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DESIGN AND CONSTRUCTION OF A SMALL SOLAR POWERED AIR BLOWER FOR CHARCOAL FIRED FURNACE

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Abstract
In Nigeria almost all the local foundry shops rely on the manually operated blowers for supplying air for the combustion of the charcoals to melt metals. This manually operated blower has showed that much man-hour is required during firing as one labourer is dedicated to driving the rotary blower. This is labourous and reduces the rate of productivity of the enterprise. Therefore, it is necessary to find easier ways of supplying the energy required for the combustion so as to increase productivity. A solar powered blower is designed and constructed in this work. The performances of manually operated and solar powered air blowers are compared. Performance results of the manually operated air blower showed that it takes about 67 minutes and 42 minutes to melt 4kg of aluminum and zinc respectively. On the other hand, for the solar-powered air blower, it takes about 30 minutes and 17 minutes to melt 4kg of aluminum and zinc respectively. This indicates that the solar-powered air blower takes a shorter time to melt metals when compared with the manually operated air blower. In addition, the solar powered air blower eliminates the labourous aspect of supplying energy for melting metals and also reduces the times spent in metal melting process.

Keywords: Solar powered, Air blower, Charcoal and Furnace

1.0 INTRODUCTION

Technological advancement of a nation depends solely on its capability to harness and convert its useful mineral resources (such as metals) into required finished products(Osarenmwinda, 2015).Metals production and processing is the ingredient of industrial development of a nation. There are many techniques used in metal processing and production, these techniques include among others: smelting, casting, forging, extruding, machining, welding, rolling, etc. Metal casting is one of the most common metal processing techniques used in metal processing industry. Small scale and local foundry workshops are found in many places in Nigeria. At the core of the foundry processes is the melting of metals, which often involves the supply of air into the furnace to achieve combustion. According to Okechukwu et al., (2013)familiarization trips to local charcoal foundries in Nigeria showed that much man-hours are wasted during firing as one labourer is dedicated to driving the rotary blower, this reduces the energy required by this employee for casting and invariably lowers the labour productivity of the enterprise. As cited by Adefemi et al.(2017) in the processing of mineral resources such as metals, melting and extraction have become the critical industrial practices which are mostly carried out in a furnace. A furnace is an equipment used to heat or melt metals for heat materials and casting respectively. Furnaces are usually classified according to the purpose for which the material is heated, nature of the transfer of heat to the material, method of firing the furnace and method of handling material through the furnace. The charcoal fired furnace is usually used for Aluminium recycling towards production of cooking utensils in local small scale Aluminium casting foundries (Ighodalo et al., 2011).At the core of the foundry processes is the melting of metals, which often involves the supply of air into the furnace to achieve combustion. Methods of supplying air to metallurgical furnaces include: pneumatic system, bellow system, hand-driven blowers, motor-driven blowers and engine-driven blowers(Okechukwu et al., 2013). An air blower also called a centrifugal fan or squirrel cage fan is used commonly for exhaust or in heating, ventilation, and air conditioning (HVAC) systems. A centrifugal fan is a mechanical device used for moving air or other gases, the term blower and squirrel cage fan (because it looks like a hamster wheel), are frequently used as synonyms. Centrifugal blowers are widely used in different industrial applications because of their suitability in any practical circumstance(Jayapragasan et al., 2015). As cited by Oyelami et al.(2008), the principle involved in the design of a blower is similar in virtually every important aspect as that of a centrifugal pump except for the fact that the term “centrifugal pump” is often associated with liquid as its working fluid while the blower is meant to work on air. Centrifugal fan uses the kinetic energy of the impeller to increase the volume of the air stream which in turn move them against the resistance caused by ducts, dampers, and other components. Centrifugal fans are constant displacement devices or constant volume devices, meaning that at a constant fan speed, a centrifugal fan blows air at a relatively constant rate.

