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Design and Fabrication of ANFO Mixing Machine for Safety and Proper Homogenization

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Abstract
The project is focused on the design and fabrication of ANFO mixing machine for safety and proper homogenization of ammonium nitrate and fuel oil in order to increase its production rate. The ANFO mixing machine is a replacement for the manual mixing of fuel oil (Diesel) and ammonium nitrates in bays or on concrete floors which is the common method of mixing ANFO in Nigeria. But the ANFO mixing machine designed is easy to operate, safe to use, increases production and reduces number of laborers.
Keywords: *Explosive, ANFO, Design, Fabrication, and Performance Evaluation*

1. INTRODUCTION

From prehistoric times to the present, mining has played an important part in human existence (Madigan, 1981). Here the term mining is used in its broadest context as encompassing the extraction of any naturally occurring mineral substances solid, liquid, and gas from the earth or other heavenly bodies for utilitarian purposes. Mining can also be defined as the activity, occupation, and industry concerned with the extraction of minerals.
The essence of mining in extracting mineral wealth from the earth is to drive an excavation or excavations from the surface to the mineral deposit. Normally, these openings into the earth are meant to allow personnel to enter into the underground deposit. However, boreholes are at times used to extract the mineral values from the earth. These fields of boreholes are also called mines, as they are the means to mine a mineral deposit, even if no one enters into the geologic realm of the deposit. If the excavation used for mining is entirely open or operated from the surface, it is termed a surface mine. If the excavation consists of openings for human entry below the earth's surface, it is called an underground mine. In 1947 a disastrous explosion of Ammonium Nitrate (AN) took place in Texas city (United States), as the substance was being protected with paraffin and only 1% of this constituted a good sensitizing fuel of AN.

Apart from the catastrophe itself, the attention of the manufacturers of explosives was drawn to the fact that AN had tremendous energetic potential, along with its low cost. Any combustible substance can be used with AN to produce a blasting agent. In United States at the end of the fifties carbon powder was used but, afterwards, it was substituted by liquid fuels as the mixtures were more homogeneous and intimate with AN. The most common product used is fuel oil which, when compared to other liquids such as gasoline, kerosene, etc., has the advantage of higher point of volatility and, as a consequence, less risk of steam explosions. The fuel content plays a very important role in different properties of ANFO. The decomposition reaction of the oxygen balanced system is:

$$3NH_4NO_3 + CH_2 \rightarrow 3N_2 + 7H_2O + CO_2 \quad (1.1)$$

Producing around 920kcal/kg, that could be lower in commercial products depending upon the contents of inert materials, and a gas volume of 9701. The stoichiometric mixture corresponds to 94.3% of AN and 5.7% of fuel oil, which is the equivalent of 3.7 liters of the latter for each 50kg of AN. ANFO has become an indispensable explosive for most of the surface mines and underground non-coal mines.

2.EXPLOSIVES

An explosive can be solid, liquid or a mixture of substances. When a suitable stimulus, (e.g. electric, flame, spark, percussion) is applied to the explosive substance it is capable of developing a sudden high pressure by the rapid formation or liberation of stable gases at high temperatures. Explosive is a chemical compound, mixture or device that contains oxidizing and combustible materials or other ingredients in such proportions or quantities that an ignition by fire, friction, concussion, percussion or detonation may result in an explosion (Oxford Advanced dictionary, 2010).

