

DESIGN OF A 1500 TONNES PER ANNUM ALUM PRODUCTION PLANT

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ABSTRACT

Industrial uses of alum in Nigeria is essential. The availability of kaolin in the country and the need growing demand of alum in water treatment necessitate the design of an alum plant. A 1500 tonnes per annum plant was designed using the novel technology. Cheap raw materials with less impact on the environment were fed continuously to achieve the output. Energy balance across the novel approach showed an energy requirement of 577.55 kW with an energy savings of 7.1%. Equipment design and specification, process instrumentation, plant layout and safety analyses were carried out. Economic analyses showed that the total capital investment is ₦ 979,749,091.30, were also the profit before tax of ₦ 418,758,193.10 and the profit after tax of ₦ 266,322,436.10 per annum was realised with a return on investment of 28% and a payback period of 3.2 years. The return on investment shows that the plant is feasible.

Keywords: Alum, Kaolin, Energy savings, Return on investment

1 INTRODUCTION

Aluminium sulfate ($\text{Al}_2(\text{SO}_4)_3 \cdot 14-26\text{H}_2\text{O}$) usually called alum is an odourless white lustrous crystal, powder or granules which is soluble in water [1]. Aluminium sulfate is produced from bauxite by reacting bauxite with sulfuric acid due to its alumina content. The depletion of bauxite brings the search for kaolin which is next to bauxite in alumina content [2]. Two types of alum are known; ferric and the non-ferric. Alum is used as coagulant in water treatment. It is also used in the pulp and paper industries to control pitch and improve the properties of broken fibre, in the catalyst industries for production of zeolites and catalyst support, in the pharmaceutical industries for the production of antiseptic for the skin etc [3]. Considering the wide ranges of application, most of the alum used in Nigeria is for the treatment of water. With this specific area of application and a kaolin deposit of about 2 billion metric tonnes, there is no single plant designed and built for the production of alum [4]. Most of the alum consumed in Nigeria are imported from China, USA etc [5]. Table 1 show the deposits of kaolin in Nigeria. Alum production from kaolin is quite different from that of bauxite. The reasons being that kaolin is unreactive in its natural form and as such, requires high temperature decomposition of 600 °C and above to bring about its reactivity [6, 7, 8]. Secondly, the energy demand to remove the structural alumina from silica proves to be inevitable compared to that from bauxite[2, 9]. This work was aimed at designing a plant that produces 1500 tonnes per annum alum plant from locally sourced kaolin. It will also present a suitable process that can be used to achieve this aim. Material and energy balance for the selected process and an economic analysis will be presented to show if the design is feasible.

Table 1. Kaolin deposits in Nigeria [10]

S/No	Clay	Location	Al ₂ O ₃ %	SiO ₂ %	Fe ₂ O ₃ %	CaO+MgO%
1	Alkaleri	Bauchi	25.43	54.30	1.05	1.00
2	Onibode	Abeokuta (Ogun)	39.30	42.30	Trace	1.05
3	Elefun	Abeokuta (Ogun)	37.00	53.80	2.57	0.30
4	Oshiele	Abeokuta (Ogun)	28.30	53.40	1.35	0.88
5	Orun	Abeokuta (Ogun)	34.55	50.55	2.05	1.10
6	Ozubulu	Nnewi (Anambra)	19.31	58.30	1.55	1.25
7	Enugu	Enugu	22.71	55.00	2.42	1.95
8	Nsu	Okigwe (Imo)	30.22	50.60	1.90	1.08
9	Okpekpe	Auchi (Edo)	24.30	53.20	1.45	1.30
10	Kankara	Kankara (Katsina)	38.64	44.50	Nil	1.30
11	Giro	Giro (Sokoto)	38.72	43.54	2.10	1.48
12	Warram	Warram (Plateau)	37.13	43.54	1.15	0.58
13	Sabon Gida	Jos (Plateau)	25.88	25.32	13.10	3.20
14	Ukpor	Nnewi (Anambra)	33.20	48.00	1.20	0.73
15	Ifon	Ifon (Ondo)	36.80	47.90	0.67	1.11
16	Oza Nagoga	Oza Nagoga (Edo)	38.07	46.00	0.78	0.23