An air blower can therefore be described as a device, which converts driver energy to kinetic energy in a fluid by accelerating it to the outer rim of a revolving device known as an impeller. It consists of a rotating arrangement of vanes or blades which act on the air. The rotating assembly of blades and hub is known as an impeller, a rotor, or a runner. Usually, it is contained within some form of housing or case. The principle involve in the design of a blower is similarly in virtually every important aspect as that of a centrifugal pump except for the fact that the term centrifugal pump is often associated with liquid as its working fluid(Oyelami et al., 2008).The gas or air enters from the side of the fan wheel turn 90° and accelerates due to force as it flows over the fan blades and exits the fan housing.

Charcoal fired furnaces are one of the cheapest furnaces which have metamorphosed from bellow through manual rotary blower to electric motor-driven blower systems (Okechukwu *et al*., 2013). This research was necessitated due to the high cost of fossil fuel and unreliable power supply for foundry applications in Nigeria. There is no power supply to drive the electric motor-driven blowers, the cost of fueling fossil fuel fired motorized blowers is high and also there is fatigue associated with the hand-driven blowers, hence the need for providing an alternative blowing system for charcoal foundries arises . The charcoal fired furnace is usually used for aluminum recycling towards production of cooking utensils in local small -scale aluminum casting foundries. This study aims to provide solutions to the aforementioned problems associated with means of supplying air for the operation of a charcoal fired crucible furnace for melting metals by designing and constructing a solar energy powered air blower to overcome some or if possible all the problems stated.

1.1 Centrifugal Blowers

Centrifugal blowers use high speed blades or impellers to move air and or other gases. They offer a number of blade orientations such as; radial forward curved and backward curved. In centrifugal blowers, fans affinity laws dictate that a percent reduction in speed will produce a like reduction in flow.

i. Radial Fans: are industrial workhorses because of their high static pressure and ability to handle heavily contaminated air stream, radial fans are well suited for high temperature and medium blade tip speed.
ii. Forward Curved Fans: are used in clean environments and operate at lower temperatures. They are best

suited for moving large volumes of air against relatively low pressures.

iii. Backward Inclined Fans: are more efficient than forward curved fans. Backward inclined fans are also known as ``non-over loading`` because changes in static pressure do not overload the motor.

2.0 MATERIALS AND METHOD

2.1 Blower Design

2.1.1 Velocity Profile of the impeller

For a fluid to move in a blower it must flow through a rotating impeller, the velocity of a point on the impeller is given by U. The blower has no inlet guide vanes; as such the entering flow into the impeller has no tangential component of motion, therefore it is in radial direction. The absolute velocity of the air flowing through the impeller is also given by V. The angle between V and U is called α, the angle between Vr and U extended is β and it is angle made by tangent to the impeller vane and a line in the direction of the vane.

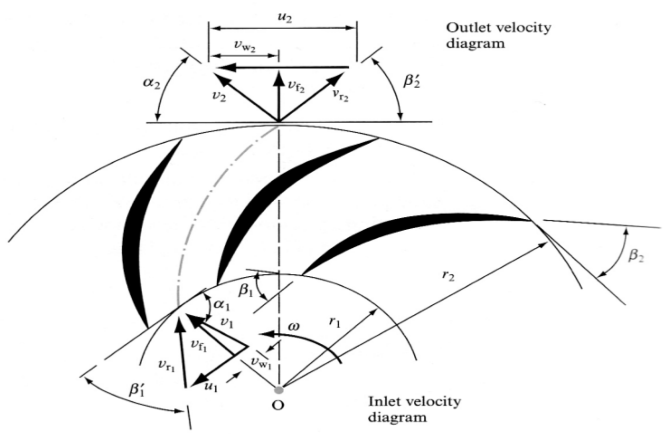

Figure 1: Inlet and Outlet velocity diagrams of the impeller (Kothandaraman and Rudramoorthy, 2007)

According to (Garba, 2015)a fan must supply at least 22.28 kg/s (0.0223m^3/s) of air into a furnace for complete combustion of 1kg of wood charcoal. In this design, 0.0223m^3/s (least air required for complete combustion of 4kg of wood charcoal) is adopted as the air flow rate of the blower.

Impeller is designed based on flow rate and rotational speed. Okechukwu et al. (2013)states that considering the fact that charcoal does not require much air to glow and the length of travel of the air via the inlet pipe, 2000 revolutions per minute can be used for the impeller-shaft.

