The Design And Development Of A Dual Fuel Burner

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***Abstract*—This project work is based on a dual fuel burner that uses both pulverized coal and butane gas as sources of fuel. The burner is unique and certainly of great importance to the development of the nation was designed and constructed to use a mixture of pulverized coal and gas. The working principle, the operations and the heat transfer process of the burner system were dealt with in details. The various analysis governing the design were made and the calculations of the design, such as mass flow rates of the fuels, the burner power, the determination of impeller assembly and the stresses induced on the cylinders were made. The functionality of the burner was established by using Aluminum, Lead and Copper to carry out the required test. The test carried out with the fuel mixture of pulverized coal and gas, using a medium size kiln as the furnace chamber, showed that Lead with a temperature of 327^0C, had a melting time of one (1) second. Aluminum with a temperature of 660^0C was eight (8) seconds and copper with a temperature of 1083^0C was twelve (12) seconds, indicating that the burner is effective in operation using the fuel mixture. It was observed during the course of the test, that the melting time is a function of the intensity of the flame, that is the greater the intensity of the flame, the lower the melting time (i.e.) a reduction in the melting time of the material employed.**

Keywords—Pulverized Coal, Butane Gas, Mass Flow rates, Melting time, Burner Power, Impeller, Kiln

1. INTRODUCTION

The utilization of heat for domestic and industrial heating purposes, such as cooking, warming and furnace services etc dates back to antiquity, when man learnt how to use solid fuel, such as wood and coal to generate heat(1). The invention of burners from literatures was observed to have started in the year 1805. This was when the English gas burners originally made for laboratory purpose was invented. It was also observed from literatures that, the contemporary gas burners, such as the Bunsen burner (which was made by Robert Wilhelm Burner) and the gas lighting burner were both made in Heidelberg, Germany in 1855. The burners used in domestic appliance operate on the principles of Bunsen burner. Researchers like Michelson Mache, Smith and Pickhending contributed to a great deal to the construction and modification of burners after Guoy in 1879 made his significant improvement on the Bunsen experiment (2). In recent times, there have been significant developments in burner design to enhance faster and more economical conversion of fuel into heat. Burners are fuel burning devices from which hot flames emit. They are therefore, the core component of any combustion process (2). The primary purpose of the burner is to mix and direct the flow of fuel and air, so as to ensure rapid ignition, continuous and complete combustion. In dual fuel burner, which uses a mixture of pulverized-coal and gas, a part (15 to 25 percent) of the air called primary air is initially mixed with the fuel to obtain rapid ignition and to act as a conveyor for the fuel. The remaining portion or secondary air is introduced through the air register doors. The dual fuel burner is designed to fire coal and can be equipped to fire any combination of the three principal fuels, if proper precautions are taken to prevent coke formation on the coal element, when gas and coal are been burnt(3). Nowadays, burners have a very wide range of application both in our homes and in the industries. Based on its wide range of application, it can be used in household appliances for cooking (e.g. as kerosene stoves, baking oven, gas cooker etc.). And in the industries also, were they are used in furnaces, drying ovens (e.g. dryer), ovens, kiln, power plant, heat treatment processes and welding torch. With the invention of burners, factors like rate of combustion, rapid and uniform mixture of fuel and air intake, for the purpose of obtaining immediate combustion and also high flame temperature are put under control(2). In order to discourage the importation of burners with very huge amount of money, there is a need to produce them locally, so as to conserve the country foreign exchange earnings. This local production will also help the country to attain a greater height technologically.

1.2 TYPES OF BURNERS

Burners can be of various shape and size depending on their structural characteristics, but as far as their operation is concerned, they appeared in three forms. (8).