2 MATERIALS AND METHODS

2.1 Process and Material Selection

Process selection is a key step to solving a design problem. It is an essential factor that a process engineer considers to obtain an alternative solution to the design method. Considering the various approach to solving the design problem, the process engineer has to choose the best out of all the processes that suit the design. Chemical engineering design is only essential when it can be translated to reality by utilizing available materials and fabricating this system of materials. As such, selection of materials of construction coupled with fabrication techniques play a vital role in the development or modification of a processing plant [6].

Production of alum from kaolin follows a general process of beneficiation to remove impurities from the kaolin, calcination to drive away water of hydration and increase the surface area for reaction, de-alumination to remove the structural alumina from silica, filtration to separate the silica from aluminium sulfate, crystallisation to form alum crystals from the solution and drying. Filtration is also carried out prior to drying to separate the excess acid from the alum crystals [5].

However, two main process are known in the production of alum from kaolin i.e. the conventional process and the novel approach process. All the processes follow the same route but vary in the de-alumination step. In the conventional process, the acid and water are mixed in a separate reactor and left to cool wasting the generated heat of acid solvation in water. The diluted acid is mixed with the meta-kaolin and external heating is applied to bring the acid concentration to 60 wt%. The heat

loss as a result of acid solvation in water is not utilised, making the process expensive and time consuming [12]. This process is mostly used by most alum producers from its feedstock (bauxite and kaolin) before the birth of the novel process. This process gives a yield of about 82.4% $\text{Al}_2(\text{SO}_4)_3$ [13].

The novel process utilises the heat generated as a result of acid solvation in water which is sufficient to provide the required energy both thermal and mechanical (for stirring) to remove the structural silica from alumina [2]. This process is proven to be more economical having a percentage yield of about 81.29% [2][4]. The yield in comparison with the conventional process is low, but the energy saved from the novel approach depicts that the yield is reasonable considering the actual percentage conversion from the equation of de-alumination of 82.23% which is enough to perform all applications related to the use of alum. Therefore, the utilised energy from the novel process made it suitable for this design. Figure 1 present the process flow diagram for process selected. Equipment selection and their materials of construction for the process at hand were considered in reference to their operational performance, basis of operation (batch or continuous), safety issue and cost. The entire beneficiation process is constructed with mild steel due to low tendency to corrosion.

Rotary kiln in comparison to shaft kiln, regenerative kiln, annular kilns and counter-current shaft kiln handle calcination process readily and better. Despite its high energy consumption, tendencies of production of NO_x is low. Modern rotary kilns have preheaters that utilises the heat via a cyclone which does 90-95% calcination [7]. In addition, rotary kilns have better gas-solid interactions and are used for most continuous processes involving calcination. The material of construction is high temperature resistance ceramics coated with mild steel.

The de-alumination process takes place in a mixing tank with a stirrer (for stirring the kaolin and water before introduction of acid) enclosed in it. The stirrer is removed once the acid is introduced to the mixture, this is essential to make the mixture boils faster and to prevent heat gain by the stirrer which creates disturbance to the reaction. The continuous stirred tank reactor (CSTR) was used for this operation, the material of construction for the CSTR and the pipe to transport the mixture through the rest of the operations in order of filtration, crystallisation, filtration, drying and distillation is the stainless steel 304 due to low tendency to corrosion [15]. Sulfuric acid tank and silica tank are constructed with stainless steel to avoid acid attack on metals while water tank and quartz tank are constructed of carbon steel.