From the optimum performance specification it is stated that the ratio of the internal diameter to the external diameter is from 0.4 to 0.7 as stated in the ASME code (Ibrahim et al., 2019).Therefore

$$0.4 < \frac{D_1}{D_2} < 0.7 \quad (1)$$

For this design, the ration of $\frac{D_1}{D_2} = 0.45$ Is taken (2)

For optimum performance according to ASME Code, the number of blades is given by

Number of blades (C) $C = \frac{8.5 sin\beta_2}{1-\frac{D_1}{D_2}}$ (3)

Where β_2=outlet vane angle = 20°<β_2<90°, for this design, β_2 is taken as 45°

Number of impellers $C = 6$ Area of the impeller (A)

$$A= \frac{\pi d^2}{4} \quad (4)$$

$$A = \frac{\pi \times 0.19^2}{4}$$

$$A = 0.03m^2$$

The impeller inlet and outlet linear speeds are calculated using equation 5 and 6 respectively

$$U_1 = \frac{\pi D_{1N_1}}{60} \quad (5)$$

$$U_2 = \frac{\pi D_{2N_2}}{60} \quad (6)$$

$$U_1 = \frac{3.14 \times 0.086 \times 2000}{60}$$

$$U_1 = 9\, m/s$$

$$U_2 = \frac{\pi D_2 N_2}{60}$$

$$U_2 = \frac{3.14 \times 0.19 \times 2000}{60}$$

$$U_2 = 20m/s$$

$$V_1 = V_{r1} = U_1 \tan \beta_1 \quad (7)$$

$$V_2 = V_{r2} = U_2 \tan \beta_2 \quad (8)$$

$$V_2 = \frac{V_{f2}}{\sin \beta_2}$$

$$V_2 = \frac{1}{\sin 30}$$

$$V_2 = 2\, m/s$$

$$V_{W2} = \sqrt{V_2^2} - V_1^2$$

$$V_{W2} = \sqrt{3.8^2} - 2.02^2$$

$$V_{W2} = 3.18m/s$$

$$V_{r2} = \frac{1}{\sin 45} = 1.14m/s$$

$$V_{r2} = \frac{2.20}{\sin 29} = 4.54m/s$$

The quantity of air discharge (Q) is calculated using equation 9

$$Q = 2\pi r_1 b_1 V_{r1} \quad (9)$$

$$P_i = \rho g Q H \quad (10)$$

$$P_i = 1.166 \times 9.81 \times 0.022 \times 2$$

$$P = 0.5kW$$

$$P_i = 500W$$

The torque is calculated by using equation 11

Torque (T)

$$T = \frac{P_i}{W} \quad (11)$$

$$T = \frac{500}{2 \times \pi \times 2000}$$

$$T = 0.04N\text{-mm}$$

According to the Choure (2017) for the design of transmission shaft, the maximum permissible shear stress as 42MPa for shafts with allowance for keyways and the equation for calculating the shaft diameter (ds) is presented as equation 12

$$ds = \sqrt[3]{\frac{16 \times T}{\pi \times f_S}} \quad (12)$$

$$dS = \sqrt[3]{\frac{16 \times 0.04}{3.14 \times 42}} = 0.17m$$

According to (Sani et al., 2016), the width of the blade can be calculated by using the ASME Code presented in 13