1. Solid -fuel burners
2. Liquid-fuel burners
3. Gas burners

1.3 SOLID FUEL BURNERS

The main purpose of solid fuel burners is to provide the required favourable condition of furnace operation. To achieve this aim, the burner should be fed with the desired fuel to enhance its ability. In solid fuel burner, the desired fuel (i.e. coal) should ensure to have the following: (i) the coal used must have low sulphur content at most one percent or less; (ii) The coal used must be a free-burning coal; (iii) The grindability index of the coal must be very high that is, it should be possible to grind the coal into a powder form, finer than face powder to increase the rate at which the coal burns; (iv) The energy content or heating value of the coal must be adequate.

In practice, it have been found that there are cases where one type of fuel is burnt together with another (for instance gaseous fuel and pulverized coal is burnt together) is possible. This is one of the reasons why combined solid fuel burner (i.e. pulverized coal and gas) has found wide use. Common dual fuel burners can burn a mixture of pulverized coal and gas easily. They are employed in heating and melting furnaces. In this type of burner, the fuels are supplied to the combustion zone via separate pipes. The fuel (pulverized coal), being always fed through the central or main pipe, that is the pulverized coal pipe, since it is mixing with air. The gas is supplied through the secondary pipe to the combustion zone. Solid fuel burners, in most cases usually fire horizontally and are commonly either fired from the furnace corners, so that the flames are directed toward an imaginary circle (tangential firing) or the burners are mounted in the wall opposite to each other and the flames are directed toward each other (opposed firing)[9].

1.4 LIQUID FUEL BURNERS

Most liquid fuels are extremely difficult to burn in the liquid state. More also, a steam of many liquid fuel will extinguish an ignition source and make the combustion of such liquid-fuels impossible.

Based on these facts, liquid-fuel burners should meet the following requirement [8]. (i) They should atomize liquid fuel and mix it thoroughly with air; (ii) Ensure stable combustion and form an uninterrupted flame of a desired length; (iii) Should be reliable in operation, simple in design and convenient for cleaning.

Liquid-fuel burners are divided into two large groups:

(1) Low pressure and

(2) High pressure burners

1.5 GAS BURNERS

The main purpose of gas burners is to provide the specific economically favourable conditions of furnace operation. To serve this purpose the burner should ensure the following: (i) The supply and mixing of gaseous fuel and air in the required amounts; (ii) Complete combustion of the fuel within the working space of furnace; (iii) The formation of a flame that can ensure the required level of heat transfer in the furnace space.

Thus, the whole cycle of fuel combustion (mixing, burning and heat transfer) should be carried out with the maximum efficiency. The principal feature by which gas burners are classified is the method of mixing gas and air. Accordingly, all gas burners are divided into three large groups as follows: (i) Full premixing of gas and air burner; (ii) Partial premixing burners; (iii) Outside mixing burners.

1.6 FUELS

Fuel is any substance that produces useful heat when burnt. [11]. Fuels are the main sources of energy that can be converted into heat and used to raise the temperature of furnaces, kilns and ovens to the desired temperature.

1.7 TYPES OF FUELS

Fuels can be classified as raw or prepared. Refined products like coke and pitches are examples of prepared fuels, while un-refined coal and crude oil are examples of raw fuel [12].

Table 1: Classification of Fuel

Types of Fuels	Raw	Prepared
SOLID	Wood, peat, lignite, sub-bituminous, bituminous, semi-antracite	Charcoal, Pulverized coal, Coke
LIQUID	Crude oil	Gasoline, Napthal, Gas, Oil, Fuel oil, Solvent sprint, Kerosene, Light fuel oil, Heavy oil and Residue
GASEOUS	Natural gas	Refinery gases, coke oven, blast furnace retort gas, town gas, producer and water.