The gravity filter was selected for separation of silica and alum solution. The fluidized bed crystalliser was selected for the crystallisation; the rotary filter was selected for the separation of excess acid (38wt%); the conveyor belt dryer was selected for final drying process and the atmospheric distillation column (to increase acid purity to 98%) was selected for the simple distillation process. All equipment listed above are made up of stainless steel 304 except the conveyor belt dryer which is made up of mild steel (due to excess acid removed). Table 2 show the selected equipment and their materials of construction.

2.1.1 Description of Selected Process

Figure 1 shows the selected process flow diagram (PFD). The kaolin from the mines is crushed in crusher CR01 to obtain equal size distribution. The exit of CR01 enters the bucket classifier (BC1) to remove all coarse material of about 250 μm at room temperature (25 $^\circ\text{C}$) before sand removal (quartz and feldspar). The less than 250 μm from BC1 is pumped to hydrocyclones HC01. The overflow from the HC01 which are thickened and less than 53 μm (fine fraction) are fed into the hydro-separator where the suspension is allowed to settle via gravity to remove less than 15 μm fraction. The kaolin is separated into fine grain fraction (about 2 μm) as it moves to the centrifuge (CF01). The fine fractions from CF01 are conveyed to the rotary dryer DR01 and dried at 120 $^\circ\text{C}$. The exit of DR01 is send to the rotary kiln (RK01) for calcination to about 750 $^\circ\text{C}$ to drive away water of hydration. The exit of the hot air in RK01 is utilised using heat exchanger (E01) to preheat the incoming kaolin before entering RK01. The exit of RK01 is send to the stoichiometric reactor (R01) in which there is presence of water and a stirrer to stir the mixture. Calculated amount of sulphuric acid based on stoichiometry at 98% purity is poured into the solution of meta-kaolin and water in R01 (no further stirring of the mixture after addition of acid). The mixture is allowed to boil vigorously for some residence time (when the solution becomes calm). The exit of R01 is pumped to the vacuum filter (F01). The filtrate from F01 is moved to heat exchanger

E02 to utilise the heat coming from TK01 to the reactor while the residue containing rich silica is conveyed to an open tray for storage. The tube side exit of E02 is send to the fluidized bed crystalliser (CF1) to obtain granulated crystals. The slurry crystals are further filtered in F02 to separate the alum crystals from the acid rich liquor. The residue of F02 (alum crystals) are further dried in a rotary drum dryer (DR02) which are further conveyed and stored in polymer bags while the filtrate is further distilled in a simple distillation column, the bottom is cooled using a cooler and recycled back to the acid tank, the top is further cooled and recycled back to the water tank. See Figure 1 for detailed process flow diagram.