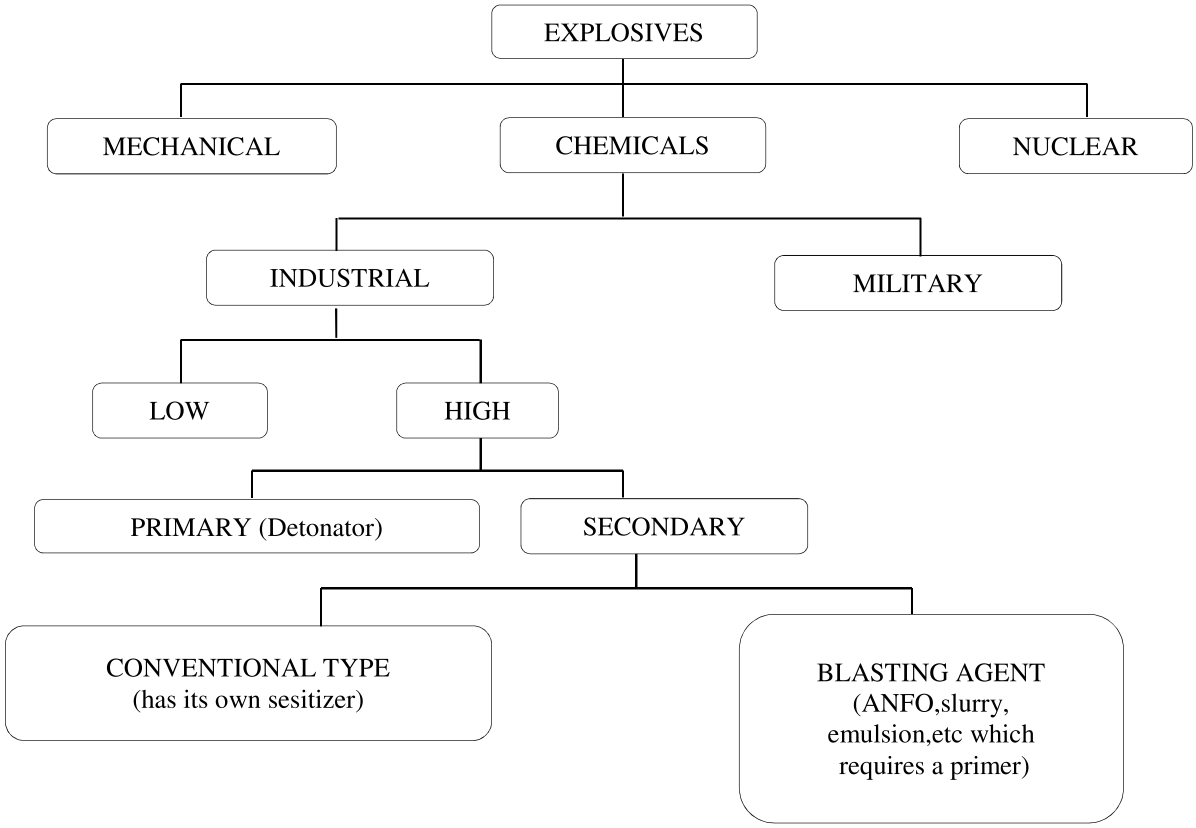

Figure 1: Family tree of Explosives (Source: School of Materials and Mineral Resources Engineering, USM 2006)

2.1 Classification of Explosives

Based on the sensitivity, explosives are classified as: Low and High Explosives

2.1.1 Low Explosives

A low explosive is generally defined as one which does not require a detonator to initiate it. It is a mechanical mixture of ingredients such as charcoal (15%), sulfur (10%) and potassium nitrate, KNO_3, (75%). It is initiated by ignition (deflagration) and decomposition is slow. Its flame propagates slowly; few m/sec. and burning particles are liable to remain in contact with the surrounding atmosphere for a considerable duration (Ratan, 2005).

2.1.2 High Explosives

High explosives detonate at velocities which vary between 4,000 and 7,500 m/s depending on their composition, densities, degree of confinement, diameter etc. They produce large volume of gas with the reaction being exothermic and consequently the temperatures of detonation are extremely high. These explosives require a shock wave to initiate them and this is provided by a detonator. When confined in a drill hole, the explosive on detonation produces extremely high pressure gases which impart energy in the form of shock and heave into the surrounding rock. The performance of a high explosive depends upon the volume and temperature of the gases produced and on the velocity of detonation (VOD).

2.2 Type of Anfo Mixing Methods

2.2.1 Mechanical

In this type of process, the ammonium nitrate is mixed with the fuel oil in the right proportion of 94% to 6% respectively with the use of mechanical device. Machine does the mixing with different types of machine doing the mixing.

2.2.2 Manual

In this process Anfo is gotten by the use of crude or simple tool in mixing of Anfo. The use of shovels and bucket are used for the mixing while the mixing is done either on a concrete floor or in a mixing bay. Conventional Hand Mixing is time Consuming and does not give Homogeneous Mixture.

2.3 ANFO Mixing Machine

Recently ANFO is being used extensively by the Mining industry. Usually it is hand mixed in a tray which exposes ANFO to dirt and humidity. Moreover if more quantity is required then more hands are to be engaged. To overcome these difficulties as well as to provide pure homogeneous ANFO mixers have been developed.

