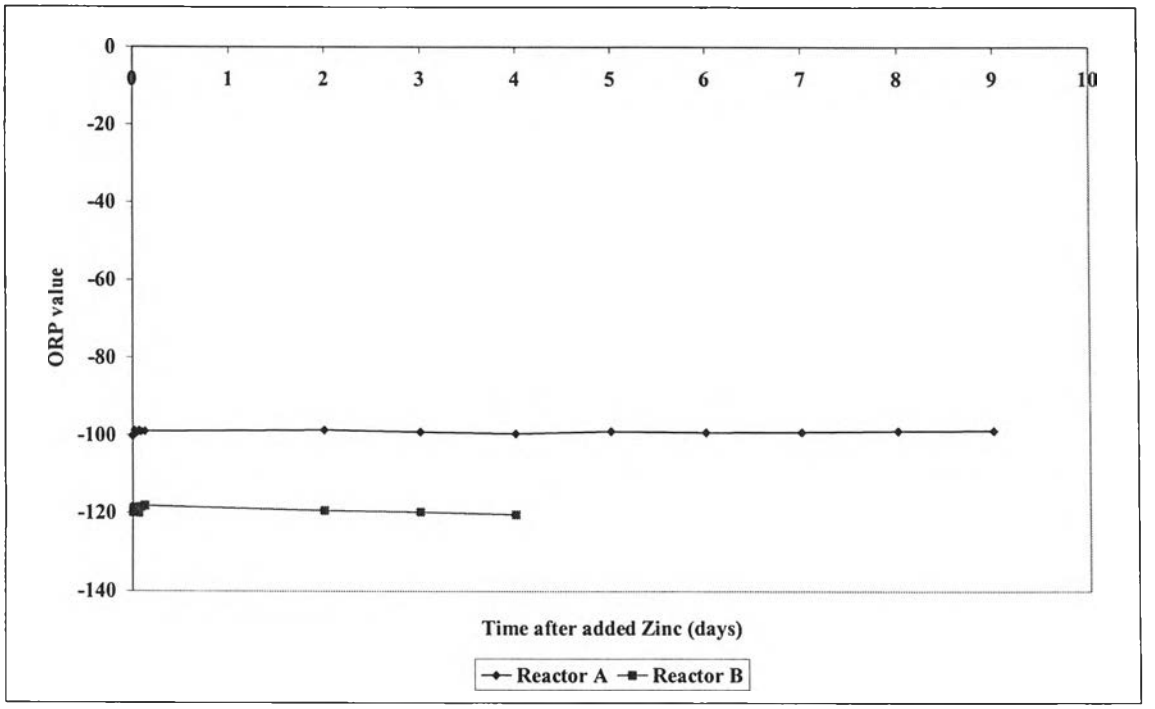



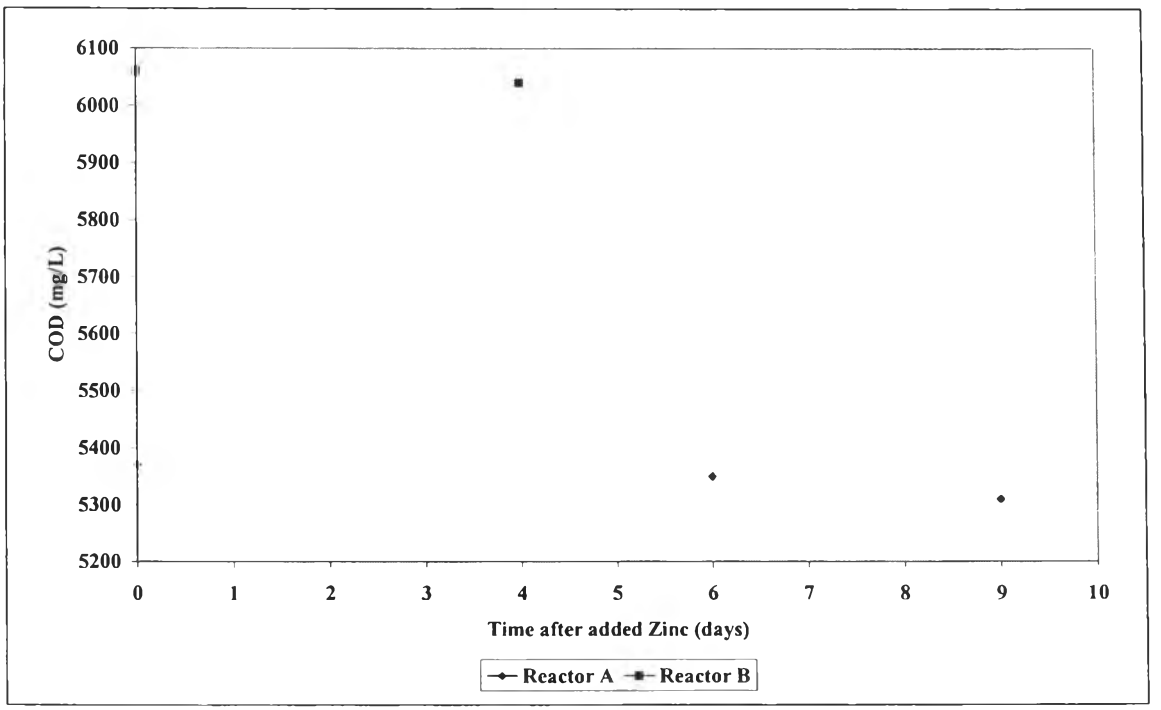
The result after the second addition of 50 mg/L of Zinc (Cont.).