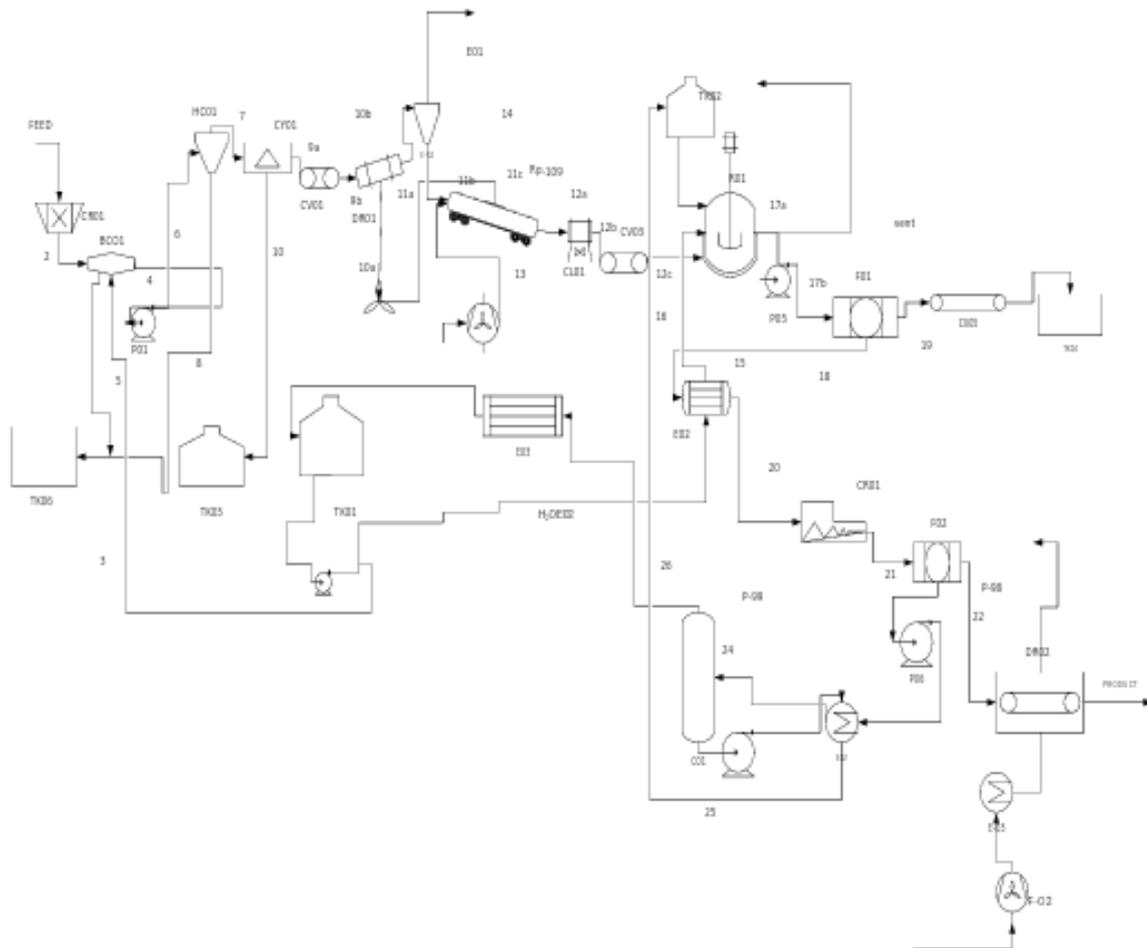


Figure 1. Process flow diagram

Table 2. Materials of construction for the unit equipment

Unit	Materials of construction
Crusher	Manganese steel
Classifier	Low carbon steel
Pump	Low carbon steel
Hydro-cyclones	Low Carbon steel
Centrifuge	Low carbon steel
Rotary Dryer	Carbon steel
Rotary Kiln	Refractory ceramics and Mild steel
Reactor	Stainless steel 304
Fluidized bed filter	Low carbon steel
Crystalliser	Carbon steel
Sulphuric acid tank	304 stainless steel
Rotary Dryer	low carbon steel
Distillation column	Stainless steel 304

3 RESULTS AND DISCUSSIONS

3.1 Results

3.1.1 Material and Energy Balance

Material balances are considered to be the basis in process design [8]. Material balance over the whole process determines the raw material consumed and the products formed. The simple general expression for material balance at steady state is given by equation (1) below

$$\text{Material in} = \text{Material out} + \text{Generation} - \text{Consumption} \quad (1)$$

The plant is stipulated to operate at 94% attainment (343 days), the remaining 6% are for equipment downtime and other turn around maintenance. The total material balance across the plant is 1688 kg/hr. Table 3 and show a summary of material and energy balance of selected equipment with engineering equipment rating like volume, heat transfer area (HTA), pressure head (PA) and area for both processes.