3. MATERIALS

In the fabrication of the ANFO mixing machine, the following factors were put into consideration during the selection of materials and choosing of methods: safety, strength, wear and tear, resistance to chemical and corrosion, reliability, rigidity, stability, size and shape, power consumption, cost, maintenance, resource material, market availability and ability to mixing Ammonium nitrate and fuel oil (diesel) in the ratio 94:6 respectively.
The main components of the ANFO Mixing machine are Frame, Hopper, Fuel tank and support, Auger and pipe, Fuel pump, drive system (Reduction gear electric motor etc.). The design and functions of these components are highlighted below.

a. Frame

A frame is a free standing structure designed to carry the unit and other components of the mixing machine mounted on it. It is the support for the mechanism of the whole machine. It provides a base for the units of the fabricated parts as well as stability and rigidity of the entire machine in order to prevent vibration during operation. It was made of mild steel. Other components are attached to it in one way or the other by a screw.

b. Hopper

A hopper is a large, pyramidal shaped container used in industrial processes to hold particulate matter that has been collected a source or a storage container used to dispense granular materials through the use of gravity or a chute to resist flow. This is where the ammonium nitrate is poured into, before the mixing process. The hopper acts as a temporary container and passage for ammonium nitrate to pass into the mixing conduit.

c. Fuel Tank

A fuel tank is a safe container for flammable fluids. Fuel tank ranges in sizes. Typically, a fuel tank stores fuel, provides a method for determining level of fuel tank, feeding the fuel pump. From this tank the fuel is pumped by a fuel pump to the mixing conduit.

d. Pipe

A long tubular section or hollow cylinder, usually of a cross section, used mainly to convey substances which can flow fluids, slurries, powders, masses of small solids and other material. Here ammonium nitrate and fuel oil (diesel) is conveyed together through it and mixed simultaneously by the help of an auger.

e. Drive system

The drive system is the heart of the machine. It supplies power necessary for the rotation of the concentrating cone. The drive system is made up of the following components: electric motor, shaft, bearing and coupling.

i. Electric motor:

The electric motor provides power to the machine. It converts electric power to mechanical power which is transferred through the axle to the coupling and then to the shaft which causes its rotation. This electric motor is a reduction gear motor i.e. having a gear to reduce the initial speed of the electric motor to the required speed. A single phase, one horsepower motor was installed which has a 40rpm. These specifications of the motor were chosen because of the machine and speed required to achieve optimum separation of particles involved.

ii. Bearing

A bearing is a machine element that constrains relative motion between moving parts to only the desired motion. The design of the bearing provide for free linear movement of the moving part or for free rotation around a fixed axis. It has small balls of the same diameter permanently fixed on the circumference of the inner circular rolling element. Bearing permit a relative motion between the contact surfaces of the members, while carrying the load. For this project work, two ball bearings were firmly fixed at both ends of the shaft. The diameter of the bearing is 25mm and the bearing house has a length of 52mm and a diameter of 34.1mm.

iii. Auger/ Flight screw

Auger conveyor sometimes called screw conveyor is a mechanism that uses a rotating helical screw blade, called a flighting usually within a tube, to move liquid or granular materials. They are used in many bulks handling industry it can be used horizontally as it is used in this project or at a slight incline as an efficient way to move aggregates and many others. They usually consist of a trough or tube containing either a spiral blade coiled around a shaft, driven at one end and held at the other, or a shaft-less spiral, driven at one end and free at the other. The rate of volume transfer is proportional to the rotation rate of the shaft. This project makes use of the auger with a spiral blade coiled around a shaft.

f. Fuel Pump

This is an essential component on a car or other internal combustion engines device. It is used in non-gravity feed designs, fuel has to be pumped from the fuel tank to the engine. For the purpose of this project the fuel pump shall be used in pumping fuel from the fuel tank to the mixing conduit. Super power HEP-02A fuel pump is been used having an operating current of <1.2A and a voltage of 12V (which will be connected to a step down transformer circuit). The body material is made of iron; it is a single cylinder, auto nozzle and two strokes.

g. Fasteners

These are bolts and nuts used to hold different parts or units of the machine together and permit the dismantling of these units when necessary. Various sizes of these elements were used with washers depending on their area of application.

3.1 Design Considerations and Analysis

3.1.1. Design consideration

During the design and fabrication of this ANFO mixing machine, attentions were given to the following considerations;

i. **Economic consideration:** This aspect relates to the machines production, subsequent maintenance and servicing. These include cost of fabrication, local availability of component part and ease of maintenance.

ii. **Technical consideration:** The technical consideration relates to the ease of operation of the machine. These include: portability and simplicity, component failure and malfunction, reliability and safety operations, efficiency of machine, factor of safety, workability of machine, physical and mechanical properties of component parts used, shape, size, weight and surface finish.

3.1.2 . Design Analysis and Calculations

These are the design parameters considered during the fabrication of the centrifugal concentrator. Specifications from individual components were carefully chosen so as to achieve a near perfect working condition for the machine.

