Acid Mine Drainage Problem

In the early 1900’s, Western Pennsylvania was a great coal mining region. The remnants of this industry include abandoned mines that underlay a great portion of the land on which we live. An unfortunate side effect of this industry is the drainage of acidic waters from these abandoned mines into our streams and rivers. Studies have shown a drastic reduction in fish counts in polluted streams as the runoff from these mines is causing the pH of the water to fall, and heavy metals from the drainage are precipitating out of solution and entering our rivers as toxic materials.

The main culprit in the formation of acidic mine runoff is pyrite, (FeS$_2$). Natural pyrite exists underground, and is harmless because it is not exposed to rainwater or air. When mines are dug to remove coal, the pyrite is exposed to air and water. As shown in the reaction below, the pyrite reacts with oxygen in air and water to form iron(III) hydroxide, Fe(OH)$_3$, and sulfuric acid, H$_2$SO$_4$.

\[
4\text{FeS}_2(s) + 14\text{H}_2\text{O}(l) + 15\text{O}_2(g) \rightarrow 4\text{Fe(OH)}_3(s) + 8\text{H}_2\text{SO}_4(aq)
\]

The solubility of Fe(OH)$_3$ is both temperature and pH dependent. In the highly acidic waters of the mine, the Fe(OH)$_3$ will be very soluble. As the mine runoff is mixed with the waters of streams and rivers, it is diluted and the Fe(OH)$_3$ that was in solution precipitates out, and pollutes the riverbed. This is shown in the accompanying picture. Notice the red solid, Fe(OH)$_3$, that has been deposited in the stream just outside the mine exit.

In this activity, we will model acid mine drainage at various levels of sophistication. We'll consider a mine that puts out 10 liters of effluent every hour. The stockroom of the Virtual Lab contains a sample of such an effluent. This sample is a solution of H$_2$SO$_4$ that is saturated with Fe(OH)$_3$. The pH of this effluent is 1.0. The river itself flows by the mouth of the mine at a rate of 10,000 liters/hour. A sample of the river water is also included in the stockroom of the Virtual Lab for these problems.

We will consider three models of this system, with increasing sophistication. We will consider both the change in pH of the river due to the mine effluent and the amount of Fe(OH)$_3$ that precipitates outside of the mine.

- **Problem 1** starts with a simple model of the river as pure H$_2$O at 25 C.
- **Problem 2** considers the effect of temperature changes.
- **Problem 3** takes into account the buffering capacity of the chemical species in the river.
**Virtual Lab Problem 1:** *Assuming that the river is pure water at 25°C*

1a). As the mine effluent enters the river, it is diluted. What would you expect the pH of the river to be if the only factor you considered was the effects of dilution on the concentration of \([H^+]\)?

1b). Use the Virtual Lab to explore the chemical system and measure the change in pH resulting from the dilution.
1c). Compare the result you predicted in part (a) against pH you measured in part (b). Explain qualitatively the chemical processes that account for the observed behavior.

1d). Based on the measured pH in part (b), calculate the amount of Fe(OH)₃ that should precipitate as a result of the dilution. Check your answer using the Virtual Lab. How much Fe(OH)₃ will be deposited outside the river each hour?
Virtual Lab Problem 2: Assume that the river is still pure water, but consider the changes in solubility of Fe(OH)₃ due to temperature changes throughout the year.

2a). Perform experiments to determine if the amount of Fe(OH)₃ that precipitates outside the mine is greater in the winter or in the summer.

2b). Based on your measurements from part (a), what can you say about the thermodynamic properties of the following reaction:

\[ \text{Fe(OH)}_3 \rightarrow \text{Fe}^{3+} + 3 \text{OH} \]
Virtual Lab Problem 3: Our previous assumption that a river consists of pure water was obviously a simplification. Water arrives at the river after flowing over land and through the ground, and it carries some dissolved chemical species it picks up along the way.

3a). Predict how the buffering capacity of the river will affect both the pH of the river and the amount of Fe(OH)$_3$ precipitated in the river. Will the pH of the river be larger or smaller than you obtained in problem 1? Will more or less Fe(OH)$_3$ precipitate? Please explain your reasoning.

3b). Use the Virtual Lab to explore the chemical system and measure the pH and amount of Fe(OH)$_3$ that precipitates when the effluent is mixed with the sample of river water.

3c). Did your measurements agree with your predictions from part (a)? If not, can you adjust your reasoning, for instance by including additional chemical processes, to account for the observed behavior?
3d). Based on the pH you measured in part (b), calculate how much Fe(OH)$_3$ precipitates when the acidic mine effluent is discharged into the buffered model of the river. Check your answer against the amount of precipitate you measured in part (b). How much Fe(OH)$_3$ will be deposited outside the river each hour? How does this result compare with that obtained from the simpler, unbuffered, model in part (d) of problem 1.