Table 3. Material and energy balance of selected equipment for the Novel Process

S/No	Equipment	Material flow (kg/hr)	Heat flow (kJ/hr)	Parameter rating	Rating value
1	Reactor (R01)	1265.000	Nil	Volume (m ³)	0.700
2	Rotary kiln (RKO1)	65.000	8305.660	HTA (m ²)	0.643
3	Exchanger (E01)	62.140	11042.920	HTA (m ²)	0.467
4	Pump (P01)	217.210	Nil	Pressure head	2286.320
5	Filter (F01)	1265.000	-76845.620	Area (m ²)	13.760
6	Centrifuge	165.000	Nil	Area (m ²)	8.270

Table 4. Material and energy balance of selected equipment for the Conventional Process

S/No	Equipment	Material flow (kg/hr)	Heat flow (kJ/hr)	Parameter rating	Rating value
1	Reactor (R01)	1265.000	147598.36	Volume (m ³)	0.700
2	Rotary kiln (RKO1)	65.000	8305.660	HTA (m ²)	0.643
3	Exchanger (E01)	62.140	11042.920	HTA (m ²)	0.467
4	Pump (P01)	217.210	Nil	Pressure head	2286.320
5	Filter (F01)	1265.000	-76845.620	Area (m ²)	13.760
6	Centrifuge	165.000	Nil	Area (m ²)	8.270

2.3 Plant Location and Layout

Plant location is a consideration that need to be placed in mind at the course of designing. To obtain a suitable location for the plant, factors such as raw materials availability, market location, nearness to market, ease to transportation, availability of labour, availability of utilities (water and electricity), environment impact and effluent disposal, local community consideration, climate around the site, political and strategic consideration [11]. Considering the above conditions, the plant designed should be sited in Ogun. Plant layout basically deal with the placement and arrangement of equipment in the selected location. Plant layout is essential due to economic consideration, process requirements, convenience for operation, convenience for maintenance, safety, future expansion, modular construction. Due to the factors listed above, the plant layout is as thus; Minimum distance between each main unit should be 5 m, the Total number of main process units in the plant should be 13, the allowable distance for auxiliary units should be 3 m and safety allowance = is taken to be 30% [8].The total estimated area covered by the equipment is 1330 m². For 30% safety allowance, the estimated area covered is 1729 m². Figure 2 shows the plant layout considered in this design.

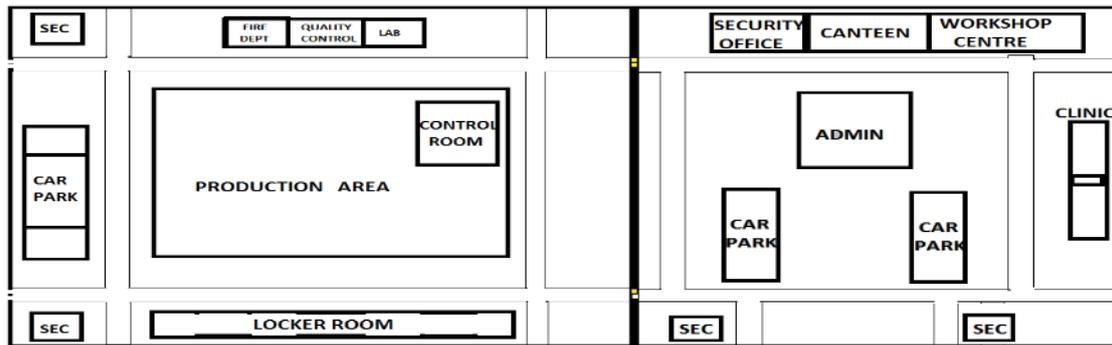


Figure 2. Plant layout

3.1.2 Economic Analysis

The proposed design can only be acceptable if the process is profitable. Hence an estimate of the investment required and the cost of production are needed before the profitability of the project can be assessed. This involves the acquisition of capital and operating cost data probably from the equipment sizing parameters or any other source. Although published cost is used whenever possible, the lack of information which will be provided by tenders from contractors, after compilation of final design details, necessitated the use of estimating techniques [9]. For a viable alum plant to be built a techno-economics assessment should be made. For this, two set of cost-benefit analyses have to be carried out i.e the macro-economic analysis (economic analysis) which compares the cost of alum plant and the benefits for the country or the society and the micro-economic analysis (financial analysis) which judges the profitability of alum production from the point of view of the user. Table 5 shows the analysis of the plant from raw material to the final product and the cost incurred in the setup of the plant carried out at exchange rate of \$360 to a Naira (₦). See appendix for formulae and sample calculations.

