International Journal of Advance Industrial Engineering
E-ISSN 2320 –5539
Available at http://inpressco.com/category/ijaie/

Research Article

Design and Manufacturing of Mini Steam Power Plant

Sunil Chore†*, Pratik Kshirsagar† and S. A. Kulkarni†

†Department of Mechanical Engineering, Sinhgad College of Engineering Pune-41, India

Received 01 Sept 2017, Accepted 01 Nov 2017, Available online 12 Nov 2017, **Vol.7, No.6 (Nov/Dec 2017)**

Abstract

The mini steam power plant is an example of Multiple Input Multiple Output (MIMO) control system. For the steam generator, pressure and temperature of water, heat input are the input key parameters while for turbine pressure, temperature and mass flow rate of steam are key variables at input. The thermodynamic design of boiler involves time taken for the superheated steam at design pressure at required mass flow rate. This superheated steam is given to the turbine. This reaction type steam turbine is designed and manufactured as conventional steam turbine is not possible to manufacture to miniature size. With two major modifications stepper motor is upgraded to steam turbine on the lines of Tesla Turbine. The instrumentation for boiler and steam turbine are mentioned in this paper. The trials are conducted on steam generator and turbine together, by connecting the steam generator output to steam turbine through insulated pipes. So heat input is overall input to mini steam power plant while angular velocity and torque generated by the steam turbine are the overall outputs of this mini power plant. In the case discussed here, the superheated steam at 2 bar pressure and 110^{0}C at 5gm/ sec is produced by steam generator and the steam turbine with 30,000 rpm at 0.217 Nm torque.

Keywords: *Mini Steam Power Plant, Rankine Cycle, Heat Flux, Steam Generator, Bond Graph, Superheated Steam, Screened Rankine Cycle, Tesla turbine, Steam turbine, Bladeless Turbine.*

1. Introduction

This paper shows work of manufacturing of miniature steam power plant. Multiple inputs and multiple outputs (MIMO) control system were required to be demonstrated as a part of Mechatronics curicullam. The steam power plant is one of the best demonstratives for such examples. The commercially available laboratory steam power plants are costlier. These power plants are required to be maintained which adds to the cost and apart this specially trained manpower is required to be deployed as the accident could be serious. Therefore a mini power plant is designed, simulated and fabricated by making reliable modifications in the stepper motor assembly.

The designed system consists of a mini steam generator of 7 liters capacity, with 2 gm/sec mass flow rate of steam, at 2 bar absolute pressure, with steel pipe of maximum 150 mm diameter with suitable and available thickness, with level gauge, over pressure protection, over temperature protection using electrical heater of maximum 3 kW capacity, so that it will be tested for various heights of water inside the tank, which shall establish mathematical model to support the experimental results of time taken to reach desired pressure and temperature. The generated steam is then feed the steam turbine assembly.

*Corresponding author **Sunil Chore** (ORCID ID: 0000-0002-7288-8307) and **Pratik Kshirsagar** are M.E. Scholars; Corresponding author's, **S. A. Kulkarni** is working as Associate Professor

2. Literature Survey

A. Sudheer Reddy *et al* have discussed in detail the basic information of steam turbine and has described steam turbine as mechanical device that converts thermal energy in pressurized steam into useful mechanical work. The steam turbine has better thermodynamic efficiency because of the use of multiple stages in the expansion of the steam. This is a closer approach to the ideal reversible process.

The moving blades rotate on the central turbine rotor and the fixed blades are concentrically arranged within the circular turbine casing which is substantially designed to withstand the steam pressure. In power generation mostly steam turbine is used because of its greater thermal efficiency and higher power-to-weight ratio. Because the turbine generates rotary motion, it is particularly suited to be used to drive an electrical generator about 80% of all electricity generation in the world is by use of steam turbines. Rotor is the heart of the steam turbine and it affects the efficiency of the steam turbine.

T.G. Arul *et al* have discussed various characteristics of steam turbine. Steam turbines are custom built, hence efficiency and operating characteristics can be optimized for each application. Retrofitting a steam turbine into a facility's steam system can be done quite easily, minimizing installation costs. Most facilities that have a steam plant usually are unaware of their potential to cogenerate. This paper describes a miniature steam power plant made with the boiler and the water pump from an old starch iron. It uses boiler as vaporizer to vaporize the water it receives from the water pump. Then the steam is injected on the turbine fan making it twirl. Thermodynamic analysis of the Rankine cycle has been undertaken to enhance the efficiency and reliability of steam power plants.

