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Development and Optimization of a Corncob-Fueled Fluidized Bed Water Tube Boiler for Sustainable Energy Generation: A Review

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Abstract: *This research investigates the design, performance, and optimization of a fluidized bed water tube boiler fueled by corncobs for sustainable energy generation. The study evaluates various boiler designs, including "A," "D," and "O" types, focusing on their suitability for corncob combustion. Additionally, the research explores the operation and characteristics of bubbling fluidized bed (BFB) and circulating fluidized bed (CFB) boilers, analyzing their potential for corncob utilization. Furthermore, the investigation delves into biomass energy extraction methods and the significance of utilizing agricultural waste as a renewable energy source. Through a review of past works, including studies on biomass energy production, fluidization regimes, and boiler design, the research identifies gaps and opportunities for the development of a corncob-fueled boiler. The study proposes a novel approach to harnessing agricultural waste for steam generation, aiming to address fuel shortages, reduce emissions, and promote sustainable energy practices. The outcomes of this research contribute to advancing boiler technology for environmentally friendly energy production and offer insights into optimizing biomass utilization for industrial and domestic applications.*

Keywords: *Fluidized Bed Boiler, Corncob Fuel, Biomass Energy, Sustainable Energy Generation*

INTRODUCTION

Steam generator is a complex integration of furnace, superheater, reheater, boiler or evaporator, economiser and air preheater, along with various auxiliaries such as pulverizers, burners, fans, stokers, dust collectors and precipitators, ash-handling equipment, and chimney or stack. The boiler (or evaporator) is that part of the steam generator where phase change (or boiling) occurs from liquid (water) to vapour (steam), essentially at constant pressure and temperature (Nag, 2008). Thermal energy released by combustion of fuel is transferred to water, which vaporizes and gets converted into steam at the desired temperature and pressure.

The steam produced is used for:

i. Producing mechanical work by expanding it in steam engine or steam turbine

ii. Heating the residential and industrial buildings

iii. Performing certain processes in the sugar mills, chemical and textile industries

Boiler is a closed vessel in which water is converted into steam by the application of heat. Usually boilers are coal or oil fired. A boiler should fulfill the following requirement:

i. Safety: The boiler should be safe under operating conditions.

ii. Accessibility: The various parts of the boiler should be accessible for repair and maintenance.

iii. Capacity: The boiler should be capable of supplying steam according to the requirements.

iv. Efficiency: To permit efficient operation, the boiler should be able to absorb a maximum amount of heat produced due to burning of fuel in the furnace.

v. It should be simple in construction and its maintenance cost should be low.

vi. Its initial cost should be low.

2.2 Boiler Terms

In designing a boiler for any applications, the terms used are as follows (Rajput, 2010).

i. Shell: The shell of a boiler consists of one or more steel plates bent into a cylindrical form and riveted or welded together. The shell end is closed with end plate.

ii. Grate: It is the platform in the furnace upon which fuel is burnt and it is made upon cast iron bars. The bars are arranged that air may pass onto the fuel for combustion. The area of the grate on which the fire rests in a coal or wood boiler is called grate surface.

iii. Furnace: It is a chamber formed by the space above the grate and below the boiler shell, in which combustion takes place.

iv. Water space and steam space: The volume of the shell that is occupied by the water is termed water space while the entire shell volume less the water and tubes space is called steam space.

v. Mountings: The items such as stop valve, safety valve, water level indicator, pressure gauge, fusible plug, blow-off cock etc., are termed as mountings and a boiler cannot work safely without them.

vi. Accessories: The items such as superheaters, economisers, feed pumps etc., are termed as the accessories and they form an integral part of the boiler. They increase the efficiency of the boiler.

vii. Water level: The level at which water stands in the boiler is called water level. The space above the water level called steam space.

viii. Foaming: Formation of steam bubbles on the surface of the boiler water due to high surface tension of water.

ix. Scale: A deposit of medium to extreme hardness occurring on water heating surface on boiler because of an undesirable condition in the boiler water.

x. Blowing off: The removal of mud and other impurities of water from the lowest part of the boiler (where they usually settle) is termed as blowing off. This is accomplished with the help of a blow cock or valve.

xi. Lagging: Blocks of asbestos or magnesia insulation wrapped on the outside of the boiler shell or steam piping.

