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TEACHING ARD RECLAMATION TECHNIQUES IN HIGH SCHOOL

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ABSTRACT

It is well known that mining is not well perceived by the dominant North America society. The general public typically has a poor understanding of the entire mine cycle and are often influenced by negative news, especially those related to environmental issues. Initiative to rectify this problem should start by showing successful examples of environmentally friendly and socially responsible mining operations. In particular, the mining industry has endeavored to introduce to the general public, and in particular children, the basic ideals of the modern mining industry, which is revolutionizing both its practices and its image through the implementation of best mining practices. A proven technique for raising awareness of mining issues with children is that of hands-on education; hands-on methods are those that involve the student in the problem and attract their interest. The objective of this paper is to illustrate how land reclamation by the mining industry can be taught in the secondary school classroom. A kit was developed to show high school students how the mining industry is reclaiming the land and addressing acid mine drainage problems. An experiment on acid mine drainage, treatment and reclamation was devised to be taught to Earth Science 11 Geological Science (resources and environment) students. The topic to be covered relates to identification of environmental problems related to the development of a natural resource. The students take a sample of pyrite-rich mine waste or crushed pyrite and perform an experiment to see if it produces an acidic solution under certain variable conditions. Either a bicycle pump to add air into the solution or hydrogen peroxide provides the chemical conditions for pyrite oxidation. Bacteria *(Thiobacillus ferrooxidans)* is added to another vial with pyrite to increase the oxidation reactivity and to compare with the chemical oxidation procedure. After obtaining an acidic pH, the students raise the solution's pH to a neutral condition using lime. A flocculent is then added to precipitate the metal ions from solution and to create metal-hydroxide sludge; this also aids in the subsequent dewatering stage. The sludge is then used to grow marigolds when mixed with peat moss. It has been found that the marigolds grow easily in the sludge/peat moss soil and in some cases have performed better than the control potting soil. The various phases of the experiment development including student responses are documented in this paper.

INTRODUCTION

The purpose of this paper is to show how mine reclamation can be taught in the secondary school classroom using experiments that utilize a specially prepared kit, Table 1. Students will find these experiments exciting to do as they bring "real-world" science into the classroom; this hands-on approach will motivate students to learn more about Earth Science and the Mining Industry. Throughout these experiments, students will directly observe the natural world and in so doing will satisfy the Prescribed Learning Outcomes described in the Integrated Resource Package as described for the Earth Science 11 curriculum. The Prescribed Learning Outcomes that students will be learning are: *identify environmental problems related to development of a natural resource such as coal, oil, gas, or any metallic mineral of economic value; describe the value of resource conservation;* and *suggest strategies to conserve both material and energy resources*[1] This paper will explain how these experiments are conducted. The primary focus of these experiments is to look at acid rock drainage and flocculation. An integral component of this lesson is to grow plants in waste sludge; this is an effective means of illustrating how land used in mineral processing can be reclaimed. The lesson can be done in two experiments but the ARD experiment leads nicely into the flocculation activity. Students enrolled in Earth Science 11 and Science & Technology 11 of Westview Secondary School in Maple Ridge, British Columbia performed these experiments successfully during the spring semester of 2002.

Table 1. Material provided in the mine reclamation kit

Item
pyrite tailings
high-grade pyrite (pre-ground to -65 mesh)
1 bottle of hydrogen peroxide (100 ml of H_2O_2 @ 10%)
1 bottle of stored mesophile bacteria (60 ml)
1 bag of CaCO3 powder (100 g)
flocculent(l00g)
5 filter papers
Litmus paper
potting soil peat
moss marigold
seeds
2 small pots

EXPERIMENTS

The experiments are broken into two labs. The first experiment looks at factors that cause acid rock drainage. The second experiment shows how acidic tailings in solution can be neutralized and reclaimed. In the first experiment titled *Acid Rock Drainage* students need four beakers, distilled water (or deionized water), hydrogen peroxide, crushed pyrite, a bicycle pump, limestone, and the bacteria *Thiobacillus ferrooxidans.* Pyrite is used because it is a waste rock that causes acid rock drainage.[2] The crushed pyrite represents rock in a waste rock pile. Although crushed pyrite can be obtained from the kit, Table 1, these experiments can be performed again with pyrite purchased from a local mineral museum and "crushed" by using a hammer.