Table 5. Economic evaluation data

S/No.	Items	Cost
1	Raw Material / Utilities	₦360,276.19
2	Physical Plant Cost (PPC)	₦1,883,440,029.00
3	Fixed Capital (FC)	₦753,376,011.70
4	Working Capital (WC)	₦37,668,800.59
5	Total Investment (TI)	₦979,749,091.30
6	Direct Production Cost (DPC)	₦188,704,279.10
7	Annual Production Cost (APC)	₦226,445,134.90
8	Annual sales	₦645,203,328.00
9	Profit Before Tax (PBT)	₦418,758,193.10
10	Profit After Tax (PAT)	₦266,322,436.10
11	Pay Back Period (PBP)	3.2 years
12	Return on Investment (ROI)	28%

3.3 Discussion of Result

The novel approach process compared to the conventional process was selected due to its energy savings as no external heat is required. The novel approach as stated earlier utilises the heat generated as a result of acid solvation in water to remove the structural silica from alumina. From the material balance, the total material balance shows that the process is operated at steady state. The total energy required by the plant is 577.55 kW for the novel process. This imply that, the plant will consume 577.55 kW every hour to operates to its full capacity. While the energy saved using the novel approach process is 41 kW. Meanwhile, using the conventional process, 41 kW will be required to heat the mixture to its de-alumination temperature amounting to about 618.55 kW overall energy demand for the conventional process. This savings is about 7.1% of the total energy balance. This shows that for every operation using the novel approach, 7.1% is the energy saved reducing cost in heating amounting to about ₦2,050 per hour. The parameter rating in the specification of the selected equipment shows that the equipment will perform at medium range, their anticipated cost will be less and with the materials selected for their constructions, they will last longer than 20 years (plant lifespan) with proper maintenance employed.

The plant can be sited in Ogun due to closeness to raw materials to carry out the operation (see table 1 for available deposits). Solids are easier transported than liquids. Therefore, if the basis of the raw material is Kankara kaolin due to its low ferric oxide, it can easily be transported to Ogun than for sulfuric acid to be transported from Lagos to Kankara. In the other hand, deposits of kaolin are found in Ogun in the areas of Abeokuta which have higher aluminium oxides than the Kankara kaolin can be used in place of Kankara kaolin. Lagos can be the target market since most of alum imported to the country passes through the borders of Lagos. Little or no concern about crisis will be a formulating factors as most economic crisis result from areas of the north and the south-south.

The negative flowsheet is considered. The quartz, silica which are bye-products of this design have some economical values as quartz is used by ceramics industries and silica is also used in the coating of zeolites and by the ceramic industries. Considerations on the type of fuel which is relatively cheap and has no impact to the environment was duly studied. Butane which yield no sulfur and soot upon combustion is selected. This eliminates the tendencies of air polluted sulfur with soot causing acid rain and asthma. The blue paint on the rotary kiln provides the indication of caution if a refractory brick falls from the kiln while operation is going. The economic analysis carried out shows that the selected raw materials/utilities cost ₦360,276.19. This is due to the abundant raw materials and utilities available. The payback period of 3.2 years and a profit after tax (PAT) of ₦266, 322,436.10 indicates that when an investment of ₦979,749,091.30 with the above realisable PAT, the investor will receive his total 3.2 years with a return on investment of 28%. The realisable high value of ROI is due to the products such as alum, silica and quartz that are being sold.

