Design of a Hybrid Natural Gas Power Plant Boiler for South African International Airports

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Abstract

Insufficient supply of electricity has necessitated research in renewable energy fields such natural gas power plants. Many diseases in society today are traced to greenhouse gases that are emitted into the atmosphere from many power plant operations. Boilers are the main components for electricity generation but they have high carbon footprint and provide insufficient steam to generate sufficient electricity. Natural gas power plant boilers was designed as a cost effective alternative to satisfying electricity demand and carbon footprint reduction .The boiler is used in power plant to produce high pressured steam and passes it into a turbine to power the generator to generate electricity. Three concepts were developed and rated with the one with highest score chosen. The model in this paper is novel since some features were added in this project.

Keywords

Steam, Natural gases, electricity, greenhouse effect, boiler, turbine design concept.

1. Introduction

The boiler of natural gas power plant was designed to generate electricity while reducing carbon footprint and cost. Boilers in power plants are used to produce high pressured steam, so that electricity will be generated. This process of generating electricity is known as rankine cycle. It must be taken into consideration that this type of boiler should not release harmful gases to atmosphere because it may result to global warming which is caused by greenhouse gases that are emitted by energy sources to the atmosphere and the temperature on earth will gradually increase.

South Africa as a country is facing the problem lack of sufficient electricity to meet all the customers demand. .To overcome this problem more boilers of natural gas must be designed to boost electricity supplied to the customers meets demand. The main goal of designing a boiler of a gas power plant is to extract as much of the energy from the fuel as possible. In this design cow dung (as natural gas) is

burned in a boiler to heat water up until steam is produced that will generate electricity (Mohammed 2009).

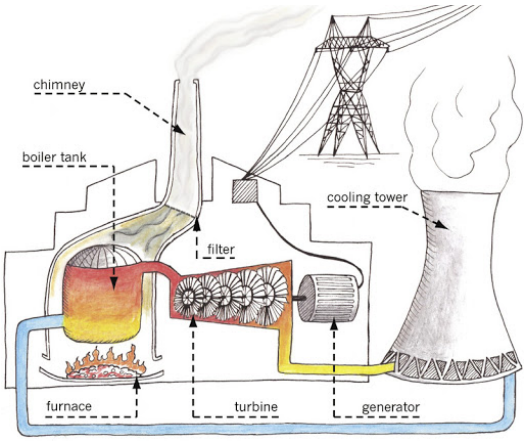

Figure 1 Operation in power plant (1)

Figure 1 shows use of a boiler during electricity generation. Water is heated by combination of fuel and oxidising agent (oxygen in most cases) and water is converted into steam which will move at a very high speed to power the turbine to generate electricity (Mohammed 2009). Some Natural Gas Boilers

2.1. Industrial gas hot water boiler

Label	: Hot water
Product thermal capacity	: 0.35 -14 MW
Working pressure	: 0.7 -1.25MPa
Available fuel	: Natural gas
Available industries	: heat supplying, hospital, hotel

2.2. Oil steam boiler

Label	: steam
Product thermal capacity	: 0.5 -20 t/h
Working pressure	: 0.7 – 2.5MPa
Available fuel	: Natural gas
Available industries	: heat supplying, chemical, food, textile, printing and dyeing

2.3. Atmospheric hot water boiler

Label	: Hot water
Product thermal capacity	: 0.1 -2.8 t/h
Working pressure	: Atmospheric pressure
Available fuel	: Natural gas
Available industries	: heat supplying, chemical, food, textile, printing and dyeing

2.4. Low pressure boiler

Label	: Hot water
Product thermal capacity	: 0.23 -0.7 t/h
Working pressure	: Atmospheric pressure
Available fuel	: Natural gas
Available industries (Dominic 2002)	: heat supplying, chemical, food, textile, printing and dyeing

3. Components of a Natural Gas Boiler

The boiler has many components (Figure 2) which help in increasing the efficiency during the process of producing steam.

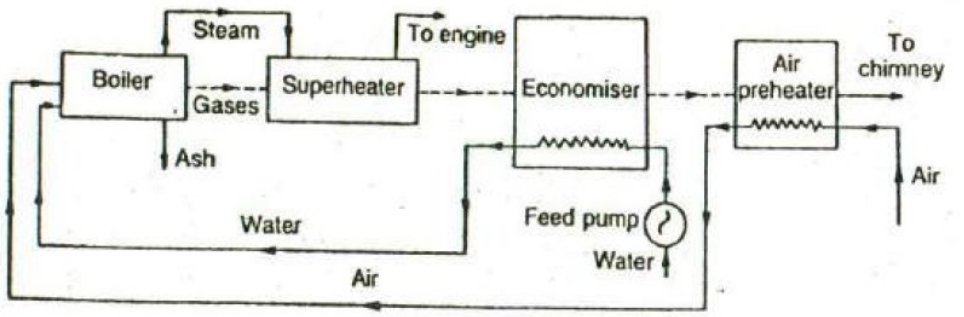

Figure 2: schematic diagram of a boiler plant [7]

3.1 Feed Water Pump

For the whole process of boiling to occur firstly there must be constant water supply at high pressure. Feed water pump is well known as boiler component that supplies water to the boiler at high pressure from the water feed tank water.

