DESIGN OF AMMOXIDATION PROCESS FOR THE PRODUCTION OF FIFTY THOUSAND TONS PER ANNUM OF ACRYLONITRILE

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ABSTRACT

Propylene, the raw material for the production of acrylonitrile is in production at olefins plant, Eleme, Nigeria in liquid form and fluid catalytic cracking Units of Nigerian Petroleum refineries in the form of propylene rich feed but acrylonitrile is yet to be produced in Nigeria. Varying its polymeric composition result in many other raw materials due to the reactivity and polar nature of acrylonitrile. Nigeria needs acrylonitrile for raw materials that cannot be produced from polyethylene and polypropylene e.g. acrylic fibre, adiponitrile, etc. If a petrochemical plant for production of acrylonitrile is set-up in Nigeria, Nigeria will begin to be earning the foreign exchange it would have used for importing these raw materials. Study reveals that ammoxidation process technology is the most suitable. With this technology, 3739.70 kg of acrylonitrile could be produced from 4,200 kg propylene, 1,700 kg of ammonia and 20,600.12 kg of air besides other useful secondary products such as water, carbon monoxide, carbon dioxide, Hydrogen cyanide, methyl cyanide, acetonitrile, acrolein (Propenal), ammonium sulphate and sulphuric acid. A pay-back period of 2 years and a rate of return of 50.48 % show that an acrylonitrile production process plant if well managed could be economically viable in Nigeria.

KEYWORDS: Acrylonitrile; Propylene; Ammoxidation process; Pay-back period; Rate of Return on Investment; Petrochemical; Process-flow.

1.0. INTRODUCTION

The Nigerian government has initiated economic policies aimed at stimulating export of non-oil and value added products, thus encouraging private investors to establish petrochemical process plants (Louis *et al*., 2019; Ekpo, 2014). This could help Nigeria earn the foreign exchange it could have used for importing raw materials for local industries. Nigeria will no longer depend on exportation of crude petroleum alone but also on exportation of petrochemicals.

Acrylonitrile is an important petrochemical not yet produced in Nigeria. Although Olefins plant in Eleme in Rivers State, Nigeria is producing polymer grade ethylene and propylene for manufacture of polymer resins, Nigeria still need acrylonitrile for raw materials which cannot be produced from ethylene and propylene. The versatility in uses of acrylonitrile polymers result from the Polar nature and characteristic reactivity of acrylonitrile.

Mark *et al*. (1988); othmer (2007) stated that many raw materials can be produced by varying the polymeric compositions of acrylonitrile. The polar nature and reactivity of acrylonitrile is illustrated in figure 1.

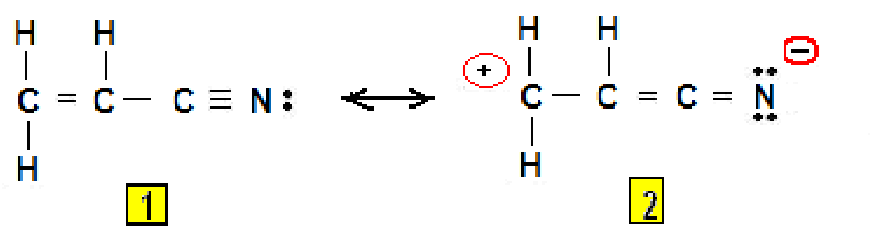


Fig. 1: Resonance Structure of Acrylonitrile
Source: Lewis (2019)

From this resonance structure, the (+) and (-) poles make acrylonitrile attract and be attracted to ions of other elements and compounds. The dots represent active interaction sites. The characteristic double and triple bonds are due to its unsaturation and show the high degree of reactivity of acrylonitrile molecules.

Acrylonitrile is a better source of higher quality plastics and resins than ethylene and propylene because of its versatile uses. Conversion of propylene to acrylonitrile helps improve the physical and chemical properties of the resultant polymer.

Adhesives, binders, antioxidants, medicines, dyes, artificial insulations, emulsifying agents, graphic arts, insecticides, leather, paper, plasticizers, soil modifying agents, solvents, surface coatings, textile treatments, viscosity modifiers, azeotrope distillations, artificial organs, lubricants, asphalt additives, water soluble polymers, hallow spheres, cross linking agents, and catalyst treatments are some of the areas of application of acrylonitrile polymers.

Acrylonitrile co-polymerises with styrene to produce Styrene Acrylonitrile (SAN) which is superior to polyethylene and polypropylene in the areas of toughness, rigidity, chemical and thermal resistance and hence have many commercial applications which implies a wider market.

Acrylonitrile – Butadiene-Styrence (ABS) Polymer can be produced by addition of an elastomeric component (Butadiene) within the SAN matrix. This help increase the impact resistance of the SAN polymer. The ABS has useful SAN properties of rigidity, resistance to chemicals and solvents while the elastomeric component contributes to its high impact resistance.

Polymer database (2015) stated that besides styrene acrylonitrile and acrylonitrile-butadiene – styrene, other co-polymers of Acrylonitrile are Acrylate-Styrene – Acrylonitrile (ASA); Acrylonitrile –Butadiene-Rubber (NBR); Acrylic fibers or Poly Acrylonitrile (PAN); Acrylonitrile Acrylate (ANA) and Methyl methacrylate – Acrylonitrile – Butadiene – Styrene (MABS) also known as transparent ABS.

