World Journal of Engineering Research and Technology
WJERT
www.wjert.org
SJIF Impact Factor: 5.218

DESIGN OF A PNEUMATICALLY OPERATED MAIZE GRINDER

Fatoki, Francis Tekenate*, Isaac, Okwu Elemchuku and Leol, Anthony Kpegele

Mechanical Engineering Department/Rivers State University, Port Harcourt, Nigeria.

Article Received on 01/01/2019 **Article Revised on 22/01/2019** **Article Accepted on 12/02/2019**

***Corresponding Author**
Fatoki, Francis Tekenate
Mechanical Engineering Department/Rivers State University, Port Harcourt, Nigeria.

ABSTRACT

This research is centred on the design of a pneumatically operated maize processor. It serves as a shift from over reliance on the Nigerian National power grid and fossil fuel generators which have been the major ways for processing agricultural products in Nigeria. This study also analyses pneumatic machine operations and how it can be fused into agricultural use. A set of rotor blades in a cylindrical housing is connected to a shaft at an angle that if pressurised air (13bar, 33.86CFM) impinges on the blade tips. This causes the blades to rotate. This subsequent rotation is the production of mechanical energy generated from the action of the compressed air, which is then used to run a belt and pulley system connected to the grinding bits of the maize processor assembly for work to be done. The sum cost of operation is considerable low given that air is the source of fuel. The Volumetric Efficiency of this pneumatically operated maize grinder obtained is 90.76%.

KEYWORDS: Pneumatic, Compressor, Compression Ratio, Maize Grinder, Cubic feet per meter (CFM).

I. INTRODUCTION

A pneumatic system is a system that uses compressed air to transmit and control energy. Pneumatic systems are used in controlling train doors, automatic production lines, mechanical clamps, manufacturing etc. Compressed air is one of the oldest forms of energy known to man and applied to enhance his work capability. The deliberate utilisation of air as a medium can be traced back thousands of years. The first man whom we know with certainty to have engaged himself with pneumatics that is, the use of compressed air as a medium was the Greek, Ktesibios, (Govt. of Western Australia, 2016). More than 2000 years ago, he built a compressed-air-impulse catapult. One of the first writings concerning the application of compressed air as energy dates back to the first century AD and describes devices which were driven by compressed air, (Govt. of Western Australia, 2016). But it was not until the last century that the behaviour and fundamental characteristics of compressed air were researched systematically. Real, practical application of pneumatics in industrial production dates back only to about 1950. There were, of course, some other earlier applications in areas such as the mining and construction industries and on the railways (compressed air brakes), (Govt. of Western Australia, 2016).

The true and worldwide introduction of pneumatics in industry, however, began only when the need for automation and rationalisation of operational sequences continued to increase. In spite of initial rejection, which in the main was due to ignorance and lack of education, the fields of application continued to expand. Today, it is not possible to imagine modern factories being without compressed air. Compressed air equipment is an everyday feature in almost every factory, because it allows for the operation of many labour-saving devices and machines.

In order to understand the importance of Pneumatics and its applications, some cases of where it has been effectively applied will be review.

The importance of this research is to awaken the public and government (especially in Nigeria) to the energy source around us that can be harnessed in agricultural processing. It can also serve as reference for future research and improvement.

Pneumatic Vehicle Research and Design

According to Mihai (2017), a research and design of a pneumatic driven vehicle was carried out in which he (Mihai Simon) constructed and tested a pneumatic driven vehicle. According to him, the aim of the pneumatic vehicle was to find a more efficient way of driving vehicles with renewable energy to reduce air pollution and energy cost in urban areas. He conducted a test study on an actual programmable logic controller one person pneumatic driven vehicle. In his prototype pneumatic driven vehicle he converted the energy of compressed air into mechanical work.

The frame structure of the pneumatic vehicle consisted of aluminium aviation grades tubes, profiled parts and sheets. The segments were bended according to project and WIG welded.

The main structure was built around the pneumatic engine that acts also the structural part. The body of the pneumatic cylinder was housed entirely in the frame and it was used also as reinforcement for the engine box. Due to the restrictive safety, the frame covered entirely the air bottle, pneumatic engine and puffer. The pneumatic engine parts were made up of the following

- Gas reduction, security and emergency stop module
- 5/2 directional valve, electrically operated
- 3/2 two way directional valve, electrically operated
- Quick exhaust valve
- Fine setting valve
- Puffer manometer
- 2/2 way stop valve (manual)
- Silencer
- Double acting cylinder engine

The obtained experimental prototype vehicle as shown in Plate 2.1 was constructed, tested, competition piloted and optimised for best results. The results were obtained by heating liquid nitrogen in an atmospheric heat exchanger, extracting heat from the ambient air and using the resulting pressurised gas to operate the piston engine. These allowed stalling of large quantities of liquid compressed gas in bottles acting as a fuel tank, (Mihai, 2017)

The overall obtained performance of the pneumatic vehicle includes

- Top speed of 60km/h
- 43km/h optimal speed
- Minimum 3km/recharge
- Top distance at 6 bar: 6150m/10 litre of 180 bar nitrogen gas

Figure 1: A pneumatic one person driven vehicle (Mihai S., 2017).

Sukup Cyclone Pneumatic System

Sukup claims that air system gives you flexibility that you can't get with traditional legs and conveyors and thus it easily directs grain to multiple bins from one location, even around corners and into areas that are difficult to reach. An air system also makes expanding your system simple to include more bins, by adding more tubing, (Sukup, 2017). The Sukup Cyclone Pneumatic System is made up of heavy-duty, industrial-grade components and easy-to-use controls, (Sukup, 2017). A pneumatic system is a convenient, efficient way to move grain; however, attention must be given to the operation of the system to maintain grain quality. This is true with any pneumatic grain moving system, (Sukup, 2017). The key to minimizing grain damage is controlling the velocity of the grain; if grain is moved too fast, it will be damaged. Sukup claims that the grain speed is regulated by air pressure. The higher the pressure, the slower the grain moves, and the less damage that will occur. A rule of thumb is to have at least 20.68KPa (3psi) of line pressure and to frequently check the quality of grain that is being discharged into storage. The tubing must properly installed and aligned and that the airlock is turning in the correct direction to utilize shear protection (counter clockwise when looking at the non-drive end of the airlock), (Sukup cyclone installation and operation manual). Sukup uses Positive Displacement Pumps (a type of compressor) and electric motors with shielded belt drive provide the air pressure for Sukup Cyclone Systems. Blower components are mounted on a heavy-duty galvanized skid. An industrial air filter on the blower cleans the air entering the system. A filter restriction gauge lets you know when the filter needs to be cleaned, (www.sukup.com).