1. Volume of Ammonium nitrate to be contained by the hopper

Density of Ammonium Nitrate = 1.725g/cm^3

50kg $\longrightarrow$ 50,000g

$$\text{Density} = \frac{\text{Mass}}{Volume} \quad (3.1)$$

$$\text{Volume} = \frac{\text{Mass}}{Density} = \frac{50{,}000}{1.725} = 28985.51\text{cm}^3 \quad (3.2)$$

2. Volume of truncated frustum of the pyramid (Volume of upper part of hopper)

Where:

V= volume of upper part of hopper

h= depth of frustum

A= area of the larger rectangle (upper opening of hopper)

A^1= area of smaller rectangle (lower opening of truncated pyramid)
L = length of larger rectangle (upper opening)
L^1 = length of smaller rectangle (lower opening)

$$V = \frac{h}{3}\left(A + A^1 + \sqrt{A.A^1}\right) \quad (3.3)$$

Volume designed = 31500cm^3

A = L × L   L = 50cm
A = 50 × 50
A = 2500cm^3
$A^1 = L^1 \times L^1$ L = 15cm
A^1 = 15 × 15
A^1 = 255cm^3

Volume of frustum = designed volume

$$V = \frac{h}{3}\left(A + A^1 + \sqrt{A.A^1}\right)$$

$$31500 = \frac{h}{3}\left(2500 + 225 + \sqrt{2500 \times 225}\right)$$

$$31500 = \frac{h}{3}(3475)$$

$h = \frac{31500\times 3}{3475} = \frac{94500}{3475}$ = 27.19 cm (for technical reasons 27.6cm was used)

3. Volume of rectangular prism
   Volume = l×b×h (3.4)
   where: l = length, b= width, h = height
   Volume = 15× 15 ×10
   Volume = 2250 cm^3
4. Total volume of hopper
   Total volume of hopper = volume of truncated frustum + volume of rectangular prism
   V_T = 31500 + 2250
   V_T = 33750cm^3
5. The hopper can thus contain the below kg of Ammonium Nitrate
   Density = $\frac{mass}{volume}$ (3.5)
   Mass = density × volume
   = 1.725 × 33750
   = 58218.75g
   = 58.2188kg
6. Volume of oil Tank
   Volume of container $= \pi r^2 h$ (3.6)
   Designed volume to be contained = 15litres = 15,000,000
   $V = \pi r^2 h$ (3.7)
   $15{,}000{,}000 = \frac{22}{7} \times r^2 \times 570$
   $r^2 = \frac{15{,}000{,}000 \times 7}{22\times450} = \frac{105{,}000{,}000}{9900}$ 1060606mm^2
   $r = \sqrt{1060606} = 102.9 \cong 103$mm
   Diameter = 2r = 2 × 103 = 206mm
7. Auger calculation
   D = diameter of the auger = 0.144m
   Pitch = p = $\frac{1}{2}$ D
   Pitch = p = $\frac{D}{2} = \frac{0.144}{2}$ = 0.072m
   Assuming an efficiency of 80% in the medium thus allowing with 20% slip
   (i) Power transmitted to the shaft of auger
   Power, P = $\frac{80}{100} \times 750$
   P = 600w
   (ii) Rotational speed to the shaft of auger by reduction gear electric motor (N)
   N = 40rpm
   (iii) Power, P = $T.w = \frac{T\times 2 \times N}{60}$ (3.8)
   $W = \frac{2\pi N}{60}$; where N is the speed in rpm (3.9)
   (iv) Torque (Nm) = $\frac{power\ (in\ watts)}{2\pi \times 40}$

$$T = \frac{600w}{2\pi \times 40} = 4.77\text{Nm}$$

3.2 Construction Procedure and Assemblage

The design of the mixing machine was carefully and systematically drawn out putting into consideration the type of material to be mixed, theoretical studies of the power needed to enact mixing, sizes and specifications of individual components readily available in the market.