Mayank R Pawar *et al* have discussed the characteristics of turbines used in thermal power plant. In thermal power plants, the primary purpose of a surface condenser is to condense the exhaust steam from a steam turbine to obtain maximum efficiency and also to convert the turbine exhaust steam into pure water so that it may be reused in the steam generator or boiler as boiler feed water. The difference between the heat of steam per unit mass at the inlet to the turbine and the heat of steam per unit mass at the outlet from the turbine represents the heat which is converted to mechanical power. Therefore, more conversion of heat per kilogram of steam to mechanical power in the turbine, the better is its efficiency. Energy efficiency of any power plant strongly depends on its turbine- condenser system operation mode. Operating the condenser at optimum circulation water flow rate is essentially important to ensure maximum efficiency and minimum operating cost of the plant.

Vedavalli G. Krishnan *et al* have given a basic information and working of Tesla turbines. The Tesla turbine is a bladeless centripetal flow turbine patented by Nikola Tesla in 1913. It is referred to as a bladeless turbine. The Tesla turbine is also known as the boundary layer turbine, cohesion-type turbine, and Prandtl layer turbine (after Ludwig Prandtl) because it uses the boundary layer effect and not a fluid impinging upon the blades as in a conventional turbine. Bioengineering researchers have referred to it as a multiple disk centrifugal pump. One of Tesla's desires for implementation of this turbine was for geothermal power, which was described in Our Future Motive Power.

Thermodynamic analysis of the steam power plant has been undertaken to enhance the efficiency and reliability of steam power plants by Anjali T H *et al*. In the presented work, most of the electricity produced throughout the world is from steam power plants. The present work deals with the comparison of energy and energy analysis of thermal power plant stimulated by coal. Generally, it is predicted that even a small improvement in any part of the plant will result in a significant improvement in the plant efficiency. Factors affecting efficiency of the Thermal Power Plant have been identified and analyzed for improved working of thermal power plant.

Anjali T H *et al* have discussed various methods to improve efficiency of steam turbine. In a power plant, burning of coal produces the heat energy. However, the coal is normally coming in big chunks. Burn this chunks is not possible. So pulverize the coal, and then blow it with the air. That goes along with the air to the chamber, where there is a flame. Therefore, the whole things burns and the complete burning occur. There are pipes that bring all the way down, it is inserted from here, and there are pipes along the wall. Water by natural circulation will come down. This paper deals with the importance of the efficiency of a thermal power plant and Rankine cycles used in thermal power plants. In order to improve the efficiency and performance of a plant, it is necessary to regularly check all the equipment's and estimate their efficiencies separately and periodically.

Ivan Sunit Rout *et al* have discussed in details the losses in steam turbine. The steam turbine is not a perfect heat engine. Energy losses tend to decrease the efficiency and work output of a turbine. This inefficiency can be attributed to the following causes. The velocity of the steam that leaves the turbine must have certain absolute value. The energy loss due to absolute exit velocity of steam is proportional. This type of loss can be reduced by using multistage turbine. In real thermodynamic systems or in real heat engines, a part of the overall cycle inefficiency is due to the frictional losses by the individual components (e.g. nozzles or turbine blades). The turbine rotor and the casing cannot be perfectly insulated. Some amount of steam leaks from the chamber without doing useful work. Each turbine rotor is mounted on two bearings, i.e. there are double bearings between each turbine module.

3. Steam Generator

The mini steam generator designed for the super-heated steam formation at 3bar pressure.

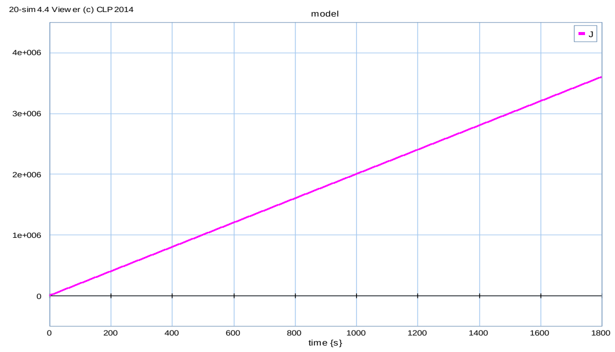
3.1 Simulation of Steam Generator

The modeling of system is done in a single model in 20-Sim software. Using equation model physical systems are represented as a graph of parameter and elements. The simulation model runs with the different parameter to design steam generator. The temperature and pressure of water and quantity of heat supplied are the factors to be considered while simulation. From simulation result obtained, the selected tank of 150mm diameter with 3 mm thickness, and 420mm height, is filled up-to 60% of the total capacity that is 285mm. It is heated by electric heater 2 kW. The required output achieved with this parameters.