ASA has high resistance to ultraviolet radiation, heat, cracking and weathering. NBR is an important elastomer with Acrylonitrile content between 15 and 45%. NBR grades with high Acrylonitrile contents have better oil and abrasion resistance whereas NBR grades with low Acrylonitrile content have better low temperature flexibility and resilience. Acrylic fibers have acrylonitrile content of at least 85%. Typical co-monomers are vinyl acetate and methyl acrylate. Both co-monomers improve flexibility, toughness and resilience of the rather brittle acrylonitrile fiber. Other synthesized acrylonitrile co-polymers which have found commercial uses are Acrylonitrile Acrylate (ANA) and Methyl methacrylate – Acrylonitrile – Butadiene – Styrene (MABS). Poly acrylonitrile copolymers (ABS; SAN; MABS; NBR and ABS blends) are important thermoplastics. They are produced on a large scale and sold under various trademarks. Important manufacturers include sabic; ineons; Lgchem; Trinseo and Basf to mention but a few.

Polymer database (2015) stated the following as applications of acrylonitrile polymer. ABS is a low cost engineering and commodity plastic that is easy to mold and fabricate. ABS is widely used for applications in kitchen and household appliances (ovens, washing machines, dryers, toaster, refrigerators, vacuum cleaners etc.). It is also extensively used for toys including Lego and Kre-O bricks. Other important industries for ABS include automotive, construction, and electronics. Due to its similar mechanical properties, ASA copolymers are used for similar applications as ABS. However, ASA has superior weathering resistance which makes it more suitable for outdoor applications than ABS. One of the most important markets for ASAs are automotive body parts such as mirror housings and radiator grills. ASA thermoplastics are also extensively used in many other industries including building and construction, appliance, electrical and electronics, and sports goods. Nitrile Butadiene Rubbers (NBR) are mainly used for disposable non-latex gloves and for elastomeric parts such as transmission belts, O-rings, gaskets, hoses, and oil seals whereas amine, carboxy, and epoxy functionalized butadiene-acrylonitrile rubbers are important tougheners for epoxy formulations such as coatings and adhesives. SAN is one of the most important acrylonitrile copolymers. Like ABS, it is widely used for applications in appliances (refrigerators, coffee machines, kitchen utensils, etc.). Other important applications include housings for scales, batteries, computers, and other consumer products. Acrylic fibers are sometimes used in the apparel industry for sweaters, socks, and tracksuits. Other important textiles made with acrylic fibers include blankets, area rugs, upholstery, luggage suitcases, awning, and outdoor furnitures.

Ammoxidation process involves the reaction of ammonia, air and propylene to produce acrylonitrile along with several secondary products such as hydrogen cyanide, water, carbondioxide, carbon monoxide, methyl cyanide, acetonitrile, acrolein (propenal) which is toxic, ammonium sulphate and sulphuric acid. Selectivity for acrylonitrile is enhanced by the help of a catalyst NS733A which contains iron, antimony and other compounds.

NS733A catalyst is active and effective resulting in 79.5 % propylene conversion. 80 % acrylonitrile selectivity requires less propylene and ammonia and forms less secondary products. This catalyst acts as an initiator of the free radical polymerisation.

Following its generation, the initiating free radical adds to monomer units thereby growing the polymer chain. Polymer growth can be terminated by addition of a chain terminator e.g. water. One of the termination steps for polymer growth is the transfer of free radical to another molecule.

Carraher (2013) gave an example of a chain transfer process as the transfer of hydrogen atom at one end of the chain to a free radical end of another chain. Thus, hydrogen is often used as a chain transfer agent in free radical polymerisation. The polymer chain can be transferred to the initiator or to the monomer or to the chain transfer agent.