The fabrication was jointly carried out with a well experienced fabricator and the procedures for the fabrication were;

1. Buying of materials (angle iron, metal sheets, pipes, electrodes, reduction gear electric motor, fuel pump, bearings shaft etc)
2. Cutting of metal sheets, angle iron and pipe to appropriate dimensions as designed
3. Welding the angle iron to form the required frame shape
4. Welding the sheets to form the required shape of the hopper
5. Bending and welding of metal sheet to the shaft to form an auger.
6. Fitting together of different parts
7. Painting

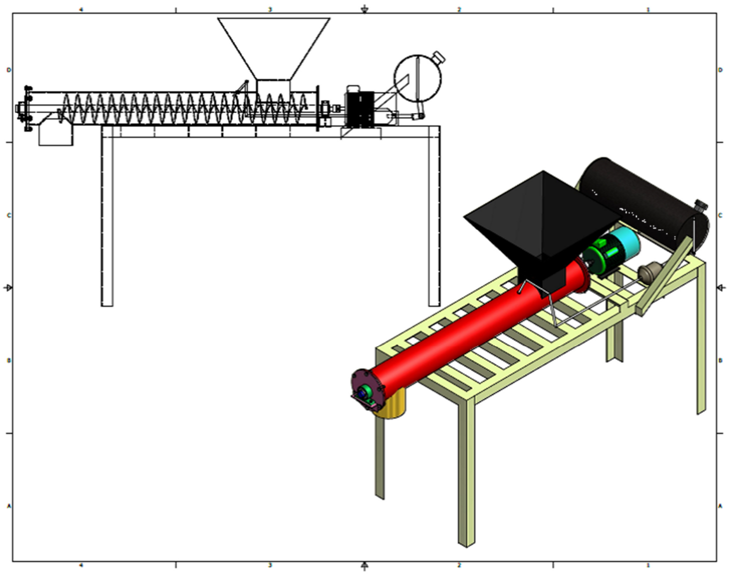

Figure 2: Schematic and 3-D diagram

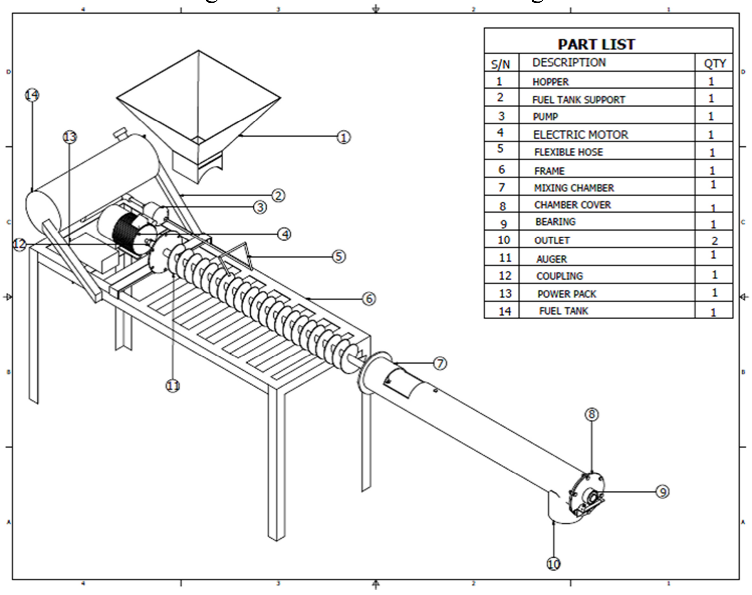

Figure 3: Exploded view

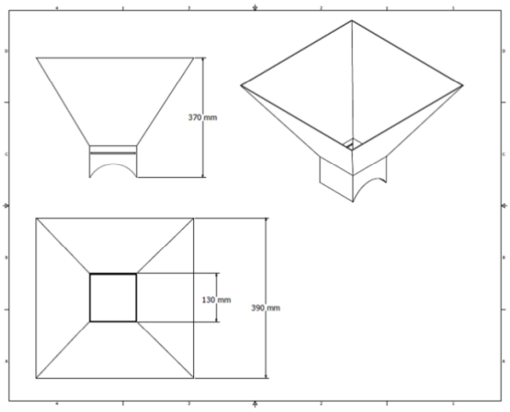

Figure 4: Hopper

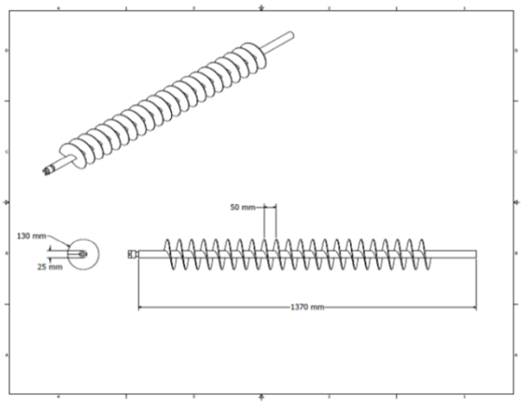

Figure 5: Auger/ Flight screw

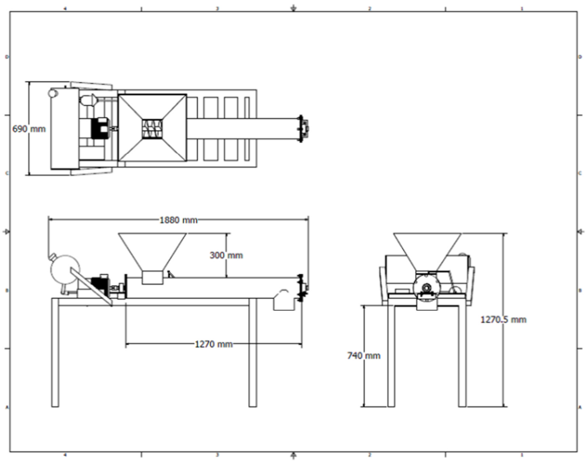

Figure 6: Isometric drawing

4. RESULT

4.1 Overview of the Fabricated ANFO Mixing Machine

These results are based on the outcome of the design and fabrication of the ANFO mixing machine and its performance evaluation when used to mix 94% of ammonium nitrate and 6% of fuel oil (Diesel).


Plate 1: ANFO Mixing Machine

Plate above shows the photo of the fabricated ANFO mixing machine. Plates of its components parts and assembly drawings of the ANFO mixing machine are shown below.

4.2 Working Principle of ANFO Mixing Machine

The principle of operation of the ANFO mixing machine is in the mixing by proportion of granular ammonium nitrate pills passing through the hopper to the mixing conduit i.e. the pipe housing the auger. Mixing occurs under the operation of the reduction gear electric motor which rotates the shaft of the auger, simultaneously the fuel pump also pump the required amount of diesel needed. As the auger rotates, the diesel is sprinkled by jet action into the mixing conduit, in turn, mixing both the ammonium nitrate and diesel, and also transporting it to the exit point. Mixing continues to the end of the pipe where it is discharged as ANFO.

