# STUDY OF WATER NEUTRALIZATION IN AN OPEN CHANNEL USING MIXTURES OF LIMESTONES, ORGANIC MATTERS AND LATERITE SOILS

MOHAMAD FAIZAL TAJUL BAHARUDDIN

NUR HALIZA MANSOR

PROSIDING KEBANGSAAN AWAM 2007
29 – 31 MEI 2007
LANGKAWI KEDAH

# Study of Water Neutralization in an Open Channel Using Mixtures of Limestone, Organic Matters and Laterite Soils

[1]Mohamad Faizal Tajul Baharuddin, [2]Nurida Mohd Yusop, [3]Nur Haliza Mansor
[1,3] Jabatan Kejuruteraan Air dan Persekitaran, Fakulti Kejuruteraan Awam dan Alam Sekitar, Kolej Universiti Tun Hussein Onn, Parit Raja, 86400 Batu Pahat, Johor.
[2] Petronas Berhad, R&T Division, Group Research, Lot 3288 & 3289, Off Jalan Ayer Itam, Kawasan Insitusi Bangi, 43000 Kajang, Selangor.
Tel:[1] 07-4537402, [2]03-38928100
Fax: [1]07-4536070,[2]03-89284104
*Email: [1]mdfaizal@uthm.edu.my,[2]nuridayusof@petronas.com*

**Abstract**

Batu Pahat District with a population of almost 650,000 has encountered water supply woes since year 1999. The water in Sg. Bekok and Sg. Semberong experienced very low level of acidity down to pH 2.5 to 3.0 especially during rainy season. Water treatment plants have to be shut down during the low pH thus causing water shortage in Batu Pahat. The water acidification occurs when the open channels were constructed in Bekok and Semberong basin to improve the watering system to enable farming activity in the swampy area. Oxidation occurs when pyrite ($FeS_2$) minerals in the rock were exposed to the air and water to form sulfuric acid ($H_2SO_4$) which leach out into the river and cause the lowering of the river pH. The purpose of this study was to neutralize the acidic water using limestone, organic matter and laterite soils in an open channel experiment which were conducted using a physical model. Two steps of managing the acidic water were carried out; laterite channel and anaerobic open channel limestone incorporated with organic matter. The experiments were conducted in four stages, namely experiment A, experiment B, experiment C and experiment D where each experiment consist of different composition of limestone, organic matter and laterite soils. Each material had its own function in neutralizing the acidic water. Limestone was the main material that acts as buffer to neutralize the acidic water. Laterite was use to prevent the iron in the pyrite from combining with the limestone that will decrease the efficiency of the limestone to neutralize the acidic water. The organic matter contains bacteria that will consume the oxygen in the water to provide the anaerobic condition. The results indicated that experiment D with the combinations of 80% limestone, 18% laterite soil and 2% organic matter was the optimum materials ratio to increase the pH of the water to pH of around 8 in the shortest time. The results of the study can be used to design the remediation process to increase the pH of the acidic water to neutral in the shortest possible time therefore meeting the pH requirement of the raw water quality at the intake.

*Keywords*: Acidic water, neutralization, physical model, limestone, organic matter

## 1.0 Introduction

The water crisis at Batu Pahat area was caused by the acidic raw water resource from Bekok River (Khadijah, 2005). The acid level in this river was very high (pH 2.5 to 3.0) where the value falls outside of the Malaysia National Water Quality Standard: Recommended Raw Water Quality Criteria (pH 5.5 to 9.0). Syarikat Air Johor (SAJ) water treatment plants have to be shut down during the low pH thus causing water shortage in Batu Pahat. The water acidification occurs when the open channel were constructed in Bekok and Semberong basin to improve the watering system to enable farming activity in the swamp area. Oxidation occurs when pyrite ($FeS_2$) minerals in the rock are exposed to the air and water to form sulfuric acid ($H_2SO_4$) which leach out into the river and cause the lowering of the river pH.

