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A Short Review on Aluminium Smelting and Its Future Prospect in Malaysia Metal Industries

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Abstract: Smelting is process to produce aluminum from its ores. Domestic demand for aluminium had increased during the past several years and expected to grow in the future. Non-ferrous metal like aluminium was important because of desirable properties such as low weight despite the higher cost compared to ferrous metal. This paper presents a review of aluminum smelting in Malaysia industries. The survey covered the alternative aluminum processes including the alumina, electrical energy, some carbon, and possibly some other recyclable chemicals as an input. The outputs are aluminum and varying amounts of carbon oxides. The results introduce the fact of the aluminum industry must be based on discovering a new bauxite fields and the stability of the price of aluminum.
Keywords: aluminum, refinery, reduction smelting.

1. Introduction

Aluminum is the most abundant metal and the third most abundant element after oxygen and silicon in the world. It makes up about 8% by weight of the earth's solid surface and it never occurs as a free element in nature.

Aluminum is the third most abundant element in the earth's crust, but because of its chemical re-activity, it is always found in an oxidized form not in pure. Mostly bauxite exists in three main variants, each containing hydrated forms of aluminum oxide. The variants depend on the number of molecules of water of hydration and the crystalline structure and are known as gibbsite, bÄohmite and diaspore [1]. The former exists in trihydrate form, as opposed to a monohydrate for the other, and is currently the most dominant form being mined. Trihydrate forms contain approximately 50% alumina by weight.

Aluminium is one of the most popular metals in today's industrialized world. It was discovered since 1825 in Denmark by Hans Christian Oersted. Aluminium came from "alumen" meaning "alum" from Latin word [2]. Aluminium color is in silver with atomic number 13 and weight 26.98 g/mol. The abundance of aluminium in earth's crust and the easy recycling possibility made this metal very famous in today's world. The application of it is almost everywhere starting from cold drinks can to the aero plane. There are 5 basic steps in aluminium smelting process as shown in Figure 1.

Malaysia's mineral resource industry consists of a sector of coal, ferrous and nonferrous sector in metals mining, metal processing, industrial minerals extraction and processing. Mining and mineral-processing businesses incorporated mostly in Malaysia were privately owned or a joint venture with State-owned Company.

Aluminium is produced from bauxite. It is still being produced in Malaysia but in a rather small quantity. Most of the bauxite produced was exported to Asian countries such as Japan, Taiwan and Thailand. The remaining ore reserves of the bauxite mine is small located in Johor, but there are potential resources of bauxite in the other states of Malaysia, namely Sabah and Sarawak [3].

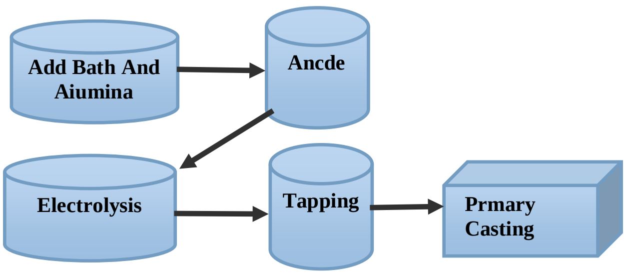

Figure 1. Sketch of basic aluminium smelting process

Press Metal Sarawak Sdn Bhd (a subsidiary of Press Metal Berhad) completed the construction of a 120,000-metric-ton-per-year (t/yr) aluminum smelter in Mukah in the State of Sarawak; the smelter was fully operational by the second half of 2012. Press Metal had chosen the Aluminum Corp. of China Ltd. (Chalco) as its technical partner for the first phase of the aluminum smelter project. Chalco's Guiyang Aluminum and Magnesium Research Institute installed the prebaked cells. The company signed a memorandum of understanding with Sarawak Energy Berhad to supply 510 megawatts (MW) of electricity-generating capacity for the smelter in 2010. After the smelter was fully operational, the company started the construction of its second potline. The second potline would be equipped with 400-kiloampere prebaked anode cells and was scheduled to be completed in 2013 increase the smelter's total output capacity to 300,000 t/yr. Sumitomo Corporation of Japan acquired a 20% share in the second phase aluminum project and had sales rights to some of the output [4].

