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Design and Construction of a Portable Boiler

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Abstract **Original Research Article**

The article describes a research which is focused on the design and construction of a portable boiler. This is to enhance energy system in Africa and the world at large. Water at atmospheric pressure of 1.613252bar, 25°c was supplied to the pressure to an absolute pressure of 4.5bar, a burner and liquefied petroleum gas (LPG) were used to supply heat to the boiler that raised the water at the copper piping to a saturation temperature or 147.9°c there by producing steam. During testing 0.5kg of gas was burnt for 25min and the wet steam generated at the exist pipe was at a gauge pressure of 3.2bar. The steam generated find application in textile industries for sizing and bleaching, sugar mills, chemical industries and production of hot water for hot water supply. In conclusion, the developed modular boiler is efficient and effective at optimal working condition.

Keywords: Boiler, LPG, Generated Steam, Gauge Pressure.

1. INTRODUCTION

Boilers are pressure vessels designed to heat water or produce steam which can then be used to provide space heating and/ or services water heating to a building. In most commercial heating applications, the heating in the boiler is a natural gas fired burner.

Oil fired burners and electronic resistance heaters can be used as well. Steam is preferred over hot water in some application including kitchen, laundries, sterilizers, and steam driven equipment. Boiler is multipurpose equipment in all manufacturing industries, industries like, Nigeria bottling company, textile mail, laundries, breweries, Matches Company etc. A boiler is an enclosed vessel that provides a means for combustion and transfer heat to water until it becomes hot water or steam. In time past the use of Solar became much popular [1]. The hot water or steam under pressure is useable for transferring the heat to a process when water is boiled into steam, its volume increases about 1600tones, producing a force that is almost as explosive as gun power. This causes the boiler to be extremely dangerous equipment and should be treated carefully when liquid is heated up to the gaseous state, it evaporates, and this process is known as evaporation. Any part of the boiler metal that actually contributes to making steam is known as heat surface. Heating surface is any part of the boiler but on the other side. The burner is meant for the combustion generation, while the boiler is meant for building steam. According to [2] system made of solar can compete with boiler operation. The combination of the boiler and the burner and vertical boiler can be easily differentiated apart from their physical view. Horizontal boilers are bottom supported while the vertical boiler is top supported. Since boiler is close metallic vessel, heating water above the atmospheric pressure, steam could be generated at the desired pressure and temperature. To heat the fuel like, coal, diesel, oil, gas etc. may be used, the function of a boiler is to evaporate water into state at constant pressure and supply the required type of steam.. The aim of this study is to design a portable boiler that can efficiently produce steam at a gauge pressure of 3.2bar. The objectives of this project are to determine the stochiometric air fuel ratio for the burner; determine the heat loss by the boiler during operation; determine the pressure and temperature produced; determine the rate of steam production; fabricate a portable boiler using mainly locally sourced material. The scope of this project is to design a portable boiler that can produce steam at a pressure of 3.2bar, with a pump flow rate of 1.5PH. The challenge encountered in this project was the possibility of Overcoming corrosion as to the proper material to be selected for the construction of the boiler. Furthermore, the proper coiling of the coil into a spiral shape was another challenge encounter during construction. The industrial structures of power merging several energy resources, together with renewable are accessible in articles available in literature of energy resources globally [3-6].

2. REVIEW OF LITERATURE

The field of energy is expanding, as researchers are gradually shifting research attention from fossil fuel to renewable energy [7-10]. A boiler is an enclosed pressure vessel were by fluid (water) is heated and vapour or steam is generated by means of direct application of energy from combustion of fuel (LPG) [11]. The steam generating boilers roots go back to the late 1700s and early 1800s with the development of the Kettle-type boiler, which simply boiled water into steam. The water was placed above a fire box and then boiled into steam. It wasn't until around 1867, with the development of the convection boiler that the steam generating industry began. It may be debated who developed the first steam generating boiler. However, most will agree that George Babcock and Steven Wilcox were the two of the founding fathers of the steam generation boiler. They were the first to patent their boiler design, which used tube inside a fire brick walled structure to generate steam, in 1867, and they formed Babcock and Wilcox Company in New York City in 1891. Research on renewable energy is becoming far popular [12]. The research conducted by [13] gave deeper insight into the existing design, with a grate at the bottom of the boiler. As the fuel traveled across the inside of the boiler, it was burned and the ash or unburned fuel would drop into a happer. It is important to detail the types of boiler in the next section of this research.

