RECYCLING OF WASTE: A TOOL FOR ENVIRONMENTAL AND SUSTAINABLE NATIONAL DEVELOPMENT. PRODUCTION OF ALUM [$2KAl(SO_4)_2.12H_2O_{(S)}$] FROM ALUMINIUM CANS.

Ibrahim M. S[a,b],*, Kurfi Y. M.[c], Mohammed.A. I[d]

[a]Sciences Department, Maude International Schools, Zaria, Nigeria
[b]Break-Free Plastic Movement, Nigeria
[c]Department of Pure and Industrial Chemistry Bayero University, Kano
[d]Department of Chemistry Federal College of Education, Zara

ABSTRACT

Modern beverage containers are usually composed of either aluminium, in the form of aluminium cans, or polyethylene terephthalate (PETE), the clear plastic beverage bottles. Aluminium is one of the most indestructible materials used in metal containers. The average "life" of an aluminium can is about one hundred years. Although aluminium is the third most abundant element in the earth's crust, the expense of extracting it from common soils is too expensive and the major source is the ore bauxite, the hydrated form of aluminium oxide, $Al_2O_3{\cdot}2H_2O$. Aluminium metal is not consumed rapidly by corrosion; the amount of scrap aluminium grows rapidly while the available supply of raw materials for the manufacture of aluminium decreases. Environmental problems thus created are typical of those of several different metals. One obvious solution to the problem is to recycle the used fabricated aluminium can into other useful products or into aluminium compounds. This research illustrate a chemical process was used that transforms scrap aluminium into a useful chemical compound, potassium aluminium sulfate dodecahydrate, $KAl(S0_4)_2{\bullet}12H_20$, commonly called "alum". The percentage yield of 46.7% was obtained using 2g of the aluminium waste cans.. 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, and in the paper industry. The study also provides an interesting energy saving method of reducing environmental pollution via conversion of waste to wealth.

Key words: *Aluminium, Aluminium can, Recycling, Alum and Sustainable Environment and National Development.*

No: of Figures: 2 **No: of Tables: 3** **No: of References: 11**

INTRODUCTION

Aluminium is one of the most versatile metals in the world. Aluminium is an excellent conductor of electricity. It is also an efficient conductor of heat and a good reflector of light and radiant heat. Aluminium is primarily used to produce pistons, engine and body parts for cars, beverage cans, doors, siding and aluminium foil. It may also be used as sheet metal, aluminium plate and foil, rods, bars and wire, aircraft components, windows and doorframes. Although aluminum is the most abundant metal on Earth, it was once found to be very difficult to extract from its various ores. At one time, aluminium was more valuable than gold. Over time, however, the price of aluminium has dropped, due in large part to the invention of the Hall-Héroult process.Aluminium electrolysis was discovered in 1886 by Paul-Louis Toussaint Héroult and Charles Martin Hall. The process is based on the use of a powerful electric current to decompose aluminium oxide (Al_2O_3). Aluminium, found in the form of bauxite ore, is first converted into pure aluminum oxide by the Bayer Process. This is then electrolyzed in solution in molten cryolite - another aluminium compound, releasing pure aluminium.

The simplified redox reactions in the electrolysis of Al_2O_3 are shown below:

$$4Al^{3+} + 12e^- \rightarrow 4Al \qquad \text{Cathode}$$

$$3C(s) + 6O^{2-} \rightarrow 3CO_2 + 12e^- \qquad \text{Anode}$$

$$2\,Al_2O_3 + 3\,C \rightarrow 4\,Al + 3\,CO_2 \ldots \text{Overall cell reaction}$$

Aluminium can either be produced from bauxite ore as described above, or from aluminium scrap. Refinement of aluminium ore is so expensive that the secondary production industry commands much of the market.

Aluminium recycling is the process by which scrap aluminium can be reused in products after its initial production. The process involves simply re-melting the metal, which is far less expensive and energy intensive than creating new aluminium through the electrolysis of aluminium oxide (Al_2O_3), which must first be mined from bauxite ore and then refined using the Bayer process. Recycling scrap aluminium requires only 5% of the energy used to make new aluminium. For this reason, approximately 31% of all aluminium produced in the United States comes from recycled scrap.

As recycling does not damage the metal's structure, aluminium can be recycled indefinitely and still be used to produce any product for which new aluminium could have been used.