2.3 Types of Boilers

Boiler systems are classified in a variety of ways. They can be classified according to the end use, such as for heating, power generation or process requirements. Alternatively, they can be classified according to pressure, materials of construction, size tube contents (for example, waterside or fireside), firing, heat source or circulation. Boilers are also distinguished by their method of fabrication. Accordingly, a boiler can be packaged or field erected. Sometimes boilers are classified by their heat source. For example, they are often referred to as oil-fired, gas-fired, coal-fired, or solid-fired boilers (Power line, 2003). Finally, boilers are distinctly classified according to their applications (Nag, 2008):

a) Utility boilers: Are those used by utilities for electric-power generating plants. Depending on weather the pressure of the steam is below or above critical pressure (221.2 bar), they can be either subcritical or supercritical 2units. The subcritical steam generators are water tube-drum type and they usually operate at between 130 and 180 bar steam pressure. The supercritical steam generators are drumless once-through type and operate at 240 bar pressure or higher. The majority of the utility steam generators are the 170-180 bar water tube-drum variety, which produced superheated steam at about 540-560^{0}C, while the steam ranges between 120 to 1300kg/s.

b) Industrial steam boilers: Are those used in process industries like sugar, paper, jute, and an institution like hospitals, commercial and residential building complexes (Nag, 2008). They can be pulverized coal fired, fluidised bed or stoker fired units, with coal mostly as fuel. They can be heat recovery types which use waste heat from various industrial processes, and are termed waste heat generators. They operate at pressures ranging from 5 to 105 bar with steam capacities up to 125kg/s.

c) Marine boilers: Are used in many marine ships and ocean liners driven by steam turbines. They are usually oil-fired and produced superheated steam at about 60 to 65 bar and 540^{0}C.

The two basic types of boilers are;

I. Fire tube boiler

II. Water tube boiler

2.3.1 Fire tube boilers

Fire tube boilers consist of a series of straight tubes that are housed inside a water-filled outer shell. The tubes are arranged so that hot combustion gases flow through the tubes. As the hot gases flow through the tubes, they heat the water surrounding the tubes. The water is confined by the outer shell of boiler. To avoid the need for a thick outer shell, fire tube boilers are used for lower pressure applications. Fire tube boiler are subdivided into three groups; Horizontal return tubular (HRT) boilers typically have horizontal, self-contained fire tubes with a separate combustion chamber. Scotch, Scotch marine, or shell boilers have the fire tubes and combustion chamber housed within the same shell. Firebox boilers have a water-jacketed firebox and employ at most three passes of combustion gases (Nag, 2008). Most modern fire tube boilers have cylindrical outer shells with a small round combustion chamber located inside the bottom of the shell. Depending on the construction details, these boilers have tubes configured in one, two, three, or four pass arrangements. Because the design of fire tube boilers is simple, they are easy to construct in a shop and can be shipped fully assembled as a package unit.

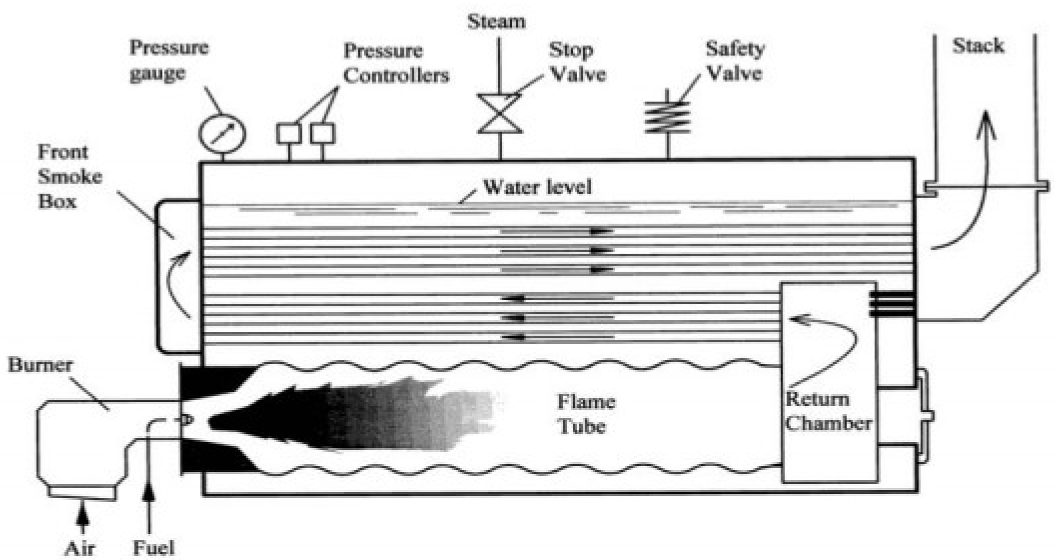

Figure 2.1: Schematic Diagram of a Fire Tube Boiler
(Source: Nag, 2008)