$$W = \frac{6\left(\frac{D_1}{2}\right)}{C+1} \quad (13)$$

$$W = \frac{6\left(\frac{0.086}{2}\right)}{6+1}$$

$$W = 0.037m$$

The efficiency (η) of the blower is presented below

$$\eta = \frac{P_O}{P_i} \quad (14)$$

$$P_i = T\omega \quad (15)$$

$$P_i = 0.04 \times 2 \times \pi \times 2000$$

$$P = 0.5024kW$$

$$\eta = \frac{0.50}{0.5024}$$

$$\eta = 99.5\%$$

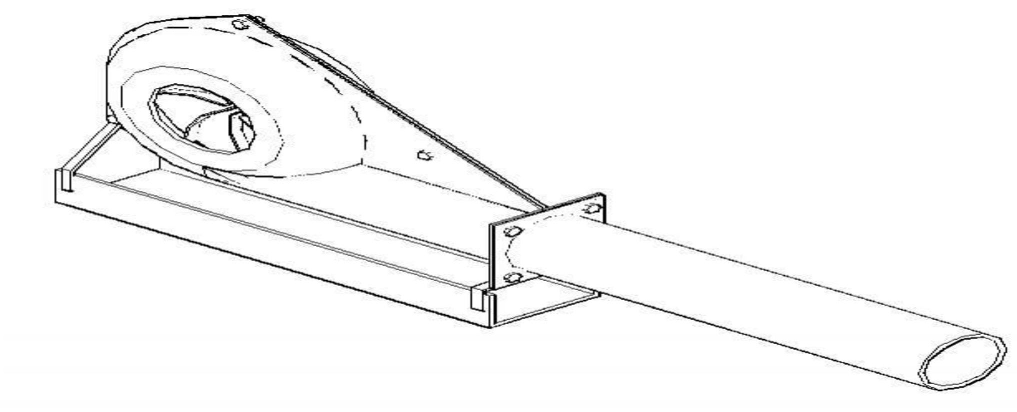

Figure1: Schematic Diagram of the blower

2.2 Sizing and integration of solar power system

Abdul Kadir (2014) reported that the integration of solar power generation using photovoltaic power systems can boost the rate of productivity, therefore, the integration of solar energy into metal working industry will assist the industry by reducing the production time and also eliminating or reducing the fatigue been experienced by the local foundry men. The integration of solar photovoltaic system into manufacturing industry will have either positive or negative impact depending on the manufacturing method and the photovoltaic system (PVS) characteristics. PVS can be valuable if it meets at least the basic requirements of the system operating perspective (Begovic, 2001). According to Daly and Morrison (2001), the effect of PVS on power quality depends on its interface with the utility system, the size of DG unit, the total capacity of the PVS relative to the system and the size of generation relative to load at the interconnection point

2.2.1 Sizing of Solar Power System

Solar energy potential of a location is used in the designing and sizing of solar energy power system. The solar energy potentials of the semi-arid region of northern Nigeria is characterized by the high intensity of solar radiation of 6.176kW/m^2/day in Maiduguri and the average sunshine hour in the arid region is about 9 (Muhammad, 2016).The optimum tilt angle for the PV module in fixed tilt orientation to maximize Irradiation and to ensure same condition for all locations, the optimum tilt degree of Maiduguri is 11.9 (Eseosa & William, 2017).

$$capacity\ of\ PV\ Wp\ panel\ needed = \frac{power\ rating\ of\ the\ blower}{sunshine\ hrs/day \times tilt\ angle \times deviation\ cell\ tempt \times losses}$$

$$capacity\ of\ PV\ Wp\ panel\ needed = \frac{502.4\ \times 6}{9 \times 11.9 \times 0.49 \times 0.7} = \frac{3014.4}{36.7353} = 82.0573$$

$$Number\ of\ PV\ Panels\ needed = One\ 100\ Wp\ Module\ is\ required$$

2.2.2 Sizing of Battery

The battery's task is to compensate for the non-simultaneity of energy supply and energy consumption. The battery capacity is stated in AMP hours (Ah). Following is a formula that will enable to calculate what size of battery they should have. (Leonics, n.d.)

$$\text{Battery Capacity (Ah)} = \frac{\text{Total Watt} - \text{hours per day used by appliances x Days of autonomy}}{\text{(0.85 x 0.6 x nominal battery voltage)}}$$

Total appliances use = (1DC Motor x 502.4 W x 6 hours) =3014.4 Watt

Nominal battery voltage = 12 V

Days of autonomy = 1 days

$$\text{Battery Capacity (Ah)} = \frac{3014.4 \text{ x } 1}{(0.85 \text{ x } 0.6 \text{ x } 12)} = 492.55 \text{ Ah}$$

Total Ampere-hours required 492.55 Ah

So the battery should be rated 12 V 500 Ah for 1 day autonomy.

3.0 RESULT AND DISCUSSIONS

The picture of the constructed blower is presented in plate 1. Also, the results of the calculated parameters for both impeller and blower casing design are presented in Table I.