The environmental benefits of recycling aluminium are enormous. Only around 5% of the CO_2 is produced during the recycling process compared to producing raw aluminium (and an even smaller percentage when considering the complete cycle of mining and transporting the aluminium). Also, open-cut mining is most often used for obtaining aluminium ore, which destroys large sections of world's natural land.

Figure 1: Aluminium Beverage Containers

Recycling of materials that would otherwise be discarded is a key component of environmental sustainability, National Development and self-reliance. Reducing the amount of items bought is the most significant of all the options to manage waste, and a careful look at things we are throwing away, will definitely reinvigorate an idea that they are materials that can be reused to solve everyday problems and satisfy everyday needs. The numerous environmental and economic advantages from recycling process is overwhelming as it creates more jobs than the landfilling industry, saves energy, reduces pollution by reducing the need to extract and transport virgin resources. Also, it greatly reduces greenhouse gas emissions, including harmful methane thereby conserving resources for future generations. Aluminium recycling is the process through which scrap aluminium is reprocessed to be used in products after its initial production. Modern beverage containers are usually composed of Aluminium in the form of aluminium cans which can be recycled.

This paper describes a chemical process that would be used to transform scrap aluminium cans into a useful chemical compound, potassium aluminium sulphate dodedecahydrate, KAl(SO4)2.12H2O, usually called alum.

Alum. Alum is the common name given to several chemical compounds that consist of a positively charged ion (K^+, Na^+, NH_4^+ ect.), an aluminium (Al^{3+}) ion, several sulfate ions (SO_4^{-2}) and twelve water of hydration. The compound to be synthesized in this procedure is Potassium aluminium sulfate dodecahydrate, **$KAl(SO_4)_2$•12 H_2O**. When compounds crystallize out of an aqueous solution, water molecules can fit into the crystalline structure and become bound up in the solid. This water is included in the formula weight of the compound and is represented by a dot (**•**) and then the number of water molecules for each molecule of solid. This adds up for the above alum compound to a formula weight of 474.3884gmol^{-1}.

Uses of Alum

Alum is widely used in the following:

i. Flocculating agent: Alum is used to clarify water by catching the very fine suspended particles in a gel like precipitate of aluminium hydroxide. This sinks to the bottom of the containing vessel and can be removed in a variety of ways.

ii. Shaving alum: is a powdered form of alum used as an astringent to prevent bleeding from small shaving cuts. The styptic pencils sold for this purpose contain aluminium sulfate or potassium aluminium sulfate. Similar products are also used on animals to prevent bleeding after nail-clipping. Alum in block form (usually potassium alum) is used as an aftershave, rubbed over the wet freshly shaved face.

iii. Hair Stiffener: Alum was used in rock form in the 1950's to rub on the front short hair of a "crew cut". When the hair dried, it would stay up all day.

iv. Crystal deodorant: Alum was used in the past as a natural underarm deodorant in Europe, Mexico, Thailand where it is called Sarn-Som, the Far East and in the Philippines where it is called Tawas. It is now commercially sold for this purpose in many countries, often in a plastic case that protects the crystal and makes it resemble other non-liquid deodorants. Typically potassium alum is used.

v. Alum powder, found amongst spices at most grocery stores, is used in pickling recipes as a preservative, to maintain crispness, and as an ingredient in some play dough recipes. It is also commonly cited as a home remedy or pain relief for canker sores.

vi. Fire retardant: By soaking and then drying cloth and paper materials they can be made fireproof.

vii. Wax: Alum is used in the Middle East as a component in wax, compounded with other ingredients to create a hair-removal substance.

viii. Foamite: Alum is used to make foamite which is used in many fire extinguishers for chemical and oil fires.

ix. Adjuvant: Alum is used regularly as an adjuvant (enhances immune response to a given immunogen when given with it) in human immunizations.

x. Antibacterial agent: Alum works as a deodorant because Alum inhibits bacterial growth. This fits the definition of an antibacterial agent. Styptic pencils or Alum powder/crystals can be applied to cuts that have a mild infection.