Tests were carried out using fertilizer and diesel to determine the mixing ratio of the two materials and the rate at which the machine will mix the two substances.

Table1: Values of initial weight to final weight with respect to conveyance time

s/n	**Initial(dry) Weight of fertilizer (kg)**	**Final(mixed/wet) weight of fertilizer (kg)**	**Weight Of Liquid (Final-inital)kg**	**Total Time of conveyance(min)**
1	4	4.6	0.6	8.05
2	4	4.9	0.9	8
3	4	4.7	0.7	8.14
4	4	4.8	0.8	8.05
5	4	4.87	0.87	8.15

a. Weight of water = final weight of fertilizer – initial weight of fertilizer (kg)
   I. 4.6 - 4 = 0.6
   II. 4.9 – 4 = 0.9
   III. 4.7 – 4 = 0.7
   IV. 4.8 – 4 = 0.8
   V. 4. 87 – 4 = 0.87

Time of conveying first output = 30s
Distance of conveying = 0.97m
Speed of conveyance

$$= \frac{distance\ of\ conveying(m)}{time\ taken\ for\ conveying\ output}$$

$$= \frac{0.97s}{30} = 0.0323\text{m/s} = 3.23\text{cm/s}$$

Table 2: Values of wet material at different interval

s/n	Time (min)	Weight of wet Material at interval (kg)
1	2.03	1.24
2	4.06	1.99
3	6.09	1.21
4	8.12	1.24

Table 3: Weight of liquid and equivalent volume of liquid

s/n	Weight of diesel (Final-inital)kg	Volume of diesel (Litres)
1	0.6	0.6
2	0.9	0.9
3	0.7	0.7
4	0.8	0.8
5	0.87	0.87

Table 4: Initial weight to volume of liquid

s/n	Initial(dry) weight fertilizer(kg)	Volume of diesel (Litres)
1	4	0.6
2	4	0.9
3	4	0.7
4	4	0.8
5	4	0.87

Table 5: Weight of dry material at intervals of 30 seconds

s/n	Time(seconds)	Weight of dry material at interval of 30s
1	30	0.3
2	30	0.4
3	30	0.35
4	30	0.35
5	30	0.4
6	30	0.3
7	30	0.3
8	30	0.3
9	30	0.3
10	30	0.3
11	30	0.28
12	30	0.1

Table 6: Cumulative weight of liquid and dry material at intervals of 30 seconds

s/n	Time(secs)	Weight of dry material at interval of 30s (kg)	weight of fertilizer (kg)	cummulative weight of liquid	cummulative weight of ferilizer
1	30	0.3	1.5016	0.6	1.5016
2	30	0.4	2.0021	1.5	3.5037
3	30	0.35	1.752	2.2	5.2557
4	30	0.35	1.752	3	7.0077
5	30	0.4	2.0021	3.87	9.0098