2.3.2 Water tube boiler

Water tube boilers are designed to circulate hot combustion gases around the outside of a large number of waters filled tubes. The tubes extend between an upper header, called a steam drum, and one or more lower headers or drums. In the older designs, the tubes were either straight or bent into simple shapes. Newer boilers have tubes with complex and diverse bends because the pressure is confined inside the tubes, water tube boilers can be fabricated in larger sizes and used for higher-pressure applications (Power line, 2003). Small water tube boilers, which have one and sometimes two burners, are generally fabricated and supplied as packaged units because of their size and weight, large water tube boilers are often fabricated in pieces and assembled in the field. In water tube or "water in tube" boilers, the conditions are reversed of "fire tube" with the water passing through the tubes and the hot gases passing outside the tubes. These boilers can be of a single or multiple-drum type. They can be built to any steam capacity and pressures, and have higher efficiencies than fire tube boilers. Almost any solid, liquid or gaseous fuel can be burnt in a water tube boiler (Mozes, 2001). The common fuels are coal, oil, natural gas, biomass and solid fuels such as municipal solid waste (MSW), tire-derived fuel (TDF) and refuse derived fuel (RDF). Designs of water tube boilers that burn these fuels can be significantly different.

According to (Power line, 2003), Package water tube boilers come in three basic designs: A, D and O type. The names are derived from the general shapes of the tube and drum arrangements. All have steam drums for the separation of the steam from the water, and one or more mud drums for the removal of sludge.

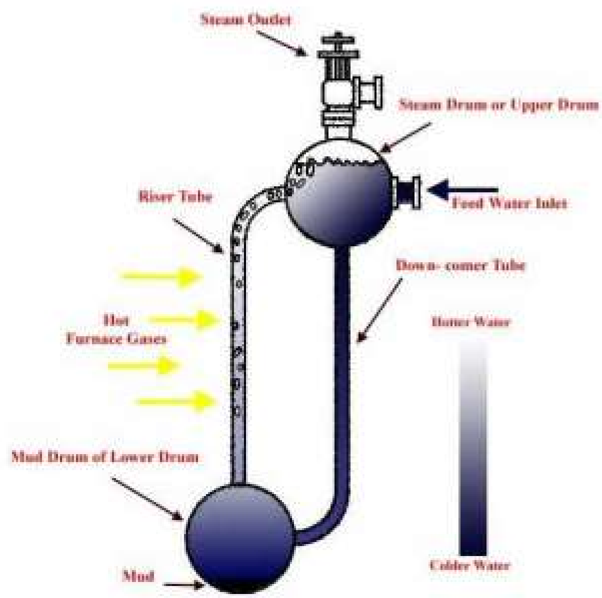

Figure 2.2: Schematic diagram of Water-Tube Boiler
(Source: http://www.electric4u.com)

2.3.2.1 "A" type boilers

This design is more susceptible to tube starvation if bottom blows are not performed properly because "A" type boilers have two mud drums symmetrically below the steam drum. Drums are each smaller than the single mud drums of the "D" or "O" type boilers. Bottom blows should not be undertaken at more than 80 per cent of the rated steam load in these boilers. Bottom blow refers to the required regular blow down from the boiler mud drums to remove sludge and suspended solids (Power line, 2003).

2.3.2.2 "D" type boilers

"D" type boilers have the most flexible design. They have a single steam drum and a single mud drum, vertically aligned. The boiler tubes extend to one side of each drum. "D" type nboilers generally have more tube surface exposed to the radiant heat than do other designs. "Package boilers" as opposed to "field-erected" units generally have significantly shorter fireboxes and frequently have very high heat transfer rates (788.120kW/m^2). For this reason, it is important to ensure high-quality boiler feed water and to chemically treat the systems properly. Maintenance of burners and diffuser plates to minimize the potential for flame impingement is critical (Power line, 2003).

2.3.2.3 "O" types boilers

"O" design boilers have a single steam drum and a single mud drum. The drums are directly aligned vertically with each other and have a roughly symmetrical arrangement of riser tubes.

Circulation is more easily controlled, and the larger mud drum design renders the boilers less prone to starvation due to flow blockage, although burner alignment and other factors can impact circulation (Power line, 2003).

2.4 Fluidised Bed Boiler

Fluidised bed boiler produce steam from fossil, biomass and solid fuels such as municipal solid waste (MSW), tire-derived fuel (TDF) and refuse derived fuel (RDF) by using a technique called fluidised bed combustion. The boiler is excellent for burning low value fuels and has a great advantage as it can burn several different fuels at once. The characteristic feature of the fluidised bed combustion compared to conventional boilers is that the combustion takes place in a fluidised bed of inert solid material. The fluidization is created by the upward flow of combustion air. The operating temperature of a fluidised bed boiler is narrow, around 800-900°C. Lower temperatures lead to decreased boiler efficiency while a too high temperature can lead to ash sintering, causing the bed to clog. The fluidised boilers are of mainly two types viz.

i. Bubbling fluidised bed (BFB) boiler
ii. Circulating fluidised bed (CFB) boiler