2. Reduction Smelting

In Smelting is a unit process for pyrometallurgical extraction of metal in which gangue minerals are

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separated from the metal in a liquid state. The components of the materials are heated above the melting points so that they are separated in the liquid state. Matte smelting is a process where the metal is separated as molten sulphides and when the metal is separated as the liquid metal it is called reduction smelting.

Aluminum was considered as one of the rare and semiprecious metals during the late nineteenth century. Although it is one of the third most abundant element and the most abundant metal in the Earth's crust, the Hall-Heroult process, which invented in 1880 were proposed to dissolve aluminum oxide (alumina) in molten cryolite as electrolyte and a powerful DC current passed through it that resulted to leave the molten aluminum at the bottom of the bath and the oxygen which derives from aluminum reacts with carbon anode to form carbon dioxide [5]. Until the discovery of Bayer process in 1887, the production cost of aluminum was expensive to separate from the liquor by dissolving aluminum from bauxite.

So far, this is the only industrial way to produce this metal. Primary Aluminum is produced in a liquid form, through an electrolytic reduction of alumina (Al_2O_3) in a cryolite bath (Na_3AlF_6). This reaction takes place in electrolytic pots, as shown in Figure 2.

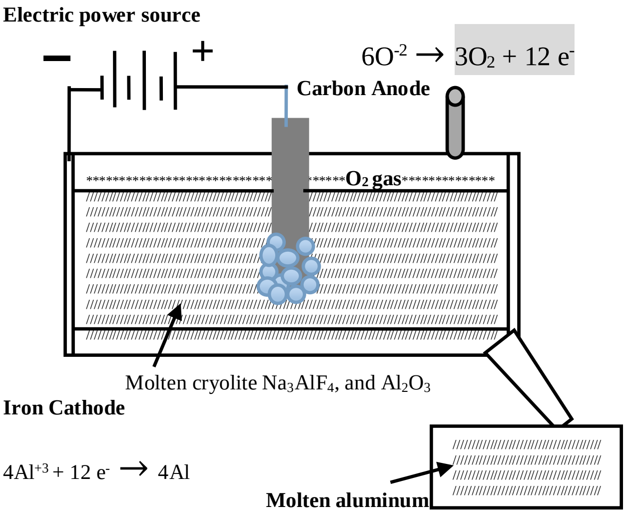

Figure 2. Sketch of an alumina reduction in electrolysis pot.

The aluminum hydroxide is then dried and calcined to give aluminum. This discovery tumbled the cost of aluminum about 80% by 1890. Both Hall-Heroult and Bayer's process are used industrially to produce aluminum in today's world. The Hall-Heroult process is considered as a type of aluminum smelting process and can be written as:

$$2Al_2O_3\,(\text{dissolved}) + 3C\,(s) \rightleftharpoons 4Al\,(l) + 3CO_2\,(g) \qquad (1)$$

The aluminum production relies on the usage of raw materials which are alumina, carbon, cryolite, aluminum fluoride and the electric power [6]. The alumina is extracted from the aluminus ore called bauxite which contains 40-60 mass% aluminas with the presence of smaller amounts of silica, titania and iron oxide.

Bayer process is used to extract alumina from bauxite which involves the dissolving of bauxite ore in NaOH that removes the impurities from the solution. At high temperature, bauxite is added to the separation of red mud occurs at in intermediate temperature and the precipitation of aluminum occurs at low temperature. The formed alumina is attained as fine white materials.

Produced alumina is used at 2-8% with the molten cryolite (Na_3AlF_6) in the electrolyte. Particular additives like aluminum fluoride (AlF_3), calcium fluoride (CaF_2) used with cryolite-alumina mixtures to lower the melting point which also improves the current efficiency and reduce the evaporation losses.

Most often, prebaked technology is used to build the anode. In this technology, 65% petroleum coke, 20% butts and 15% coal tar pitch mixture molded into blocks and baked in separate anode baking furnace at about 1120 °C. Theoretically, to produce 1 kg of alumina: 4 kg of bauxite, 1.93 kg aluminum oxide, 0.415 kg carbon, 20 g aluminum fluoride, 2 g cryolite and 13400 kWh electrical energy is used.

