Recycling aluminium into alum crystals

This experiment was designed to recycle aluminium into alum crystals which have uses in industry. The aluminium was converted to alum by heating the metal samples with potassium hydroxide solution. The product was then reacted with sulphuric acid followed by crystallization. Overall, five trials were conducted with the only variable being the mass of aluminium used. The mass of crystals produced increased until the trial of 0. 9g, when excess aluminium was observed. These different aluminium masses consisted of 0. 3g, 0. 5g, 0. 7g and (2x) 0. 9g.

These particular research questions will be answered throughout this EEI:

- How the mass of the scrap aluminium related to the final mass of the alum crystal?
- How can stoichiometry of a sequence of chemical reactions be used to calculate the percentage yield of alum synthesized from aluminium scrap?
- How can scrap aluminium be chemically converted into a crystal?
- How does converting aluminium to alum make a worthy recycling process (make use in society, is it financially sustainable?).

2. 0 Introduction

2. 1 Background Information

Alum is a salt that in chemistry is a combination of an alkali metal, such as sodium, potassium, or ammonium and a trivalent metal, such as aluminium, iron, or chromium. The most common form, potassium aluminium sulfate, or potash alum, is one form that has been used in food processing.

Modern beverage containers are usually composed of aluminium, in the form of aluminium cans. Australians consumed over 3 billion aluminium cans in 2005. Additionally, approximately 300 million aluminium beverage cans are produced each day in the U. S. Recycling has the benefit of reducing litter from discarded cans and a number of states have passed laws requiring a deposit on aluminium cans to encourage recycling.

In this experiment, instead of recycling scrap aluminium into new metal cans, a chemical process will be used that converts scrap aluminium into a useful chemical compound, potassium aluminium sulfate dodecahydrate, KAl(S04)2 ï,· 12H20, commonly called “ alum”. Alum is widely used in the dyeing of fabrics, in the manufacture of pickles, in canning some foods, as a coagulant in water purification and waste-water treatment plants, as well as in the paper industry.

In an aqueous solution of KAl(SO4)2 , the K+, Al3+, and SO22- are surrounded by molecules of water (they are hydrated). These ions do not have an orderly arrangement in solution. When the compound is forced to crystallize, the ions must begin to join each other in their characteristic order. This process of nucleation may occur spontaneously when the ions of alum collide with appropriate orientation and with sufficiently low kinetic energy to permit them to “ stick” to each other and prevent them from rebounding. Occasionally, some foreign solids (irregularity on the wall of the container, dust particles) will serve as nuclei (or starting points) for the formation of crystals. Once a tiny crystal has formed, ions in their random motion through the solution will hit the faces of the crystal, join the orderly array of ions, and make the crystal grow. There is ionic bonding, covalent bonding and intermolecular attractions, plus hydrogen bonding, which is the attraction between water molecules. The only type of bonding not present in potash alum is metallic bonding. CAS_GIF_7784-24-9. gif

Aluminium, like almost all metals exhibits “ metallic bonding”. It can be oversimplified by saying that metallic bonding is like having positive metal ions in a sea of mobile electrons. The mobile electrons are the loosely held valence electrons that can easily move from atom to atom.

In fact, metals behave more like atoms which share orbitals to form delocalized covalent bonds. Orbitals from adjacent metals atoms overlap side-to-side to form pi- bonds.

For example, in this diagram, each iron atom, (and the same is true for aluminium) exhibits side to side overlap of the orbitals making pi bonds. Only one axis is shown in the diagram, but overlapping of the atoms in front of and behind this line also occurs. The beauty of this is that the electrons can move along the pi-bonds, from atom to atom, allowing the metal to conduct electricity.

Potassium alum is hydrated potassium aluminium sulfate KAl(SO4)2*12H2O. Since all chemical bonds are essentially covalent in nature, then this compound contains covalent bonds as well. The potassium-sulfate bond is the most polar, and the most ionic-like of the bonds. The substance crystallizes in a face-centred cubic arrangement of hydrated K and Al atoms alternating with SO4 radicals. Despite being a vast oversimplification of a complex structure, there are ionic bonds between K and SO4 and Al and

SO_4, and there are covalent bonds within SO_4. This allows an electrostatic attraction between the polar water molecules and the ions.

Although aluminium is a “ reactive” metal, it reacts only slowly with dilute acids because its surface is normally protected by a very thin, impenetrable coating of aluminium oxide; such metals are referred to as self-protecting or passivating metals. Alkaline solutions, or bases, (containing OH^-) dissolve the oxide layer and then attack the metal:

$AL_2O_3(s) + 2NaOH(aq) + 3H_2O(l) ———> 2NaAl(OH)_4(aq)$

$2AL(s) + 2NaOH(aq) + 6H_2O(l) ———> 2NaAl(OH)_4(aq) + 3H_20(g)$

Thus, in aqueous alkaline medium, aluminium is oxidized to the tetrahydroxoaluminate anion which is stable only in basic solution.