2.0. MATERIALS AND METHODS

2.1. Materials

2.1.1. Process Equipment

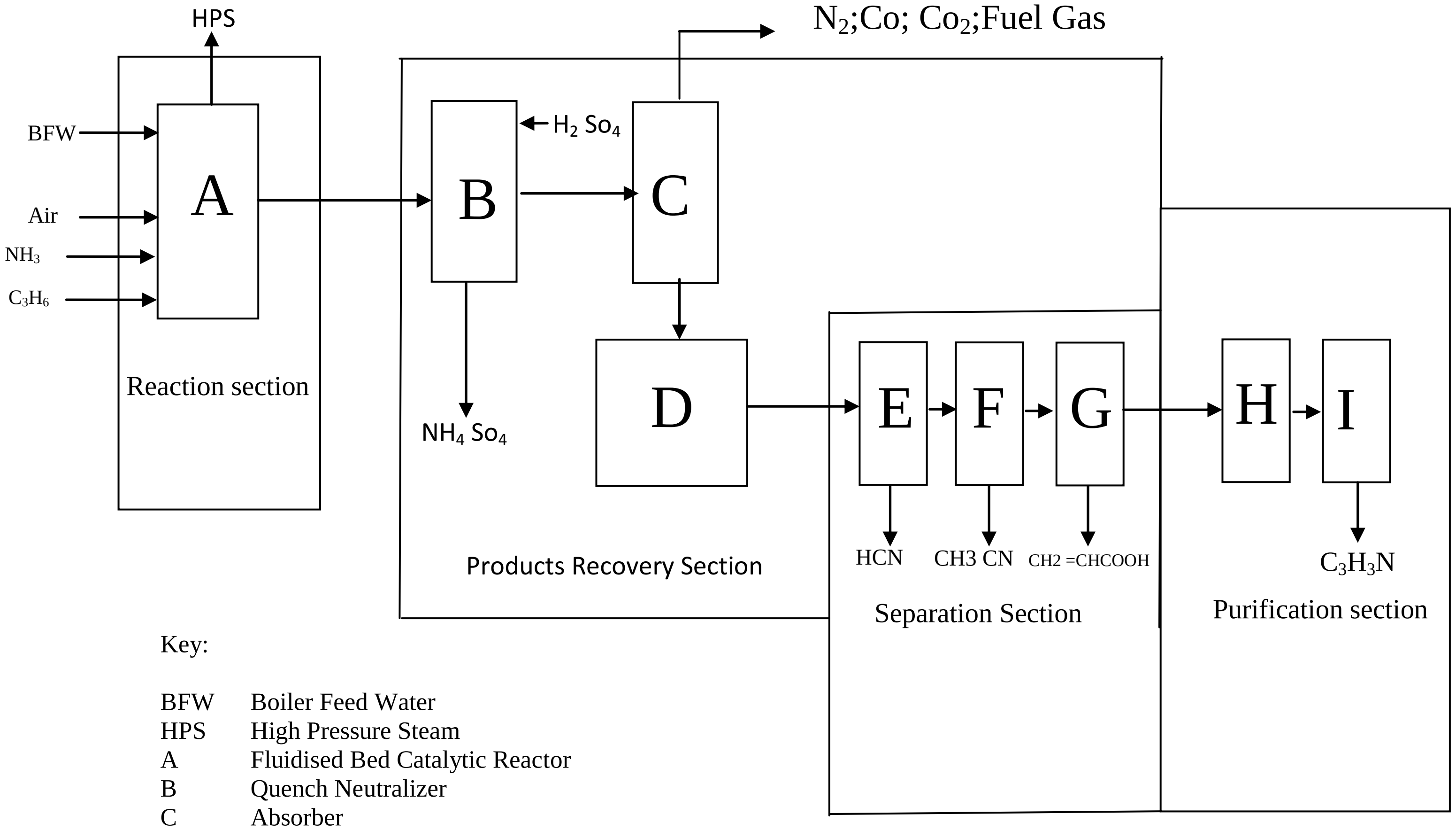
The following process equipment were used for the design:

K-01 : Feed compressor; R-01 : Fluidised bed catalytic reactor; E-01 : Heat exchanger I; R-02:Quench neutralizer; RG-01: Refrigeration compressor I;AB-01: Absorber; D-01:Knockout drum; E-02: Heat exchanger II; C-01: separating column; E-03: Heat exchanger III: C-02: Acetonitrile recovery column; C-03: Hydrogen cyanide gas stripper or lights column; C- 04: Acrylonitrile recovery column to mention just a few.

2.2. Methods

2.2.1. Process Description of Ammoxidation Process

Ammoxidation process involves the reaction of ammonia, air and propylene to produce acrylonitrile and several secondary products.



Key:

BFW	Boiler Feed Water
HPS	High Pressure Steam
A	Fluidised Bed Catalytic Reactor
B	Quench Neutralizer
C	Absorber
D	Separating Column
E	Hydrogen Cyanide recovery Column
F	Methyl cyanide recovery Column
G	Acetonitrile recovery column
H	Drier
I	Acrylonitrile recovery column