Source (Ref No. [12]

Most fuels are of fossil origin, that is, coal, oil and gas or their derivatives. Fuels maybe distinguished as expendable and renewable. The fossil fuels fall into the former category. Also included in this group are the radioactive elements, unless there are novel techniques to extract them from the oceans. Wood and peat are renewable, but at a very slow rates. Renewable energy sources such as hydropower, tidal energy, geo-thermal and solar energy are not yet being utilized on a large scale.[12]

2. RESEARCH METHODOLOGY

2.1 DESCRIPTION OF THE BURNER

The dual fuel burner is made up of the pulverized coal pipe (held in place by flanges at different sections). Gas supply pipe that supplies the gas from the gas source. Control valve that is used to regulate the amount of flow of the gas being supplied to the burner, through the mixing chamber at a desired rate and to shut off the fuel, when not in operation. A mixing chamber, were both the pulverized coal pipe and gas supply pipe are connected to. The mixing chamber is connected and linked to the burner, separating them is a seal, which is to prevent mixture leakage that is mixture of pulverized coal and gas. Attached to the mixing chamber, at its other side, is the electric motor, which serve as a prime mover to the impeller, inside the mixing chamber [9]. The impeller rotates inside the mixing chamber casing, as the motor is in operation causing the pulverized coal (primary air) to be taken, that is sucked in through the pulverized coal pipe, sending it to the mixing chamber to mix with the gas supplied there, through the gas supply nozzle, before it is then sent to the burner, after it has been thoroughly mixed. It is imperative to state here, that the impeller promotes the turbulence of the fuels (pulverized coal and gas), and air at the mixing chamber. The fuels and air is thoroughly mixed here in the mixing chamber, before it is sent to the burner for complete combustion to take place. Combustion air is generally delivered to the burner by fan (impeller). It is necessary to supply more than the theoretical air quantity to ensure complete combustion of the fuels in the combustion chamber (zone). The amount of excess air provided should be just enough to burn the fuel mixture completely in order to minimize the sensible heat loss in the stack gases. The impeller unit used is a centrifugal type of fan, designed to move air or gas over wide volume range. Generally, the wheel could be straight, forward curved; backward curved, radial - tip or other type of blades. Housing is of sheet or cast metal, with or without protective coat of rubber, head, enamel etc. It could be driven by belt or direct drive from the electric motor. [17]. For the purpose of this particular design the centrifugal type of fan is used, because it gives a continuous high volume, high pressure and reasonably high efficiency and low noise production during operation.[18]. Attached to the burner unit, are four flame retainers, which are built with the burner. These flame retainers are linked and connected side by side, at designated (measured) intervals round the burner, to aid combustion. Consequently the burner introduces the fuel mixture and air into the furnace chamber to sustain the exothermic chemical reaction of the moist effective release of heat. The burner flame is of two types:

1. Diffusion flame and
2. Aerated flame

With a diffusion flame, no air is premixed with fuel/gas before combustion, while with aerated flame some air is premixed with fuel/gas before combustion.[19]

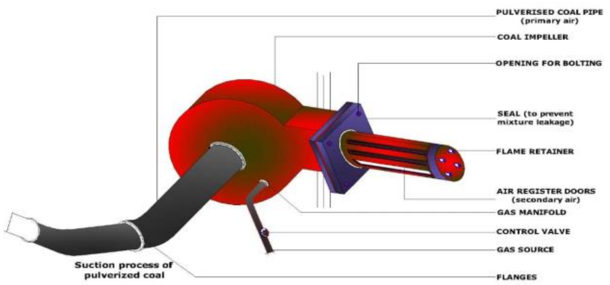

Figure 1: Dual fuel burner

2.2 MACHINE COMPONENTS

The dual fuel burner system is made up of the following parts:

(a) The pulverized coal pipe
(b) Gas supply pipe with nozzle
© Mixing chamber
(d) Electric motor
(e) Impeller
(f) Seal
(g) Burner
(h) Flame retainers

2.3 DESIGN ANALYSIS

2.3.1 FLOWS IN PIPES

Pipes are referred to as closed conduit and they are used to duct the fuels, pulverized coal and gas, to the burner. The total quantity of flowing in unit time past any particular cross section is referred to as discharge or flow at the section. Mathematically this is expressed as:

$Q = UA$ …………………………….. (1)

For flow through a pipe or through a conduit, the velocity will vary from wall to wall. However, using the mean velocity (V) the equation of continuity for steady flow can be written as:

$P_1A_1U_1 = P_2A_2U_2 = M$ ………………… (2)

Where, M = Mass flow rate
P = Density
A = Area at the section
U = Velocity

Mass flow rate of the fuels:
The mass flow rates of the various fuels used was computed using the equation:

$M = A_fP_fV_f$ …………………………… (3)

Where, A_f = Area of the nozzle for fuel exit point.
V_f = Velocity of the fuel at exit from the nozzle.
P_f = Density of the fuel.

Since the burner is to be suspended at a minimum height 'h'. By implication, the fuel is suspended at that same minimum height 'h' and applying the law of conservation of energy, the potential energy P.E. of a unit fuel will be equal to the kinetic energy of the fuel, when it discharges to the nozzle at height (h), thus:

K.E = P.E
$MV^2/2 = Mgh$

For unit mass,
$V^2/2 = gh$
$V = \sqrt{2gh}$ ……………………… (4)

This is the velocity at which fuel flow to the nozzle. In the nozzle, the law of conservation of mass requires that for steady flow, the same mass flow rates exists at every section.

Therefore: $M = P_1A_1U = P_2A_2U_2$

Substituting equation (4) into equation (3) yields:

$M = P_fA_f\sqrt{2gh}$ ………………………….. (5)

Where, P_f = Density of the fuel

$A_f = \frac{\pi d_f{}^2}{4}$ and

d_f = diameter of the orifice

2.3.2 BURNER POWER

On full valve opening of the fuel line and full operation of the impeller unit the burner power was calculated as follows:
$B_p = M_f \times H_c$ ……………… (6)

Where, B_p = burner power
M_f = mass flow rate of the fuel
H_c = heat of combustion of the fuel

2.3.3 IMPELLER ASSEMBLY

The impeller is fully dynamically balanced to reduce vibration and prolong bearing, life. A taper lock bush is employed to mount the impeller directly onto the motor shaft, which considerably eases the removal and accurate remounting of the impeller for cleaning purposes (17). The impeller is driven by an electric motor of appropriate rating. The impeller consists of section inlet and discharge outlet through which it takes and discharge air respectively.

2.3.4 Selection of Impeller and Motor

The impeller needed for this size of burner should be able to deliver a quantity of air of mass flow rate, Ma.

$Ma = M_f \times$ Air/Fuel ratio …………… (7)

An effective electric motor is needed to run this impeller effectively. This motor should be able to deliver the appropriate power input to the impeller.

2.3.5 STRESSES INDUCED IN PRESSURE VESSELS (CYLINDERS)

Pressure vessels (cylinders) are used to store and transport fluid, gases under pressure and can be classified according to their dimension as thick or thin shell vessels and their end construction as open or close ends. The deciding factor for the formal classification is the ratio of wall thickness (t) to the diameter (d), if the ratio t/d is less than 1/10 then it's called a thin shell vessel and if this ratio is greater than 1/10 it's called a thick shell vessel. When a cylinder is subjected to a very high internal fluid pressure, the walls of the cylinder must be extremely heavy or thick.
From lame's equation,
$dt\,(max) = \frac{P\,(do^2 + di^2)}{do^2 - di^2}$ ……………………(8)
Where, P = internal pressure
do = outer diameter
di = internal diameter
dt = tangential stress

Similarly, we have radial stress, (dr), given by,
$dr_{(max)} = -P$ ……………………………(9)

Thickness of the cylinder (t), given by
$t = di/2\sqrt{\frac{dt+p}{dt-p}} - 1$ ………………… (10)