The primary iron sulfides that produce Acid Mine Drainage (AMD) are pyrite and marcasite ($FeS_2$). Acidity levels, metal composition and metal concentration in AMD depend on the types and amounts of sulfide mineral and the presence or absence of alkaline materials. In areas where sulfides are present, the oxidation of Fe disulfides and subsequent conversion to acid occur through several reactions. The following chemical equations describe the processes involved in the oxidation and acidification reactions associated with reduces sulfur transformations (Pierzynski *et al.*, 2000).

$$FeS_2 + 7/2\, O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (1)$$

$$Fe^{2+} + \tfrac{1}{4} O_2 + H^+ \rightarrow Fe^{3+} + \tfrac{1}{2} H_2O \quad (2)$$

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+ \quad (3)$$

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (4)$$

Initially, Fe sulfide is solubilized (Equation 1) and ferrous iron ($Fe^{2+}$, reduced Fe), sulfate ($SO_4^{2-}$, oxidized sulfur) and acid are formed. Ferrous iron is then oxidized (Equation 2) to form ferric iron ($Fe^{3+}$, oxidized Fe). Ferric iron may be hydrolyzed and form ferric hydroxide, $Fe(OH)_3$, and $H^+$ acidity (Equation 3), or directly attack pyrite and act as a catalyst in generating more $Fe^{2+}$, $SO_4^{2-}$, and acidity (Equation 4). Under many conditions, Equation 2 is the rate-limiting step in pyrite oxidation due to the slow conversion of $Fe^{2+}$ to $Fe^{3+}$ at pH values below 5 under abiotic conditions. However, Fe oxidizing bacteria, *Thiobacillus*, greatly accelerate the oxidation of $Fe^{2+}$, bacteria activity is believed to be crucial for generation of most AMD (Pierzynski *et al.*, 2000).

One of the main open channels contribute to water acidification is Kampung Ngamarto man-made ditch which is located near the Bekok River. Study done by Mohd Hafiz (2005) and Radin Maya Saphira (2002) indicated that the Kampung Ngamarto ditch produce low acid value water (pH 3-5). Therefore, the main objective was to neutralize acidic water to pH 6.5-7.5 using combination of materials such as limestone, organic matter and laterite soil. The specific objective of this study were to determine the effectiveness of using materials of limestone, organic matter and laterite soil in neutralizing acidic water and to determine the optimum material ratio to increase the acidic water pH. The location of the study area is at the Kampung Ngamarto ditch. Physical model of the actual study area were constructed.

Limestone ($CaCO_3$) was chosen because of its ability to increase the pH value of acidic water between 6.5-7.8 (Mohd Hafiz, 2005). Dissolution of the limestone adds alkalinity to the water and raises the pH. The acidic water management by using anaerobic condition has produced a significant result compared to the aerobic condition (Mohd Hafiz, 2005). The acidic water will be neutralized in the anaerobic condition using organic matter and limestone. The function of organic matter is to absorb the dissolve oxygen and prevent the settlement of $Fe(CO)_3$ and $Fe(OH)_3$ onto the limestone which can hinder it from neutralizing the water. The laterite soil can remove heavy metal in water such as Zinc, Iron, Manganese, Cadmium and Lead (Noor Dini, 2005). The rate of removing and the percentage efficiency for every heavy metal are summarized in Table 1. The function of the laterite soil was to remove access iron in the water and to prevent it from combining with the limestone which will decrease the efficiency of the limestone to neutralize the acidic water. The combination of limestone, organic matter and laterite soil can solve such problem and the ratio of this material was determined to produce the optimum result in increasing the water pH.