II METHODS

Model for Analysis

This research work is based on two models and they are:

1. Pneumatic System
2. Fuel Powered Grain Processor

Pneumatic System: A Pneumatic System is a system based on pneumatics (Air), which is a branch of mechanics that deals with the mechanical properties of gases. It works with study of pressurized air that produces mechanical motion and the application of such air to produce motion.

Fuel Powered Grain Processor: A Fuel Powered Grain Processor is a local machine used commonly in Nigeria to grind grain to flour of different fineness.

Pneumatically Operated Maize Grinder Design Considerations

There is a wide choice of different types of compressor designs available today. The type of compressor chosen has direct implications on the lifetime energy costs. When designing a compressed air system, the parameters that require considerations when designing this system includes

- Type of compressor
- Size of compressor
- Required pressure
- Variable or steady load

Type of Compressor

System selection is a decision controlled by the type of work expected. The variables that need evaluation in order to determine suitability are:

- What are the hours of operation per month or year?
- Is the compressed air demand steady during operations, or does it vary greatly?
- What are the pressure requirements of the compressed air system?

Constant speed air compressors are most efficient when operated at full load. It is important to choose a compressor that operates as closely as possible to full load. For the purpose of this project design a Rotary Screw Compressor is used. Rotary screw air compressors are best suited for steady loads with long hours of operation. Under 24 hour-a-day, 7 day-a-week service, a rotary screw will last longer than a reciprocating compressor. Under steady load conditions, they can be price competitive since they perform best at full load, in contrast to the reciprocating compressor, which should not be loaded more than 75% over long periods of time. Rotary screw compressors are the most widely applied industrial compressors, the popularity of the rotary is due to the relatively simple design, ease of installation, low frequency maintenance requirement, ease of maintenance, long operating life, and affordable cost, (Bhatia, 2010).

Sizing of a Compressor

Two factors affect the determination of the total compressor capacity.

- The required compressor capacity (flow) in SCFM (or Nm3/hr);
- The maximum air pressure (psig or bar gauge) required.

Properly specifying the capacity required is often the most difficult aspect of sizing a compressor. To size a compressor the capacity must be stated as the volume it will occupy at the compressor's suction. This volume is normally referred to as inlet cubic feet per minute (ICFM). The metric equivalent is inlet cubic meters per hour (Im3/hr), (Blackmer, 2000).

With Port-Harcourt as case study, the suction pressure and the discharge pressure are affected by the city's elevation above sea level (52ft) which is equivalent to a local barometric pressure of 14.69psi, (Blackmer, 2000). Hence the suction and discharge pressure are as follows:

Ps (Suction Pressure) = 145 + 14.69 = 159.69psi

Pd (Discharge Pressure) = 175 + 14.69 = 189.69psi

$$\text{ICFM} = \text{SCFM}\ \frac{Pstd}{Ps} \times \frac{Tstd}{Ts} \tag{1}$$

$$\text{SCFM} = \text{CFM}\ \frac{Pactual}{14.7\,psi} \times \frac{528\,R}{Tactual} \tag{2}$$

SCFM = Standard Cubic Feet per Minute. The metric equivalent is Nm^3/hr - Normal Meters Cubed per Hour. The agreed upon standard references for SCFM are 14.7 psi and 520°R (Nm3/hr is referenced to 1.014 Bar and 273 °K).

$$\therefore \text{ SCFM} = \text{CFM } \frac{Pactual}{14.7\,psi} \times \frac{528\,R}{Tactual}$$

Where: Pstd = Standard barometric pressure 14.7 psia (1.014 Bar-a)

Tstd = Standard temperature 520 °R (273 °K)

Ps = Compressor suction pressure psia (psia) = 159.69psi

Ts = Compressor suction temperature °R (°K) = Tactual = 540.27 ^{0}R (27^{0}c)

CFM = 30

$\therefore$ SCFM =318.39 Nm^3/hr

Where: SCFM = 318.39

$$\text{ICFM} = \text{SCFM } \frac{Pstd}{Ps} \times \frac{Tstd}{Ts}$$

$\therefore$ ICFM = 30.34CFM

The calculated ICFM of value 30.34CFM is approximately equal to the CFM of 30 used in this work. This proves that the parameters used are correct and the machine can run.

Selecting the Proper Compressor

Knowledge of the gas, required capacity, suction pressure, suction temperature, and discharge pressure will enable the proper compressor to be selected. The basics steps involved are:

- Calculate the compression ratio.
- Choose between a single-stage or two-stage compressor.
- Calculate the discharge temperature
- Determine the minimum RPM required of the selected compressor.
- Determine the actual RPM
- Calculate the actual piston displacement.
- Calculate the power required.

Calculate Compression Ratio

$$\text{Compression Ratio (R)} = \frac{Td}{Ts} \quad (3)$$

Where: Td = Discharge Temperature = 189.7

Ts = Suction Temperature = 159.7

$$\therefore \qquad R = \frac{189.7}{159.7} = 1.188$$

The choice of the proper number of compression stages is largely based on the compression ratio. Therefore from the calculated Compression Ratio of 1.188, a single stage compressor is used.

Discharge temperatures and the duty cycle could also be considered when determining the number of stages to use.

Table 1: Guidelines for Choosing the Proper Number of Stages.

R Value	Compressor Stage
1 – 3	Single-stage
3 – 5	Normally single-stage, occasionally two-stage
5 - 7	Normally two-stage, occasionally single-stage
7 – 10	Two-stage
10 – 15	Usually two-stage, occasionally three-stage
15+	Three Stage

(Blackmer, 2000)

Discharge Temperature (Td)

$$Td = TsR^{\frac{(n-1)}{n}} \tag{4}$$

where: Ts = Suction Temperature = 540.27^0R

R = Compression Ratio = 1.188

n= Specific Heat Ratio of Air = 1.4

$\therefore$ Td = 567.499^0R = 42.127^0C

Continuous duty applications should be limited to about 300°F (149°C) maximum. The published maximum allowable temperature for Blackmer compressors is 350°F (177°C). Applications with temperatures higher than 350°F (177°C) should be closely reviewed. Unless extremely short duty cycles are involved, additional stages of compression or a water cooled unit should be considered, (Blackmer, 2000).

Determine the Volumetric Efficiency

Volumetric efficiency is the ratio of the amount of gas compressed versus the physical size of the compressor's cylinder volume. For estimating purposes, the following formula can be used.