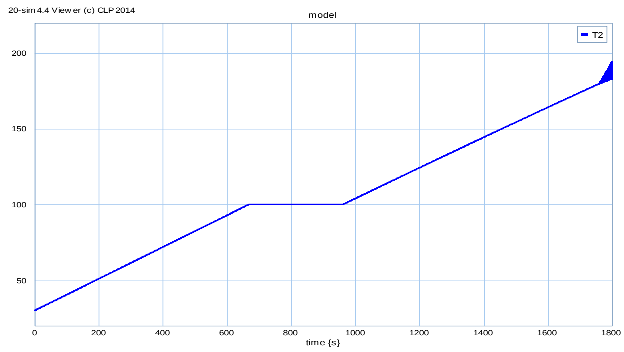
The simulation model contains the condition that allows the heat flow to the air capacity after saturation temperature of water is reached for corresponding pressure. The water temperature reaches to the boiling point then only the condition is true and the heat flow to water is zero and entire heat is directed to the steam generation. The process of steam formation is happens in the next stage. Simulation code is developed and tested in specialized simulation software 20-sim. Simulation code is as below.

```
parameters
string filename1, filename2, filename3, filename4, filename5, filename6;
    real height = 0.45;
    real dia = 0.144;
    real wHeight = 0.28;
    real Cp = 4180.0;
    real dW = 1000.0;
    real aP = 1.013e5;
    real T1 = 30;
    real R = 2870;
    real Q = 2000;

variables
    real vg, vfg, hf, hfg, uf;
    real TSat, x;
    real T2, Pr1, p;
    real nV, mS, sV;
    real MassFlow, SteamMass, Ts;
    real tArea, wVol, mW, tW, aVol;
    real J;
    real hfg1;
    real pr2, sPr;
    real A, TS;


initialequations
    TSat = 100;
    nV = 0.0040694;
    A = 0;
    x = 0.0;
    //sPr = 101420;
    tArea = 0.25 * pi * dia^2;
    aVol = (height-wHeight)*tArea;

    vg = table(filename1,TSat);
    hf = table(filename2,TSat);
    hfg = table(filename3,TSat);
    sPr = table(filename4,TSat);
    uf = table(filename5,TSat);

code
    mW = wHeight * tArea * 1000;
    J = int(Q,0);
    T2 = T1 + (J/(mW * Cp));
    A = J - (hf * mW);
    //if T2 > TSat then

    //end;

    if T2 > TSat then
        T2 = TSat;
```

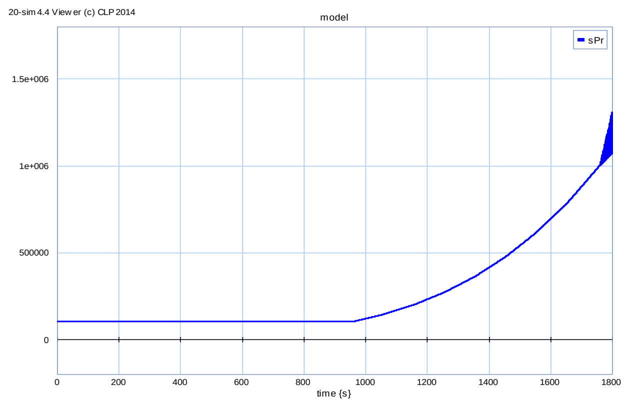
The modeling done is adaptive to the changes in variables. The system that has been designed is modeled considering the influential parameters hence the system is close to the actual system. Various graphs developed in 20-sim related to simulation time for steam formulation are mentioned below



Heat Flow



Temperature



Saturation Process

3.2 Design Specifications of Steam Generator

The selection criterion for the pipe is availability and the maximum diameter and length. Though the boiler is non IBR type, all the function and safety features are required to be involved in it. So the level gauge, pressure controller and temperature controller are incorporated. The heating of water is electrical and done by immersion type heater. The experimental setup is fabricated for this purpose.