4 CONCLUSIONS

The following can be concluded from the results of the work

1. Available and cheap raw materials with low impact on the environment were selected. Theses raw materials were feed to the plant continuously at a specific rate (kg/hr) to meet the required output capacity. Other equipment were used for separation to attain purity and desired physical property (column).
2. An energy balance was carried across the whole plant showing a total power requirement of 577.55 kW
3. Detailed equipment design was carried out specifying the parameter ratings of the equipment.
4. Economic analysis showed that the total capital investment was ₦979,749,091.30, profit before tax was ₦418,758,193.10, and profit after tax was ₦266,322,436.10, with a payback period of 3.2 years and a return on investment of 28%.

From the above, it can be concluded that the project is profitable and economically viable since the return on investment agrees with the literature value of 2 to 6 years for any process plant.

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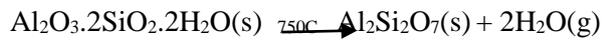
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REFERENCES

1. Etuaful, R. K. (2013). Kwame Nkrumah University of Science and Technology, Production of Alum from Bauxite waste from Awaso.
2. Aderemi, B. O., Edomwonyi-Otu, L.C, and Adefila, S. S. (2009). A New Approach to Metakaolin Dealumination, *Aust. J. Basic Appl. Sci.*, vol. 3, no. 3, pp. 2243–2248.
3. Armarego, W. L. and Chai, C. (2009). *Aluminium Compounds, Inorganic*. Butterworth-Heinemann.
4. Foramfera, Kaolin Mining in Nigeria, The Pre-feasibility Report (2016). *Investment Opportunities in Nigeria, Mining and Quarrying*. [Online]. Available: <https://foramfera.com/2016/03/02/kaolin-deposits-and-mining-in-nigeria-the-opportunities/>. [Accessed: 25-Apr-2019].
5. Kriss, B. (2013). Alum Processing Plant, *The Nation*.
6. Mohammed, J., Faizu, A., Usman, D. and Murtala, A. (2013). Production of Alum from Alkaline Kaolin, Nigeria, *Int. J. Adv. Sci. Res.*, vol. 2, no. 3,.
7. Edomwonyi-Otu, L.C., Bawa, G., and Aderemi, B. O. (2010). Effect of Beneficiation on Alumina Yield and Quality from Kankara Kaolin, *Niger. J. Eng.*, vol. 16, no. 2, pp. 27–35.
8. Edomwonyi-Otu, L. C., Aderemi, B. O., and Ahmed, K. (2010). Beneficiation of Kankara Kaolin for Alum Production, *Niger. J. Eng.*, vol. 16, no. 2, pp. 36–43.
9. Edomwonyi-Otu, L. C. and Aderemi, B. O. (2010). Alums from Kankara Kaolin, *Int. J. Mech. Eng.*, vol. 2, no. 1, pp. 38–44.
10. Rasheed, B. (2015). Development and Characterisation of Zeolite-Y from a Nigeria Local Raw Material, Covenant University.
11. Maccido, U. M. (2014). Design of a 5000 tons per Annum Stearic Acid Plant, Ahmadu Bello University.
12. Edomwonyi-Otu, L.C, Aderemi, B.O and Ofoku, A. (2010). The Effect of Kaolin Calcination Temperature and De-alumination Time on Alum Yield from Kankara Kaolin, *African J. Nat. Sci.*, no. 13, pp. 69–74.
13. Chigondo, F., Nyamunda, B. C. and Bhebhe, V. (2015). Extraction of Water Treatment Coagulant from Locally Abundant Kaolin Clays, pp. 1–8.
14. Fidaros, D. K., Baxevanou, C. A., Dritselis, C. D. and Vlachos, N. S. (2007). Numerical modelling of flow and transport processes in a calciner for cement production ☆, *Elsevier J. Power Technol.*, vol. 171, pp. 81–95.
15. Towler G., and Sinnott, R. K. (2008). *Chemical Engineering Principles , Practice and Economics of Plant and Process Design*. Boston: Butterworth Heinemann.
16. Sinnott, R. K. (2003). Coulson & Richardson’s Chemical Engineering Design, in *Coulson and Richardson*, 3rd ed., Butterworth Heinemann, pp. 34–85.