2.1 Types of Boiler

Boilers are of different types. They include but not limited to: Water tube boiler, fire tube boiler, solid fuel firing and others

2.2 Parts of Boiler

Boiler Burner – This is the central element of effective combustion system design which includes fuel preparation, air fuel distribution, furnace design and come vice that supplies required amount of fuel and air and creates a condition of rapid mixing and produce flame. The mixing rate of air and fuel directly affects the flame stability, shape and emission. Stable and proper operation in the range of design parameters, Low pollution, Low level of noise, longer life time, Security of operation

Types of Burner

Depending on the type of fuel, design and application there are different types of burners. Gas burners and oil burners.

Feed Water Pumps

In feed water pump, water is drawn through the inlet of the pump and discharged through the outlet of the pump as the column of water is moved by the pump. Since this is a rotary pump, the flows of feed water maintain its speed. For example, at 40% of boiler output, the pump runs at 40% of full/maximum speed.

The rotary feed water pump, designed and manufactured to delivers feed water continuously into the heating coils. The pump can handle water up to 4640F (240° C) and the output flow is not affected by back pressure. The pump is operated hydraulically by fluid displaced within the pump crankcase.

Heat Exchanger Coils

The heart of a boiler is the Heat Exchanger, Heat is transferred from the combustion gases to the feed water via this unique spirally wound coil. The coil has been designed to control the feed water flow inside the tubes. The heating coils consist of three sections: a main generating section, an upper water wall section and a lower water wall section that forms the combustion chamber. The upper water wall section is a single wrap around the outer top portion of the generating section. The main generating section is typically comprised of three to five spirally wound layers. Lower water wall sections are a single outer wrap of coil around the main combustion chamber which provides heat transfer surface area. The flow of water in the coil is counter to the flow of hot gases. This counter flow design helps provide optimum heat transfer and is one of the factors which lead to the high efficiency of the Steam Generator (boiler). The entire coil is encased in carbon steel and an insulator at the outer shell.

Steam Separator

Temperature and moisture control are paramount to almost all manufacturing processes. A mechanical separator is design to helps maintain process stability by providing constant high quality steam throughout its operating range. Higher quality steam means fewer contaminants in the steam and less fouling of the system and products. 99.5% quality steam separator minimizes moisture. This steam separator yields the driest saturated steam available in a size range. The water removed during separation is sent to the feed water tank.

A 99.5% quality steam separator is ideally suited to projects where high quality steam is required to provide optimum performance in the steam system. Typical applications include food processing (such as grain).

Valves

Valve is a component 3which add or increase the energy of a fluid, it also regulate fluid flow. Long life, corrosion resistance springs, disk and seal etc are used in the check valve housing. Snubbers are added or attached in check valve to absorb pressure pulsation and ensure stability water plow. Relieve valve is provided to protect the valve against excessive over pressure.

Metal Pipes

Is a hollow cylindrical component through which water flow.

Pressure Gauge

The pressure of this boiler was ascertain using pressure gauge, the pressure gauge is mounted on the boiler shell to read the boiler pressure, it is also mounted on the feed water tank as well as on the separator to know the pressure of the steam.

Bolt/Nuts

Bolt is required to ensure stability on both the shell and the tank, bolt is fastened through a drilled hole and is used to tie the necessary part together to the base.