The stainless steel pipe, selected as a shell of boiler as it was available in required length and thickness. The pipe has outer diameter of 150mm and thickness of 3mm. The length of pipe is taken as 420mm.This dimensions of shell can accommodate a maximum of 7.42 liters of water in it.

The boiler shell has flanges on the top and bottom. Insulation to the shell is provided by asbestos thread. The tank provides opening for inlet of water, pressure gauge and level sensors through end flanges.

The total four tie rods of stainless steel of height support the flanges on the top and bottom. The 420 mm as of shell with diameter of 22mm are manufactured. The threading of pitch 1 mm for length of 25 mm is provided for the bolts to hold the flanges tightly together with the stainless steel pipe made for shell.

The toughened glass of 12 mm OD with two gate valves at the end are mounted on the shell. When both the valves are opened the water from bottom enters in the tube to indicate the level. The bottom end of the level indicator is 20 mm above the heater height so that the issue of tank going dry when the heater is on is automatically taken care of.

3.3 Fabrication of Steam Generator

The designing of the system is done and the exact dimensions are obtained, de-pending on the process requirements. The steam is taken out through a globe valve of 1" NB.

The mini boiler is shown in above figure. The proper insulation is made to minimize the heat loss to atmosphere. The connections are made and the instrumentation is done properly. The boiler flanges are bolted in stand with help of tie-rod on stand which gives the support; stability and proper placing of the boiler that is important due to boilers are subject to wide load variations and require quick responding control to maintain required level

Fig 3.1 Fabrication of Steam Generator

4. Steam Turbine

4.1 Tesla Steam Turbine

The designed steam turbine is based on Tesla Turbine approach and it's a reaction type steam turbine. A rotor of turbine is obtained from stepper motor. On this rotor, serrations are provided for fixing steam flow discs. This rotor is made of a cast iron material so it possesses magnetism and hence the Aluminium steam flow discs are used instead of ferrous material discs. 25 discs and 25 spacers are stack alternately on each other in such a way that the steam flow path is in involute shape along the axis of rotor. The spacer and the steam flow disc are stuck together by using high grade lock tight. The motion is imparted to the steam flow disc due to reaction of superheated steam. As there is no other provision provided hence its simple in construction and easy to manufacture compared to conventional steam turbine. Installation and maintenance cost of this turbine is also low

4.2 Design Modifications in Stepper Motor

This is derived from the stepper motor. After the stacking's removed, the rotor is taken out to use it for steam turbine. The outer diameter of the rotor is 53mm. The material is cast iron which possesses magnetism. The overall length of the rotor without shaft is 50 mm.

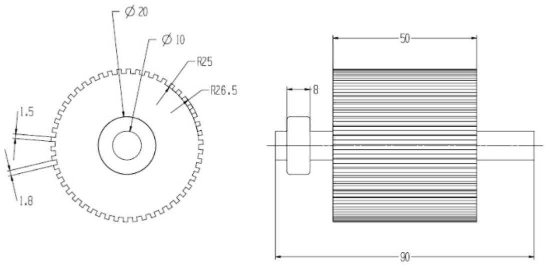


Fig. 4.1 Rotor of steam turbine

4.2.1 Steam flow disc

There are 25 steam flow discs used in steam turbine and are stacked with spacer in between any two consecutive discs using loctite-272 as sticking material. Steam flow discs are arranged in such manner that it provides involute passage along the axial direction.

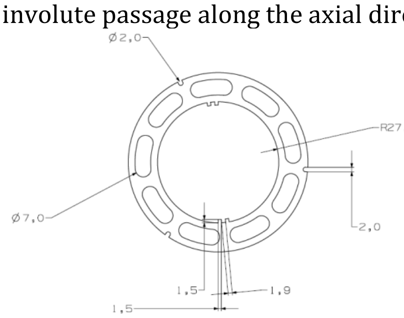


Fig. 4.2 Schematic of steam flow disc

4.2.2 Spacers

Fig 4.3 shows the dimensional details of the space. The spacer is used to separate the steam disc of the rotor.

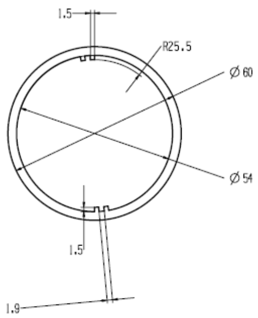


Fig. 4.3 Spacer

4.3 Assembly of Tesla Steam Turbine

Steam turbine consists of casing in which rotor shaft, steam flow rings and spacers are placed. The overall design and assembly is carried out with reference to the rotor which have serrations on its outer diameter. Then the combination of steam flow ring along with the spacer which have serrations on the inner diameter are placed on rotor with the tooth's engaged. The spacer and steam flow rings are stuck together by using lock tight.