Fig. 2: Block Flow for Ammoxidation Process

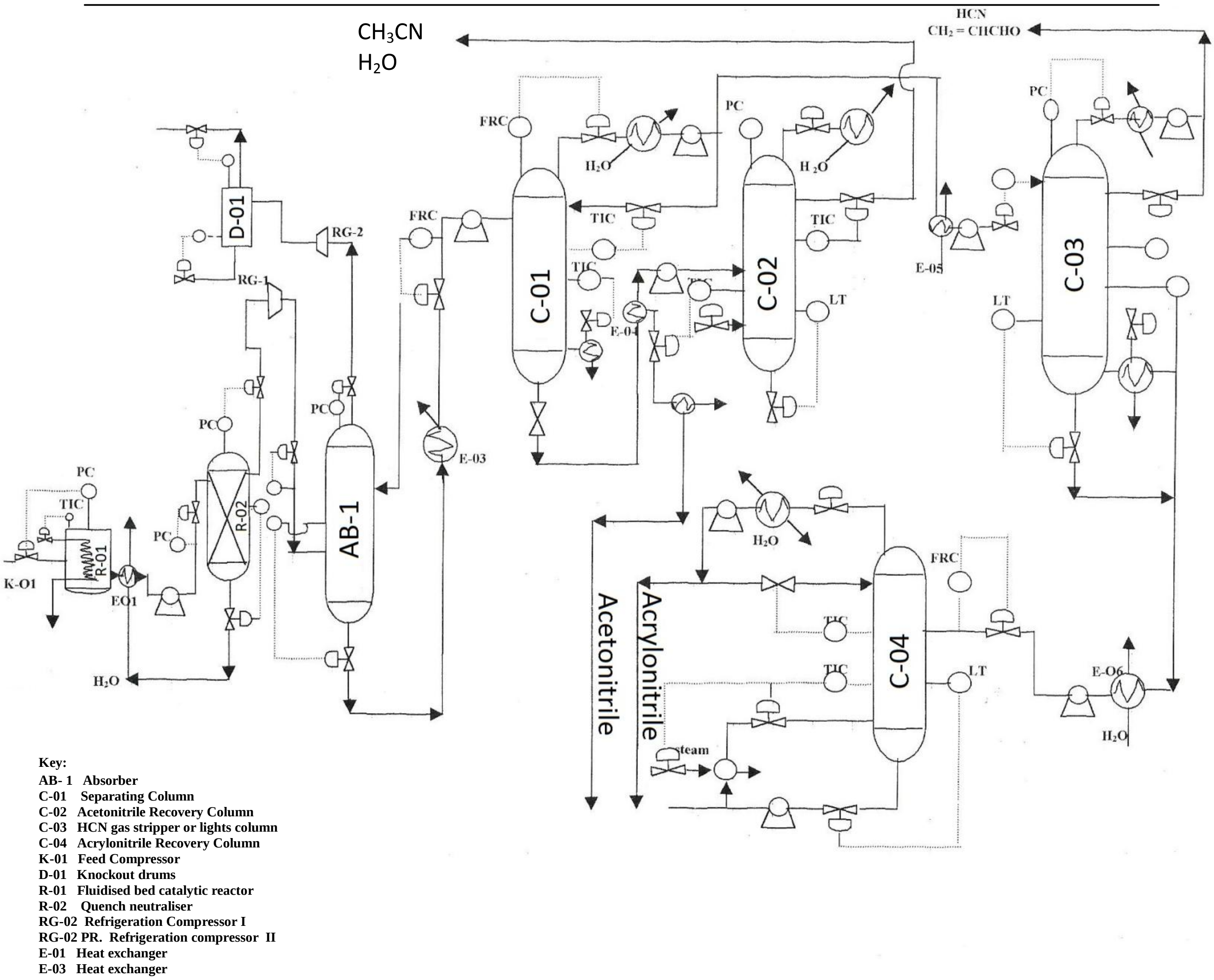


Fig. 3: Process flow for Ammoxidation process

2.2.1. The Reaction Section

Propylene, ammonia and air are fed into a fluidised bed catalytic reactor at controlled ratios of 90 % propylene and 100 % ammonia. Air, ammonia and propylene at 400 °C – 510 °C and 49 – 196 kpa (0.5 – 2.0 gcm^{-2} G) contact NS733A solid catalyst in a single pass process with about 98 % conversion of propylene and uses about 1.1 kg propylene per kilogram of acrylonitrile produced.

The equation for the reaction is:

$$C_3H_6 + NH_3 + {}^3/_2\, O_2 \xrightarrow{\text{Catalyst}} C_3H_3N + 3H_2O \qquad (1)$$

That is

$$1 \text{ mole } C_3H_6 + 1 \text{ mole } NH_3 + 1.5 \text{ mole } O_2 \xrightarrow[\text{Catalyst}]{} 1 \text{ mole } CH_2 = CHCN + 3 \text{ moles } H_2O \quad (2)$$

In the fluidised bed catalytic reactor exothermic reactions take place. The reactor temperature is controlled by removing the heat of reaction to generate high pressure steam which is used to drive the air compressor. The effluent gas at 440 °C contains acrylonitrile, hydrogen cyanide (0.1kg/kg of acrylonitrile) used in the manufacture of methyl methacrylate and some carbonyl compounds.

2.2.1.2. The Products Recovery Section

After the heat of reaction has been removed and used for generating high pressure steam, the product overhead gas of the reactor enters into the quench neutralizer where the effluent is scrubbed to remove the catalyst fines and neutralise the small amount of residual ammonia with sulphuric acid.

By this, scrubbing and neutralising takes place in the quench neutraliser. The neutralisation of residual ammonia with sulphuric acid yields ammonium sulphate which is sent to intermediate storage. Ammonium sulphate is useful as fertilizer. The ammonia free gas is then absorbed in water and uncondensed residual propylene, propane, Nitrogen, carbon monoxide and carbon dioxide are vented or used as fuel. The crude acrylonitrile solution from the absorber is passed to a recovery column that produces crude acrylonitrile stream overhead which also contains hydrogen cyanide. This crude passes through a stripper which strips any gases.

2.2.1.3. The Separation Section

The recovery column bottoms are passed to a second recovery column to remove water and produce crude methyl cyanide mixture. The mixture is distilled to remove the by product hydrogen cyanide as gas or liquid and then separate all high boiling carbonyl impurities which are normally incinerated. The remaining is a mixture of acrylonitrile and acetonitrile which need to be separated. This mixture is separated by extractive distillation using water as solvent to generate heterogeneous azeotrope. The separated acetonitrile passes through a stripping column which produces pure crude acetonitrile. The dilute acetonitrile solution is concentrated to recover the acetonitrile.

2.2.1.4. The Purification Section

The acrylonitrile recovered from the separation process is passed though a drier or a dehydration column where it is dried. After being dehydrated, it is sent into the acrylonitrile return column where it is purified to yield high quality acrylonitrile.