**Table 1: The Removal Percentage of Heavy Metal in Granular Laterite Treatment (Noor Dini, 2005)**

| Heavy Metal | Percentage of Efficiency (%) | Rate of Removing Heavy Metal (mg/L)/day |
|---|---|---|
| Iron | 73.29 | 0.161 |
| Lead | 79.02 | 0.054 |
| Cadmium | 77.33 | 0.008 |
| Manganese | 73.27 | 0.138 |
| Zinc | 75.20 | 8.280 |

## 2.0 Materials and Method

### *2.1 Site Selection*

Kampung Ngamarto ditch was selected as the research area. The location of Kampung Ngamarto ditch is shown in Figure 1. The acidic water at Kampung Ngamarto ditch occurs due to the pyrite-mineral exposed to atmosphere (Mohd Hafiz, 2005). The pH values at Kampung Ngamarto ditch are shown in Table 2. Oxidation occurs when pyrite ($FeS_2$) minerals in the rock are exposed to the air and water to form sulfuric acid ($H_2SO_4$) which leach out into the river and cause the lowering of the river pH (Radin Maya Saphira, 2002).

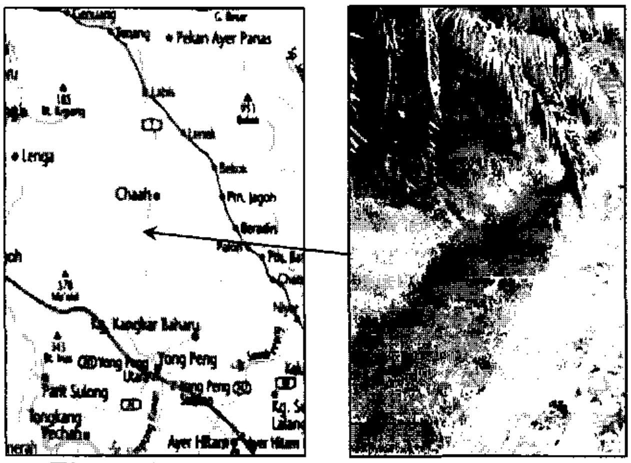

**Figure 1: The location of Kampung Ngamarto ditch**

**Table 2: pH value at Kampung Ngamarto ditch (Mohd Hafiz, 2005)**

| Station | pH Value | | |
|---|---|---|---|
| | 16/8/2005 | 18/8/2005 | 22/8/2005 |
| 1 | 3.95 | 5.78 | 4.88 |
| 2 | 7.71 | 5.96 | 5.76 |
| 3 | 4.43 | 4.24 | 3.90 |
| 4 | 3.77 | 4.70 | 3.98 |
| 5 | 5.51 | 3.21 | 3.29 |
| 6 | 3.74 | 4.56 | 4.46 |
| 7 | 3.66 | 3.87 | 4.58 |
| Average | 4.68 | 4.62 | 4.41 |

### *2.2 Materials*

The source of limestone that used, was collected from Batu Caves, Selangor. The laterite soil was taken from Parit Haji Salam, Benut, Johor. The laterite from this area has been proven the effective in removing heavy metals such as Iron, Lead, Cadmium, Manganese and Zinc (Noor Dini, 2005). Organic matter is comprised of carbon compound, nitrogen, sulfur, phosphorus and bacteria. The organic matters used were commercially available.

*2.3 Physical Model*

The data obtained from the Kampung Ngamarto ditch such the area, length, depth, width and flow rate were considered in constructing a physical model. The main material for this physical model was flexi-glass. The size of the physical model was 50 cm length, 20 cm width and 10 cm height. The arrangement of the neutralization process, limestone, organic matter and laterite soil are illustrated in Figure 2. There were two steps of management, i.e., the "Laterite Channel" and the "Anaerobic Open Channel Limestone". The flow rate of the physical model is shown in Table 3.

