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How much milk of magnesia would be required to neutralise Kawah Ijen's acid lake?

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Abstract
This paper investigates the amount of milk of magnesia, a common antacid, that would be required to neutralise the lake of sulfuric acid present in the crater of the Kawah Ijen volcano. The mode of neutralisation is discussed in terms of ionic interactions, and the theoretical volume of antacid was calculated using the mathematical relationship between pH and concentration. Assuming that the pH of the lake was, on average, 0.3, it was found that approximately 2.192×10^{12} 400 mg milk of magnesia tablets would be required to elevate the average pH to 7.

Introduction
Located in Java, the lake within the crater of the Kawah Ijen volcano is the largest acidic lake on Earth. With a pH of <0.3, lower than commercial battery acid [1]. The acidity of the lake affects the chemistry of local river ecosystems, including the river Banyupahit which is responsible for delivering water to many of the more populated areas downstream. In 2005, the average pH of the river water used to irrigate crops was between 2.5 and 3.5. For comparison, according to the US Geological Survey the typical pH range for river water is between 6 and 8 [2].

The neutralisation of this lake would raise the pH of the Banyupahit, increasing the pH of the river and allowing more crops to grow. This paper investigates how much milk of magnesia, a common antacid, would be required to raise the pH of the lake to 7. For the purposes of this calculation, it is assumed that the pH of the lake is constant (i.e. there is not a constant influx of acidic material due to volcanic activity).

Theory
The mode of neutralisation
Milk of magnesia (magnesium hydroxide), $Mg(OH)_2$, is an antacid that is commonly used to treat symptoms caused by too much stomach acid, such as heartburn or indigestion. Although intended for use in the stomach in the presence of hydrochloric acid (HCl), this paper will investigate how much $Mg(OH)_2$ would be required to neutralise the sulfuric acid present in the Kawah Ijen crater.

As $Mg(OH)_2$ is a weak base and H_2SO_4 is a strong acid, the H_2SO_4 would react with the $Mg(OH)_2$ to form aqueous magnesium sulfate, as shown in equation 1.

$$Mg(OH)_{2(s)} + H_2SO_{4(aq)} \rightarrow MgSO_{4(aq)} + 2H_2O_{(l)} \tag{1}$$

Due to the fact that $Mg(OH)_2$ is a weak base, it does not dissociate completely in an aqueous solution. Instead, an equilibrium is established between the undissolved solid and the dissolved ions (equation 2).

$$Mg(OH)_{2(s)} \rightleftharpoons Mg^{2+}{}_{(aq)} + 2OH^-{}_{(aq)} \tag{2}$$

On the other hand, as H_2SO_4 is a strong acid, it will ionise completely in an aqueous solution to release hydrogen ions and sulfate anions (see equation 3).

$$H_2SO_{4(aq)} \rightarrow 2H^+{}_{(aq)} + SO_4^{2-}{}_{(aq)} \tag{3}$$

The hydrogen ions then react with the hydroxide anions, neutralising each other. This drives the dissociation equilibrium further to the right, which dissolves the solid further and causes the production of more hydroxide anions. As the magnesium cations and sulfate anions are spectator ions, the net ionic equation is as follows:

$$2OH^-_{(aq)} + 2H^+_{(aq)} \rightarrow 2H_2O_{(l)} \qquad (4)$$

How much milk of magnesia would be required?

According to measurements taken in 2008, the pH of the lake varies depending on the proximity to the boundary. At the edges, the pH was measured to be 0.5, and the middle of the lake was found to have a pH of 0.13 due to the upwelling of sulfuric acid [1]. For the purposes of this paper, the average pH of the entire lake has been assumed to be 0.3 [3] and the volume of the lake has been found to be contain approximately 30 million cubic metres of liquid [4].

$$pH = -\log_{10}[H^+] \qquad (5)$$

$$[H^+] = 10^{-pH} \qquad (6)$$

Using equations 5 and 6, the concentration of the sulfuric acid in the lake, assuming a constant pH of 0.3, was determined to be 0.501 $moldm^{-3}$. It was then found that there were 1.503561701×10^{10} moles* of protons in the entire body of water. This was established by multiplying by the volume of the lake (converted to decimetres), which gave the total number of moles in the solution.

Using the same method, it was determined that the same volume of water at pH 7 would contain approximately 3000 moles of protons. To get the pH of the lake from 0.3 to 7, 1.50356140×10^{10} moles* of protons would have to be removed.

$$mass\ (g) = moles\ (mol) \times molar\ mass\ (gmol^{-1}) \qquad (7)$$

The molar mass of $Mg(OH)_2$ was found to be 58.3197 g mol^{-1}. Hence, using equation 7, it was found that the neutralisation of the Kawah Ijen lake would require 8.77×10^{11} g of $Mg(OH)_2$. Generally, milk of magnesia ($Mg(OH)_2$) is dispensed in 400 mg tablets [5]. Therefore, increasing the pH of the lake to a more neutral pH 7 would require approximately 2.192×10^{12} tablets.

Consequences

Neutralisation of the lake in the crater of Kawah Ijen would have the knock-on effect of raising the pH of the Banyupahit. As this water is used to irrigate crops, an increased pH is likely to increase yields and overall crop health. However, the use of $Mg(OH)_2$ to achieve neutralisation would cause an inevitable build-up of magnesium sulfate in the water, the effects of which are unknown at such high concentrations.

As these calculations have been performed under the assumption that the lake is a static system, it is unlikely that they would provide a good basis for a long-term neutralisation. As Kawah Ijen is currently active, there is a constant influx of sulfur and other acidic materials into the lake. Therefore, the neutralisation of the lake using antacids would only be a temporary solution.

Conclusion

To entirely neutralise all 30 million cubic metres of sulfuric acid present in the Kawah Ijen crater, it would require approximately 2.192×10^{12} 400 mg milk of magnesia tablets. This would increase the pH of the lake from 0.3 to 7, thereby elevating the pH of the Banyupahit and, by extension, the pH of the surrounding farmland. However, as the sheer amount of $Mg(OH)_2$ required to perform the neutralisation reaction is so large and the effects on the local ecosystems are unknown, it would be unrealistic to attempt it.

(*Note: It is important to keep this number of significant figures due to the change being so small as to not appear if the numbers were stated to two significant figures.)

References

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