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Research Paper

AN INVESTIGATIVE STUDY ON THERMAL CHARACTERISTICS OF THE EXISTING BOILER AND ENERGY AUDITING OF A COGENERATION PLANT

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The mammoth development in the industrial and automobile sectors has elevated the socio-economic status of a country. This development is majorly attributed to the energy and its profile. In view of this continuous and reliable energy have become the key issue and this calls for a powerful qualitative approach with regard to energy and its effective utilization. The conventional method of power generation and supply to the customer is not effective in that only about one third of the primary energy fed to the power plant is actually made available to the user in the form of electricity. This necessitates additional techniques or methods to satisfy the energy requirement. Cogeneration plant is one of very effective and popular energy producing methods gaining importance in the recent years. Cogeneration provides a wide range of technologies for application in various domains of economic activities. The overall efficiency of energy use in cogeneration mode can be up to 85% and above in some cases. For the existing power boiler of Cogeneration plant, the thermal analysis and energy audit was carried out proposed work.

Keywords: Industrial and automobile sectors, Energy, Power plant, Cogeneration, Economic activities and energy audit

INTRODUCTION

Thermal power plants or Steam Power Plants are a major source of electricity supply in India. The conventional method of power generation and supply to the customer is wasteful in the sense that only about a third of the primary energy fed in to the power plant is actually made available to the user in the form of electricity. In conventional power plant, efficiency is only 35% and remaining 65% of energy is lost. The major source of loss in the conversion process is the heat rejected to the surrounding water or air due to the inherent constraints of the different thermodynamic cycles employed in power generation. Also further losses of around 10-15% are

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associated with the transmission and distribution of electricity in the electrical grid. The tyre manufacturing industries has gained reputation because of cogeneration plant. The combined thermal energy and power generated in the plant is satisfying the requirements to greater extent. Before the installation of Cogeneration plant, the production rate of tyres was moderate. Because of Cogeneration unit, the production of tyres in the company is increased by 20%.

Cogeneration or Combined Heat and Power (CHP) is defined as the sequential generation of two different forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Mechanical energy may be used to drive an alternator for producing electricity, or rotating equipment such as motor, compressor, pump or fan for delivering various services. Thermal energy can be used either for direct process applications or for indirectly producing steam, hot water, hot air for dryer or chilled water for process cooling. Cogeneration provides a wide range of technologies for application in various domains of economic activities. The overall efficiency of energy use in cogeneration mode can be up to 85% and above in some cases. Cogeneration technologies that have been widely commercialized include extraction/back pressure steam turbines, gas turbine with heat recovery boiler (with or without bottoming steam turbine) and reciprocating engines with heat recovery boiler (Nifes U K).

The term “Thermal Analysis” refers to the overall analysis of boiler using the concepts and principles of Thermodynamics. Thermal Analysis for a Boiler plant is compulsory to know the relevant information about the Thermodynamic aspects, behavioral features, performance characteristics and operational capabilities. Energy Audit is the key to a systematic approach for decision-making in the area of Energy Management. It attempts to balance the total energy inputs with its use, and serves to identify all the energy streams in a facility. It quantifies energy usage according to its discrete functions. Industrial energy audit is an effective tool in defining and pursuing comprehensive energy management programmes. As per the Energy Conservation Act, 2001, Energy Audit is defined as “the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action to reduce energy consumption.”

The concept of energy audit as a prelude to the identification of energy conservation schemes in any industrial complex, and the selection of the final one for implementation based on criteria dictated by the cost appraisal techniques. The identity of energy audit as a tool for energy management has been recognized. The ultimate objective of conducting an energy audit of an industrial complex is to examine and conclude whether the total energy in any form being spent in the plant is being used efficiently or not (George Polimeros, 1981).

LITERATURE REVIEW

An investigative review was carried out on the co-generation plant concerning with a tyre manufacturing industry. The company has a cogeneration plant of 6 MW capacity equipped with a huge water tube travelling grate stoker coal fired boiler. Cogeneration plant in the company is helpful for the manufacture of tyres based on quantity of steam generation. For the existing power boiler of Cogeneration plant, the thermal analysis and energy audit was carried out in the work. Further, the theoretical study on selection of fuel and properties, steam system, environmental protection, water treatment, energy conservation opportunities, control and instrumentation and cost economics were also carried out.

COGENERATION PERFORMANCE PARAMETERS

Cogeneration is an added advantage for any power generating industry as it is capable of generating great intensity power depending on Steam Turbine based Cogeneration. On the whole, the company furnishes its best to generate maximum steam generation for processing units. The cogeneration plant is very comfortable in operating Boiler using combined heat and power beneficial for processing unit.