Single-stage compressors VE% = 93 - R - 8 $(R^{\frac{1}{n}} - 1)$ (5)

Where: R = Compression Ratio (Pd/Ps) = 1.188

n = Air Specific Heat Ratio = 1.4

$\therefore$ VE % = 93 – 1.188 – 8 $(1.188^{\frac{1}{1.4}} - 1)$ = 90.764%

Determine the Required Piston Displacement (PDR)

Piston displacement (PD) is a measure of the compressor's size and is dependent on the size, number and type of cylinders, and compressor RPM. Required piston displacement (PDR) is a calculated number that will determine how large a compressor will be required to handle the specified capacity.

$$PD_R = \frac{ICFM}{VE} \quad (6)$$

Where; PD_R = Required piston displacement (CFM or m^3/hr)

ICFM = Capacity (inlet cubic feet per minute) = 30.34

VE% = Volumetric Efficiency = 90.764%

$\therefore$ PD_R = 33.427 CFM Required

Choosing an Appropriate Compressor Size

Once the choice of single-stage or two-stage and the calculation of required piston displacement have been made, the compressor can be sized.

Table 2: Sizing of Types of Compressor Stages.

	Size	Piston Displacement
Single Stage	161, 162, 163	7.16 - 16.9 CFM (12.2 - 28.7 m^3/hr)
	342, 343	6.89 - 16.25 CFM (11.7 - 27.6 m^3/hr)
	361, 362, 363	15.3 - 36.0 CFM (26.0 - 61.2 m^3/hr)
	642, 643	13.4 - 31.7 CFM (22.8 - 53.8 m^3/hr)
	601, 602, 603	27.2 - 64.2 CFM (46.3 - 109.0 m^3/hr)
	942	52.5 - 125.2 CFM (89 - 212 m^3/hr)
Double Stage	172, 173	3.6 - 8.4 CFM (6.1 - 14.3 m^3/hr)
	372, 373	10.2 - 26.1 CFM (17.3 - 40.8 m^3/hr)
	612, 613	22.9 - 53.7 CFM (38.9 - 91.2 m^3/hr)

(Blackmer, 2000)

From Table 2 It is obvious that a single stage compressor with a piston displacement of 33.427cfm will work with a 362 sized compressor.

Determine the Minimum RPM Required. (RPMmin)

With the compressor model and Required Piston Displacement known, the minimum RPM required can be calculated.

$$RPM_{min} = 100\frac{PD_R}{PD100} \quad (7)$$

PD_R = Required Piston Displacement

PD_{100} = Piston Displacement per 100 RPM

$\therefore RPM_{min} = 766.67RPM$

Table 3: Compressor Size and Corresponding Piston Displacement.

	Compressor Size	PD per 100 RPM (PD100)	
Single Stage	161, 162, 163	2.05 ft^3	3.48 m^3
	342, 343	1.97 ft^3	3.34 m^3
	361, 362, 363	4.36 ft^3	7.41 m^3
	642, 643	3.84 ft^3	6.52 m^3
	601, 602, 603	7.78 ft^3	13.2 m^3
	942	14.99 ft^3	25.5 m^3
Double Stage	172, 173	1.02 ft^3	1.73 m^3
	372, 373	2.92 ft^3	4.96 m^3
	612, 613	6.54 ft^3	11.1 m^3

(Blackmer, 2000)

A size 362 compressor was compatible with a required Piston Displacement of 33.42 CFM.

Select an Actual RPM (RPM).

To select actual RPM, an RPM slightly above the minimum RPM required just calculated should be used. Therefore we are using an actual RPM of 776.67RPM will be used.

Calculate the Compressor's Actual Piston Displacement (PD)

After determining the compressor's actual speed, the actual piston displacement can be calculated.

$$PD = RPM\frac{PD_{100}}{100} \quad (8)$$

$\therefore$ PD = 33.863 CFM

Calculate the Power Required BHP (KW)

Single-Stage Models Power (BHP) = $0.00528\left(\frac{n}{n-1}\right)(Ps)(PD)\left(R^{\frac{n-1}{n}}-1\right)$ (9)

Where: n = Specific heat ratio of the gas = 1.4

Ps = Suction Pressure (psi) = 159.7

PD = Actual Piston Displacement (CFM) = 33.863

R = Compression Ratio (Pd / Ps) = 1.188

$\therefore$ Power = 5.0369BHP = 3.758KW

Required Pressure

The cut in air pressure (the pressure of the air when it has not been compressed by the compressor) is usually 2bar lesser than cut out air pressure (the pressure of the air after it has been compressed by the compressor). This means the compressed air the compressor gives out is usually 2bar higher than the initial air pressure sucked in by the compressor. For this reason, a 10bar (145Psi) compressor is connected to a receiver tank of 12bar (174Psi) as a safety measure to prevent tank failure (explosion). This is according to the standard of compressor-receiver tank relationship, which states that the maximum working pressure of the compressor should be 2bar less than the minimum working pressure of the receiver tank, (www.atlascopco.com).

Design, Components and Functions of a Pneumatically Operated Maize Grinder

These are;

- Compressor
- Receiver tank
- Pneumatic Valves
- Filters
- Belt drive system
- Rotor Blade Assembly and Housing
- Skid
- Hopper
- Grinding bits
- Conveyor and outlet

Table 4: Design Specification of the Compressor.

Parameter	Specification
Compressor Type	Rotary Screw
Air Flow Rate	33.863CFM
Pressure	11bar
Type	One-Stage
Lubrication	Oil-less
Oil-less type	ISO Class 0

Receiver Tank (Reservoir)

Generally the size of receiver depends on,

- Delivery volume of compressor (CFM)
- Air volume required by the work (Maize Grinder)
- Pipeline network (the length and inner diameter of the tubing)

Pneumatic Valves

The pneumatic valve is one of the most important components in the circuit or system. Its function is to regulate the pressure of the compressed air to a desired pressure level. This is useful in making sure the pressure of the compressed air entering the machine is as desired and is enough to the work required of it. For this research work, a relief pressure regulatory valve will be used.

Relief Pressure Regulator valve

Relief valve is the simplest type of pressure regulating device. It is used as a backup device if the main pressure control fails. It consists of ball type valve held on to the valve seat by a spring in tension. The spring tension can be adjusted by using the adjusting cap. When the air pressure exceeds the spring tension pressure the ball is displaced from its seat, thus releasing the air and reducing the pressure. A relief is specified by its span of pressure between the cracking and full flow, pressure range and flow rate. Once the valve opens (cracking pressure), flow rate depends on the excess pressure. Once the pressure falls below the cracking pressure, the valve seals itself.

Rotor Blade Assembly

The rotor blade assembly is the portion of the pneumatic turbine where expansion takes place and hence the expanding air is being used to turn the rotor blades which in-turn does the transfer of the kinetic energy in the compressed air to the mechanical energy of a rotating shaft. It works just like the impeller in the most centrifugal machines but the inverse of it.

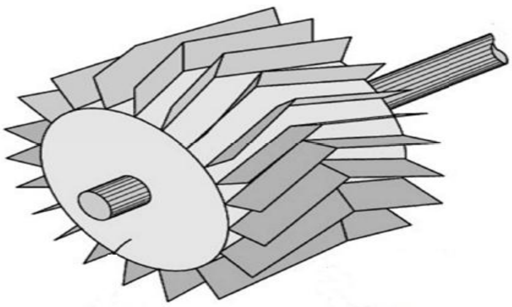

Figure 2: The Rotor Blades Mounted on the Transmitting Shaft.

