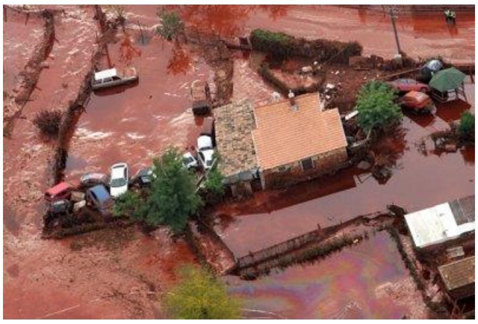
Red Sludge

On October 4, 2010, at 12.10 PM the dam of reservoir no. 10 of alumina plant of MAL Hungarian Aluminium (MAL Zrt.) collapsed causing a catastrophe without precedent. The sour cream like, highly alkaline thick mud flooded the area of Kolontár and Devecser near the reservoir. The damage caused casualties, injuries, psychological trauma and quite serious property damage.



The news went around the world and much ambiguous information came to light concerning the disaster. Besides the efforts taken to solve the situation and to reduce the damages, investigation has been started to uncover what led to the occurrence of the tragedy and what are those main direct and indirect effects that the experts who work on minimising the damages and (last but not least) the people concerned have to reckon with.
Exploration and evaluation of the causes and consequences require further investigation, so this section will not deal with these, but with some phenomena related to the production of red sludge (and to the use of aluminium).
Cleaning the red sludge is difficult; the inhalation of the dried red sludge can be harmful to the health. (One of its reasons is its grain size; the other is its high alkalinity.)

During the following experiment we get to know distinct features of sludge. After conducting the experiment summarise your results, estimations and explanation in a record. (20 points)

Before starting the experiment check up the following:
What do we call sludge? What are the differences between sludge and red sludge?

You will need the following items for the experiment:

- 3 pieces of transparent, cylindrical bottle (e.g. PET bottle)
- pens for making labels (e.g. alcohol pens)
- coarse-grained sand
- fine-grained sand
- clay
- water
- stopwatch
- ruler

Conducting the experiment:

- Put labels onto the bottles
- Put sand and clay in the bottoms of all the bottles. (Put materials with similar grain size distribution into the different bottles if possible.)
- Fill the bottles full of water and close their caps.
- Shake the bottles thoroughly. After shaking place all the 3 bottles vertically.
- Observe what happens. For our observations it is practical to use a stopwatch.

After conducting the experiment give the most thorough and accurate description of your observations.
How does settling rate depend on grain size?
Determine the amount of the deposited material over time.

(2)
Prepare a mind map of the uses of aluminium. (5 points)

(3)
The name 'aluminium' comes from the Latin word 'alumen' which means alum. Collect some information about alum. (7 points)

- What was alum used for in ancient times?
- What is the E number of potassium aluminum sulfate? What is it used for nowadays?

(4)
Make a list of the chemical differences between alum and alumina? (8 points)

(5)
It is worth trying to recrystallise alum. The reward of our efforts can be a beautiful mass of translucent crystals. Before recrystallisation it is worth making estimations with calculations. The following task will help you with this:
5.9 g KAlSO4 dissolves in 100 g of water at 20 °C, while 71 g alunite can dissolve in 100 g of water at 80 °C.
In theory, how many grams of $KAlSO_4$ solution saturated at 80 °C do you need to cool down to 20 ºC if you want to get 100 grams of alum ($KAl(SO_4)_2 \cdot 12\ H_2O$) crystal? (10 points)

(6)
One phase of aluminium production is the so called Bayer process.

Make a flow chart about it and mark on it where usable materials for the industry are produced.
How is the Bayer process connected to the production of red sludge? How can the amount of unusable by-products of the Bayer process be reduced? (8 points)

(7)
During the so called Hall-Héroult process of aluminium production alumina is dissolved in 15-20% molten cryolite (Na_3AlF_6) and is electrolysed at about 1000 ºC. Our task is connected to this process.
(Perhaps it is worth looking for a picture about the process before answering the question.) (12 points)

a) Where can natural cryolite be found?
b) What is the source of cryolite used in industry?
c) What is the reason that molten alumina is not directly electrolysed?