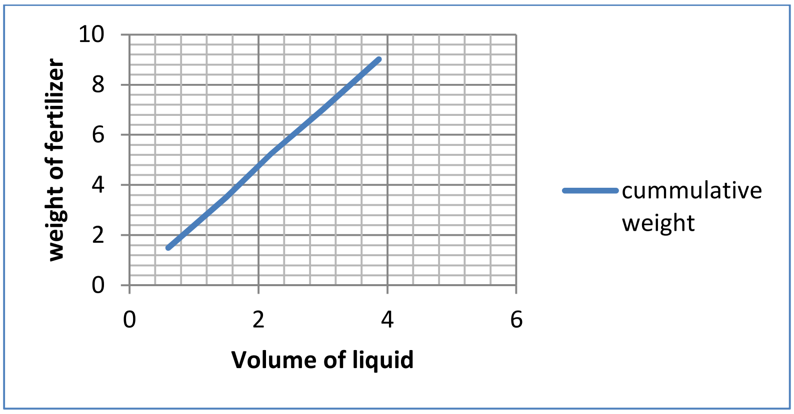

Figure 7: Graph of weight of fertilizer against volume of liquid

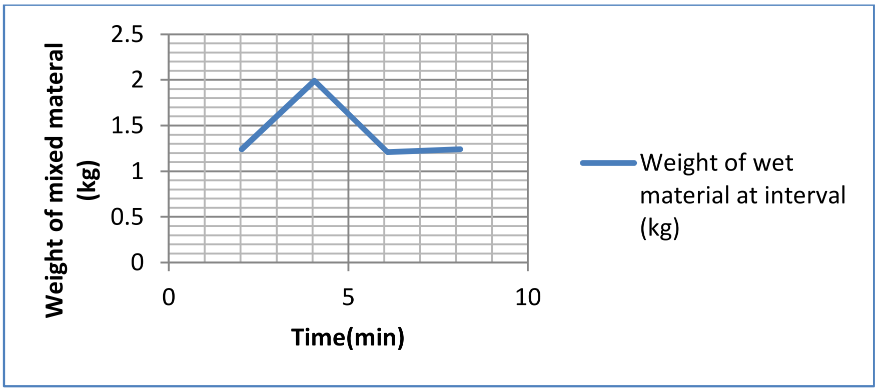

Figure 8 Graph of mixed material against time

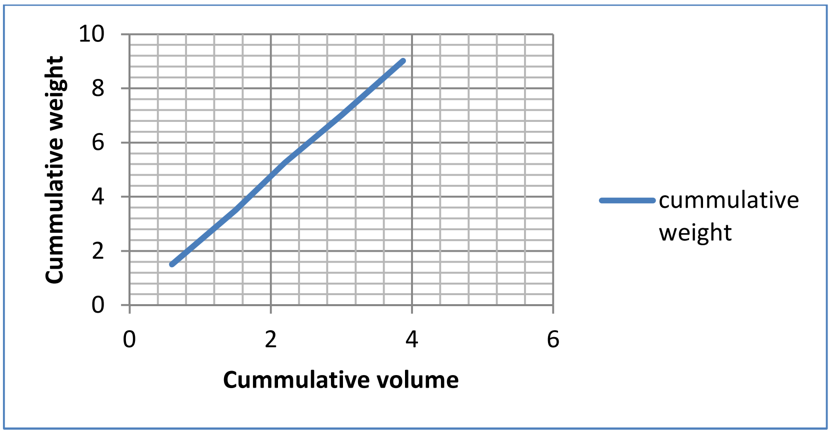

Figure 9. Graph of cumulative weight against cumulative volume

Table7: % of fertilizer against % of liquid with respect to total time of conveyance

s/n	Initial(dry)weight of fertilizer (kg)	Final(mixed/wet)weight (kg)	Weight of liquid (litres)	Total Time of conveyance(min)	% of fertilizer in mixture	% of liquid in mixture
1	4	4.6	0.6	8.05	86.95	13.04
2	4	4.9	0.9	8	81.63	18.37
3	4	4.7	0.7	8.14	85.11	14.89
4	4	4.8	0.8	8.05	83.33	16.67
5	4	4.87	0.87	8.15	82.14	17.86

Calculation of percentage of each content

For percentage Weight of fertilizer = $\frac{initial\ weight}{final\ weight} \times 100\%$