2.3. Kinetic Models

Odian (2004) gave rate of polymerisation as:

$$\frac{-d[M]}{dt} = R_i + R_P \qquad (3)$$

Where [M] is the monomer concentration

R_i, the rate of initiation
R_p, the rate of propagation
and t, the time.
Neglecting Ri

$$\frac{-d[M]}{dt} = R_P \quad (4)$$

$$Rp = kp\ [M^*]\ [M] \quad (5)$$

Where [M*] is the total concentration of all chain radicals which increases initially and instantaneously reaches a constant, steady state value.

$$R_i = R_t = 2k_i\ [M^*]^2 \quad (6)$$

$$[M^*] = (\frac{Ri}{Rt})^{1/2} \quad (7)$$

Substituting this for [M*] in $R_p = k_p\ [M^*][M]$

$$\text{Gives: } R_p = k_p\ [M]\ (\frac{R}{2ki})^{1/2} \quad (8)$$

Wikipedia (2019) gave the following reaction rates:

$$R_i = d\ [M^*]/dt \quad (9)$$

$$= 2k_i f\ [I] \text{ for chain initiation} \quad (10)$$

$$Rp = kp\ [M^*][M] \quad \text{for chain propagation} \quad (11)$$

$$R_t = \frac{-d[M*]}{dt} = 2k_t\ [M^*]^2 \text{ for chain termination} \quad (12)$$

Where f is the efficiency of the initiator. K_i, K_p and K_t are rate constants for chain initiation, chain propagation and chain termination respectively.[I], [M] and [M*] is the concentration of initiator, monomer and the active growing chain respectively. Under Steady State approximation, [M*] remains constant. Hence $R_{i=} R_t$

[M*] is expressed in terms of other known species as

$$[M^*] = (\frac{K_i[I]]f}{K_t})^{1/2} \quad (13)$$

R_p as a function of [I] and [M]

$$= K_p(\frac{fK_i}{K_t})^{1/2}\ [I]^{1/2}[M] \quad (14)$$

Dynamic chain length without chain transfer:

$$V = \frac{R_p}{R_i} = \frac{K_p[M][M*]}{2fK_i[I]} \quad (15)$$

$$V = \frac{K_p\,[M]}{2(fK_iK_t[I])^{1/2}} \quad (16)$$

2.4. Design Equations

2.4.1. Mass Balance Equations

The overall reaction.

$$C_3H_6 + NH_3 + 1.5O_2 \xrightarrow{400 - 460°} CH_2{=}CHCN + 3H_20 \quad (17)$$

The side reactions

$$C_3H_6 + 4.5O_2 \rightarrow 3C0_2 + 3H_20 \quad (18)$$

$$C_3H_6 + 3O_2 \rightarrow 3C0 + 3H_20 \quad (19)$$

$$C_3H_6 + 3NH_3 + 3O_2 \rightarrow 3HCN + 6H_20 \quad (20)$$

$$C_3H_6 + 1.5NH_3 + 1.5O_2 \rightarrow 1.5CH_3CN + 3H_20 \quad (21)$$

$$C_3H_6 + 1.5O_2 \rightarrow CH_2 = CHCOOH + H_20 \quad (22)$$

$$C_3H_6 + O_2 \rightarrow CH_2 = CHCHO + H_20 \quad (23)$$

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4 \text{ for quench neutralizer} \quad (24)$$

Basis: 100 kmol C_3H_6 taken as the basis

$$100 \text{ kmol } C_3H_6 + 100 \text{ kmol } NH_3 + 150 \text{ kmol } O_2 \rightarrow 100 \text{ kmol} CH_2 = CHCN + 300 \text{ kmol } H_2O \quad (25)$$

Purity of propylene: 90 %; 10 % for inerts

Conversion: 98 %

Selectivity for Acrylonitrile : 80 % ; 20 % for secondary products

$$\text{kmols} \times \text{Molar mass} = \text{kg mass} \quad (26)$$

kg of side products = kg of acrylonitrile desired – kg of acrylonitrile produced (27)

Moles of reactant not reacted = moles of Inert + moles of unconverted (28)

Quantity of air supplied = % of oxygen in air × kmoles of oxygen (29)

Quantity of Nitrogen supplied = Quantity of air supplied – Quantity of oxygen supplied (30)

$$\text{kilomole} = \frac{\text{kg mass}}{\text{molar mass}} \quad (31)$$

$$\text{Reflux Ratio} = \frac{\text{Overhhead Product}}{\text{Distillate}} \quad (32)$$

$$\text{ScaleFactor} = \frac{\text{Production Capacity } (\text{kgh r}^{-1})}{\text{Amount Produced for 335 days plant operation from mass balance}} \quad (33)$$

kg product = Amount produced from mass balance × scale factor ×number of operational hours per day×number of days of operation per year (34)

2.4.2. Energy Balance Equations

Work of Compression

$$W_{isen} = \frac{RT_1}{\gamma_{AV} - 1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\gamma_{AV}-1/\gamma_{AV}}\right] \quad (35)$$

$$\gamma_{AV} = c_p / c_v \quad (36)$$

$$\text{Actual Work } (W_s) = \frac{\text{Work of Compression}}{\text{Efficiency}} \quad (37)$$

$$Cp_{mixture} = A + BT + CT^2 + DT^3 \quad (38)$$

Where A, B, C and D are characteristic constants for a particular compound and T, the temperature in Kelvin.

$$Cp_{mean} = \frac{\int_{T_1}^{T_2} Cp_{mixture}\, dT}{T_2 - T_1} \quad (39)$$

$$\text{Volume flow rate} = \frac{\text{Mass flow rate}}{\text{Density}} \quad (40)$$

$$Q = MCp_{mean}\,\Delta T \quad (41)$$

Heat removed to maintain reactor temperature:

$$Q = \Delta H_{products} - \Delta H_{Feed} - \Delta H_{reaction} \quad (42)$$

$$Q = Ms\lambda s + MsCp\,\Delta T \quad (43)$$

Where λs is the latent heat of vapourization.