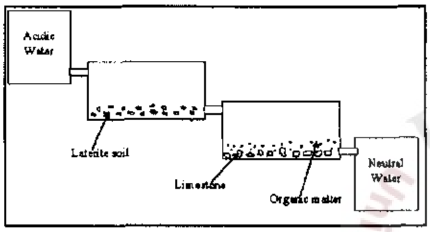


**Figure 2: The Acidic Water Neutralization Process Using Physical Model**

**Table 3: The flow rate in Physical Model**

| Types of Channel | Flow Rate ($m^3/s$) |
|---|---|
| Sample | $1.11 \times 10^{-4}$ |
| Laterite | $1.10 \times 10^{-5}$ |
| Anaerobic Open Limestone | $1.04 \times 10^{-5}$ |

The acidic water was retained in the laterite channel for 75 minutes before it was allowed to flow to the anaerobic open channel limestone. The anaerobic open channel limestone consists of limestone and organic matter.

*2.4 Experimental Set-up*

The experiments were conducted in four stages, namely experiment A, experiment B, experiment C and experiment D. Every experiment has different percentage of materials in terms of limestone, organic matter and laterite soil and was summarized in Table 4. The justification for conducting four stages experiments was to obtain the optimum material ratio for neutralizing the acidic water effectively.

**Table 4: Summary of Experiment Composition**

| Experiment | Laterite (%) | Limestone (%) | Organic Matter (%) |
|---|---|---|---|
| A | 19 | 62 | 19 |
| B | 26 | 57 | 17 |
| C | 23 | 75 | 2 |
| D | 18 | 80 | 2 |

*2.5 Analytical Methods*

The pH values were measured using a pH meter according to the Standard Methods for the Examination of Water and Wastewater APHA 4500-$H^+$B (APHA *et al.,* 1998). The dissolved oxygen were measured according to the APHA 4500-O G using a DO meter. The temperature was measured using a thermometer.

**3.0 Results and Discussion**

*3.1 Laboratory Results*

The results of the time taken for neutralization process, pH, dissolved oxygen and the condition of the outflow water for each experiment are summarized in Table 5.

**Table 5: Summary of the results for each experiment**

| Exp. | Time (min) | pH | DO (mg/l) | Outflow Water |
|---|---|---|---|---|
| A | 75 | 8.68 | 7.14 | Black |
| B | 75 | 9.16 | 7.19 | Black |
| C | 240 | 6.75 | 6.54 | Light Brown |
| D | 165 | 6.98 | 6.05 | Light Brown |

The pH measurements in Anaerobic Open Channel Limestone for all Experiment are illustrated in Figure 3, 4, 5 and 6.