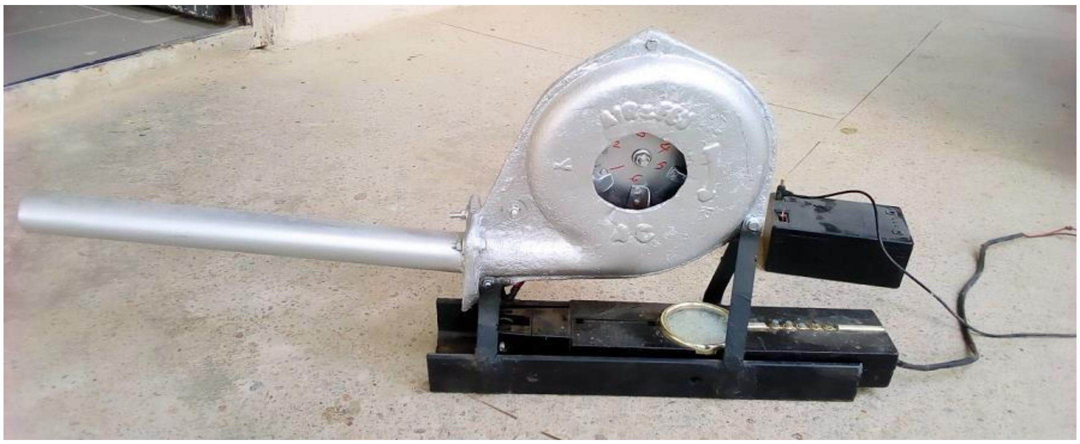

Plate 1: Picture of the Constructed Solar Powered Blower

3.1 Discussion

3.1.1 Performance Evaluation

During the performance evaluation of the constructed blower, the performance of the manually operated air blower is compared with the solar powered blower. The results of test of the two air blowers are presented in Tables1 and 2 respectively. During the performance evaluation test of both the manual and the solar powered blowers, 4 kg of charcoal was measured to melt 4 kg of aluminum and zinc respectively. When the manually operated air blower was used to supply air for ignition and burning of the charcoal for melting the metals, out of the 4 kg of charcoal measured only 2.9 kg and 0.84kg of charcoal are used to melt the 4 kg of aluminum and zinc respectively. Using the manually operated air blower it took about 67 and 42 minutes to melt 4 kg of aluminum and zinc at melting temperatures of 698.39˚C and 442.1˚C respectively. While using the solar powered air blower it was observed that it took 30 and 17 minutes to melt 4 kg of aluminum and zinc at melting temperatures of 780.8˚C and 430.6˚C respectively under an average atmospheric temperature of 37˚C.

Table 1: Performance evaluation of manually operated air blower

Materials	Aluminium	Zinc
Ambient temperature	34.3˚C	36.5˚C
Weight of aluminium	4 kg	4 kg

Weight of charcoal used	2.9 kg	0.84 kg
Melting temperature	698.39˚C	442.1˚C
Time taken	67 minutes	42 minutes

Table 2: Performance evaluation of motorized solar powered air blower

Materials	Aluminium	Zinc
Ambient temperature	35.6˚C	38.3˚C
Weight of aluminium	4 kg	4 kg
Weight of charcoal used	2.8 kg	1.2 kg
Melting temperature	780.8˚C	430.6˚C
Time taken	30 minutes	17 minutes

4.0 CONCLUSION

A solar powered air blower for charcoal fired furnace was constructed and its performance was evaluated. The blower was constructed to increase the air velocity for igniting the charcoal. A photovoltaic system was used to power the blower and also a DC battery used to the energy from the photovoltaic panels for use during off peak periods. The performance of solar powered blower was compared with the manually operated blower and the results showed that the solar powered blower blows air faster. It takes the solar-powered air blower about 30 minutes and 17 minutes to melt 4kg of aluminium and zinc respectively while on the other hand It takes about 67 minutes and 42 minutes to melt 4kg of aluminium and zinc respectively by the manual blower. This indicates that the solar-powered air blower takes a shorter time to melt metals when compared with the manually operated air blower. In addition, the solar powered air blower eliminates the labourous aspect of supplying energy for melting metals and also reduces the times spent in metal melting process.

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