Aluminium is obtained from a raw material called bauxite predominantly in Latin and South America, Africa, and Australia. Recent technological improvements have seen the energy cost of producing one tonne of aluminium drop to 15, 000 kW, but that is still a lot of energy on top of which must be added, the energy of transporting the metal obtained around the world. Therefore aluminium recycling is extremely important and very easy for everyone to do.

Because of the energy used during extraction of aluminium from bauxite, aluminium is the only commonly used packaging material with a value that exceeds the financial costs of recycling it. To recycle an aluminium can, it costs only 5% of the energy used to create it in the first place. Additionally, aluminium can be recycled many times without any loss in quality.

2. 2 Aim

The aim is to investigate the effect of the amount of scrap aluminium on the amount of alum crystal produced when the amounts of potassium hydroxide and sulphuric acid used are kept constant.

2. 3 Hypothesis

It was hypothesized that if the weight of the scrap aluminium is increased or decreased then the amount of the alum crystal will adjust accordingly, when potassium hydroxide and sulphuric acid are kept the same.

3. 0 Materials

3. 1 Chemicals

Potassium hydroxide, KOH, 1. 0 M solution

Sulphuric acid, H2SO4, 6 M solution

3. 2 Apparatus

Aluminium beverage can

Sandpaper

Scissors

Ruler

Beakers: 3x 50-100mL, 3x 250mL, 3x600mL

Bunsen burner

Buchner funnel

Filter paper

Stirring rod

Spatula

Graduated cylinder

4. 0 Method

4. 1 Variables

4. 1. 1 Independent Variables

Independent Variables are those that are changed on purpose. The Independent Variables of this experiment are:

The mass of the scrap aluminium

4. 1. 2 Dependent Variables

The Dependent Variables are the factors that change according to the independent variables. The Dependent Variables of this experiment are:

The amount of alum crystal produced

The size of the alum crystals

4. 1. 3 Controlled Variables

Controlled Variables are the variables that are kept constant during the entire experiment. The controlled variables of this experiment are:

Amount of potassium hydroxide poured into the beaker

Amount of sulphuric acid poured into the beaker

Same size beakers for all five experiments

4. 1. 4 Uncontrolled Variables

The uncontrolled Variables are those that cannot be kept regular and may affect the validity of the experiment. The uncontrolled variables of this experiment are:

The impurity of the scrap aluminium

4. 2 Procedure

4. 2. 1 Risk Factors

Before the procedure can be commenced, certain safety precautions must be implemented prior to the beginning of the experiment. First of all Alum is non-toxic, although alum solutions can cause eye irritation (potassium hydroxide solutions are caustic). Therefore it is crucial to wear goggles or safety glasses when working with the solution. It is essential that the growing solutions are stored in a safe environment and not be disturbed. In the event of contact with skin or eyes (with any of the solutions – especially sulphuric acid which is highly corrosive), the affected area must be washed immediately with lots of water. If necessary, medical assistance should be obtained. Sulphuric acid is corrosive. The aluminium metal may have sharp edges, so it must be handled with care. Before handling any beakers, they must be inspected for any chipped or sharp edges, which may cause injury. Bunsen burners can be very hazardous due to its roaring flame so it must be used with caution. The flame must not be anywhere near the rubber hose because it can be easily melted. As long as all chemicals are kept distant from the human body, the Bunsen burner, and any other dangerously reactive materials, safety will be optimized.

4. 2. 2 Method

A piece of aluminium was scraped with sandpaper to eliminate the strong, thin aluminium oxide layer.

The mass of the clean piece of aluminium was carefully measured; 0. 300g (+/- 0. 001g).

The aluminium piece was then cut into smaller pieces, allowing larger surface area for the following reaction. C: UsersGeorgioDesktopSchoolChemistryMaterials Assignment – Yr 11Photos18052010030. jpg

These smaller pieces of aluminium were then placed in a 250mL beaker, with an added 50mL of 1M KOH (potassium-hydroxide).

A Bunsen-burner was then used to heat up the solution to boiling point, to completely dissolve the aluminium (a stirring rod is useful for enhancing the rate of reaction).

Once the aluminium was completely dissolved, the solution was then filtered using filter paper, removing insoluble impurities.

After being filtered, 20mL of 6M H_2SO_4 (sulphuric acid) was then added to the solution.

Immediately white crystals began to form in the solution.

The alum was removed from the liquid by filtration.