Ms, the mass flow rate.

$$\Delta Hrxn = \Delta H^0 r + \Delta H_{products} - \Delta H_{reactants} \quad (44)$$

Process heat added to maintain the required reactor temperature:

$$Q_p = H_2 - H_1 - Q_s \quad (45)$$

Where H_2 is enthalpy of outlet stream

H_1, the enthalpy of inlet stream

Q_s, heat generated in the system which is positive for exothermic processes and negative for endothermic processes.

2.4.3. Cost Analysis Equations

Coulson *etal*. (2009) gave the following costing and economic evaluation equations:

$$PEC = a + bs^n \times MF \quad (46)$$

Cost in year A = Cost in year B × $\frac{\text{cost index in year A}}{\text{cost index in year B}}$ (47)

PPC = PEC (1 + f_{1+} ....+f_9) (48)

FC = PPC (1 + f_{10} + f_{11} + $f_{12)}$ (49)

WC = 10 % of fixed capital (50)

Total Investment = Fixed Capital + Working Capital (51)

Operating Cost = Fixed Cost + Variable Cost (52)

Total Cost = Total Investment + Direct Production Cost (53)

Direct Production Cost = Operating Cost + 20 % of operating cost (54)

Total Cost =Total Investment + 20 % of operating cost + operating cost (55)

2.4.4. Economic Evaluation Equations

Sale of product (Acrylonitrile)

= Mass flow rate of product × Operating time per day × No. of days of operation per year × Cost per kilogram (56)

Net Annual Profit = Sale of product (Acrylonitrile) – operating cost – Fixed capital (57)

Cash flow for any particular year = Cash in (profit) – Cash out (expenditure) (58)

Cash flow for any particular year = Net Annual Profit (after salaries, Taxes, charges and fees has been paid as obtained from equation 57) – [Cost of NYSC and student Industrial Training] –[Sponsorship of organisations and voluntary donations cost] – [Agricultural development program cost] – [Cost of unforeseen procurement of materials and equipment that were not included in costing] – [Dividends paid to shareholders] – [Cost of Unforeseen salaries and wages that were not included in costing] (59)

The cost of each item in equation (59) was estimated from expenditure of other companies that embark on similar programs although different companies spend their profit in different ways.

Rate of Return on Investment = $\frac{\text{Cumulative net cash flow}}{\text{Plant most Useful Life} \times \text{Total Investment}} \times \frac{100}{1}$ (60)

Pay-back period = $\frac{\text{Total Investment}}{\text{Average Annual cash flow}}$ (61)

Average Annual cash flow = $[\text{cummulative net cash flow}] / [\text{Plant most useful life}]$ (62)

Therefore:

$$\text{Pay-back period} = \frac{\text{Total Investment}}{[\text{cummulative net cash flow}]/[\text{Plant most useful life}]} \quad (63)$$

Pay-back period is the inverse of Rate of Return on Investment, Hence:

$$\text{Pay-back period} = \frac{1}{\text{Rate of Return on Investment}} \quad (64)$$

3.0. RESULTS AND DISCUSSION

3.1. The Plant Capacity

50,000 Tons per year of acrylonitrile = 50,000,000 kg per year of acrylonitrile. For 335 days per year and 24 hours per day, the production capacity

$$= \frac{50{,}000{,}000}{335 \times 24} = \frac{50{,}000{,}000}{8{,}040}$$

$$= 6{,}218.90547263 \text{ kghr}^{-1}$$

$$\approx 6{,}218.91 \text{ kghr}^{-1}$$

3.1.1. The Scale Factor

$$\text{The scale factor} = \frac{\text{ProductionCapacity}}{\text{AmountProduced}}$$

$$= \frac{6{,}218.91 \text{ kghr} -1}{3{,}759.8504} = 1.654$$

3.2. Raw Materials

Propylene: Taking a basis of 100 kmol C_3H_6

From equation (2):

100 kmoles propylene requires 100 kmoles Ammonia and 150 kmoles Oxygen, to produce 100 kmoles of acrylonitrile and 300 kmoles of water .

kg mass of Propylene = kmoles of propylene × Molecular mass of propylene

= 100 × 42 = 4200 kg of Propylene

Ammonia:

kg mass of ammonia = kmoles of ammonia × Molecular mass of ammonia

= 100 × 17 = 1700 kg of Ammonia

Air:

Majorly (21 %) O_2 and N_2 (78 %). Other components are negligible.

O_2 : kg mass of oxygen = kmoles of oxygen × molecular mass of oxygen

= 150 × 32 = 4800 kg of oxygen

N_2: Oxygen = 21% of air. Therefore quantity of theoretical air required = $\frac{150\ kmols\ \ of\, O_2}{^{21}/_{100}}$

= 714.29 kmoles of air.

Quantity of Nitrogen required = 714.29 – 150

= 564.29 kmoles of Nitrogen.

Molar mass of air = 29

kmoles of air = $\frac{714.29}{29}$ = 24.6 kmoles of air.

kg mass of N_2 = kmoles of N_2× Molecular mass of Nitrogen

= 564.29 × 28 = 15800.12 kg of N_2.

kilograms of air:

kg O_2+ kg N_2

= 4800 + 15800.12

=20,600.12 kg

3.3. Mass and Energy Balances

Mass and energy balances across each equipment in the ammoxidation process are shown on Table 4, appendix 1. The laws of conservation of mass and conservation of energy is being upheld as kg inlet = kg outlet and kJ inlet = kJ outlet.