2.4.1 Bubbling fluidised bed (BFB) boiler

Bubbling fluidised bed boilers (BFB) are often preferred in small-scale applications, with fuels having low heat value and high moisture content. The core of the BFB boiler is the combustion chamber or furnace. The bed is fluidised by means of an arrangement of nozzles at the bottom of the furnace which create turbulence that enhance the mixing of the fuel, increasing the boiler's efficiency by converting unburned carbons remaining too usable energy. The bed is usually formed by sand and with a small amount of fuel and fluidization depends on particle size and air velocity, recent test suggests that sand particles of about 350µm give better bubbling. Solids fluidization occurs when a gaseous stream (primary air) passes through a bed of solid particles at enough velocity (above the minimum fluidization velocity) to overcome the particles gravity force. The bed depth of almost all BFB is usually between 0.9m – 1.5m deep. However, bed height as low as 52, 105, 131 and 157mm (Rozainee *et al.,* 2013) has been used for experimental purpose. Since part load are usually considered in designing BFB boilers, heat absorption in the bed can be changed by adjusting the bed depth allowing load change of up to 5% per minutes. More so, deeper beds give greater combustion efficiency since they provide longer residence time for combustion. In addition, choices of fuel and combustion requirement are factors to be considered when determining the bed depth (Basu, 2006). Limestone might be added to the bed to eliminate sulphur and/or chlorine. The boiler overall constructive simplicity, together with the turbulent, low temperature bed and the ability to regulate the fluidization velocity and secondary and tertiary air quantities, is what drives the BFB to excel other non-fluidised technologies in terms of fuel flexibility, efficiency, emissions and lower capital and maintenance costs. A schematic figure of the bubbling fluidised bed boiler is shown in figure 2.3 below.

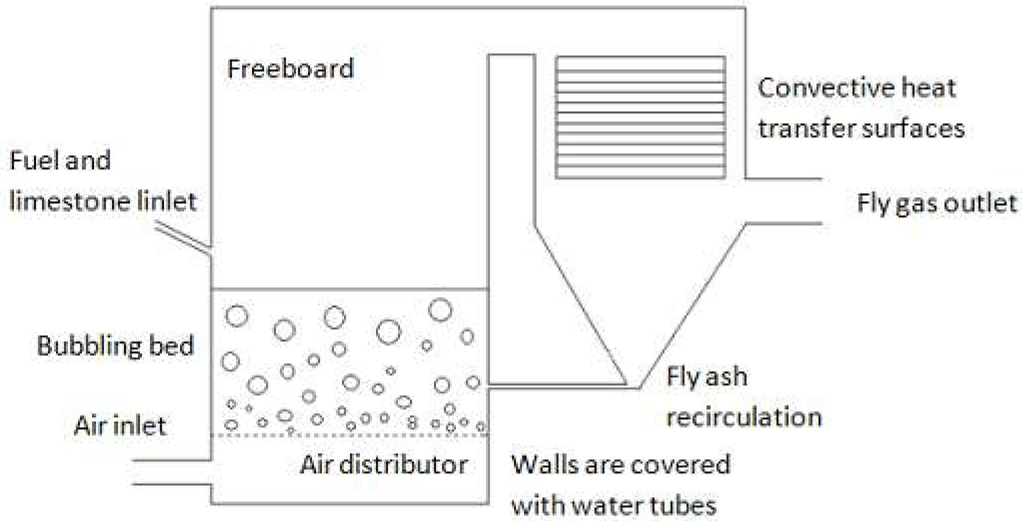

Figure 2.3: Bubbling Fluidised Bed Boiler
(Source: Mattias, 2012).

2.4.2 Circulating fluidised bed (CFB) boiler
CFB boilers are normally used in larger applications, being similar in basic concept to the BFB. The configuration includes solid separators that separate the entrained particles from the flue gas stream and recycles them to the lower furnace. The collected particles are returned to the furnace via the loop seal. The addition of the solid separators as well as other measures as the superheater allows CFB technology to reach the higher values regarding efficiency and availability and provides excellent fuel flexibility (Jose Alberto, 2011).