APPENDIX**Material balance across Rotary kiln**

The reaction for calcination is given by equation 2 below

**Meta-kaolin Balance**

258 kgmol of kaolin produces 222 kgmol of meta-kaolin

65 kg/hr of kaolin produces 55.93 kg/hr of meta-kaolin

Water Balance

258 kgmol of kaolin produces 36 kgmol of water

65 kg/hr of kaolin produces 9.07 kg/hr of water

Energy Balance Across Reactor

$$T_{15} = 25^\circ\text{C} \quad M_{15} = 462.53 \text{ kg/hr} \quad T_{16} = 30^\circ\text{C} \quad M_{15} = 629.53 \text{ kg/hr}$$

$$T_{15} = 140^\circ\text{C} \quad M_{17} = 217.25 \text{ kg/hr} \quad \Delta H_{12} = -12931.90 \text{ kJ/hr}$$

Water;

$$\Delta H_{15} = M[-5.7296 + 1.9145T - 3.9574T^2]_{Tr}^{Ts}$$

$$\Delta H_{15} = 0$$

Sulfuric Acid

$$\Delta H_{15} = M[59.83 + 0.3952T - 5.207 \times 10^{-4}T^2]_{Tr}^{Ts}$$

$$\Delta H_{15} = 61.80 \text{ kJ/hr}$$

$$\Delta H_{15} = M[-5.7296 + 1.9145T - 3.9574T^2]_{Tr}^{Ts}$$

$$T_{17} = 140^\circ\text{C} \quad M_{17} = 243.48 \text{ kg/hr} \quad M_{17alum} = 204.07 \text{ kg/hr}$$

$$M_{17silica} = 30.23 \text{ kg/hr} \quad M_{17water} = 13.60 \text{ kg/hr}$$

Energy Balance for alum

$$\Delta H_{17alum} = M[292]_{Tr}^{Ts} + n \times -8.874$$

$$n = 0.2519$$

$$\Delta H_{17alum} = 246.83 \text{ kJ/h}$$

Energy Balance for Silica

$$\Delta H_{17silica} = M[10.87 + 0.008712T - 241200/T^2]_{Tr}^{Ts} - n \times 3.043 \times 10^5$$

$$n = 0.2519$$

$$\Delta H_{17silica} = 76845.62 \text{ kJ/hr}$$

Energy Balance for Water

$$\Delta H_{17water} = M[-5.7296 + 1.9145T - 3.957 \times 10^{-4}T^2]_{Tr}^{Ts} + n \times -2.41814 \times 10^5$$

$$n = 0.2519$$

$$\Delta H_{17water} = 58067.76 \text{ kJ/hr}$$

Total Energy Balance

$$\Delta H_{17} = 134666.46 \text{ kJ/hr}$$

$Heat\ load = \Delta H_{17} - \Delta H_{12} = 134666.46 + 12931.90 = 147598.36\ kJ/hr\ equivalent\ to\ 41\ kW$

Return on investment

Return on Investment (ROI) = $\frac{profit\ after\ tax\ (PAT)}{Total\ investment} * 100$

$$ROI = \frac{₦266,322,436.10}{₦979,749,091.3} * 100 = 28\%$$

Payback period

Pay Back Period (PBP) = $\frac{Total\ Investment}{Netcashflow\ (NCF)}$

$$\text{But } NCF = PAT + \text{Depreciation} = ₦266,322,436.10 + ₦37,668,800.59 = ₦303,991,236.69$$

$$\text{Pay Back Period (PBP)} = \frac{₦979,749,091.3}{₦303,991,236.69} = 3.2\ \text{years}$$