2.3.6 MODE OF OPERATION

It's imperative to state here, that before starting the burner, it is important to ensure that the fuel is in place that is there is enough pulverized coal and gaseous fuels to bring about combustion capable of heating up the furnace to the desired state. Then the impeller is put on to ensure that the coal is sucked in, causing a thorough mixture with the gaseous fuel supplied in the mixing chamber, before it's sent or rather before ejecting the mixture into the furnace.
The following is the order in starting the burner:
(1) Check fuel level, that is, ensure that the fuel level for both fuels is adequate.
(2) Put on the impeller to take in (suck in) the pulverized coal to mixing chamber.
(3) Open the gas control valve to supply gas to mixing chamber.
(4) After fuel lines for both fuels have been opened, wait a bit for thorough mixing of fuels, then the flame retainers can be ignited.
(5) The burner starts.
(6) Adjust gas control valve to regulate flame.

3. RESULTS AND DISCUSSION

3.1 CALCULATION OF MASS FLOW RATES

$M = P_fA_f\sqrt{2gh}$
$= P_f\frac{\pi d_f^2}{4}\sqrt{2gh}$
For Coal;

Denoting coal with subscript C, we have;
Pc = density of bituminous coal = 1320 kg/m^3 (APP. B & C)
d_f= diameter of orifice for coal pipe = 0.1m
h = height of burner from ground level = 0.75m
g = acceleration due to gravity = 9.81m/s^2
Substituting into equation 5, we have,

$$M_c = \frac{1320\ x\ \pi\ x\ (0.1)^2}{4}\sqrt{2\ x\ 9.81\ x\ 0.75}$$

= 3.9774 x10^1 kg/s

3.2 BURNER POWER

$B_{pc} = M_c$ x H_c
Where subscript c denotes coal
Given that:
M_c = 3.9774 x 10^1 kg/s
H_{ck} = 32440 kJ/kg (Table 2.2)
Therefore,
B_{pc} = 3.9774 x 10^1 x 32440
= 129 x 10^4 kw
Similarly, the burner power when using butane gas is
$B_{pg} = M_g$ x H_{cg}
Where subscript g denotes butane gas
Given that:
M_g = 2.928 x 10^1 kg/s
H_{cg} = 45.8MJ/kg (APP. A)
Therefore,
B_{pg} = 2.928 x 10^1 x 45.8 x 10^3
= 13.4 x 10^3 kw

3.3 DETERMINATION OF IMPELLER

This is done using one of the fan (impeller) laws,
Using the equation

$Q\ \alpha\ \mathrm{Nd}^3 \rightarrow Q = \mathrm{Nd}^3$ …………… (11)

Therefore, to determine the mass flow rate of air to the burner,
Recall, Ma = eAV or eND^3
Where, eAV = Mf
Ma = mass flow rate of air
e = density of air = 1.2 (APP.D)
A = cross-sectional area of the impeller
V = velocity of air flow to the burner
Given:
Diameter of the impeller = 325mm = 0.325 m (Dcf)
Frequency = 50Hz
Speed of the fan = 3000 rpm
Voltage = 240v
Selected from the fan catalogue as per the attached

To get the discharge,
Recall again, Q = Nd^3 ……………… (12)
Where, Q = volumetric flow rate of air
N = speed of the fan
d = diameter of the fan impeller
Therefore, substituting values into equation (12)

$$Q = 3000 \text{ x } 0.325^3 \text{ x } \frac{2\text{ x }\pi}{60}$$

Q = 10.785m^3/s
But, Q = AV

$$Q = \frac{\pi d^2 V}{4}$$

$$\text{Therefore; } 10.785 = \frac{\pi \text{ x } 0.325^2 \text{ x V}}{4}$$

$$V = \frac{10.785 \text{ x } 4}{0.325^2 \text{x } \pi}$$

V = 130m/s
Therefore, mass flow rate of air to the burner
Ma = eAV
Substituting values into this, we have

$$\mathrm{Ma} = \frac{12 \text{ x } \pi\text{x } 0.325^2 \text{ x } 130}{4}$$

= 12.943kg/s
= 13 kg/s
From this result, it shows that it is within our demand of 10.17:1 air/fuel ratio, as earlier calculated for bituminous coal. It then implies that when the impeller is fully operational, it will allow 13 kg of air flow to the burner. The mass of air produced when the impeller is fully operational, will be able to burn 1kg of fuel, since the fuel requires 13 kg of air to burn the fuel completely.