The alum was then left for 24 hours to crystallize. C: UsersGeorgioDesktopSchoolChemistryMaterials Assignment – Yr 11Photos18052010039. jpg

The filtration paper was then placed under a heat lamp to rid any condensation or leftover moist on the paper.

The weight of the final alum crystal was then able to be defined by subtracting the original weight of the filtration paper from the weight of the filtration paper with the alum.

This resulted in a final given amount of produced alum crystal.

REPEATED STEPS 1-13 (x4) with weights of scrap aluminium; 0. 5g, 0. 7g, 0. 9g (2x)

5. 0 Results

5. 1 Tables

Amount of alum produced:

Beginning Amount of Aluminium

Amount of Alum Crystal

0. 3g

3. 769g

0. 5g

4. 913g

0. 7g

7. 878g

0. 9g

8. 763g

0. 9g

4. 437g

At temperature, 100 parts of water dissolve (g/100ml):

Temperature

Potash Alum

0oC

3. 90

10oC

9. 52

50oC

44. 11

80oC

134. 47

100oC

357. 48

5. 2 Graph

Beginning weight of aluminium piece

Amount of alum produced (g)

Starting weight of aluminium

Percentage Yield for alum experiments

Solubility of potash alum in water:

alum_solubility_chart. gif

Amount of books containing alum: an17-4a. gif

Consumption and Recycling of aluminium can beverages in the world:

5. 3 Experiment Yield

Theoretical Yield:

2Al(s) + 2KOH(aq) + 4H2SO4(aq) + 22H2O(l) ——> 2KAl(SO4)2-12H2O(s) + 3H2(g)

According to the chemical reaction, 2 moles of aluminium will react to form 2 moles of alum.

Formulas:

Theoretical yield = Mass of aluminium used = Mass of Alum obtained

Molar mass of aluminium Molar mass of Alum

Percent yield = Mass of alum obtained x 100

Theoretical yield of alum

0. 3g Aluminium:

0. 300 = X 3. 769 x 100 = 71. 6

27 474 5. 26

= 5. 266

The percentage yield is 71. 6%

0. 5g Aluminium:

0. 500 = X 4. 913 x 100 = 56%

27 474 8. 77

= 8. 77

The percentage yield is 56%

0. 7g Aluminium:

0. 700 = X 7. 878 x 100 = 61. 55

27 474 12. 8

= 12. 8

The percentage yield is 61. 55%

0. 9g Aluminium (trial 1):

0. 900 = X 8. 763 x 100 = 55. 46

27 474 15. 8

= 15. 8

The percentage yield is 55. 46%

0. 9g Aluminium (trial 2):

0. 900 = X 4. 437 x 100 = 28. 08

27 474 15. 8

= 15. 8

The percentage yield is 28. 08%

6. 0 Discussion

From the results obtained, it can now be determined how the mass of aluminium affects the alum crystal mass and size. After making all recordings, different qualitative and quantitative results were questioned. As seen from the results obtained in “ 5. 0 Results”, there were two trials for the experiment with the mass of 0. 9 grams of aluminium. This was decided because it was apparent that at around 0. 9g of aluminium, it would begin to cause the solution to be saturated. Therefore the procedure for these two experiments differentiates in the following way; as with the other experiments, one was filtered after adding the sulphuric acid (creating the alum), and the other was left to crystallize with no further process. These both resulted in a successful and an unsuccessful result, which provided qualitative results. The one that was filtered had completely crystallized within 24 hours. The one that was left in a solution with aluminium was left to crystallize. The alum did not precipitate from this solution. This result was an anomaly for the experiment for it gave dissimilar results which were discarded. The same procedure was successful until 0. 9g due to the fact that the aluminium was acting as the limiting reagent. At 0. 9g the potassium hydroxide became the limiting reagent allowing the aluminium to serve as the excess reactant. C: UsersGeorgioDesktopSchoolChemistryMaterials Assignment – Yr 11Photos19052010040. jpg

These were all the chemical equations step by step during the procedure:

When sulphuric acid is slowly added to an alkaline solution of this complex anion, initially, one hydroxide ion is removed from each tetrahydroxoaluminate anion causing the precipitation of white, gelatinous aluminium hydroxide, $Al(OH)_3$

$2K[Al(OH)_4](aq) + H_2SO_4(aq)$ â†’ $2Al(OH)_3(s) + K_2SO_4(aq) + 2H_2O(l)$

The excess potassium hydroxide is neutralized by some of the sulphuric acid to form potassium sulfate.