The following table gives typical cogeneration performance parameters for different cogeneration packages giving heat rate, overall efficiencies.

NEED FOR THERMAL ANALYSIS AND ENERGY AUDITING

The thermal analysis and energy audit is done for the existing power boiler in the Cogeneration plant can be considered for the future study also. The thermal analysis carried out in the work using the principles of Thermodynamics and Heat Transfer, helped the company to know the different thermodynamic aspects of a boiler. The energy auditing for a boiler will help to know the heat losses, energy savings and cost benefits. The thermal analysis done theoretically can be compared using any modeling approach to obtain the results easily by the company. The concise energy audit report will help the company to carry out detailed energy auditing in the future (Skrotzki and Vopat, 1979).

Energy Audit will help to understand more about the ways energy and fuel are used in any industry, and help in identifying the areas where waste can occur and where scope for improvement exists. The primary objective of energy audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. Energy Audit provides a “bench mark” for managing energy in the organization and also provides the basis for planning a more effective use of energy

Table 1: Cogeneration Handbook California Energy Commission (1982)

Prime Mover in Cogeneration Packages	Nominal Range (Electrical)	Heat Rate (kcal/kWh)	Electrical Conversion	Thermal Recovery	Overall Cogeneration
Smaller Reciprocating Engines	10-300 kW	2650-6300	20-32	50	74-82
Large Reciprocating Engines	500-3000 kW	2400-3275	26-36	50	76-86
Diesel Engines	10-3000 kW	2770-3775	23-38	50	73-88
Gas Turbines	10-20 MW	2770-3275	26-31	50	78-81
Steam Turbines	10-100 MW	2520-5040	17-34	–	–

throughout the organization. The energy Audit would give a positive orientation to the energy cost reduction, preventive maintenance and quality control programmes which are vital for production and utility activities. Energy Audit is the translation of conversion ideas into realities, by lending technically feasible solutions with economic and other organizational considerations within a specified time frame (Kenny, 1984).

Depending on the nature and complexity of the site, a comprehensive audit can take from several weeks to several months to complete. Detailed studies to establish, and investigate, energy and material balances for specific plant departments or items of process equipment are carried out. The audit report will include a description of energy inputs and product output by major department or by major processing function, and will evaluate the efficiency of each step of the manufacturing process.

FACTORS INFLUENCING THE CHOICE OF COGENERATION

The selection and operating scheme of a cogeneration system is very much site-specific and depends on several factors, as described below (Murphy and McKay, 1982):

Base Electrical Load Matching: In this configuration, the cogeneration plant is seized to meet the minimum electricity demand of the site based on the historical demand curve. The rest of the needed power is purchased from the utility grid. The thermal energy requirement of the site could be met by the cogeneration system alone or by additional boilers. If the thermal energy generated with the base electrical load exceeds the plant's demand and if the situation permits, exceeds thermal energy can be exported to neighbouring customers.

Base Thermal Load Matching: The cogeneration system is seized to supply the minimum thermal energy requirement of the site. Stand-by boilers or burners are operated during periods when the demand for heat is higher. The prime mover installed operates at full load at all times. If the electricity demand of the site exceeds that which can be provided by the prime mover, then the remaining amount can be purchased from the grid. Likewise, if local laws permit, the excess electricity can be sold to the power utility.

Electrical Load Matching: In this operating scheme, the facility is totally independent of the power utility grid. All the power requirements of the site, including the reserves needed during scheduled and unscheduled maintenance, are to be taken into account while sizing the system. This is also referred to as a "stand-alone" system. If the thermal energy demand of the site is higher than that generated by the cogeneration system, auxiliary boilers are used. On the other hand, when the thermal energy demand is low, some thermal energy is wasted. If there is a possibility, excess thermal energy can be exported to neighbouring facilities.

Thermal Load Matching: The cogeneration system is designed to meet the thermal energy requirement of the site at any time. The prime movers are operated following the thermal demand. During the period when the electricity demand exceeds the generation capacity, the deficit can be compensated by power purchased from the grid. Similarly, if the local legislation permits, electricity produced in excess at any time may be sold to the utility (Harker and Backhurst, 1981).