2.5 Energy from Biomass
Biomass is an organic matter produced by plants in both land and water; it includes forest crops, the crops which are grown in energy farms, and animal manure. While fossil fuels takes millions of year to form, the biomass is an alternate fuel, the source which may be considered renewable, since plant life renews and add itself every year. It is the solar energy stored by way of photosynthesis and the product of photosynthesis (or biomass), are called biofuels. The biomass can be converted to variety of solid, liquid and gaseous fuels (Nag, 2008). Wide use of solid fuels and interest associated with energy production from biofuels such as wood, sawdust, wood chips and other industrial and agricultural waste cause development of solid fuel combustion technologies. Each year, farming and agricultural processing generate millions of tonnes of residues, such as maize cobs and husks, groundnut shells, rice straw, banana stems, soy hulls and sugar beet pulp (Ruan *et al.,* 1996; Azubuike and Okhamafe, 2012). Therefore, the development of energy from biomass is one area among the various energy alternatives that has considerable promise and is receiving attention. Biomass is also a non-conventional and renewable energy obtainable mainly from organic matter and plants residue. These materials can be obtained at a low cost from a variety of sources, but the content and quality of the three major structural polymeric components (lignin, cellulose and

hemicellulose) depend on the type of material (Taherzadeh and Niklasson, 2004). Their utilizations are attracting increased interests around the world, particularly for the production of novel materials for environmentally friendly industrial applications after chemical modification (Pandey *et al.,* 2000; Richardson and Gorton 2003).A wide variety of techniques is available to utilize biomass resources (Nag, 2008):Direct combustion: The most efficient have been to burn them directly for heat the crop residues that are commonly used as sources of energy includes rice husks, sugar cane fiber, groundnut shells, maize cobs, coconut husks and palm oil fiber etc. (Kyauta *et al*., 2015). Thermochemical conversion: This takes two routes, viz. gasification and liquefaction.

Gasification is done by heating the biomass with limited oxygen to produce low heating value gas or by making biomass react with steam and oxygen at a high pressure and temperature to produce medium heating value. The latter may also be subjected to liquefaction by converting it to methanol and ethanol (Nag, 2008). Biochemical conversion: This conversion takes two routes; anaerobic digestion and fermentation. Anaerobic digestion is the bacterial decomposition of organic matter (biomass) in the absence of air or oxygen to ultimately produce a gaseous mixture (biogas) of methane and carbon dioxide in a roughly 2:1 volume ratio. Fermentation is the breakdown of complex
molecules in organic compounds with the help of ferment such as yeast, bacteria, enzymes, etc. (Nag, 2008). Furthermore, the use of biomass as alternative sources of energy is attractive because it addresses both problems of waste disposal and fuel wood shortages so the extraction of useful energy from biomass could bring very significant social and economic benefits to both rural and urban areas.2.6 Regimes of gas-solid Fluidization The regimes of a gas-solid mixture can be classified into the following categories; fixed bed, bubbling bed, turbulent bed, fast fluidization and pneumatic transport. A schematic figure of these regimes is illustrated in Figure 2.4, along with the characteristic pressure drop over the bed at the specific regime (Nag, 2008).

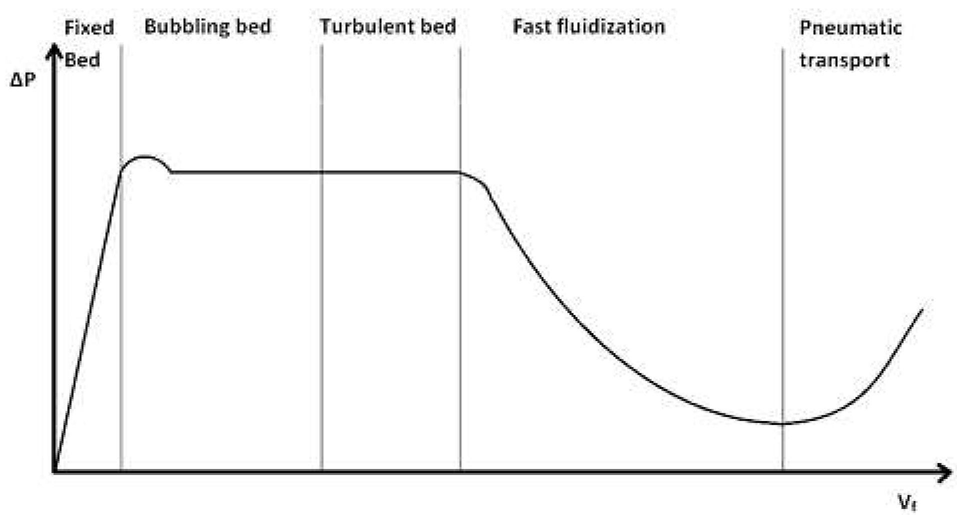

Figure 2.4: Variation of Pressure Drop with Superficial Velocity

(Source: Mattias, 2012).