The students divide into four groups and each group is given 20 g of crushed pyrite. They put the pyrite in a 500 ml beaker. One group will fill the beaker up to the top with water and seal it with a plastic cap. The sealed beaker full of water simulates a submersible tailings pond and is to be used as the control experiment. Another group puts 20 g of pyrite in 100 ml of water. They will introduce air into the system on a daily basis with the help of a bicycle pump or an aquarium pump. Simple agitation with a porous cap should do just fine if a pump isn't available. The beaker will be left uncovered. Another group will add 5% of 10% hydrogen peroxide to 100 ml of water and crushed rock. This group will also introduce air into the system using a pump or through simple agitation of the beaker. Lastly, a group will just add the bacteria to 20 g of crushed pyrite. Just add 100 ml of water plus the bacteria to show the students the role of bacteria in causing ARD. Once again, this system will also have air introduced into it. It is recommended that the students do not blow into the water with a straw; carbon dioxide introduced from the students' lungs will lead to the formation of carbonic acid and may lead to erroneous results (and the possible poisoning of the bacterial cultures). For a week the students will check the pH of the water and record the results. The students can later graph the results to see the change in pH with time for the different systems.

The students then need to neutralize the suspension using limestone. Limestone is an alkaline agent with the ability to neutralize, or partially neutralize strong acids. The neutralization process occurs when acids react with calcium carbonate ($CaCO_{3j}$ the primary constituent of limestone) to form water, carbon dioxide and calcium salts. In order to determine the amount of calcium carbonate needed to neutralize a sulfuric acid (H_2SO4) solution we need only to know the pH of the solution. Assuming that sulfuric acid acts as a monoprotic acid we can describe its dissociation as follows :[3]

$$H_2SO_4 \Leftrightarrow H^+ + HSO_4^-$$

The proton concentration, [H*], as shown on the right hand side in the above reaction can be determined using the relationship outlined in Equation 1. The resulting proton concentration can then be related to the proton concentration of sulfuric acid ($[H_2SO_4] \approx [H^+]$, as mole/liter).

Equation 1

$$pH = -\log_{10}\left([H^+]\right)$$

rearranging,

$$[H^+] = 10^{(-pH)}$$

The neutralization of sulfuric acid with calcium carbonate is shown in the following reaction. It can be seen that 1 mole of $CaCO_3$ is required for every mole of H_2SO_4 Therefore, the mass of limestone required to neutralize the sulfuric acid can be calculated via Equation 2.

Equation 2

$$CaCO_3\left(\frac{g\ CaCO_3}{1}\right) = [CaCO_3]\left(\frac{mole\ CaCO_3}{1}\right) \bullet 100.1\left(\frac{g\ CaCO_3}{mole\ CaCO_3}\right)$$

$$CaCO_3 + H_2SO_4 \Leftrightarrow CaSO_4 + H_2O + CO_2$$
$$1 \quad : \quad 1$$

If the pH is 7 or slightly higher then the students have accomplished their task. The solution has been neutralized and the heavy metals should have precipitated out. It should be noted that this mass of calcium carbonate should only be used as a first approximation as the neutralization reaction is dependent on the $CaCO_3$ grain size and purity. In addition, the neutralization is strongly dependent on the physical contact of the limestone particles with the pyrite mineral's surface; therefore strong agitation is need to ensure that the reaction is not mass transfer limited. Typically an excess of 1.5 times more limestone is needed.[4]

At this point, the student should be able to answer the following questions:

1. In which beaker did the pH drop the fastest?
2. What color did the solution become and what element caused this color change?
3. What chemical reaction were you trying to cause with the pump (air?), peroxide and bacteria?

4. What is calcium carbonate: acidic, neutral, or basic?

5. How does adding limestone to an acidic solution help solve ARD?

The following are the answers or desired student responses to the above questions.

1. pH should drop the fastest in the system that had the bacteria.

2. The color will be red caused by iron in the suspension (as Fe^{3+} ion).

3. We were attempting to oxidize the pyrite in these experiments.

4. $CaCO_3$ is a basic reagent.

5. The solution is neutralized and metals are precipitated out of solution.

The second experiment is titled *Flocculation.* Students need mine tailings that are acidic. Not all tailings are acidic. The tailings that are provided in the kit are acidic. Materials that are needed are: two beakers, flocculent, a funnel, mine waste, filter paper, tap water, pH paper, a flower pot, peat moss, and marigold seeds. The procedure is to mix the tailings with tap water to form slurry. Test the pH of the suspension with pH paper or a meter. If the pH is acidic add the powdered limestone (CaCOs) as required until a neutral pH of 7 is obtained, (refer to Equation 2).