3. RELATED MATHEMATHICAL MODEL

Mass flow rate of water converted to steam

$Q_w = M_W C_P (T_2 - T_1)$ 1

Where

M_W = mass flow rate of water

C_P = specific heat capacity

T_1 = atmospheric temperature

T_2 = internal temperature of the boiler

Total heat supplied to the water

$Q_w = Q_H - Q_L$ 2

Where

Q_H = heat produced

Q_L = heat loss

Heat loss

$Q_L = Q_C + Q_{FP}$ 3

Where

Q_C = rate of heat transferred to a cylindrical material

Q_{FP} = rate of heat transferred to a flat plate

The rate of heat transferred to a cylindrical material

$$=Q_C = \frac{2\pi L\,(t_i - t_0)}{\frac{1}{h_i} + \frac{in(\frac{r2}{r1})}{K_S} + \frac{in(\frac{r3}{r2})}{K_{ins}} + \frac{in(\frac{r4}{r3})}{K_S}} \quad 4$$

Where

L = length of the plate

r = radius of the plate

t_i = internal temperature

t_0 = outer temperature

The rate of heat produced

$Q_C = M_{LPG}$ x Cv 5

Where

M_{LPG} = mass of LPG (methane)

CV = calorific value of methane

Static pressure head

Sph = Bpr x 2.31 6

Where

Bpr = boiler pressure

Boiler pressure

SPH = ρgh 7

Where

SPH = static pressure head

ρ = density

g = gravity

h = height

The rate of heat transferred to a plat plate

$$Q_C = \frac{K\,A\,(T_i - T_0)}{X} \quad 8$$

Where

K = the coefficient thermal conductivity

A = area of the boiler

T_i = inside temperature of the boiler

T_0 = outer temperature of the boiler

X = thickness of the plate

Area of the boiler

$$A = \frac{\pi\,(D^2 - d^2)}{4} \quad 9$$

D = external diameter of the boiler

d = internal diameter

3.1 Basic Materials for Construction and Uses

Carbon steel

Is a steel with carbon content up to 2.1% by weight. The term "carbon steel" may also be used in reference to steel which is not stainless steel; in this use carbon steel may include alloy steels. As the carbon percentage content rises, steel has the ability to become harder and stronger through heat treating; however, it becomes less ductile. Regardless of the heat treatment, higher carbon content reduces weldability. In carbon steels, the higher carbon content lowers the melting point.

Mild steel

Mild steel (steel containing a small percentage of carbon, strong and tough but not readily tempered), also known as plain-carbon steel and low-carbon steel, is now the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Mild steel contains approximately 0.05-0.259% carbon making it malleable and ductile. Mild steel has a relatively low tensile strength, but it is cheap and easy to form Bailyn, (1994).

Refractory materials

Are used in boilers, furnaces, kilns, incinerators, and reactors, they are also used to make crucibles and moulds for casting glass and metals and for surfacing flame deflector systems for rocket launch structures. Today, the iron - and steel - industry uses approximately 70% of all refractories produced. Refractory materials must be chemically and physically stable at high temperatures. Depending on the operating environment, they must be resistant to thermal shock, be chemically inert, and/or have specific ranges of thermal conductivity and of the coefficient of thermal expansion. Refractories must be chosen according to the conditions they face. Some applications require special refractory materials. Zirconium is used when the material must withstand extremely high temperatures. Silicon carbide and carbon (graphite) are two other

refractory materials used in some very severe temperature Conditions, but they cannot be used in contact with oxygen, as they will oxidize and burn.

Fiber glass

Fiber glass is simply consist of glass fiber, continuous or discontinuous, contained within a plastic matrix composition (weight %) of a glass that is most commonly drawn in fibers (sometimes referred to as E-glass) is a shown in Table 1.