2KOH(aq) + H2SO4(aq) â†’ K2SO4(aq) + 2H2O(l)

On addition of more sulphuric acid, the aluminium hydroxide dissolves forming the hydrated aluminium cation

2Al(OH)3(s) + 3H2SO4(aq) â†’ Al2(SO4)3(aq) + 6H2O(l)

Addition of alkali to the Al(OH)3 precipitate will also bring about dissolution by reforming [Al(OH)4]. A hydroxide, such as aluminium hydroxide, that can be dissolved by either acid or base is said to be amphoteric. When the acidified aluminium sulfate solution is cooled, potassium aluminium sulfate dodecahydrate (“ Alum”) precipitates.

Al2(SO4)3(aq) + K2SO4(aq) + 24H2O(l) â†’ 2K[Al(SO4)2]-12H2O(s)

The overall reaction that takes place is the sum of the previous reactions.

2Al(s) + 2KOH(aq) + 4H2SO4(aq) + 22H2O(l) â†’ 2KAl(SO4)2-12H2O(s) + 3H2(g)

All of the filter papers that were to be used were weighed, and an average filter paper mass was recorded for later purposes. For each of the alum solutions that were produced, once filtered (excluding the one that wasn’t filtered), were then given 24 hours to crystallize before data and measurements were recorded. It was apparent that in the beaker that contained the solution of the filtered alum, there were small crystal seeds that had formed. This was due to the saturated solution which still contained alum, therefore in the 24 hours it was able to grow into bigger alum seeds. The remaining liquid in all the beakers was decanted leaving only the crystals; they were placed under heat lamps for 10 minutes to evaporate any adhering water. Some final results from the measurements were now conductible. Knowing the beaker mass, the beaker mass with alum, the filter paper mass and the filtration paper mass with alum, the amount of alum produced was established. These final crystal masses were:

0. 3g = 3. 769g (+/- 0. 004g)

0. 5g = 4. 913g (+/- 0. 004g)

0. 7g = 7. 878g (+/- 0. 004g)

0. 9g = 8. 763g (+/- 0. 004g) (with filtration paper)

0. 9g = 4. 437g (+/- 0. 002g) (without filtration paper)

It is quite obvious to state that a trend in this experiment was recognized after noticing that (as stated in the hypothesis) when more aluminium is used, more alum crystal is produced, so long as the aluminium remains the limiting reagent. As the aluminium mass increases, the alum product remains at a fairly relative mass for all four scenarios.

In reference to the results obtained from “ 5. 3 Experiment Yields”, it was found that the percentage yield for all experiments (excluding the non-filtered one) were relatively impressive, but predictable. In practice, getting 100% yield is incredibly difficult if not essentially impossible. Often reactants or products can be lost to the environment, not all of the reactants could react or other factors could impede the reaction. Although in this experiment, a different factor was the cause of the loss of yield percentage. The manufacturers of aluminium cans use an aluminium alloy when making the cans, therefore causing the aluminium to have impurities. This was also noticeable when the reaction of the aluminium with the potassium hydroxide took place; the black residue which was produced was the sign of impurity. A procedure which could have helped prevent this error would have been to soak the aluminium in NaOH (sodium hydroxide) which would get rid of the oxide layer that the aluminium contains and any other impurities. Another possible solution to increasing the percentage yield would be to immediately put the beaker in water and ice, straight after adding the sulphuric acid to the solution; allowing it to chill thoroughly for about 15 minutes. Considering this solubility data, some product will not precipitate from the solution. Considering this table and graph (shown in Results), an improved result would be obtained by precipitation in ice water. This would cool the solution down much faster allowing the crystals to grow at a much greater reaction rate. Whereas when it isn’t iced, but filtered immediately, much of the alum saturated solution will fall through into the beaker losing some content. Furthermore, when the alum crystal was being handled (transport to filter paper from beaker, etc.) alum would have been eluded. The consequence of this would result in less alum.

7. 0 Conclusion

This experiment aimed to investigate the effect of the amount of scrap aluminium on the alum crystal, when potassium hydroxide and sulphuric acid were kept constant. Regarding the outcome of each trial, the results were supported by the theory stated in the hypothesis: It was hypothesized that if the weight of the scrap aluminium is increased or decreased then the amount of the alum crystal will adjust accordingly, when potassium hydroxide and sulphuric acid are kept the same. It was found that the aluminium’s mass had a definite effect on the amount of alum produced. It can be concluded that when the potassium hydroxide is kept constant as well as the sulphuric acid, the outcome will be relatively similar and will adjust accordingly to the weight of the scrap aluminium.

The crucial errors which were encountered in this experiment, which had a vast impact on the percentage yield, was the impurity of the scrap aluminium, the imprecision of handling the alum, and the improper cleaning procedure which was undertaken with each of the scrap aluminium pieces.

The results obtained prove the hypothesis correct which stated that if the weight of the scrap aluminium is increased or decreased then the amount of the alum crystal will adjust accordingly.

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