Sustainable Environment and National Development

For the past few decades the need for introducing environmental requirements into design and development of materials and products became a vital issue. The sustainable development agenda is now significant within public and industrial sectors and is one of the fundamental objectives. Current world economies are materials and energy intensive. Unfortunately, sustainability is a broad but not precisely defined term, it's basically a guiding principle or a goal laid down by the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, 1992 (attended by representatives from 150 countries) in which an action plan was adopted, known as Agenda 21(UNCED, 1992) for the pursuit of the sustainable development. It was pointed out that achieving sustainable economic development will require changes in industrial processes, in the type and amount of resources used and in products which are manufactured (CAETS, 1996). The most commonly used current definition of sustainability came from the report (Brundtland Commission, 1987) in 1987 as *meet the needs of the present without compromising the ability of future generations to meet their own needs*. This report prompted numerous actions, which called on governments, local authorities, businesses and consumers to define and adopt strategies for sustainable development.

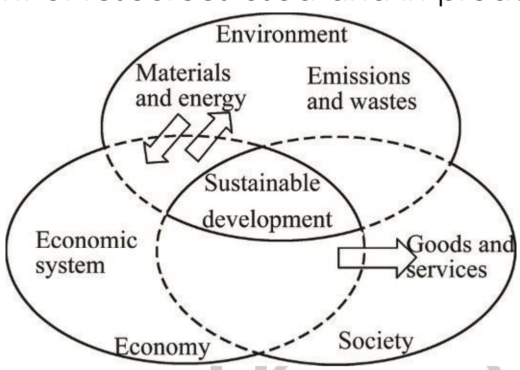

Figure 2: *A model of sustainable development*

Today, recycling of post-consumer aluminium products saves over 90 million tonnes of CO_2 and over 100,000 GWh of electrical energy. For most aluminium products, the metal is not actually consumed during the product's lifetime, but simply used, with the potential to be recycled without any loss of its inherent properties. Therefore, the life cycle of an aluminium product is not the traditional "cradle-to-grave" sequence, but rather a renewable "cradle-to-cradle". This property of infinite recyclability has led to a situation where today around 75% of the almost one billion tonnes of aluminium ever produced is still in productive use, some having been through countless loops of its lifecycle. Through the use of only 5% of the original energy input, this metal can be made available not just once but repeatedly from these material resources for future generations. The growing global markets for aluminium products are supplied by both primary (around 65%) and recycled (around 35%) metal sources. The increasing demand for aluminium and the long lifetime of many products, limiting their availability for short term recovery but maximizing their in-use benefits, mean that the overall mass of primary metal consumed will continue to be around double that of recycled metal, for the foreseeable future. However, improving the overall collection rates of used products is an essential element in the pursuit of sustainable development. Industry continues to recycle, without subsidy, all the aluminium collected from end-of-life products as well as from fabrication and manufacturing process scrap. With a growing number of industry initiatives and the help of appropriate authorities, local communities and society as a whole, the amount of aluminium collected could be increased further.

Purpose of the Study

i. To recycle aluminium cans and make a useful product, Alum [potassium aluminium sulfate $KAl(SO_4)_2 \cdot 12H_2O$.]
ii. To understand the processes involved in recycling, their importance, and the difficulties in doing so.

Materials and Method

Table 1: Chemicals and Equipment

Chemicals	Equipment and Supplies
2.0 g aluminum can	steel wool
1.5 M Potassium hydroxide (KOH)	Buchner funnel
9.0 M sulfuric acid	Vacuum flask
Ice for ice bath	scissors
50%:50% Ethanol: water mixture	Bunsen burner and ring stand
	150 and 250 mL beakers
	100 mL graduated cylinder
	large beaker for ice bath
	balance

The first part of this experiment was to remove the paint from the outside of the aluminium can using sand paper followed by cutting the cans into pieces and then weighing the mass of the amount to be used. The weighed amount was dissolved in 1.5M potassium hydroxide solution by placing both in a beaker and placing it on a hot plate heated to a temperature of about 250°C. Once the solution started to bubble vigorously, it was removed from the hot plate and continually stirred to dissolve all of the aluminium can. The solution turned a grey/black color. During this process, hydrogen gas is released (Ugwekar and Lakhawat, 2012). Once the aluminium was fully dissolved, the solution was filtered through a Buchner funnel lined with filter paper, which removed the undissolved plastic lining and residual paint that was present from the aluminium can. The solution that was drained was then transferred into a beaker and 20mL of 9M sulfuric acid was added to it. This solution was then placed in an ice bath for about 15 minutes, to allow the solution to produce white crystals, which are the alum.