The result after the second addition of 50 mg/L of Zinc (Cont.).



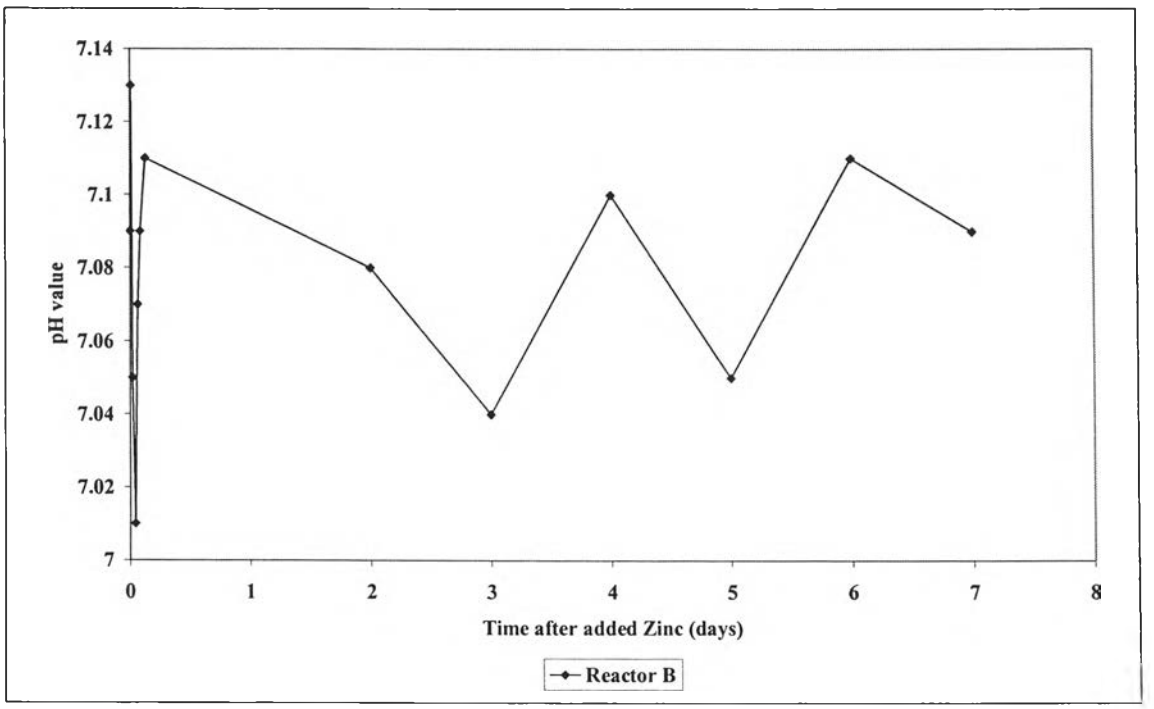
Appendix F

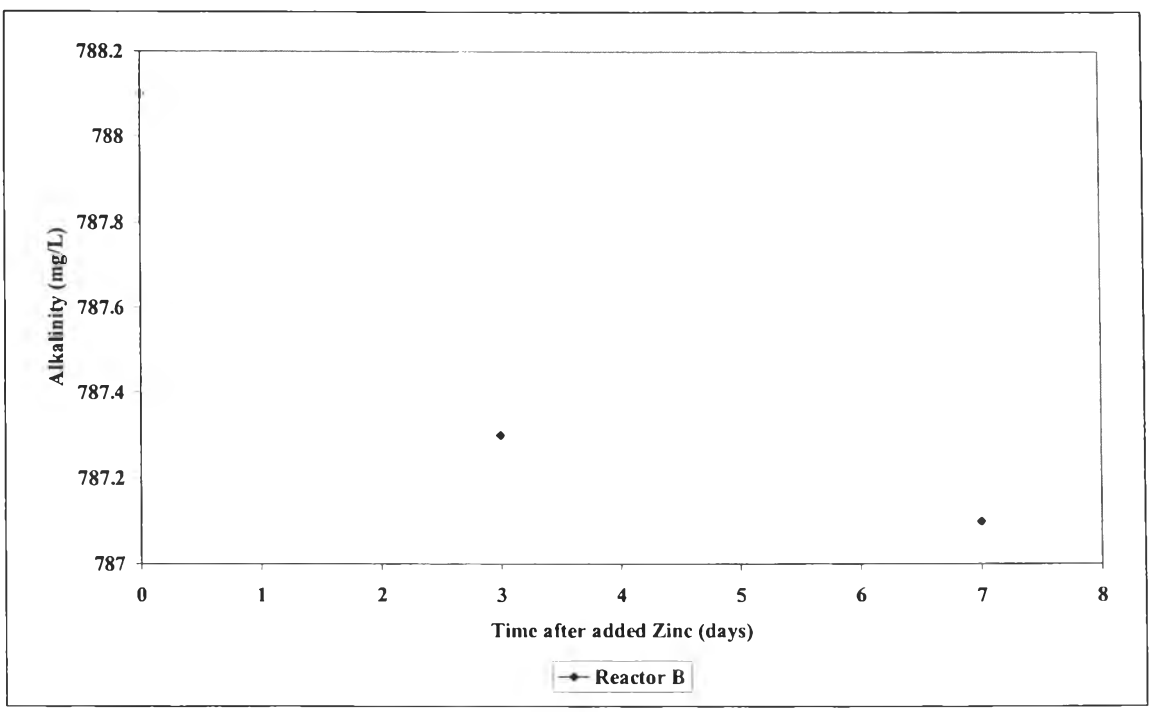
The data after the third addition of 50 mg/L of Zinc.

| **50 ppm 2nd (N)** | **pH** | **ORP** | **$SO_4^{2-}$ (ml/l)** | **$S^{2-}$ (mg/l)** | **Conc. Of Zinc (mg/l)** | **Gas (mL)** |
|---|---|---|---|---|---|---|
| | N | N | N | N | N | N |
| Control | 7.09 | -121.2 | 7.75 | 24.15 | 5.08 | 5 |
| 10 min | 7.13 | -119.8 | 7.81 | 24.07 | 5.15 | |
| 30 min | 7.05 | -120.5 | 7.79 | 24.11 | 5.11 | |
| 1h | 7.01 | -119.2 | 8.13 | 20.45 | 28.31 | |
| 1.5h | 7.07 | -119.5 | 8.34 | 20.08 | 30.89 | |
| 2h | 7.09 | -118.9 | 8.29 | 18.19 | 35.87 | |
| 3h | 7.11 | -119.6 | 8.31 | 17.89 | 36.57 | |
| Day 2 | 7.08 | -120.3 | 8.44 | 17.96 | 36.49 | 10 |
| Day 3 | 7.04 | -122.1 | 8.37 | 17.67 | 36.56 | |
| Day 4 | 7.1 | -121.7 | 8.22 | 17.24 | 36.13 | 5 |
| Day 5 | 7.05 | -120.5 | 8.25 | 17.15 | 36.21 | |
| Day 6 | 7.11 | -119.2 | 8.19 | 17.18 | 36.16 | 10 |
| Day 7 | 7.09 | -119.4 | 8.21 | 17.10 | 36.13 | 10 |