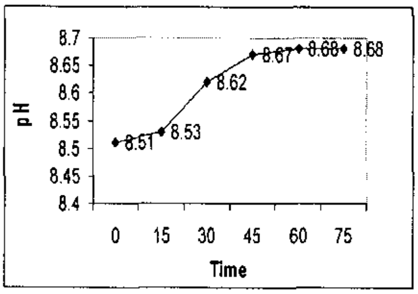


**Figure 3: Graph of pH Versus Time in Anaerobic Open Channel Limestone for Experiment A**

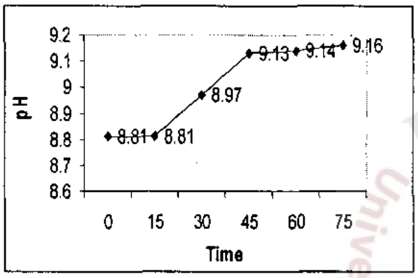


**Figure 4: Graph of pH Versus Time in Anaerobic Open Channel Limestone for Experiment B**

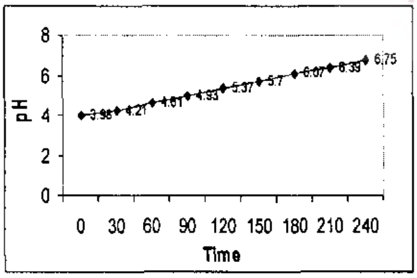


**Figure 5: Graph of pH Versus Time in Anaerobic Open Channel Limestone for Experiment C**

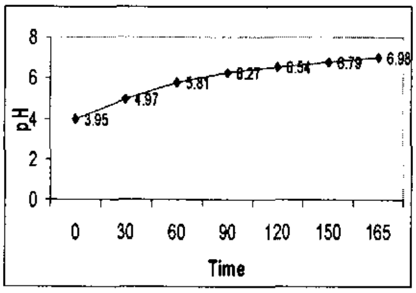


**Figure 6: Graph of pH Versus Time in Anaerobic Open Channel Limestone for Experiment D**

*3.2 Analysis of Results*

Results of the experiments A and B (Figures 3 and 4) show that the pH increased sharply even at the beginning of the experiment (pH 8.51 and 8.81) where the values were more than the expected result (pH 6.5-7.5). The effluents were in black colour and unsuitable to be used as raw water intended for domestic water supply. Therefore, Experiments C and D were proceeded with lesser amount of organic matter content.

Experiments C and D were conducted by fixing the composition of the organic matter at 2% and varying the ratio of limestone and laterite. Experiment C consists of 23% laterite and 75% limestone whereas Experiment D consists of 18% laterite and 80% limestone.

With 80 % of limestone, 18 % of laterite soil and 2 % of organic matter, Experiment D showed the optimum material ratio to increase and neutralize the acidic water (pH 6.98) in a reasonably short time (165 min).

The laterite channel consists of laterite soil, where the function was to remove the access iron in the acidic water. The function of organic matter was to absorb oxygen from the water and to provide the anaerobic condition in the channel. As a result, it could prevent the settlement of $Fe(CO)_3$ and $Fe(OH)_3$ onto the limestone which could decrease the effectiveness of the limestone to neutralize the acidic water.

**4.0 Conclusion**

Material ratio in experiment D (80 % of limestone, 18 % of laterite soil, and 2 % of organic matter) was the best composition to neutralize the acidic water because it can increase the pH of acidic water to neutral in reasonably short time. The anaerobic condition is an additional advantage in the neutralization process because it could prevent the settlement of $Fe(CO)_3$ and $Fe(OH)_3$ onto the limestone which could decrease the effectiveness of the limestone in neutralizing the acidic water. Therefore, it was expected that by using this material ratio as a neutralizing agent of acidity water pollution, it is hope that the water quality will be improved which offers a better quality of water for the raw water intake.

The study has shown that the treatment of the acidic water in Sungai Bekok can be done in-situ by constructing the Laterite and Anaerobic Open Channel Limestone at site. The easy availability of the materials such as limestone which could be obtain from Batu Caves, Selangor and the laterite soil from Parit Salam, Benut, Johor enables the treatment process to be done economically.

**References**

APHA, AWWA and WEF (1998) Standard Methods for the Examination of Water and Wastewater, 20th Ed. 1998, Published jointly by American Public Health Association , Washington, DC 20005, American Water Works Association and Water Environment Federation.

Khadijah @ Liza Bte Sulaiman (2005). "Kajian Kualiti Air Mentah di Sungai Semberong dan Sungai Bekok Sebagai Punca Bekalan Air di Parit Raja." KUiTTHO: Tesis Sarjana Muda.

Malaysia National Water Quality Standard: Recommended Raw Water Quality Criteria, IWA (Revise Dec, 2000).

Mohd. Hafiz Zahar (2005). "Pengurusan Asid Sulfurik Secara Saluran Terbuka Dalam Keadaan Aerobik Dan Anaerobik." KUiTTHO: Tesis Sarjana Muda.

Noor Dini Hussain (2005). "Kajian Pengaruh Media Penapis Di Dalam Sistem Tanah Bencah Buatan Jenis Aliran Sub Permukaan Terhadap Penyingkiran Logam Berat Di Dalam Air Larut Lesap." KUiTTHO: Tesis Sarjana Muda.

Pierzynski, G. M., Sims, J. T. and Vance, G. F. (2000). "Soils and Environmental Quality." 2nd Edition. CRC Press LLC. United State.

Radin Maya Saphira Bt. Radin Mohamed (2002). "Kajian Logam-logam Berat Terpilih di Sungai Bekok, Johor." KUiTTHO: Tesis Sarjana.