While the crystals were forming, the filter paper from the draining was rinsed through the Buchner funnel using water, to collect the paint and undissolved plastic in a pile to weigh using an analytical balance. The mass was then recorded and used to calculate the percent yield of alum.

Calculation of Theoretical Yield:

The theoretical yield is the amount of alum you would obtain from your starting mass of aluminium if all reactions worked perfectly and you were able to obtain all intermediate compounds and products. The theoretical yield can be calculated from the overall balanced reaction:

$2Al(s) + 2KOH(aq) + 4H_2SO_4(aq) + 22H_2O(l) \rightarrow 2KAl(SO_4)_2 \cdot 12H_2O(s) + 3H_2(g)$ ------(1)

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

To calculate the theoretical yield of the alum, use the equation:

$$\text{Theoretical Yield} = \text{mass of aluminium used} \times \frac{1 \text{ mole aluminium}}{\text{atomic weight of aluminium}} \times \frac{\text{moles of alum produced}}{\text{moles of aluminium used}} \times \frac{\text{formula weight of alum}}{1 \text{ mole of alum}}$$

Where the middle term of the equation is the mole ratio of *moles of alum produced* to *moles of aluminium used* from the balanced equation, above.

Percent Yield:

The percent yield is the percent of the theoretical yield you actually obtained. To calculate the percent yield, use the equation:

$$\text{Percent Yield} = \frac{\text{Mass of Alum Obtained}}{\text{Theoritical Yield of Alum}} \times \frac{100}{1}$$

The equations below show the complete sequence of reactions involved in the experiment. Reaction of aluminium with KOH (the dissolution step):

$Al(s) + 2KOH_{(aq)} + 6H_2O_{(l)} \rightarrow 2 KAl(OH)_{4(aq)} + 3H_{2(g)}$ ------------------------(2)

Initial addition of sulfuric acid (precipitation of Al(OH)₃):

$2KAl(OH)_{4(aq)} + H_2SO_{4(aq)} \rightarrow 2Al(OH)_{3(s)} + K_2SO_{4(aq)} + 2H_2O_{(l)}$ ------------------------- (3)

Further addition of sulfuric acid (dissolving of Al(OH)₃):

$2Al(OH)_{3(s)} + H_2SO_{4(aq)} \rightarrow Al_2(SO_4)_{3(aq)} + 6H_2O_{(l)}$ -----------------------------------(4)

Precipitation of alum on cooling:

$K_2SO_{4(aq)} + Al_2(SO_4)_{3(aq)} + 24H_2O_{(l)} \rightarrow 2KAl(SO_4)_2 \cdot 12H_2O_{(s)}$ -------------------------- (5)

Results

The summary of the experiment procedure/Pictorial Presentation of the synthesis process is shown in figure 2 which comprises images 1-6 and also results on qualitative analysis of the synthesized alum crystal is given in table below and for the calculated values in table 2 and 3 respectively.

1

Figure: 2: Pictorial Presentation of the synthesis process

Table 2: Qualitative analysis result of ions presence in synthesized Alum crystal.

Test	Observation	Inference
Alum solution + Aqueous $BaCl_2$ Solution	White Precipitate formed, and insoluble (After 20 hours)	SO_4^{2-} Confirmed
Solid Alum Crystal + heat (10 minutes)	Red flame turned to lavender (pale purple) flame color	K^+ Confirmed
Aluminate ion Solution + $H_2SO_{4(aq)}$ In drop and in Excess	thick, white gelatinous precipitate formed, insoluble in drop but soluble in excess $H_2SO_{4(aq)}$	Al^{3+} Confirmed

Table 3: Summary of calculated values

Parameter	Calculated value
Mass of Alum obtained	16.4g
Mass of aluminium used	2.0g
Atomic Weight of Aluminum	27
Number of mole of Aluminium used	0.074 moles
Molar Mass of Alum	474.3884gmol^{-1}
Number of mole of Alum	0.035moles
Theoretical yield of Alum	35.14 g
Percentage yield of Alum	46.7%