From the figure above, it is clear that the pressure drop increase with increasing gas velocity until the onset of fluidization and thereafter maintain a constant value, equal to the weight of the bed. The small peak of the pressure drop at the onset of fluidization is due to the presence of adhesive forces between the particles, which disappear as the particles begin to move. With velocities slightly above minimum fluidization velocity, bubbles begin to form and the bed can be considered to be composed of two phases; the emulsion phase with solids and gas at fluidization and the bubble phase, which is almost free of particles. The bubbles contribute largely to the mixing of the bed, with particles flowing upwards in the wake of the bubbles and particles flowing downwards around the bubbles and at the walls. When bubbles reach the surface they burst, hurling particles far above the bed (Mattias, 2012). As the gas velocity is increased the bubbling bed is expanding and finally reaches the turbulent fluidization regime where larger bubbles are split into smaller and irregularly shaped voids and the bed starts to homogenize. The transition from bubbling to turbulent bed takes place gradually as the velocity is increased and an exact limit can be hard to determine.

By further increasing the fluidization velocity the bed reaches the so called fast fluidization regime where the number of particles entrained in the flow abruptly increases. During this regime a large part of the particles are entrained in the flow, even though many fall back as they come further up in the boiler. This backward flow of solid particles creates a very intense mixing and large solid-gas interaction and some units are therefore designed to operate in this regime, these are called circulating fluidised beds. As many particles escape the boiler during this fluidization regime a large recirculation is needed as the whole bed otherwise will be transported out of the boiler (Mattias, 2012). At even higher velocities the back-flow of particles ceases and the particles move uniformly upwards with the gas flow without any strong particle-particle interaction. This flow regime is called pneumatic transport.

2.7 Water Circulation

The flow of water and steam within the boiler circuit is called circulation. Adequate circulation must be provided to carry away heat from the burner system. If circulation is caused by density difference, the boiler is said to have a natural circulation. If it is caused by a pump, it has a forced or controlled circulation.

2.7.1 Principle of natural circulation

In natural circulation boilers, (Figure 2.5), the circulation of water depends on the difference between the density of an ascending mixture of hot water and steam and a descending body of relatively cool and steam-free water. The difference in density occurs because the water expands as it is heated, and thus, becomes less dense (Ganapathy, 2003). Another way to describe natural circulation is to say that it is caused by convection currents which result from the uneven heating of the water contained in the boiler. Natural circulation may be either free or accelerated. In a boiler with free natural circulation, the generating tubes are installed almost horizontally, with only a slight incline toward the vertical. When the generating tubes are installed at a much greater angle of inclination, the rate of water circulation is definitely increased. Therefore, boilers in which the tubes slope quite steeply from steam drum to water drum are said to have natural circulation of the accelerated type (Nag, 2008).

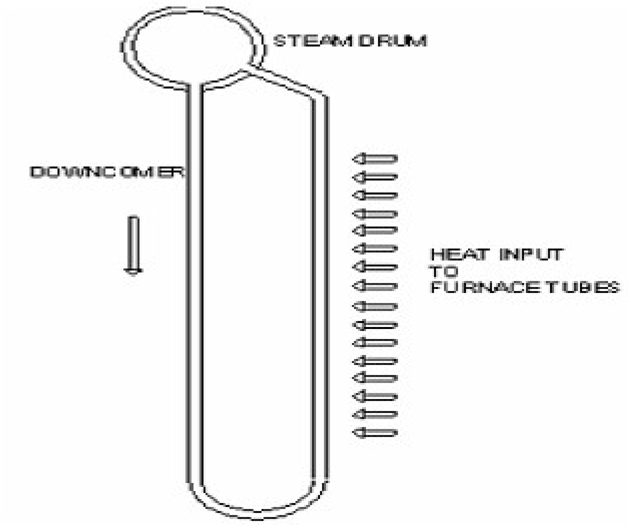

Figure 2.5: Natural Circulation in a Downcomer – Riser Circuit
(Source: Nag, 2008).

2.7.2 Principle of forced circulation

Forced circulation boilers as their name implies, are quite different in design from the boilers that use natural circulation. Forced circulation boilers depend upon pumps rather than upon natural differences in density for the circulation of water within the boiler. Because forced circulation boilers are not limited by the requirements that hot water and steam must be allowed to flow found in forced circulation boilers.