3.2 Pre-Heating

Steam from the turbine is used by the preheater to heat up water before entering the boiler.

3.3 Air preheater

Heat on exhaust flue gases is recovered by air preheater, this component is usually mounted between the economiser and the chimney.

3.4 Economiser

This component contains a set of steel coils located at the bottom of the boiler. Natural gases that are released from combustion of heat and oxidizing agent heat up water in the coils. This is the point where lot of sensible heat is absorbed. Form this component water with temperature less than that of saturation is sent to the drum.

3.5 Drum

This is the large cylindrical vessel which is used to store and feed water to other parts of the boiler in assuring that sufficient water is supplied for the process. This part of the boiler is conceded as one of useful parts. Weight of 250 Tons is enough for 600 MW power plant.

3.6 Water Walls

This is the place where boiling of water takes place. Water walls are tubes that form walls of the furnace and they are filled with water. The selected concept have down comers which are large pipe connected to the drum to supply water to water walls. At the end two legs of water column is formed by water wall tubes and down comers. It is noted that the temperature under this part of the boiler is saturated which mean produced steam will be wet. The main objective of heating water in water wall tubes is to convert water into highly pressured steam. The process of changing state of substance from liquid to steam or gas lowers the density of water-steam mixture compared to that of water alone. This density is to make sure that water that was not converted into steam goes back to the drum. The steam is then sent to the turbine using superheated steam exit to leave the boiler.

3.7 Superheater

As the steam moves from the drum superheater coils, the temperature of steam will increase above the saturation temperature until the maximum required temperature to produce superheated steam is determined. The produced superheated steam moves to a turbine at a very high pressure. For large power plants the maximum temperature ($T_{superheater}$) ranges between 540 °C and 570 °C and the superheated steam pressure is approximately 175 bar (Dominic 2002).

Development of Hybrid Natural Gas Boiler Model

Under this concept the heat caused by combustion of the gases experienced on the pipes filled with water, the material of these pipes are good enough for heat transfer from combustion to water through water tubes. The thermal conductive of the material used to manufacture these tubes is very high to achieve good heat conduction. Water is released from water tank and passed into economizer which provides high ovarall boiler thermal efficiency by recovering low energy from flue gases before it is exhausted to the atmosphere, this is done by heating feed water. This concept also has superheaters to make sure that the steam is heated enough to power the turbine. Since the other objective of this design is reduce cost when generating electricity, waste product from animal species is used as the source of heat in this design. Cow dung are stronger than chacoals in terms of generating heat for a long period. Under this type of boiler the volume of one unit of steam is 100 times that of water, tubeless boiler convert this volume in a closed vessel for a purpose of increasing pressure to generate highly pressured steam in tubeless boiler, Figure 3.

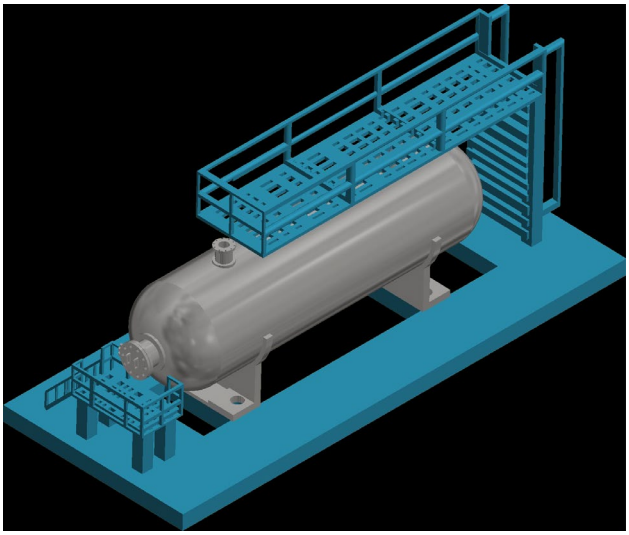

Figure 3 Hybrid boiler design

Three stages on how water is converted into steam are;

- **Sensible heat addition**

Water is heated by burning cow dung from cold condition to saturation temperature also known as boiling point.

- **Latent heat addition**

After water reaches the boiling point at saturation temperature steam is produced.

- **Superheating**

The steam is heated again from saturation temperature to higher temperature. This high temperature of steam will increase power plant output and efficiency.