Transmitting Shaft

The transmitting shaft is welded to the rotor blade assembly; it rotates as the compressed air acts on the tip of the rotor blades. It transmits the mechanical energy that the rotor blade has transferred from the compressed air to the outer part of the machine section where it can be used by the grinder.

Belt Drive System

It's a system use to transmit power efficiently linking two or more rotating shaft mechanically. It consists of pulleys (two or more) and a belt.

Filters

Filtration is a key factor in the proper operation and performance of a compressed air system. Removal of liquid and particulate contaminants is the basic requirement of a filtration package; however, the requirement for vapour removal, ultra-fine filtration, and catalyst filtration are encountered in specialized applications. Air filters can be located throughout the system and the number and type of filters will vary according to the quality of air required. The air inlet filter for air compressors is intended to protect the compressor, but often is inadequate to protect downstream equipment and the compressor itself may add contaminants, including wear particles and carbon deposits. These require filtration and is achieved by installing an in-line filter especially given that this machine is applied in food processing.

Inlet Nozzle

The function of this component is to channel the compressed air directly at the tip of the rotor blade for rotary motion.

Skid

The skid is the frame on which the pneumatic components are mounted on (welded or bolted). It is made from steel (3mm thick) and has two tyres for vibration absorption and for mobility.

Turbine Housing

It is the enclosed chamber where the blade assembly is housed. It has holes containing bearing at the side to allow the rotor blade assembly to rotate freely when subjected to pressurised air. It is manufactured and mounted beside the compressor on the receiver tank.

Hopper

This is the fabricated part of the machine via which the maize is fed into the system for grinding. It also entails grinding bits which are powered a belt and pulley system connected to it.

Grinding Bits: These are sharp cutting bits that grind the grains that have been fed into the system for processing (grinding). It's made of hardened steel with sharp zigzag edges that meet.

Outlet: This is the part through which the processed grain comes out as flour.

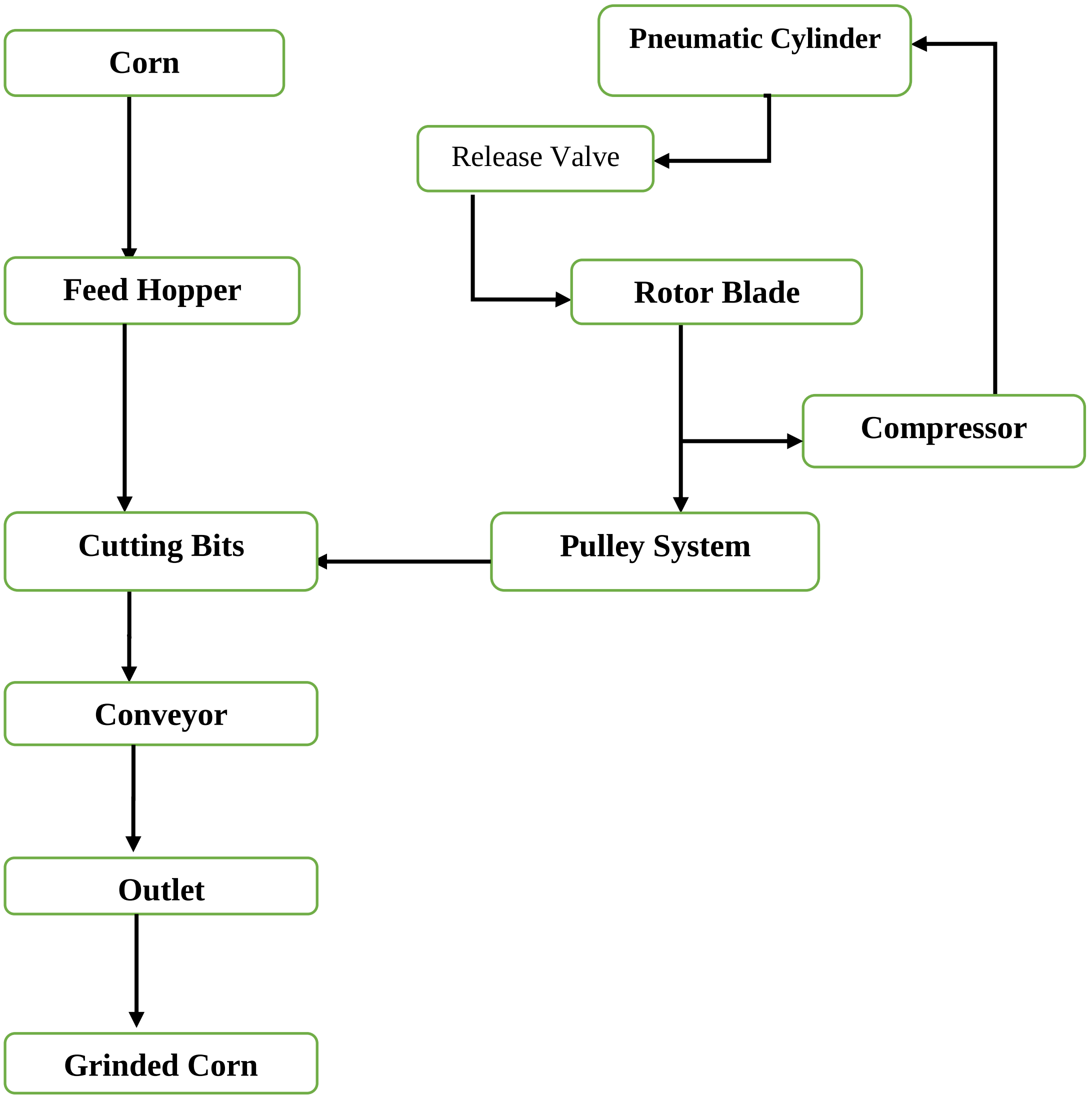

Figure 3: Flow Chart Showing Operation of a Pneumatic Maize Grinder.

III RESULTS

This research project is a modification of the conventional fuel powered maize grinder used in Nigeria with the aim of designing a machine that replaces the fuel engine that powers the maize processor with a pneumatic engine (an engine that relies on air). The result of this modification is a pneumatically powered maize processor as shown in Figure 4 and Figure 5.