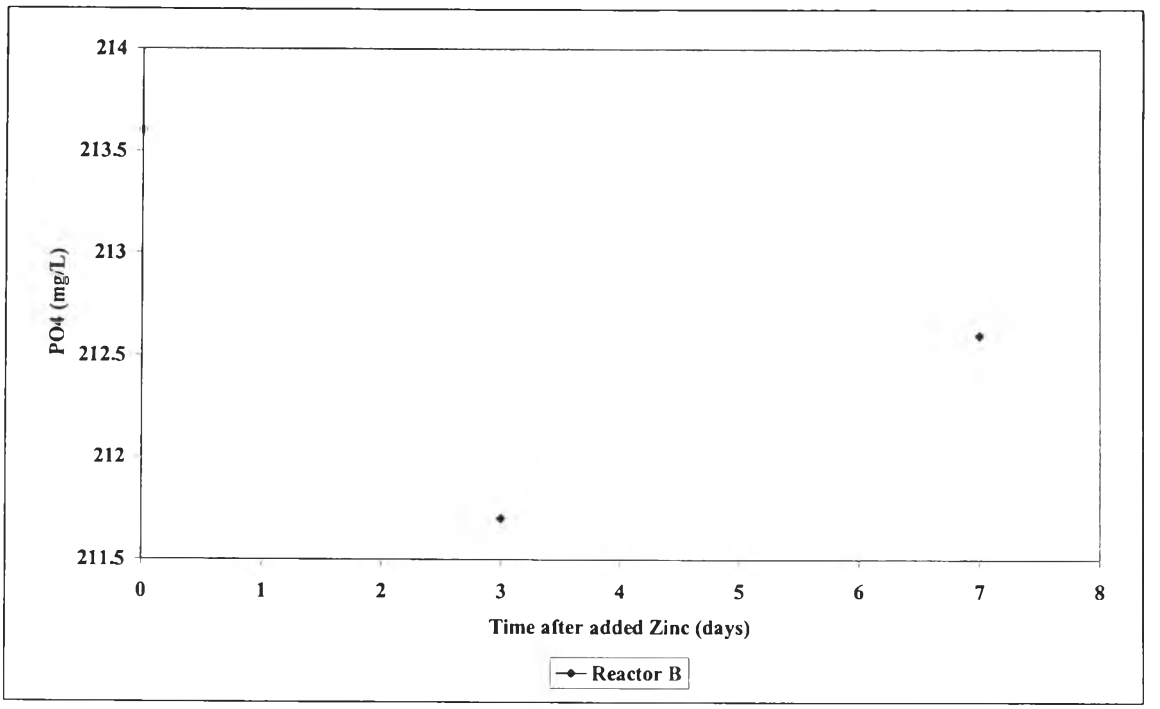
| **50 ppm 2nd (N)** | **$PO_4$** | **$NH_3$** | **COD** | **Alkalinity** |
|---|---|---|---|---|
| | N | N | N | N |
| Control | 213.6 | 251.8 | 6040 | 788.1 |
| 10 min | | | | |
| 30 min | | | | |
| 1h | | | | |
| 1.5h | | | | |
| 2h | | | | |
| 3h | | | | |
| Day 2 | | | | |
| Day 3 | 211.7 | 249.7 | 6040 | 787.3 |
| Day 4 | | | | |
| Day 5 | | | | |
| Day 6 | | | 6030 | |
| Day 7 | 212.6 | 248.9 | | 787.1 |

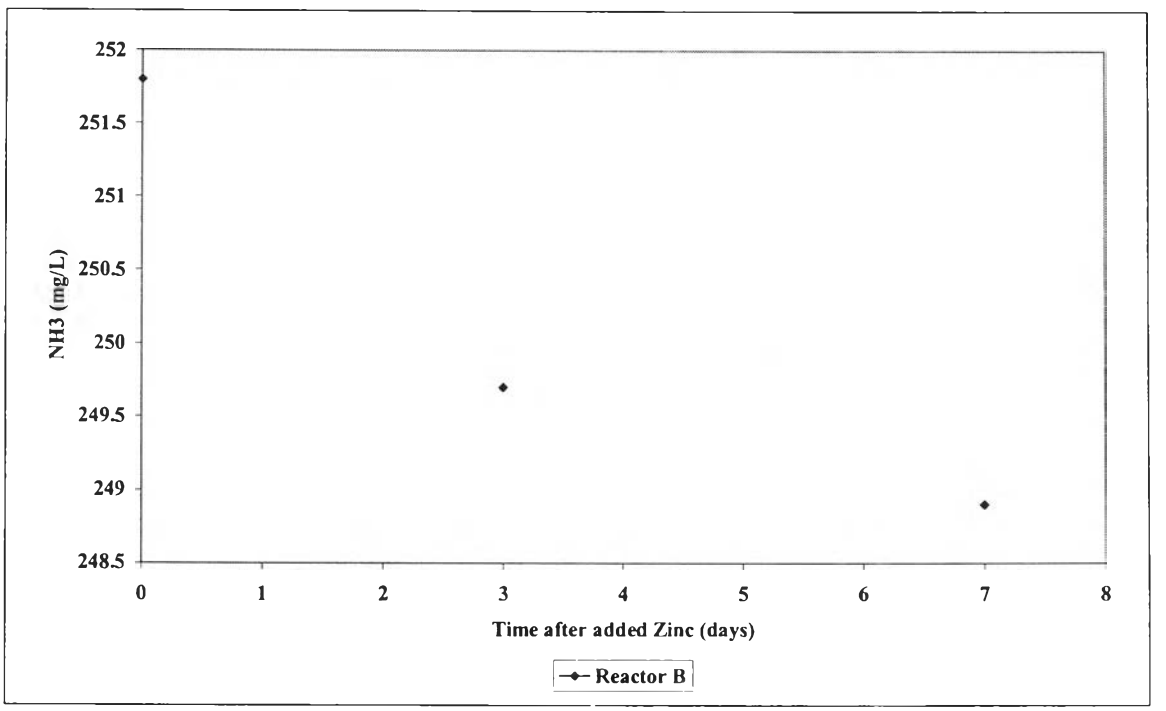
The result after the third addition of 50 mg/L of Zinc.