4. Model Testing

According to theory of boilers performance, the factor of evaporation must be greater than the boiler efficiency. Table 1 with summary of calculation has the calculated values of the two parameters, which obeys to the theory of boilers performance. The designed pressure vessel is seem to be safe when looking at its safe pressure and the maximum pressure of existing pressure vessels.

Table 1 summary of design calculations

Parameter	Value
Dry steam	$h = h_g = 2234\ kj/kg$
Wet steam	$h = 2173.5\ kj/kg$
Superheated steam	$h = 2466\ kj/kg$
Equivalent evaporation	$h = 3.94\ kg/h$
Factor of evaporation	0.864
Boiler efficiency	24.43%
Heat supplied by 1 kj of fuel	$h = 34629 kj/kg$
Heat utilised in raising steam	$h = 8724.6\ kj/kg$
Heat carried away by dry fuel gases	$h = 8.88\ kj/kg$
Heat carried away by moisture in fuel	$h = 6.9\ kj/kg$
Heat lost to steam by combustion	$h = 4036\ kj/kg$
Maximum safe pressure	$P = 769.23\ kPa$
Maximum shear stress	$\tau = 65.12\ MPa$
Shear strain	$\gamma = 436.35 \times 10^{-6} rad$

5. Cost Analysis

The design must be affordable (as stated under design requirements) to attract many customers. Prices by local vendors for components needed to develop this design were assessed. Prices were sought for online to populate Table 2.

Table 2 cost analysis of the project

Component	Material	Price
Thermometer	Grass	R160
Drum	Alloy steel	R3600
Feed water	Alloy steel	R1200
Water heater pump	Cast Iron	R1200
Furnace Drum	Ducal W30	R4000
Economiser	Low carbon steel	R3750
Super heater	Stainless steel	R4200
Steam absorber	Copper	R 4000
Total		**R 20910**

6. Other Design Considerations

6.1 Safety, maintenance and repair considerations

Boilers in power plants are operated at a very high temperature, thus some safely precautions must be followed. There is an object known as boiler platform designed for boiler maintenance, repair and inspection. Care to be taken while maintaining a boiler are stated here:

- The boiler must operate below designed pressure.
- All natural gas safety precautions must be followed to avoid unnecessary explosion.
- Dirty water not to be introduced into the boiler.
- Boiler must be inspected now and then.
- Movable mechanical parts must be cleaned continuously.
- There must be no leak in the boiler to avoid escape of steam that may result to decrease in efficiency of the boiling process.
- Hot parts of a boiler not insulated are not to be touched.
- All gases removed from the boiler before maintenance of the furnace part of the boiler. The temperature in the furnace is to be lowered to ambient temperature.
- Electricity supply must be switched off to maintenance the boiler.
- Earthling of all electrical equipment to be done.
- Lather grooves must be used while touching hot parts.
- Ensure that there is no pressure in the pressure part of the boiler before opening it.
- Furnace part of the boiler must be removed from the boiler 24 hours before the maintenance for it to get time to cool down.

6.2 Impact of design

Every model has bad and good impacts on the environment, social and health sectors.

6.2.1 Social

The natural gas power plant brings good social life to people. Electricity is one of the things that is needed for electrical appliances and equipment to operate.

6.2.2 Legal

This design obeys all regulations by SANS.

6.2.3 Health

Any project that is potentially harmful to health must not be promoted. The following are bad impact of this project.

- May result to respiratory ailments.
- Causes asthma through harmful gases that are released into the atmosphere.

However, the boiler is designed to increase the generation of electricity that can help in other sectors such as hospitals by providing power.

6.2.4 Environment

Power plant boilers can have some negative impact on the environment. This design is also about reducing carbon footprints but some gases will be emitted to the atmosphere though at lower levels. The boiler has many negative impacts stated here:

a) Ai pollution

Since this design will use natural gases as source of heat, several pollutants will be release from the power plant to air, including greenhouse gases.

b) Water pollution

A lot of greenhouse gases in atmosphere will result to climate change affecting rainfall patterns.

c) Land degradation

If the water and land pollution is not treated, unexpected heavy rains may result casing soil erosion.

d) Noise pollution

There is a lot of noise from power plants causing partial deafness [9].

7. Conclusion

The design of a boiler of natural gas power plant to generate electricity at low cost and reduction in carbon footprint is the aim of this paper. The model reported in this paper generates electricity but is expensive to construct and maintenance. For this reasons, the superheater was introduced into the boiler to increase the temperature and pressure of steam so that the highly pressured steam will leave the boiler at a very high speed to increase the rotation in the turbine to generate electricity. It was noted that some exhaust gases leave the boiler with some heat which was going to be useful in increasing in the efficiency of a cycle in the boiler. As a result heat absorber was introduced before the end of exhaust gas duct.

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