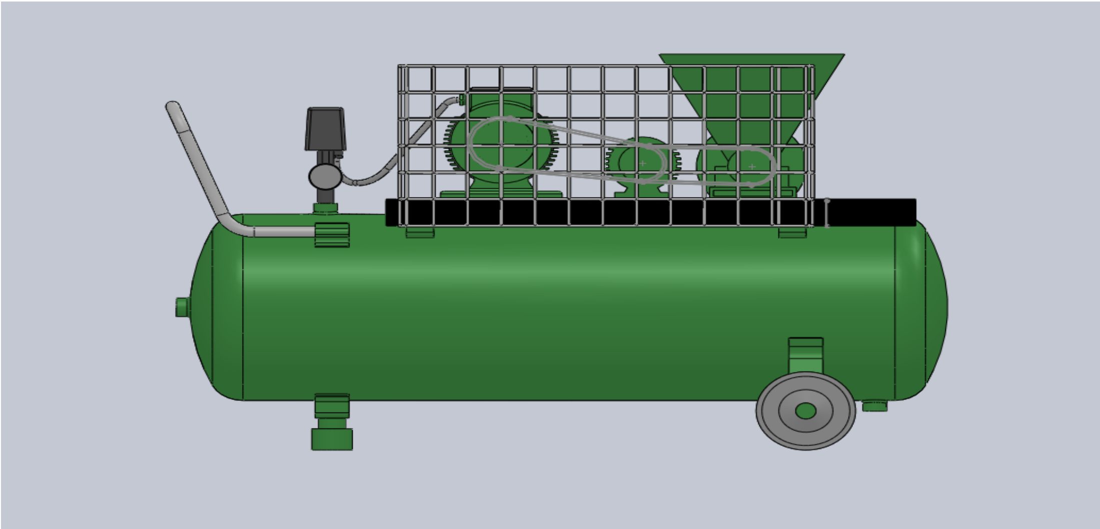

Figure 4: 2D View of the Pneumatically Operated Maize Processor (Model using SolidWorks).

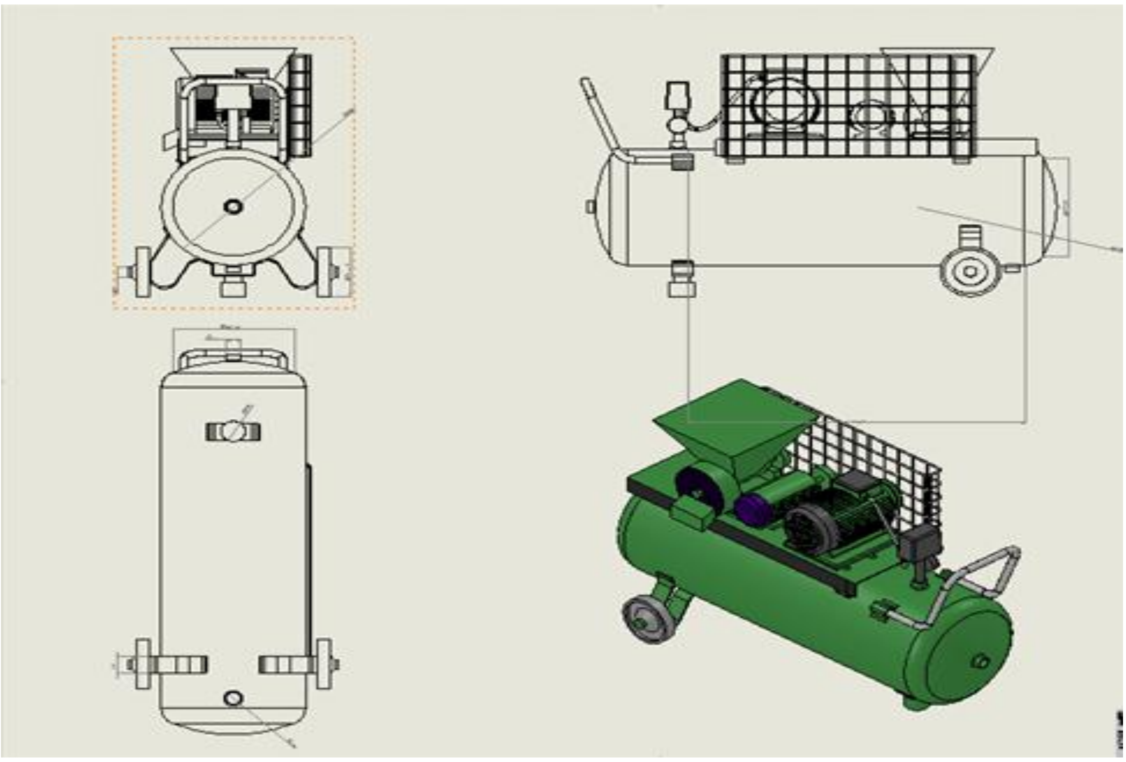

Figure 5: 3D View and Schematics of the Pneumatically Operated Maize Processor (Model using Solid Works).

Table 5: Pneumatic Maize Grinder Data Sheet.

<table>
<tr><th colspan="6">Model No: TT001</th></tr>
<tr><td>Gas</td><td>Type
Air</td><td>n
1.4</td><td>Suct. Temp
27^{0}c</td><td>Dis. Temp
42.13^{0}c</td><td></td></tr>
<tr><td>Compressor</td><td>Type
Rotary Screw</td><td>Stage
Single</td><td>Size
362</td><td>Compression
Rat. 1.188</td><td>RPM
776</td></tr>
<tr><td>Capacity</td><td>Inlet
30.34ICFM</td><td>Std. Con
318.39SCFM</td><td>Disp. CFM
33.43</td><td>Act. CFM
33.86</td><td></td></tr>
<tr><td>Receiver Tank</td><td>Type
Stainless Steel</td><td>No
1</td><td>Dimension
850mm by 300mm</td><td>Colour
Blue</td><td>Litre
19</td></tr>
<tr><td>Volumetric Eff.</td><td>90.76%</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Pressure</td><td>In
159.7psi (11bar)</td><td>Out
189.7Psi (13bar)</td><td></td><td></td><td></td></tr>
<tr><td>Power</td><td>3.758KW</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Belt and Pulley System</td><td>No. of Pulley
3</td><td>No of Belts
2</td><td>D. of Grind Pulley
150mm</td><td>D. of Comp. Pulley
130mm</td><td>D. of Motor Pulley
130mm</td></tr>
<tr><td colspan="2">L. of Belt (Motor to Com)
360mm</td><td colspan="3">L. of Belt (Motor to Grinder)
400mm</td></tr>
<tr><td>Hopper</td><td colspan="2">Material Cast Iron</td><td colspan="3">Thickness 2mm</td></tr>
<tr><td>Grinding Bits</td><td colspan="2">Material Hard Steel</td><td colspan="3"></td></tr>
</table>

Table 5 is the data sheet of the Model showing the parameters, dimensions and components considered to build a Pneumatic Maize Grinder.

Table 6: Showing Calculated Parameters.