Table-1: Composition of fiber glass

Comp	Percentage	Comp.	Percentage
S_1O_2	55%	C_aO	16%
AL_2O_3	15%	B_2O_3	
MgO	4%		

Glass is popular as a fiber reinforcement material for the following reason: Glass is easily drawn into high strength fibers from the molten state; It is readily available; as a fiber, glass is relatively strong and when embedded in plastic matrix, it produces a composite having a very high specific strength; when coupled with the various mastics, it possesses a chemical useful in a variety of corrosive environments; the surface characteristics of glass fiber are extremely important because even minute surface flaws can deleteriously affect the tensile properties; a large number of different plastic material are utilized for the matrix in fiber glass, the polyesters being the most common, some of the relatively new commercial fiber reinforced composites utilize glass fiber in a matrix, these material are extremely strong and highly impact resistant; in spite of having high strength, most fiberglass materials are united to service temperature below 200^0c and cannot burn easily at high temperatures.

3.2 Material Requirement and Selection

Material selection is a major step in the construction process, because construction duration and aesthetic depend greatly on material selection. The choice of material for this project was reached base on the properties of each of the material and how best they fit the purpose for which they are used. Each of the components was produced with a material that provides the best in degree of effectiveness and efficiency in the operation of the boiler. The different material and their properties which made them applicable for the boiler construction are given in Table 2.

Table-2: Properties of Materials and reasons for their use

PARTS	CHOICE MATERIAL	OF PROPERTIES AND REASONS
Shell	Carbon Steel	Carbon Steel has a percentage carbon up to 2.1%. It has the following properties which are as follows: ductility, weldability, hardability, machinability.
Pipes	Galvanize Pipe	This material has properties which made it usable, which are as follows: corrosion and rust resistance quality.
Tank and separator	Mild Steel	Mild steel has a percentage carbon up to 0.15%. It has the following properties which are: Machiability, weldability.
Refractory material	Fiber Glass	This material also has properties which made them useable which are as follows: Low thermal conductivity, low density, ability to withstand extreme temperature, machiability, tensile strength.

3.3 Joining and Assembling Operation

The assembling of a boiler involved coupling the various components part to form a whole unit. The step involved is as follows: The tank which contains feed water is suspended with a stand at a level and a pipe runs from the tank through the pump to the inlet of the boiler shell; pump is a device which helps to lift the feed water from the tank to the coil, and is connected between pipes with a valve; a valve is connected to a pipe and the valve regulates the flow of feed water; the coiling spiral form is connected at inlet of the boiler shell to the outlet of the boiler shell, and is house in a casing called shell; a burner is attached at the bottom of the boiler which generates heat to heat up the feed water to steam; separator pipe is connected from the outlet of the boiler casing to the separator tank were the steam is finally collected as shown in Figure 1 below.