3. Reduction of Alumina

Aluminium is reduced by a combination of chemical and electrical energy according to the following two reactions in parallel:

$$Al_2O_3 + 3C \rightarrow 2Al + 3CO \qquad (2)$$
$$2Al_2O_3 + 3C \rightarrow 4Al + 2CO_2 \qquad (3)$$

This use of a consumable carbon anode lowers the required voltage by 1.0 V at the operating temperature of (950 - 980) ºC in an ionic form. It is dissolved in molten cryolite, Na_3AlF_6 (an electrolyte, i.e. anionic compound), and forms conducting complex anionic oxyfluorides. The electrolysis requires a large amount of energy because aluminium's affinity for oxygen makes the reaction highly exothermic.

$$4Al + 3O_2 \rightarrow 2Al_2O_3 \qquad (4)$$

The enthalpy of formation of Al_2O_3 is -1676 kJ mol-1. The electrolysis is carried out in an electric furnace using carbon electrodes. Carbon anodes are a major requirement for the Hall-Heroult process. About 0.5 tons of carbon is used to produce every ton of aluminum. There are two types carbon anode are made from the same basic materials and react in the same way.

A mixture of petroleum coke and pitch is strongly heated causing the pitch to bind the coke particles together. "Pre-baked" anodes are made before they are added to the pot, but "Söderberg" anodes are actually formed and baked in the pot. The Söderberg anode uses the waste heat of reaction in each pot to pyrolyze the coke and pitch [5]. As the lower part of the anode is consumed in the reaction, more raw materials are added at the top.

During the baking process, many volatile products are driven off as the pitch hydrocarbons are dehydrogenated. Solid carbon is left as the anode.

Although the Söderberg anode may be more energy efficient, to treat the volatile wastes easier is if they are not mixed with the other emissions from the pot. Dehydrogenation is often less complete in the Söderberg anode causing more hydrogen fluoride to be formed during the anode reaction. Recently, modern smelters use prebaked anodes for environmental reasons.

4. Alternative Aluminium Production Processes

All alternative aluminium processes have some same elements. The primary input resources will be alumina, electrical energy, some carbon, and possibly some other recyclable chemicals. Outputs are aluminum and varying amounts of carbon oxides. Heat will always be released to another process or the environment because all alternatives involve high temperatures and energy. Commonly, when an impure alumina source is being used, the aluminium processing will produce a secondary metal as a by-product. In several of the aluminium process methods, the alumina is converted to a more easily decomposed (relative to the process) intermediate, such as $AlCl_3$, Al_2S_3, Al_4C_3, or aluminum oxy-carbide [6].

Based on these general features, the process at low a temperature and energy as possible is the best process, but with the highest productivity per unit volume while possessing the fewest number of processing stages in the overall conversion process. There has only been sustained R&D on the first two of five discussed alternative processes as shown in the last 25 years (Table I) [7].

Table I: Alternative Processes Investigated for Aluminum Production.

Production Process	**Features**
Drained-Cell Technology*	Cathode sloping and coated with aluminum-wettable TiB_2. By eliminating metal pad, the anode-cathode gap could be halved to ~25 mm, enabling substantial voltage lowering. Other basics would remain the same as present technology (E° ~ 1.2 volts, $\Delta_{min,}$ electrolysis = 6.34 kWh/kg).
Inert Anode Cells* (Oxygen Evolution)	Eliminate consumable carbon anode by having an electrode material that evolves oxygen. Although the electrochemical potential would increase by 1 V (E° ~ 2.2 volts), the voltage increase would be less because of lower anode polarization ($\Delta_{min,electrolysis}$= 9.26 kWh/kg). The superstructure of the existing cell could be refined, reducing capital costs. If drained-cell materials development were successful, further design options are possible
Chloride Process†	Aluminous material converted to (anhydrous) $AlCl_3$ of adequate purity. $AlCl_3$ electrochemically decomposed in a multi-electrode cell at ~700°C (E° ~ 1.8 volts, Δmin, electrolysis = 6.34 kWh/kg). Electrochemically generated chlorine is recycled.
Sulfide Process†	Aluminous material converted to (anhydrous) Al_2S_3 of adequate purity. Aluminum sulfide electrochemically decomposed to recyclable S2 and aluminum (E° ~ 1.0 V) in a multipolar (Δmin,electrolysis = 5.24 kWh/kg) cell.
Carbothermal Reduction†	Convert aluminous material to an intermediate Al_4C_3 (or oxycarbide) chemically at T > 1,700°C. React carbide with further oxide to evolve CO and produce aluminum (or alloy) at T > 2000°C. Refine the metal quality to a usable grade (Δmin = 9.0 kWh/kg).