3.4. Costing and Economic Evaluation

3.4.1. Costing

Table 1: Cost Analysis

Parameter	Amount (£)
Purchased Equipment Cost	8,330,19.94
Physical Plant Cost	2,849,267.796
Fixed Capital	4,131,438.304
Working Capital	4,131,43.8304
Total Investment	4,544,582.134
Fixed Cost	4,473,808.89472
Variable Cost	2,711,799.95152
Direct Production Cost	8,622,730.615488
Operation Cost	7,185,608.84624
Total Cost	13,167,312.749488

Naira could not be used due to instability of the Naira. However, conversion can be made based on the exchange rate at any time the conversion is made. The company is expected to be financially self sufficient as money obtained from sales of secondary products will be kept in the company bank account as company reserve.

3.4.2. Economic Evaluation

3.4.2.1. Cash Flows

Applying equations 58 and 59 for the plant most useful life of 15 years at 3 % rate of increase in Production capacity per annum, the following cash flows were obtained from equation 59:

$$\text{£ } 15{,}142{,}000.00 - \text{£ } 627{,}000.00 - \text{£ } 1{,}253{,}000.00 - \text{£ } 1{,}880{,}104.08899 - \text{£ } 2{,}507{,}000.00 - \text{£ } 3{,}133{,}000.00 - \text{£ } 3{,}759{,}000.00 = \text{£ } 1{,}982{,}895.911$$

Table 2: Cash Flow for each Year

Year	Cash Flow (£)
1	1,982,895.911
2	2,042,382.788
3	2,103,654.272
4	2,166,763.900
5	2,231,766.817
6	2,298,719.822
7	2,367,681.416
8	2,438,711.859
9	2,511,873.215
10	2,587,229.411
11	2,664,846.293
12	2,744,791.682
13	287,135.437
14	2,911,949.496
15	299,307.98
Cumulative	**344,093,98.3**

3.4.2.2. Rate of Return on Investment

The rate of return on investment is given in equation (60)

$$\text{ROI} = \frac{\text{Cummulative Net Cash flow}}{\text{Plant most useful life} \times \text{Total Investment}} \times \frac{100}{1}$$

$$= \frac{344{,}093{,}98.3}{15 \text{ x } 4{,}544{,}582.134} \times \frac{100}{1}$$

$$= \frac{344{,}093{,}98.3}{68{,}168{,}732.01} \times \frac{100}{1}$$

$$= 0.504768 \times 100$$

$$= 50.48\ \%$$

3.4.2.3. Pay – back Period

The Pay-back period is given in equations (61), (63) and(64).

$$\text{PBP} = \frac{\text{Total Investment}}{\text{Average Annual Cash Flow}}$$

The Average annual cash flow

$$= {[\text{cummulative net cash flow}]}\big/{[\text{plant most useful life}]}$$

Therefore:

$$\text{PBP} = \frac{\text{Total Ivestment}}{[cummulative\ \ net\ cash\ flow]\big/[plant\ \ most\ \ useful\ \ life]}$$

$$= \frac{4{,}544{,}582.134}{[344{,}093{,}98.3]\big/[15]}$$

$$= \frac{4{,}544{,}582.134}{2{,}293{,}959.886667}$$

$$= 1.98 \approx 2 \text{ years}$$

Also: Pay – back period = $\frac{1}{\text{ROI}}$

$$\frac{1}{[\frac{50.48}{100}]} = \frac{1}{0.5048}$$

$$\approx 2 \text{ years}$$

Table 3: Economic Analysis

Parameter	**Value**
Market Survey: Cost of 1kg of Acrylonitrile	£ 0.88
Sales of Product	£ 26, 459,125.44
Net Annual Profit	£ 15,142,078.28976
Rate of Return on Investment	50.48 %
Pay-back Period	2 years.

A product sales of £ 26, 459,125.44 is quite high. A net annual profit of £ 15,142,078.29 is extremely high. A pay – back period of 2 years show that the loan can be repaid within a short period of 2 years. A rate of return of 50.48 % is quite reasonable. This show that an acrylonitrile petrochemical process plant if well managed could be economically viable in Nigeria.

4.0. CONCLUSION

An acrylonitrile petrochemical production process plant of 50,000 Tons per annum capacity has been designed. Economic analysis show that the acrylonitrile petrochemical production process plant if well managed could be economically viable in Nigeria. Government and the private investors are therefore encouraged to invest in the acrylonitrile production project.

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6.0. APPENDIX 1

MASS AND ENERGY BALANCES

Table 4: Mass and Energy Balances

MATERIALS			ENERGY	
Component	**Inlet** kghr^{-1}	**Outlet** kghr^{-1}	**Inlet** kJhr^{-1}	**Outlet** kJhr^{-1}
Fluidised Bed Catalytic Reactor			**10,416,364 kJhr^{-1}**	**10,416,364 kJhr^{-1}**
Propylene	4200	495.60		
Ammonia	1700	200.61		
Air	20600.12	16366.52		
Water	-	4762.80		
Acrylonitrile	-	3739.70		
Carbon Monoxide	-	162.340		
Carbon Dioxide	-	255.10		
Hydrogen Cyanide	-	156.50		
MethylCyanide	-	118.85		
Acetonitrile	-	139.147		
Acrolein (Toxic)	-	108.23		
Total	**26500.12**	**26500.40**		
Quench Neutralizer			**163360 kJhr^{1}**	**163360 kJhr^{-1}**
Ammonia	578.2	-		
Sulphuric acid	1445.5	-		
Ammonium Sulphate	-	1854.286		
Water	-	169.214		
Total	**2,023.5**	**2,023.5**		