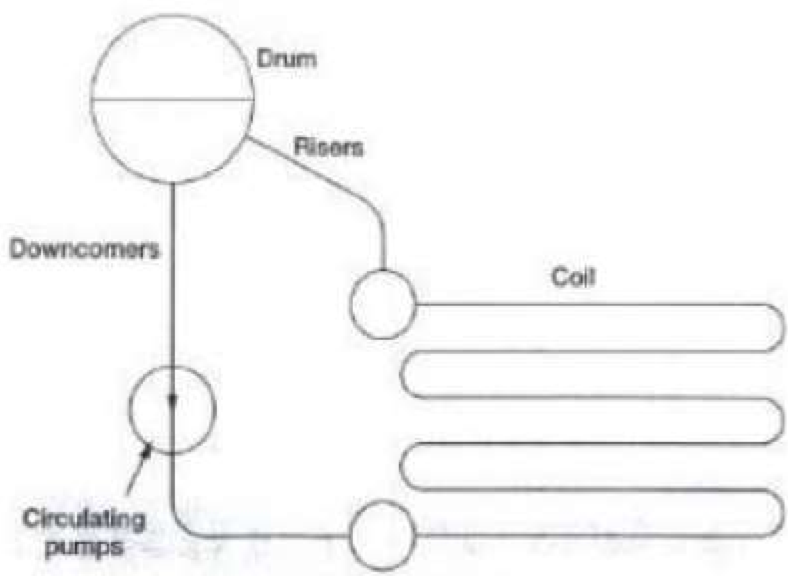

Figure 2.6: Forced Circulation System

(Source: Ganapathy, 2003)

2.8 Review of Related Past works

Folayan et al., (2015) discuss the environmentally friendly methods of extracting biomass energy for rural use. One such means is energy recovery using fluidised bed combustors. This system uses agricultural waste as fuel source to produce heat energy as an alternative to power rural community for light load applications. Test results recorded high flue gas and bed temperatures of over 300°C and 850°C respectively, suitable for rural application including grain drying and water boiling. Kyauta et al., (2015) their paper handles the production and comparative study of solid fuels

from agricultural waste (i.e. maize cobs and groundnut shell) that can serve as alternative energy sources for domestic use, using the densification process. The material were grounded and sieved to particle sizes of 0.425mm and below and was compressed into pellets of 2.5mm diameter and 13mm length at a minimum pressure of 275 bars. The characteristics of the pellets determined were moisture content, ash content, combustion rate and calorific value. The result showed that groundnut shell pellets attained a higher temperature than maize cobs.

The temperatures attained by 100g of each type of fuel were 756oC and 600oC for groundnut and maize cob pellets respectively. The result of the net calorific value test for maize cob was found to be 13.8MJ/kg while that of groundnut shell pellets was 13.9MJ/kg. These results showed that the pellets are capable of generating heat that is sufficient for domestic use if appropriate appliances are used. Ohijeagbon *et al.,* (2013) their work focused on the design of laboratory fire tube boiler for eventual construction and use as teaching aid and for research purposes. Thermodynamics, heat transfer and strength of materials analysis were conducted to estimate dimensions of parts and 3D modelling process was used to draft the working drawing of the steam boiler. Operational, dimensional, and thermodynamic details of the designed steam boiler were determined. The working drawing of designed boiler was also presented. The design enables the availability of portable and affordable steam boiler for steam generation in school laboratory and to enhance research and students' learning process in the area of thermodynamics, heat transfer and energy studies. Rozainee *et al.,* (2013) the purpose of their study was to investigate the effect of bed height on the quality of rice husk ash in a 210-mm diameter pilot scale fluidised bed combustor. The degree of rice husk burning in the fluidised bed could be deduced from the temperature of the combustor and the particle size of the resulting ash.

The turbulence in the bed would break down the char skeleton of the rice husk into finer size. From this study, the bed height of 0.5 Dc was found to give the lowest residual carbon content in the ash (1.9%) and the highest bed temperature (670°C). Moreover, the problem of contamination of amorphous rice husk ash with sand increased as the bed height was increased. Nevertheless, the results from the current study needs to be validated in largerscale fluidised beds to determine whether the bed height of 0.5 Dc is still applicable. Mattias, (2012) demonstrates on dynamic model of a bubbling fluidised boiler. The created model was limited to the gas side in the boiler up to the super heater. The formulated model uses simplified reaction kinetics, fast reactions are considered instantaneous and slow reactions are modeled with

kinetics. Some of the combustion was modeled using empirical correlations only. Heat and mass transfer as well as many other areas are modeled using correlations and semi-empirical models developed specifically for fluidised bed combustion. Simulations of the model show that it yields realistic dynamic and steady state behavior. It is fast enough to run at real time and can therefore be implemented with other objects in Solvina's databases. Important aspects of the model were validated against experimental values found in literature. Comparison of the model with a real bubbling fluidised bed boiler show that it is possible to adapt it to follow the behavior of an existing unit. Jose Alberto, (2011) discussed the technology behind bubbling fluidised bed as being particularly effective when burning reactive fuels with low heating values and high moisture and ash contents, usually referred to as "difficult". The development of the fluidised bed technology over the years has allowed to achieve higher efficiency levels while reducing emissions and increasing fuel flexibility, which are key under current global market and environmental conditions. Finally, he concluded that BFB technology offers good performance in terms of efficiency, fuel flexibility, emissions, and especially in regard to the installation and maintenance costs, being in some cases a better solution than that offered by
other technologies.Agontu, (2009) developed a vertical fire tube boiler from a locally sourced materials for generation of saturated steam used for sterilizing surgical tools and equipment in rural hospitals, clinics and for other related domestic and industrial applications. The result of the
test carried out showed that the medically recommended minimum sterilization temperature of 121oC for hold time of 15 minutes was achieved in all tests and maintained at 121oC.