At 1. = $\frac{4}{4.6} \times 100\%$ At 2. = $\frac{4}{4.9} \times 100\%$

At 3. = $\frac{4}{4.7} \times 100\%$ At 4. = $\frac{4}{4.8} \times 100\%$

At 5. = $\frac{4}{4.87} \times 100\%$

For percentage Weight of liquid = $\frac{initial\ weight}{final\ weight} \times 100\%$

At 1. = $\frac{0.6}{4.6} \times 100\%$ At 2. = $\frac{0.9}{4.9} \times 100\%$

At 3. = $\frac{0.7}{4.7} \times 100\%$ At 4. = $\frac{0.8}{4.8} \times 100\%$

At 5. = $\frac{0.87}{4.87} \times 100\%$

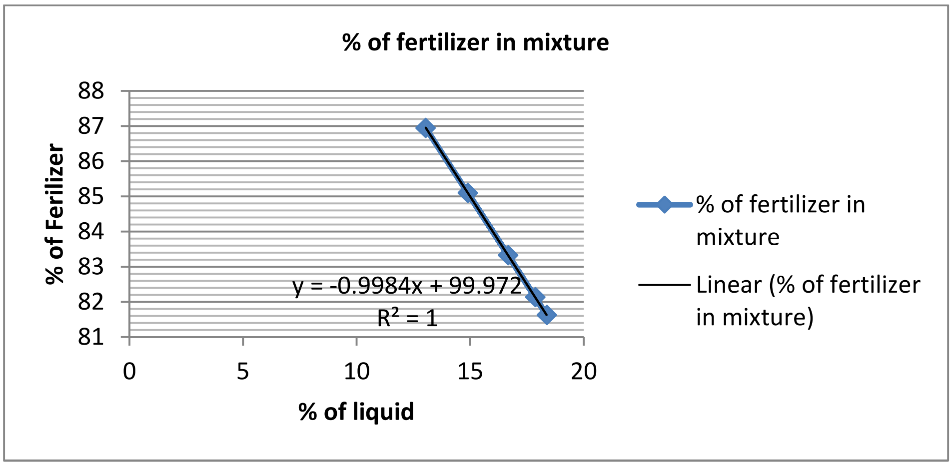

Figure 10: Graph of % of fertilizer against % of liquid

5. PERFORMANCE EVALUATION OF THE FABRICATED ANFO MIXER

From the test carried out on the ANFO mixing machine, the design time of conveyance with the actual time of the conveyance of the machine is different at about 7 minutes. During the experiment it was observed that the material used stuck to the auger/flight screw which increased time of conveyance of the final mixture.
From Fig. 8 the graph shows that proper mixing of the mixture is at 4 minutes, at a time less than 4 minutes or greater, the mixing would not be homogeneous. Fig. 10 also shows that the machine mix the two materials proportionally at an average of 83.8% of fertilizer to 16.12% of liquid.

The mining industry especially the solid mineral sector is presently in its developmental stage and currently experiencing a revolution with the major investors being small scale and artisanal miners which requires mechanization for safe, fast and profitable production. Drilling and blasting which is an aspect of mining requires mechanical aids especially in preparation for blasting (explosive preparation) which could be enormous if the blasting is a long wall or of many holes to be blasted.
ANFO mixing machine has been a great success in preparation of homogenized ANFO for effective rock blasting, increased productivity and cost reduction, easy workability of loading, mucking and transport machinery. The ANFO mixing machine is a replacement for the manual mixing of fuel oil (Diesel) and ammonium nitrates in bays or on concrete floors which was the common method of mixing in Nigeria but could easily contaminate the ammonium nitrate which reduces the power and effect of the explosive due to possible exposure to water, and waste of fuel oil as it is poured manually on the ammonium nitrate. But the ANFO mixing machine achieves proper mixing procedures, safer even to operators, increases production and reduces number of labourers in mixing. The fabricated ANFO mixing machine has shown effectiveness in mixing proportion of Ammonium nitrate to fuel oil (Diesel) in the ratio 94% to 6% respectively than the conventional mixing method which could increase the fuel oil percentage to above 6% or decrease below 6%, which eventually affect the blasting efficiency and breakage.
Also, its cost of fabrication which is ₦85,130 relatively low as compared to foreign made ones which is sold at a

factory and average price of ₦240,000 Despite having about the same mixing accuracy in terms of mixing ratio. The project can serve both small scale miners, artisanal miners and large scale miners. It has also revealed the possibility of developing a locally made machine which can perform to the same standard as foreign ones thereby minimizing cost and over dependence on foreign technology and production. This project could be a great asset to the mining industry if adopted and will help to reduce stress of ANFO production, proper homogenization, safety and increased productivity.

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