Actual Flow Rate (CFM)	RPM	Power (BHP)	Size
33.86	776.67	5.04	362
44.50	581.97	6.74	602
55.96	383.29	9.17	942
68.25	455.28	11.15	942

Table 6 shows that an increase of the flow rate in the system (capacity of compressor) is directly proportional to an increase of the power generated by the system. See Figure 6 for a graphical representation.

Table 6 also shows the relationship between flow rate and RPM. An increase in flow rate resulted in a decrease in the RPM until a sudden increase in the RPM (455.28RPM) due to a CFM of 68.25. See Figure 7 for a visual representation.

Table 6 reveals further the relationship between compressor size and power. This shows that the compressor size is directly proportional to the power generated. See Figure 8 for graphical representation.

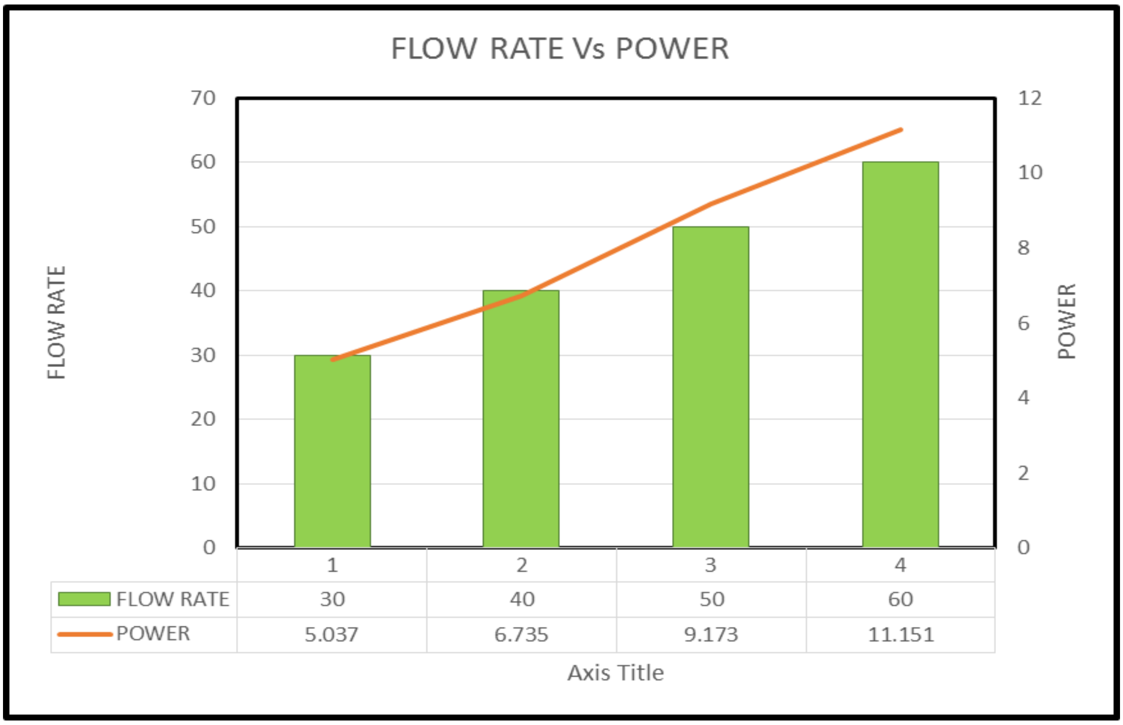

Figure 6: Relationship between Flow rate and Power.

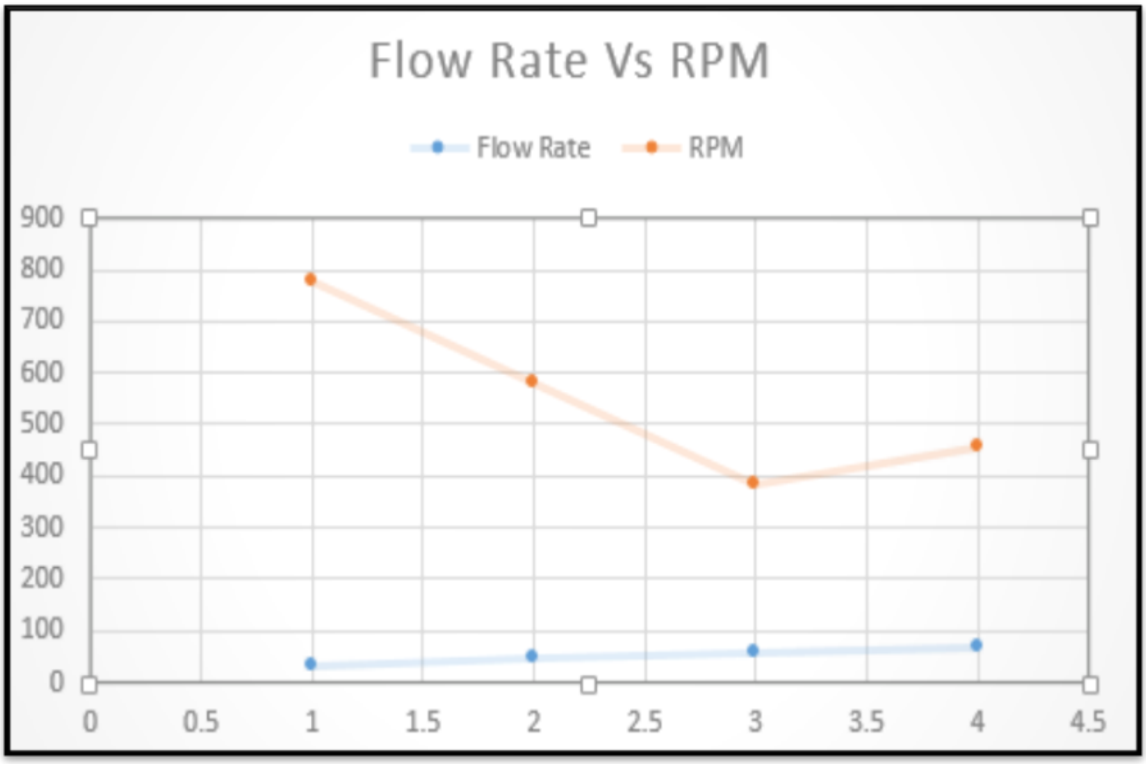

Figure 7: Relationship between Flow rate and RPM.