* Substantial retrofits using cryolite-alumina electrolytes.
† Processing using intermediates derived from alumina.

5. Usage of Aluminium

These properties lead to a variety of specialized uses [8].

5.1 Lightness.

Use in aerospace and automotive industries, as its lightness enables a greater volume of metal to be used, thus giving greater rigidity. Also used for examples in pistons and connecting rods to give better balance, reduced friction and lower bearing loads, meaning that less energy is required to overcome inertia.

5.2 Electrical conductivity

Used extensively for electrical conductors, especially in overhead cables. However, this requires a high purity grade (99.93%).

5.3 Thermal conductivity

Widely used for instance in heat exchangers, cooking utensils, and pistons.

5.4 Corrosion resistance.

This is made use of in chemical plant, food industry packaging, building and marine applications. Aluminium paint is regularly used. The oxide film can be thickened by anodizing, and the film can be dyed in a wide range of colours. This is done by making the article the anode of a direct current electrolysis cell using an electrolyte solution of approximately 15% sulfuric acid.

5.5 Affinity for oxygen

This allows it to be used in explosives, as deoxidant in steels, in thermic reactions for welding and for the manufacture of hardener alloys such as ferrotitanium. In these applications, a finely powdered form (and hence a high surface area to weight ratio) is used. Molten iron will be produced from the thermite reaction from the aluminium property and widely used for the railway industry.

6. Aluminium industries in the future

There are great prospects for aluminum products in the future, through their production, use, recycling, to reduce both resource use and environmental impact and to increase human well-being and economic activity. The potential for reduction of greenhouse gas emissions through the use of machinery in industry, cabling, turbines, solar panels, consumer durables, and intelligent control systems in energy supply networks; lightweight vehicles; green buildings and protective aluminum packaging that preserves agricultural outputs.

Recently, the economic situation for the aluminum industry is better than before. Global demand for primary aluminum is increased and estimated to reach 70 million metric tons per by the year 2020[9]. This estimate demand will create opportunities for use of aluminum. The overall demand for this metal reflects this trend. Beyond the future, the aluminium industry has a good prospect metal industry in Malaysia because recently it was one of high value and demanding mineral in the global as shown in Figure 3[10].

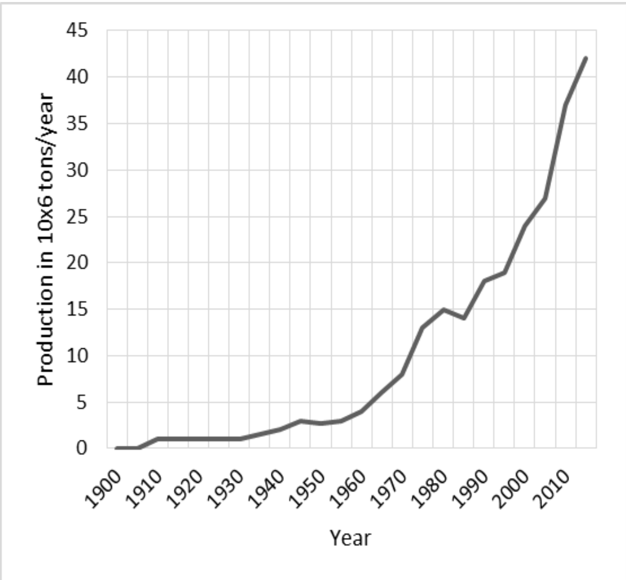

Figure 3: Aluminium- world production trend (U.S. Geological Survey)

7. Conclusion

The potential of the aluminium industry depends on the discovery of new bauxite fields and the stability of the price of aluminium. New land has to be opened by the government for prospecting by the miners. Presently, any land, agriculture or otherwise, that is converted for mining has to be surrendered to the government after mining activities has finished. The suitable aluminium process needs to be implemented. Friendly smelting process to the environment must the main priority to open and set up for new material industries especially in aluminium industry. The analysis informed that important location of primary production should be located in the region of high demand aluminium industry, low cost of energy in electricity and near the raw material for production such as bauxite and carbon.

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