DISCUSSION

The dissolution of Al(s) in aqueous KOH is an example of an oxidation-reduction or redox reaction. The Al metal is oxidized to aluminium with an oxidation number of +3 and the hydrogen in KOH or in water is reduced from an oxidation number of +1 to zero in hydrogen gas. The $Al(OH)^{4-}$ ion is a complex ion called "aluminate." The reaction between aluminate ion and sulphuric acid is an acid-base reaction in which the H^+ ions from the sulfuric acid neutralize the base $Al(OH)^{4-}$. Initially, a thick, white, gelatinous precipitate of aluminium hydroxide, $Al(OH)_3$ was formed as more acid is added, the precipitate dissolved. The solution at this point contains Al^{3+} ions, K^+ ions (from potassium hydroxide), and SO_4^{2-} ions (from sulfuric acid) equations (2) &(3). However, the qualitative analysis of the Alum crystal formed indicated insoluble white precipitate when reacted with Barium chloride confirming the presence of sulphate ions. While a blue flame of Bunsen burner and pale purple (lavender) color produced, this confirmed the presence of potassium ion (K^+) in the solid crystal.

Sequel to the results obtained from qualitative analysis of synthesized Alum crystal, the chemical recovery method was found to be effective and efficient way to recycle the aluminium scrap. The Alum crystal obtained by this process is of best quality, as the use of aluminium cans for soft drinks companies are increasing, subsequently waste are increasing and a large number of Aluminium scrap is generated. Thus, integration and design of chemical recovery plant of aluminium scrap will surely contained the environmental pollution pose by this aluminium scrap.

CONCLUSION

Most countries dig up huge holes in the ground for burying waste. Thus, by recycling aluminium, the space that would be needed for burying the aluminium waste is saved and can be used for other purposes. In the developed Nations, recycling of these wastes are successful with an average energy savings of 95 percent over refining and smelting bauxite ore. Though aluminium cans are currently recycled to make more aluminium products, scrap aluminium metal can also be used to product alum. Alum is a chemical used in a myriad of applications including water purification, make-up, deodorant, hardening gelatin, baking powders, hardening plaster casts, and as a medicinal astringent. Thus, aluminium recycling is important to the environment and the people all over the world, opens window for diversifying the economy and produces an avenue for job opportunities.

REFERENCES

A.U Birnin-Yauri & Musa Aliyu (2014) "Synthesis and Analysis of Potassium Aluminium Sulphate (Alum) from Waste Aluminium Can" *International Journal of Advanced Research in Chemical Science (IJARCS)* Volume 1, Issue 8, October 2014, PP 1-6 ISSN 2349-039X (Print) & ISSN 2349-0403 (Online) www.arcjournals.org

Apampa S. A (2017). "Reduce, reuse and recycling of waste: an alternative to sustainable environment, economic recovery and self-reliance. A case of alum from aluminum cans". A Paper presented at the 1st National Conference on Chemical Technology from 7th to 10th August, 2017 at NARICT

Brundtland Commission, Our Common Future. Report of the World Commission on Environment and Development[R]. Oxford: Oxford University Press, 1987.

Council of Academies of Engineering and Technological Sciences. The Role of Technology in Environmentally Sustainable Development. London: The Royal Academy of Engineering, 1996:

Dara S.S.,(2000). "A textbook of Environmental chemistry and Pollution Control". S.Chand Publication, pp 97-164.
David A. Katz (2000). Alum from Waste Aluminum Cans. www.chymist.com

Department of Environmental Affairs and Tourism of South Africa. Working with Waste. Guidelines on Recycling of Solid Waste. Retrieved from www.environment.gov.za on 22/06/17.

Environmental Protection Agency (2002). Campaigning against waste [EPA 530-F-02-033]. Washington, D.. Working with Waste

Fahzy Abdul-Rahman (2014): Reduce, Reuse, Recycle: Alternatives for Waste Management. Retrived from www.aces.nmsu.edu on 23/06/17.

Sharma .A , Sharma C , and Sharma A.K.(2007). Characteristics and Management of Medical Solid Waste. *Indian Journal of Environmental Protection*. 27(10): 897-904

UNCED, Agenda 21, United Nations Conference on Environment and Development in Rio de Janeiro 1992[C]//

World Business Council for Sustainable Development. http://www.iisd.ca/consume/ unep.html.

Uqwekar, R.P and Lakhawat, G.P (2012). Potash Alum from Waste Aluminum Cans and Medicinal Foil. *IOSR Journal of Engineering (IOSRJEN)*. 2(7), 62-64. www.iosrjen.org.