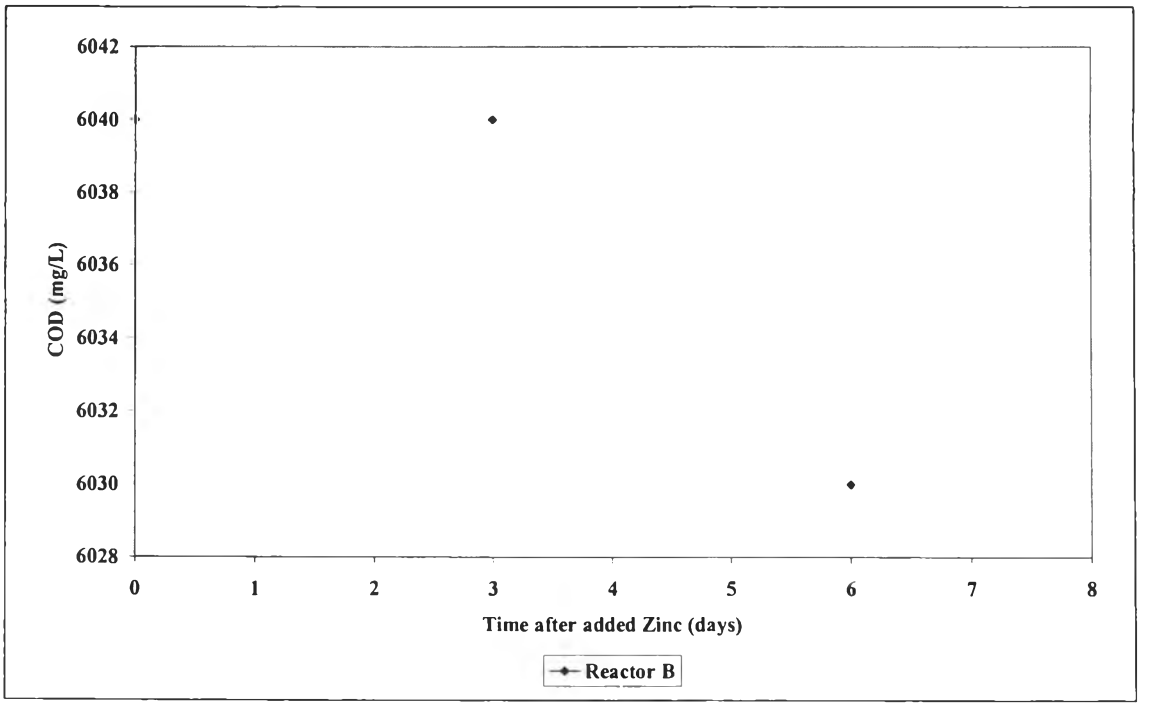



The result after the third addition of 50 mg/L of Zinc (Cont.).



The result after the third addition of 50 mg/L of Zinc (Cont.).



# BIOGRAPHY

Mr. Warut Hariwongsanupap was born on March 3, 1980 in Bangkok, Thailand. He finished his secondary school course from Mt Aspiring College, Wanaka, NewZealand in December 1997. Later he graduated a Bachelor's Degree in Environmental Technology from Sirindhorn International Institute of Technology, Thammasat University, Patumthani, Thailand in April 2003. He pursued his Master Degree studies in International Postgraduate Programs in Environmental Management, Inter-Department of Environmental Management, Chulalongkorn University, Bangkok, Thailand in May 2003. He finished his Master Degree of Science in Environmental Management in April 2005.