The average thermal efficiency, fuel consumption and steam generation rates of boiler obtained were 28.7%, 0.67kg/hr and 2.28kg/hr respectively which were consistent with the general performance of most boilers.Zhong *et al.,* (2008) studied the effects of particle size, density, and shape on the minimum fluidization velocity using wood chips, mung beans, millet, corn stalk, and cotton stalk. In this study, they used a rectangular shaped fluidised bed with a cross section of 0 .4 × 0.4 m and air was the fluidizing gas. They determined that for long, thin types of biomass, the minimum fluidization velocity increased with increasing length-to diameter (L/dpt) ratio. Their experiments showed that after the length-to-diameter (L/dpt) ratio exceeded the value of 20, the biomass was not fluidised, indicating that the biomass size and shape affected its fluidization. Hamad *et al.,* (2006) were able to design a fluidised bed combustion unit using shale oil as fuel in direct burning process. Fluidization experiments were conducted on an oil shale test sample extracted from the El-Lajjun deposit. The pressure drop across the bed was plotted against the superficial air velocity for differently sized particles. The minimum fluidized velocity for each size was obtained. The results show a good agreement with calculated values using Ergun equation which was formulated for coal fluidised bed combustion processes, a new empirical equation was formulated to calculate the pressure drop at fluidization conditions. Fast and safe ignition of oil shale was initiated using kerosene. Combustion temperatures ranged between 500 to 1000°C.

Kulla, (2003) developed an improved wood charcoal stove. The average calorific value of the wood and charcoal were to be 26.78 MJ/kg and 32.58 MJ/kg respectively. Test result of this research showed a faster controlled time of 14 minutes for the improved charcoal stove compared to 20 minutes, 26 minutes and 31 minutes for wood stove, kerosene stove, local charcoal stove and electric stoves in that order. Yang, (2003) considered at least six different fluidization regimes for gas-solid fluidized beds: fixed bed, bubbling fluidization, slugging fluidization, turbulent fluidization, fast fluidization, and pneumatic conveying. In the fixed bed regime, the air flowing across the particle does not have enough velocity to move the particles. As the superficial gas velocity (Ug) increases, the system reaches the bubbling fluidization regime. In this regime, bubbles start to form and coalesce causing solid mixing; the velocity at which bubbles appeared is

known as the minimum bubbling velocity (Umb). Hilal *et al*., (2001) analyzed the effects of bed diameter, distributor, and inserts on minimum fluidization velocity. It was shown that both the bed diameter and the type and geometry of the distributor affected Umf. Minimum fluidization velocity values increased with an increase in the number of holes in the distributor plate. Furthermore, with an increase in the bed diameter, there was a decrease in the minimum fluidization velocity. Finally, insertion of tubes along the fluidised bed reduced the cross sectional area, which produced a high interstitial gas velocity causing a decrease in Umf.2.9 Conclusion from the Review and Justification for the Present WorkIn Nigeria, boiler technology has not been accentuated to the point of sourcing local materials for the development of boiler for power generation. In recent times some works have been on boiler using fuel oil for practical purposes and fluidised bed boiler but the problem is now to harnessed agricultural waste as alternate for fuel oil in fluidsied boiler for steam generation. Therefore, this work focused on the fluidised bed water tube boiler which burns corncob as fuel pose to be an alternative to liquid fuel crises with reduced NOX, SOX due to relatively low combustion temperature, reduction in size and design and high rate of steam capacity for research purposes and commercial usage. It is also less corrosive due its ability to burn lowgrade coal and the startup and shut down operation are much easier.

Conclusion

In conclusion, the comprehensive exploration of various boiler types, fluidized bed combustion, and biomass energy utilization offers significant insights into sustainable energy solutions. The examination of "A," "D," and "O" type boilers highlights the importance of proper maintenance and operational considerations to ensure optimal performance and longevity. The discussion on fluidized bed boilers underscores their versatility in burning various low-value fuels efficiently, with bubbling fluidized bed (BFB) boilers being preferred for small-scale applications and circulating fluidized bed (CFB) boilers for larger ones. Furthermore, the review of biomass energy extraction methods emphasizes the potential of agricultural waste as a renewable energy source, promoting both environmental sustainability and economic viability. Lastly, the examination of gas-solid fluidization regimes and water circulation principles provides valuable insights into the operational mechanisms of boilers, paving the way for future advancements in boiler technology. Overall, this body of research underscores the importance of exploring alternative energy sources and efficient boiler technologies to address energy challenges while mitigating environmental impacts.

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