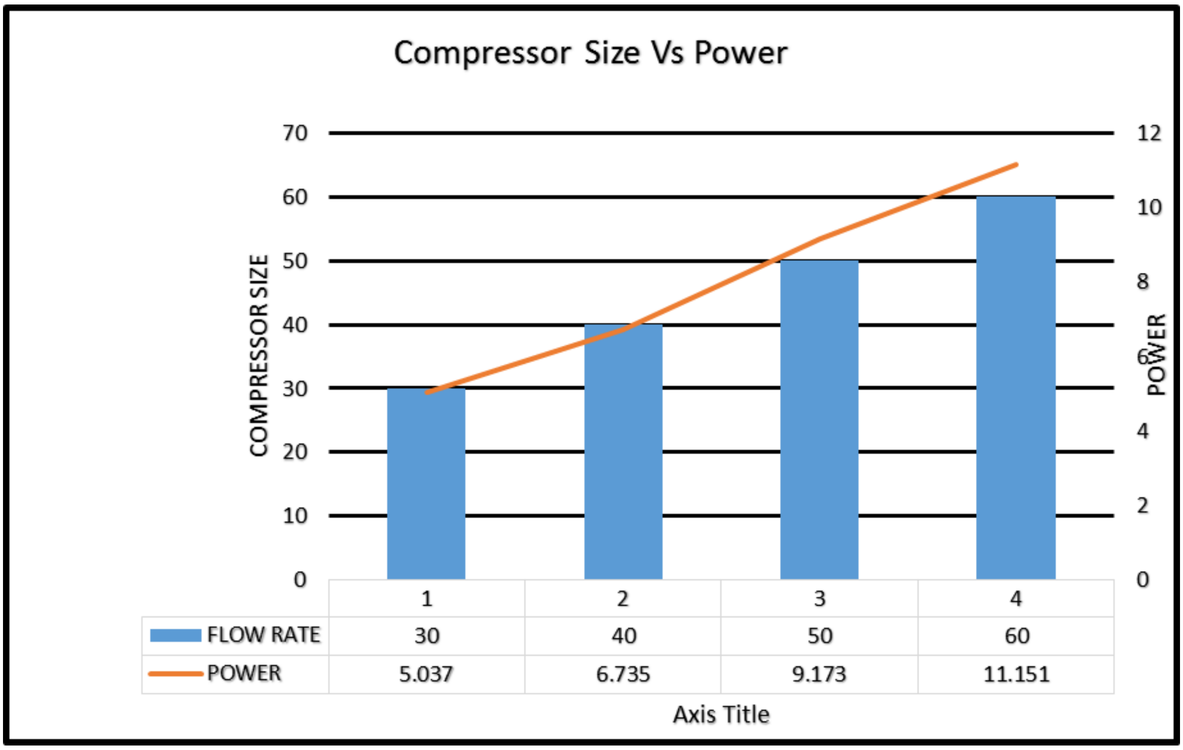

Figure 8: Relationship between Compressor Size and Power.

Table 7: Suction and Discharge Temperature at different Quarters.

Quarter	Suction Temperature (^{0}C)	Discharge Temperature (^{0}C)
1st	25.83	40.9
2nd	27.22	42.36
3rd	25.83	40.9
4th	25.83	40.9

Figure 9 shows the suction temperatures and corresponding discharge temperatures obtained at the four quarters of the year in respect to the climate of Port-Harcourt, Rivers State. The suction temperature is the temperature of air sucked in by the compressor, while the discharge temperature is the air expelled after work done by the system. From Figure 9, it can be seen that the discharge temperatures is generally higher than the suction temperature. According to Blackmer (2000), Continuous duty applications should be limited to about 300°F (149°C) maximum. The published maximum allowable temperature for Blackmer compressors is 350°F (177°C). Applications with temperatures higher than 350°F (177°C) should be closely reviewed. Unless extremely short duty cycles are involved, additional stages of compression or a water cooled unit should be considered. This means this pneumatically operated grinder can work effectively throughout the year without the experiencing overheating.

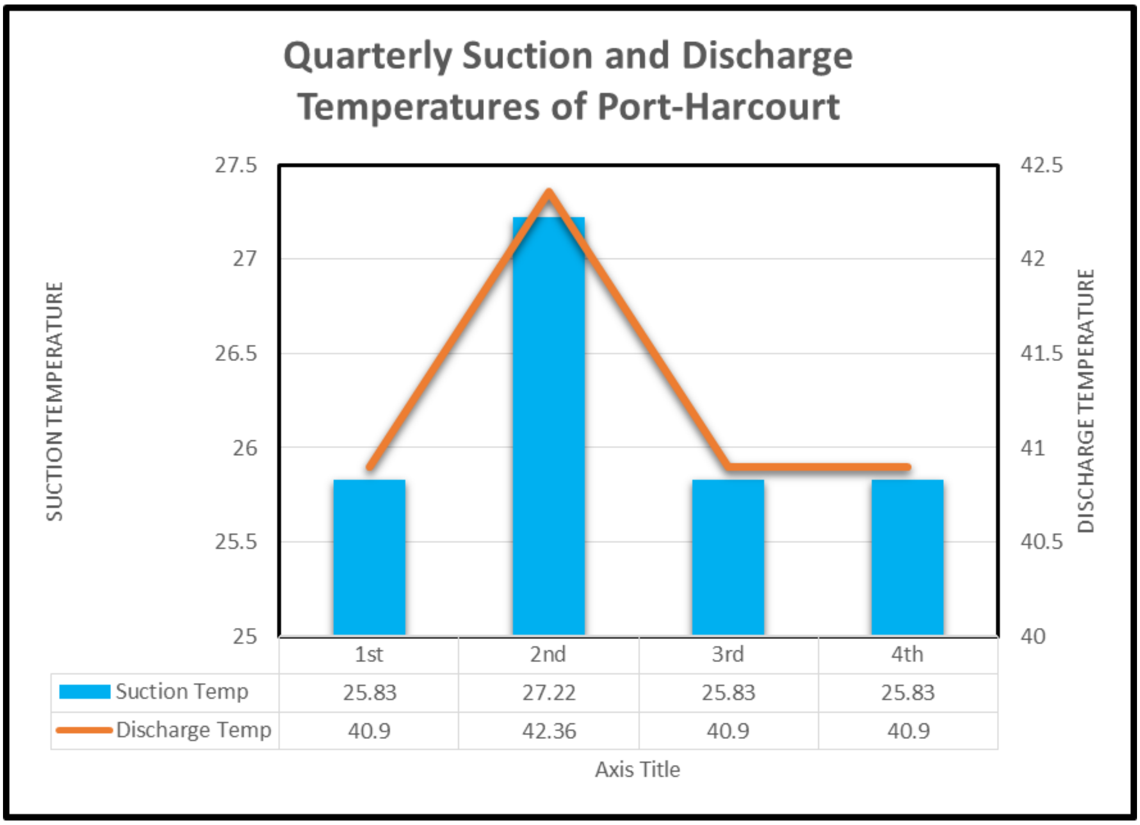

Figure 9: Relationship between the Quarterly Suction Temperatures and Its corresponding Discharge Temperature.

From the results obtained, it has been calculated and proven that an increase in the flow rate (CFM) will result in a decrease in the RPM of the machine. Therefore the ideal CFM rating to run this machine (on the medium scale) is between 30-35CFM since it gives the highest revolution.