Once a neutral solution is obtained flocculent can then be added to the solution. Agitate or gently shake the beaker to stimulate suspension of flocculent for approximately 5 minutes. Without weighing the reagent, a few grains of the flocculent (sparingly) should get the desired results. After thirty minutes of settling, the sludge will be clumped together and will settle on the bottom of the beaker. The sludge can then be filtered with the aid of the filter paper and funnel. The resulting filtered water should be clear; the clear water will demonstrate to the students that by doing this procedure water can be made safe for the environment. The sludge and any minerals as well as the limestone should be left in solid form in the original beaker. The sludge then can be taken out with a garden hand shovel and put into a planting pot. Peat moss needs to be mixed with the sludge in order to give it aeration for proper drainage of the water. Without the moss the sludge would be like clay and proper drainage of water would not occur. This would mean that the seeds would "drown "and not germinate. Next, plant some seeds. Marigolds are a good choice. They are a very hardy flower and grow reasonably well in the sludge. Also plant some marigolds in potting soil and use this as the control to which the marigolds growing in the sludge will be compared. Students will keep a daily journal observing how fast the plants sprout and grow in the sludge compared to the potting soil. Students should use the filtered water to water the plants. This meets the curriculum guidelines of resource conservation and conserving material resources. The students learn the value of environmental stewardship by using reduce, reuse, and recycle principles. The plants can be put on a windowsill or in a greenhouse if one is available at the school.

At this point, the student should be able to answer the following questions:

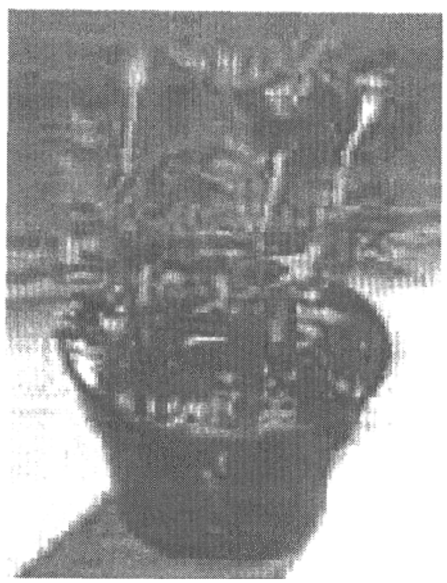
1. What type of prior knowledge would an Environmental Engineer need before doing this process at a mine?
2. What is flocculation and what does the flocculent do to the slurry?
3. How can the mine reuse the filtered water?
4. Do you think the filtered water would be safe to drink?
5. Which plants sprouted first, the ones in the mine sludge or the control?
6. After the first month, which plants showed the best results?
7. What has this experiment taught you about mining and the environment?

The following are the answers or anticipated student responses to the above questions.

1. An Environmental Engineer needs to have a strong background in both chemistry and biology.
2. Flocculation refers to the successful collisions that occur when the destabilized particles are driven toward each other by the hydraulic shear forces in the rapid mixing of flocculation basins. Agglomerates of a few colloids then quickly bridge together to form microflocs which in turn gather into visible floe masses. These floe masses then precipitate out of solution.'[51] Ultimately, the flocculent helps separated the sludge from the water.
3. The filtered water that was recovered could be used to irrigate reclaimed land to promote the growth of vegetation. This would be in accordance with the 3 R's (Reduce, Reuse, Recycle).
4. So long as the bacteria concentrations in the water were not significant, the answer would be "yes". Do not have students drink the water, but discuss how "clean" the water is.

5, The plants in the sludge should have sprouted first when I did the experiment the marigolds in the sludge came up first. When my students did the experiment the marigolds in the sludge came up first. There were lots of nutrients in the tailings that T used for marigolds to grow in.

6, The flowers in the sludge are doing just as good as the control. It should be noted that the control has potting soil, which will give the plants more nutrients than even regular garden soil. The plants in the potting soil will do better over a 1-month period but it has more nutrients than most garden soils. The plants will grow and bloom in the mine sludge (see picture 1 - see my note. The potting soil has an advantage in nutrients since it is especially prepared for growing plants, yet the marigolds did just fine in the sludge. The answer should be that mine waste could be reclaimed and put to good use such as for growing marigolds. You can use other plants, but students love marigolds because of their flowers.



Picture 1. Marigold growing in mine sludge at Westview Secondary School, June 2002

In evaluating what the students learned from these experiments a test question was put on the Earth Science Resource Test. Students were to write a paragraph clearly defining an environmental problem associated with mining and explain a solution to the problem. Many students wrote about ARD and the treatment of tailings ponds with limestone. Students also wrote about reclaiming tailings by planting grass and flowers on them. Students showed an understanding of the extent that the mining industry goes to in reclaiming land and dealing with environmental concerns.

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