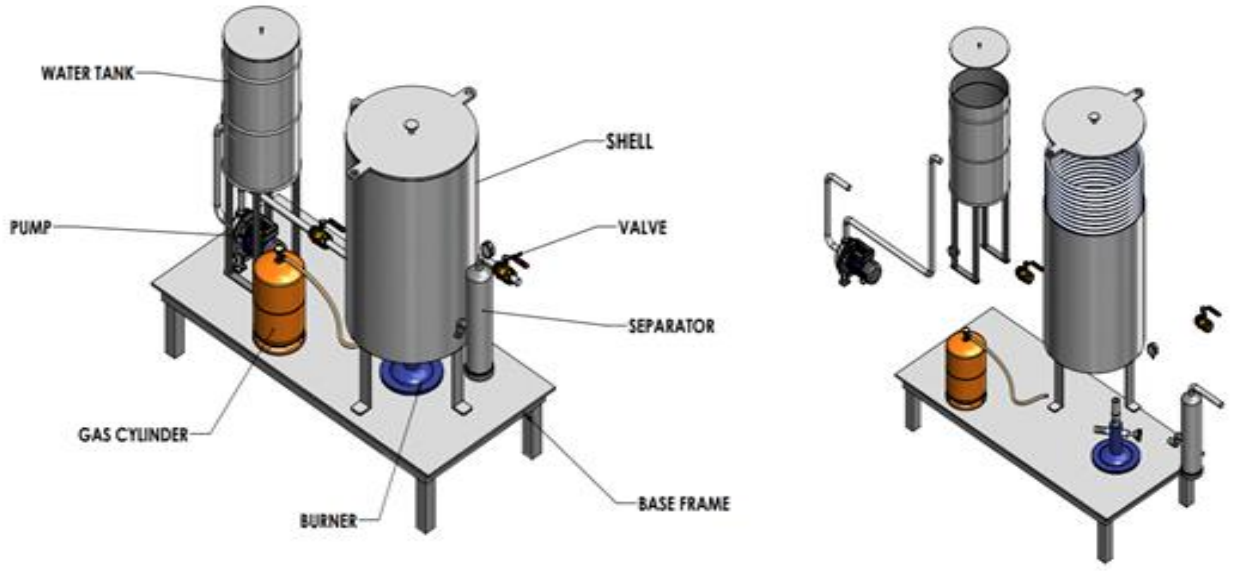

Fig-1: The Isometric and the exploded projetion of portable boiler

4. RESULT AND DISCUSSION

4.1 Result - After assembling the various component parts of the boiler, it was tasted and the result gotten was tabulated presented in Table 3.

Table-3: Result Obtained from Testing the Machine

S/N	TIME	PRESSURE	TEMPERATURE
1	15min	3.2bar	147.9°C
2	25min	3.2bar	147.9°C

4.2. Discussion

From the tabulated result, it was observed that in 15min the pressure of the steam generated was 3.2bar with a saturated temperature of 147.9°C. In 25min pressure and temperature of the steam was constant that is, at a pressure of 3.2bar and temperature of147.9°C. The pressure relive valve mounted on the discharge side of the boiler tends to maintain a required temperature and pressure throughout the operation.

4.3 Operational Procedure

The generation of steam works on the principle of force flow, water tube boiler utilize a steel helical coil heat exchanger. The feed water Pump is a rotary type that is designed and manufactured to pump feed water. The pump continuously supplies feed water to the helical coil heat exchanger through a pipe. A relieve valve attached to the pipe protect against over pressure and maintain a required fluid flow pressure. Heat is transferred from the products of combustion to the feed water; the flow of feed water is counter to the flow of the combustion gases. The flow of feed Water supplied varies in relation to the firing rate of the unit, giving the unit a very consistent and high efficiency which does not decline with firing rate. Excess feed water is supplied to the coil to assure good heat transfer and internal water circulation throughout its operating range. A mechanical steam separator is then used to effectively separate the liquid and vapor mixture exiting the coil and provide consistent steam to a process. This design offers many advantages over conventional units, due to its inherently low water volume. Among these benefits are: Compact size and low weight, high fuel-t-steam efficiency, high level of operator safety.

4.4 Safety and Maintenance

There should be proper fittings to avoid escape of steam which could be dangerous; the outer shell should be coated with an insulator to avoid burning. From indications when components are not properly maintained equipment will tend to perform below standard, when it is in used. Therefore boiler components must be maintained at a regular interval.

5. CONCLUSION

The conclusion of this research is detailed, the steam generator (boiler) produces steam at a pressure of 3.2bar and a saturated temperature of 147.9^0C with a stochiometric air fuel ratio of about 19.621/1 to ensure that the required heat needed to produce steam is generated. Therefore, it is obvious that a major breakthrough or significant success or the steam generator has been achieved, the design is modular and in a good working condition. The study further recommends upcoming researchers to focus on the use of aluminum for the water tank in order to avoid corrosion which will result into low steam production and more fuel consumption. The study further recommend that pressure relive valve should be incorporated into the system. Temperature and pressure gauge should also be incorporated to expand the work further; the steam separator should be added to the expanded boiler type. Conclusively, the developed system is efficient and productive.

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