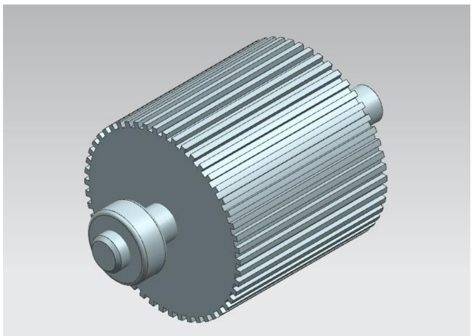


Fig.4.4 3D Model of rotor

Now another combination of steam flow ring and spacer is placed on rotor but with one tooth forward. The entire steam flow rings and spacers are placed in same manner and this creates involute shape for steam flow through the cross-sectional slots of steam flow rings.

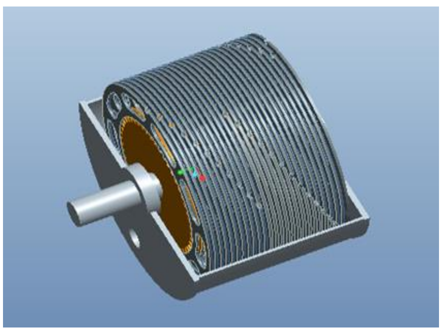


Fig.4.5 CAD model for the turbine assembly

Fig 4.4 shows the 3D model of the rotor and the rotor with the stator assembly respectively.

Fig 4.5 shoes the arrangement of steam flow discs and spacers for the rotor construction so as to create flow path for steam. These flow paths are helical in nature. This rotor is then encapsulated in the shell for the operation of the turbine.

5. Mini Steam Power Plant

The boiler is connected to the turbine with the help of piping system to provide generated steam at turbine location. The steam input is given at two locations of turbine. This piping is done in such a way that the heat loss and condensation due to other losses in the system is minimized. This various losses are minimized by providing insulation to the piping system. Between boiler and turbine the flow control valve is used to maintain steam mass flow rate. Thus steam generator and steam turbine assimilation created Mini Steam Power Plant.

5.1 Steam Generator Instrumentation

For observation and control action necessary instruments are used such as an electric heater capacity of 230VAC, 2kW for heating water, water level indicator for measuring present water level in the tank , Transmitter, Wika S10 is used to measure the pressure of water.

Water Level Indicator WikaS10 Transmitter

Fig. 5.1 Measuring instruments

5.2 Steam Turbine Instrumentation

As the rotor has magnetism the electromagnetic brakes are used to measure the break power. As the produced torque is very less the non-contact type electromagnet is used as break. Stroboscope is used to measure the shaft speed.

5.3 Integration of Steam Generator and Turbine

The steam generator is integrated to the fabricated steam turbine with the help of piping system. The steam input is given at two different locations of turbine so as to provide necessary torque condition. This piping is done in such a way that the heat loss and condensation due to other losses in the system is minimized. Thus steam generator and steam turbine integration created Mini Steam Power Plant.

The turbine is connected with the boiler. The boiler is filled up to a height of 230mm accommodating 4 liters of water. The connections to the boiler are made. The heater is with the multifunction energy meter to show the reading of the current, voltage and wattage being consumed. Thermocouple is used to measure the temperature of steam above the water surface. Thermocouple is connected to a temperature controller which is provided by Selec Technologies, it displays corresponding temperature of steam on display unit. A pressure controller is used keep the pressure within the

Fig. 5.1 System Input

Simultaneously with the help of thermocouple, we recorded corresponding temperatures. Initially water absorbs the sensible heat until reaches to its boiling point. After this, water starts boiling that is, now it absorbs latent heat of vaporization at constant temperature which is called as saturation temperature. Steam coming out of nozzle is used to run a turbine.

Fig 5.1 shows the reading of the current, voltage and the wattage being applied to the heater generating the necessary input for the steam generation in the boiler. Fig 5.2 shows the complete experimental setup used in operation for taking the trials for the experimentation.