Also a compressor capacity used in this work generated considerable power output (3.758KW) to run this system. The sizing and capacity of the compressor also points out the stage of compressor to use. In this work, a compressor of size 362 and capacity 33.86CFM is a single stage compressor.

IV CONCLUSION

After considerations which led to the design of a pneumatically powered maize grinder as to promote the campaign for the reduction of fossil fuel usage (promoting renewable energy), we can finally conclude that compressed air energy is viable and feasible. With the help of various books and consultations from engineers with like minds, I have been able to support the campaign with the success of this research. In addition, given the remoteness of most communities in Nigeria that focuses on agriculture and its processes, certain steps must be taken to bring this research development to the common man. These steps include;

i. Appropriate survey to ascertain the optimum market structure of the country, taking cognizance of the demand and gaps of the already existing processing methods.
ii. Setting up workshops to enlighten the general public on the abundant energy source (air) around us that we can harness, and to possibly train the public on safety measures of handling pneumatic components.

1. The Government support in encouraging indigenous engineers to set up standard pneumatic workshops and sale outlets to handle to foreseeable demand for pneumatic components.
2. The support of Nigerian Society of Engineers (NSE) and Council for the Regulation of Engineering in Nigeria will buttress the importance of the technology even more, given that pneumatics has a wide array of applications even beyond the Agricultural sector.
3. This study points to the different cost structure on the short term and long term viability. The startup cost of a pneumatic processor is more than that of fossil fuel powered processor, but in the long run, the operational cost and maintenance cost of pneumatics is far lower than that of the fossil fuel powered processor.

From these points given, with continuous awareness of the technology been spread, the cost of the pneumatic components will decrease which will equally reduce the start up cost.

MATLAB, Microsoft Excel and Solidworks and Simulink were used throughout this research thesis.

REFERENCES

1. Balsari, P., Manzone, M., Marucco, P. & Tamagnone, M. Evaluation of maize sowing machines performances to establish their potential dissemination of seeds dressing. Aspects of Applied Biology. 99, International Advances in Pesticide Application, 2010; 297–304.
2. Bhatia, A. Compressors and Compressed Air Systems. Course No: M06-018. Continuing Education and Development, Inc. 9 Greyridge Farm Court Stony Point, NY 10980 P: (877) 322-5800, 2010; (877): 322-4774. info@cedengineering.com.
3. Biocca, M., Conte, E., Pulcini, P., Marinelli, E. & Pochi, D. Sowing simulation tests of a pneumatic drill equipped with systems aimed at reducing the emission of abrasion dust

from maize dressed seed. Journal of Environmental Science and Health Part B – Pesticides, Food Contaminants and Agricultural Wastes, 2011; 46: 438–448.

4. Blackmer, Compressor Selection and Sizing. CB-207, 2000.
5. Compressed Air and Gas Institute (CAGI), Air Compressor, Selection and Application, 2016.
6. Foque, D., Devarrewaere, W., Verboven, P. & Nuyttens, D. Characterisation of Different Pneumatic Sowing Machines. Aspect of Applied Biology, 122, 2014. International Advances in Pesticide Application, 2014.
7. Government of Western Australia Maintain Pneumatic System Components Mem18018c Learner's Guide Engineering, Mechanical and Electrical. Email: sectorcapability.ip@dtwd.wa. gov.au, 2016.
8. Hafner-Pneumatik, Krämer-KG & Stammheimerstrabe Chapter 2: The General Design of a Pneumatic System and its Components. 10, D-70806 Kornwestheim, Germany. E-Mail: info@hafner-pneumatik.de, web: www.hafner-pneumatik.com, 2016.
9. Hydrastar Fluid Power Solutions How to Minimise Downtime with Pnuematic Plants and Machineries, 2018.
10. Khurmi, R.S. & Gupta, J.K. A Textbook of Machine Design, 4th Edition, New Delhi, India: S Chand & Company Limited, 2008.
11. Mihai, S. (2017). Pneumatic Vehicle, Research and Design. Procedia Engineering, 2017; 181: 200-205. Doi:10.1016/j.proeng.2017.02.370.
12. Nikolakis, A., Chapple, A., Friessleben, R., Neumann, P., Schad, T., Schmuck, R., Schnier, H. F.,Schnorbach, H. J., Schöning, R. & Maus, C. An effective risk management approach to prevent bee damage due to the emission of abraded seed treatment particles during sowing of seeds treated with bee toxic insecticides. Julius-Kühn-Archiv, 2009; 423: 132–148.
13. NPTEL Introduction to Pneumatics. Lecture 33. www.nptel.ac.in, 2013.
14. NPTEL Pneumatics System. Module 6, Lecture 1. www.nptel.ac.in, 2013.
15. Olimpia, P., Saracin, I., Bozgaa, I. & Tanasie, S.E. Studies regarding pneumatic equipment for sowing small seeds in cups. "ST26733", International Conference "Agriculture for Life, Life for Agriculture" University of Craiova, Faculty of Agriculture, Romania. Agriculture and Agricultural Science Procedia, 2015; 6: 690 – 695.
16. Parker Hannifin Corporation, Pneumatic Division Richland, MI 49083 USA. 8676 E. M89 P. O. Box 901. Bulletin 0600-B50-4 04/2015. Web: Web: www.parker.com/pneumatics, 2015.

17. Parker Hannifin Corporation, Pneumatic Division Pneumatic air Motors. Catalogue PDE2670TCUK, PLV – A & B Air Motors. Parker Hannific Corporation, Pneumatic Division, Europe, 2013.
18. Lynch, P. Pneumatics. Technology Subjects Support Service (T^4), Gateway Education Centre, 2009.
19. Quincy Compressor, 2017.
20. Evolution of Compressed Air. http://www.quincycompressor.com/industries/.
21. Quincy Compressor How to Size and Select an Air Compresor, 2012.
22. Saidur, R., Rahim, N. A. & Hasanuzzaman, M. A review on compressed-air energy use and energy savings. University of Malaysia, Department of Mechanical Engineering, Department of Electrical Engineering, 50603, Kuala Lumpur, Malaysia. Renewable and Sustainable Energy Reviews, 2010; 14: 1135–1153.
23. Sukup Manufacturing co. Cyclone pneumatic grain moving system. Box 677 1555 255th St. Sheffield IA 50475-0677, ph 641.892.4222, fx 641.892.4629. Email: info@sukup.com. Web: www.sukup.com, 2017.
24. Von Reding, W. Maize Processing Technology - Fortification. Buhler Holding AG. Woodcroft, B. (1851). The Pneumatics of Hero of Alexandria, 2016.
25. Yadav, J. P. & Bharat, R. S. Study and Fabrication of Compressed Air Engine S-JPSET: ISSN: 2229-7111, 2011; 2(1).