Absorber			**62,794,880.55kJhr^{-1}**	**62,794,880.55 kJhr^{-1}**
Carbon Monoxide	162.34	162.34		
Carbon dioxide	255.10	255.10		
Nitrogen	15800.12	15800.12		
Propylene	495.60	495.60		
Oxygen	566.40	566.40		
Water	9772.93	9772.93		
Hydrogen Cyanide	156.50	156.50		
Acrolein	108.23	108.23		
Acrylonitrile	3739.70	3739.70		
Methyl Cyanide	118.85	118.85		
Acetonitrile	139.147	139.147		
Total	**31,309.93**	**31,309.93**		
Separating Column			**7,890,403.034 kJhr^{-1}**	**7,890,403.034 kJhr^{-1}**
Acrylonitrile	3739.70	3739.70		
Hydrogen Cyanide	156.50	156.50		
Acrolein	108.23	108.23		
Methyl Cyanide	118.85	118.85		
Acetonitrile	139.147	139.147		
Water	9772.93	9772.93		
Total	**14,035.3613**	**14,035.3613**		
Acetonitrile Recovery Column			**179,956,567.8 kJhr^{-1}**	**179,956,567.8 kJhr^{-1}**
Methyl Cyanide	116.98	116.98		
Water	8771.355	8771.355		
Acetonitrile	139.147	139.147		
Total	**9,027.482**	**9,027.482**		
Gas Stripper			**318,766,153.9 kJhr^{-1}**	**318,766,153.9 kJhr^{-1}**

Acetonitrile	139.147	-
Water	1001.575	1001.575
Hydrogen Cyanide	156.50	156.50
Acrolein	108.23	108.23
Acrylonitrile	3739.70	3739.70
Methyl Cyanide	1.87	1.87
Total	**5,007.8757**	**5,007.8757**

Acrylonitrile Product Recovery Column 3,828,961.417 kJhr^{-1} 3,828,961.417 kJhr^{-1}

Hydrogen Cyanide	0.0374	0.0374
Acrolein	0.374	0.374
Acrylonitrile	3739.70	3739.70
Methyl Cyanide	1.87	1.87
Water	954.93	954.93
Total	**4,696.9124**	**4,696.9124**

Feed Compressor (K-01)	2,648,855.50 kJhr^{-1}
Refrigeration Compressor (RG-1)	12,940,644,313 kJhr^{-1}
Heat exchanger (E – O3)	7,976,095.22 kJhr^{-1}
Heat exchanger (E – O4)	4,003,292,780 kJhr^{-1}
Heat exchanger (E – O5)	1,710,980.38 kJhr^{-1}
Heat exchanger (E – O6)	255,354,144.50 kJhr^{-1}
Refrigeration Compressor (RG-2)	1.3313090×10^{9} kJhr^{-1}

7.0. APPENDIX 2

Table 5: Nomenclature

Symbol	Definition	Unit
Cp	Specific heat capacity at constant Pressure	kJ/kg K
Cv	Specific heat capacity at constant Volume	kJ/kg K
CH_3CN	Methyl Cyanide	
$CH_2 = CHCOOH$	Acetonitrile	
$CH_2 = CHCN$	Acrylonitrile	
$CH_2 = CHCHO$	Acrolein or Propenal **(Toxic)**	
CO	Carbon monoxide	
CO_2	Carbon dioxide	
C_3H_6	Propylene	
HCN	Hydrogen Cyanide	
H_2O	Water	
H_2SO4	Sulphuric acid	
ΔH	Change in Enthalpy	kJ/kg K
Ms	Mass flow rate	kg/hr
NH_3	Ammonia	
NH_4SO_4	Ammonium Sulphate	
P_1	Initial Pressure	bars
P_2	Final Pressure	bars
Q	Quantity of heat	kJ/kg
ΔT	Change in Temperature	K
Wisen	Isentropic work	kJ/kg
Ws	Actual work	kJ/kg

£	Currency used in Britain	
γ_{av}	Ratio of Specific heat capacities	
λs	Latent heat of vaporisation	kJ/kg

Abbreviation	Definition
ABS	Acrylonitrile – Butadiene – Styrene
ANA	Acrylonitrile Acrylate
ASA	Acrylate – Styrene – Acrylonitrile
DPC	Direct Production Cost
FC	Fixed Capital
FRC	Flow Recorder
LT	Level Transmitter
MABS	Methylmethacrylate-Acrylonitrile-Butadiene – Styrene
MF	Materials Factor
NAP	Net Annual Profit
NBR	Acrylonitrile – Butadiene – Rubber
NYSC	National Youth Service Corps
OPC	Operating Cost
PAN	Poly Acrylonitrile
PC	Pressure Controller
PEC	Purchased Equipment Cost
PIC	Pressure Indicator
PPC	Physical Plant Cost
ROI	Rate of Return on Investment

SAN	Styrene Acrylonitrile
TC	Total Cost
TI	Total Investment
TIC	Temperature Indicator
VC	Variable Cost
WC	Working Capital