3.4 FOR FAN (IMPELLER) PRESSURE,

Using equation

P = N^{2}d^2 …………………………… (13)

Substituting values into this, we have,

$$\frac{(3000 \text{ x } 2 \text{ x } \pi)^2}{60}\ x\ 0.325^2$$

P = 10427 N/m
P = 10.427 KN/m^2

3.5 FOR FAN (IMPELLER) POWER

Using equation
Power (w) = N^{3}d^3 …………………..(14)
Substituting values into this, we have,

$$W = 0.325^2\ x\ \frac{(3000 \text{ x } 2 \text{ x } \pi)^3}{60}$$

Power (W) = 112469.7
W = 1125 W
W = 112.5 KW
This is the power of the impeller (fan)

3.6 STRESSES INDUCED IN CYLINDERS

Using equation lame's equation;

$$dt_{(max)} = \frac{P(do^2+di^2)}{do^2-di^2}$$

Given that:
P = 6 bars = 6.078 x 10^5 N/m^2
do = 170 mm = 0.17m
di = 160mm = 0.16m
$dt_{(max)}$ = tangential stress = ? (Unknown)
Substituting values into lame's equation above yields, $dt_{(max)}$

$$= \frac{6.078\ x\ 10^5(0.17^2+0.16^2)}{0.17^2-0.16^2}$$

= 10.0379 x 10^6 N/m^2

Radial stress $dr_{(max)}$ = - P, from equation 9
This implies that; $dr_{(max)}$ = -6.078 x 10^{5}N/m^2
Thickness of the cylinder (t); from equation 10

$$t = \frac{di}{2}\sqrt{\left[\frac{dt+P}{dt-P}\right]} - 1$$

Substituting the values, we have

$$t = \frac{0.16}{2}\sqrt{\left[\frac{10.0379\,x\,10^{6} + 6.078\,x\,10^{5}}{10.0379\,x\,10^{6} - 6.078\,x\,10^{5}}\right] - 1}$$

$= 0.005 = 5 \times 10^{-3}$m

$= 5$mm

4. CONCLUSION

A dual fuel burner was designed and constructed. Results from the test carried out on the burner showed that it worked satisfactorily, when using the mixture of pulverized coal and gas in the ratio 1:2 compare to when using the other fuels. Results further showed that the burner worked perfectly well with the fuel mixture of pulverized coal and gas, using a medium size kiln as the furnace chamber, as it was able to melt materials like Lead with a temperature of 327^0c, in one (1) second, Aluminium with a temperature of 660^0c in eight (8) seconds and Copper with a temperature of 1083 in twelve (12) seconds. Results also showed that the melting time is a function of the intensity of the flame that is the greater the intensity of the flame, the lower the melting time (i.e.) a reduction in the melting time of the material employed. Similarly, the rate of fuels efficiency was determined, by opening the gas control valve to the maximum and switching on the impeller unit. It was observed that a bright blue-flame emerged, which was able to melt lead solder, aluminum and copper wire respectively. This shows that this burner can compete favourably and excellently with the imported ones. With its capacity, the burner could be used in melting ferrous and non-ferrous metals such as aluminum, lead, copper and also for heat treatment processes. Although, periodic checking should be carried out on the burner system to avoid blockage of the system, it is highly recommended for use in boilers to generate steam, in the pottery industries for firing ceramic products with little modification. The manufacture of this burner will in no small measure help in revamping our economy. In the sense that those manufacturing industries and companies alike that make use of this burner will be compelled to buy the parts locally.

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