Fig. 5.3 Integration of steam generator and turbine

6. Experimentation

Based on trials and analysis following observations are taken and tabled and conclusion is drawn over these observations. Table no. 1 gives steam generation time. While the table 2 gives the reading related to the steam turbine operation.

Table No.1

Sr. No.	Water Level (mm)	Pressure (bar)	Time (min)	Temp (°C)
1.	30	2.0	0.49	89
		1.5	1.50	85
		1.0	8.21	82
2.	60	2.0	0.20	80
		1.5	0.59	80
		1.0	2.14	80
		0.5	4.12	79
3.	90	2.0	0.29	85
		1.5	1.10	83
		1.0	3.19	84
4.	120	2.0	0.19	83
		1.50	0.42	81
		1.0	2.20	81
		1.5	3.30	85
		1.0	8.33	84
		0.75	9.45	81

While the table 2 gives the observations related to mass flow rate

Table No.2

Sr. No.	Mass Flow rate (gm/sec)	Pressure (bar)	RPM
1	2	2	29,892
2	1.9	1.9	29,763
3	1.7	1.6	28,543
4	1.5	1.6	28,320
5	1.4	1.4	27,892
6	1.3	1.2	23,667

The observations are made and the steam which exits from the boiler is taken as an input to the turbine. The readings are taken for the different pressure with respect to mass flow rate and for that mass flow rate the revolution of the shaft is measured.

Table No. 3

Initial Water Level (mm)	Final Water Level (mm)	Time (Sec)	Estimated Mass Flow	Valve Open %	Turbine Speed (Rpm)
30	29.4	980	0.6122	30	6000
60	59.5	1080	0.4629	40	11000
90	89.5	900	0.47	50	1300

The observation table made, the reading are taken for water level 30mm to 150mm. The firstly heat supplied and the water is heated to increase the pressure inside the boiler up to 2bar pressure gauge reading. Then, the valve is just opened that enough to maintain the desired flow rate. The pressure readings are taken down for the interval of pressure drop. At the certain point the pressure drop is zero at the 0.75bar, the constant flow is obtained, and with valve position is just open.

The design and fabrication of miniature and bladeless steam turbine and the overall working of the steam turbine is discussed so far. The miniature and bladeless steam turbine is designed and manufactured by considering the required parameters. The experimental trial was conducted and it is seen that the obtained results were satisfactory.

Conclusion

The important deductions are listed as below.

- The steam generator was successfully manufactured in ss pipe with almost all provisions
- The steam turbine was successfully implemented with up gradation of stepper motor which functions as per the definition
- The steam is wet in the shell of generator, but immediately superheats when the pressure drops to atmosphere pressure.
- The torque generated by the steam turbine was estimated by applying magnetic breaking.
- The mini steam power plant outputs 29000-23000 fairly consistent rpm at 1.2-1.5 gm/ sec at 1.9- 1.2 bar pressure respectively.

References

Thermal Analysis of Steam Turbine Power Plants Ivan Sunit Rout, Abhishek Gaikwad, Vinod Kumar Verma, Mohammad Tariq (Assistant Professor, Department of Mechanical Engineering, Sam Higginbottom Institute of Agriculture, Technology and Sciences, Allahabad, India)

P.K.Nag, Engineering Thermodynamics, (Tata McGraw Hill, New Delhi)

R.Yadav (2011), Fundamentals of Power Plant Engineering,Conventional and Non-Conventional, (Central Publishing House publication)

R.Yadav (2009), Steam & Gas Turbines and Power Plant Engineering, (7th Revised edition, Central Publishing House publication)

P.C.Sharma (2010), Power Plant Engineering, (S.K.Kataria & Sons Publication)

R.K. Naradasu, R.K. Konijeti, and V.R. Alluru (2007), thermodynamic analysis of heat recovery steam generator in combined cycle power plant, (Thermal Science, vol. 11, no. 4, pp. 143-156)

Frutschi, H.U (1999), Highest efficiencies for electrical power generation with combined-cycle plants, (ABB Review, No. 3, pp.12–18)

Akafuah, K. N. (1998), Computer Simulation of the Takoradi Thermal Power Plant, (BSc Project Report, KNUST School of Engineering, Kumasi, pp. 1-5)

R.K.Kapooria, S.Kumar, K.S.Kasana (Feb 2008), An analysis of a thermal power plant working on a Rankine cycle: A theoretical investigation, (Journal of Energy in Southern Africa , Vol 19 No 1)