The chemical reactions that happen during electrolysis can be described with the following equation:

anode:
$$3\ NaAlOF_2 + 1{,}5\ CO + 6\ F^- = 3\ NaAlF_4 + 1{,}5\ CO_2 + 6\ e^-$$
cathode:
$$2\ NaAlF_4 + 6\ Na^+ + 6\ e^- = 8\ NaF + 2\ Al$$

d) Describe the reaction on the two electrodes with word equations.
e) Write the gross equation of the chemical reaction that records the process.

According to the simplified equations

the cathode reaction:
$$4\ Al^{3+} + 12\ e^- = 4\ Al\ ,$$

the anode reaction:
$$6\ O^{2-} = 6\ O + 12\ e^-$$
$$6\ O + 3\ C = 3\ CO_2$$
$$6\ O + 6\ C = 6\ CO.$$

The energy loss of the process is about 10%. In order to produce 1 kg aluminium with a purity of 99,50% about 15-22 kWh electricity is required.

The spiked electrodes generate an electric current of 100.000 – 150.000 A in the electrolysis baths (where the reactions take place in the cell).

f) What is the reason why the electrolysis cells are connected in series and not parallel?
g) Calculate how much time it takes to produce 1 kg of aluminium if we use an electric current of 120.000 A.
h) In this case, how much is the daily energy requirement of the process?
i) In 1990 aluminium metallurgy used 280 billion kWh electricity worldwide. In theory, for the production of how much aluminium is it enough?

(8)

When aluminium is recycled, the energy requirement of the process is only 70% compared to the energy requirement of aluminium production from bauxite. (http://www.freeweeb.hu/hulladek-suli/htan/fem.html). Out of 1 ton of aluminium approximately 60.000 beverage (beer) cans can be made. (This requires about 4 tons of average quality bauxite, from which we get the aluminium by producing two tons of alumina.)

The further data of the task come from the homepage of the ÉAI Hungary Ltd. (http://www.aluminiumitaldoboz.hu)

a) With the help of the above data esteem the energy requirement of the process.

b) In Hungary about 100.000 aluminium beverage cans are distributed every year. How much electricity is used to produce them?

In 2010, 41% of beverage cans were recycled in Europe. 113204 cans are processed per minute every day.

c) How much energy would we gain if we recycled all the cans?

In 2009 in Europe about 1.9 million tons of aluminium were recycled in a year. This covered 32% of the total European demand for aluminium.

d) How much energy did the European countries save? (10 points)

(9)

In Hungary, in 2000, 835,000 tons of red sludge was generated. (This is around 56% of the domestic hazardous waste). The solid content of red sludge is 10-30%.

The chemical composition of red sludge in percentages:

40-45% Fe_2O_3

10-15% Al_2O_3

10-15% SiO_2 (in the form of sodium or calcium aluminium silicate)

6-10% CaO

4-5% TiO_2

5-6% Na_2O

<1% V_2O_3, Ga_2O_3, rare-earth metal oxides

Do calculations to estimate the weight of the individual components of this volume of red sludge. (6 points)

(10)

Using your solutions collect scientific arguments for the recycling of aluminium (6 points)

(11)

Prepare a mind map about the consequences of the red sludge disaster and about the efforts made to minimize the damage and to restore the site (8 points)

Useful links:
http://www.chem.elte.hu/q/v%C3%B6r%C3%B6siszap-katasztr%C3%B3f%C3%A1val-kapcsolatos-k%C3%A9miai-fogalmak-magyar%C3%A1zata
http://www.chem.elte.hu/system/files/ELTE_vorosiszap_lexikonja.pdf
http://ligetmuhely.blog.hu/2010/10/21/victor_andras_a_vorosiszap_katasztrofa_kemiai_hattere
http://www.katasztrofavedelem.hu/index2.php?pageid=lakossag_kolontar_vorosiszap_hatasai
http://www.kerekdomb.hu/component/content/article/1-friss-hirek/190-a-voeroesiszap-katasztrofa-
http://vorosiszap.bm.hu/
http://tests.hu/show/196/F-L
http://www.aluminiumdoboz.hu