RESULTS AND DISCUSSION

The study carried out a cogeneration aimed at enhancing the energy efficiency of Cogeneration plant by performing thermal analysis and energy audit for the existing power boiler. The theoretical study is also carried out involving fuel selection and properties, water treatment plant, steam distribution system, energy conservation opportunities, control and instrumentation and cost benefits for existing steam turbine based cogeneration. The performance evaluation of boiler is done by using direct and indirect methods, which is also helpful for tabulating energy balance sheet to analyze the heat losses.

For the existing power boiler at cogeneration plant, thermodynamic analysis involving the estimation of various boiler performance parameters, Rankine efficiency, analysis of heat transfer loss for steam pipe, percentage of heat utilized in the boiler accessories and draught calculations were carried out to understand the complete thermodynamic aspects about the plant The energy audit report in the project will provide the information about the boiler plant involving plant details, energy balance, cost benefits, energy saving opportunities, thermodynamic conditions and maintenance. Boiler Performance Curves clearly gives the idea about the performance characteristics of the water tube boiler at Falcon plant. For any plant, Cost economics plays a very dominating role to extract information about energy consumption per annum, fuel consumption and various cost factors.

The energy audit report in the study provided the information about the boiler plant involving plant details, energy balance, cost benefits, energy saving opportunities, thermodynamic conditions and maintenance. Boiler Performance Curves clearly gives the idea about the performance characteristics of the water tube boiler at Falcon plant. For any plant, Cost economics plays a very dominating role to extract information about energy consumption per annum, fuel consumption and various cost factors. The following are the major specifications of the proposed cogeneration plant (Dyer and Maples, 1986).

Table 2: Specifications of the Cogeneration Plant

Particulars	Numerical Value	General Remark/ Recommendation
Plant Details and Specifications		
1. Boiler Make	Make-CVL, Trichy	
2. Quantity of steam	40 tonnes per hour	
3. Steam Pressure and temperature	66 kg/cm^2 and 500 °C	
4. Quantity of coal consumed	6 Tonnes per hour	
5. Feed water temperature	105 °C	
6. Boiler efficiency	75%-78%	Reasonable efficiency
7. GCV of Coal	5000 kcal/kg	Variable GCV
8. Type of coal	Bituminous coal	Highly volatile
9. Air fuel ratio	6 to 18	
10. Heating surface	2700 m^2	
11. Coal size	6-8 mm	
12. Compressor pressure	6 kg/cm^2	

Table 3: Tabulation of the Results Done by Thermal Analysis

S. No.	Particulars	Statistical Value
1	1. Boiler efficiency using Direct method	η_{Boiler} = 75%
	2. Boiler efficiency using Indirect method	η_{Boiler} = 75%
	3. Heat losses in percentages	
	• Heat loss due to dry flue gases	13.49%
	• Heat loss due to Evaporation of Water formed due to H2 in fuel	4.69%
	• Heat loss due to moisture present in air	0.193%
	• Heat loss due to radiation and unaccounted losses	4.5%
	• Blow down losses	2% η_{Boiler} = 75.12%
2	Draught Calculations	24 mm of water
	1. To calculate the Draught in mm of water	
	2. To calculate the draught pressure produced by the natural draught system in the height of hot gases column	31 m of air
	3. To calculate the mass flow rate of flue gases	48.57 kg/sec
	4. To calculate the Velocity of gases	24.66 m/sec
	5. Efficiency of the boiler	75%
	6. To calculate Power required to drive Forced Draught Fan	4.68 kW
	7. To calculate Power required to drive Induced Draught Fan	7.7 kW
	8. Efficiency of the Chimney	0.14% always less than 1%
3	Estimation of heat loss in steam pipe	
	1. Total Thermal Contact Resistances	1.134 K/W
	2. Rate of heat loss	396.8 W/m
	3. Overall Heat transfer coefficient	1.75 W/m^2 K
	4. Annual heat loss	750.81 GJ/year

From the principles concepts of Thermodynamics, thermal analysis is carried out and tabulated below (Arora and Domkundwar, 1975).

Boiler Performance Curves are advantageous to correctly understand the performance characteristics of the boiler by extracting information about Fuel Consumption, Load condition, Quantity of Steam, Exhaust gas losses, Air ratio, Fuel saving rate and flue gas temperature (Robertson, 1981). The following are the performance characteristics that can be shown graphically based on the input obtained from the company.

In any industry, the performance parameters are to be completely checked. High efficiency is the result of tangible design considerations incorporated into the boiler. Reviewing some basic design differences from one boiler to another can provide a valuable insight on expected efficiency performance. Based on the results of the stack evaluation, a more comprehensive evaluation of boiler requirements should be performed. The result will be an accurate review of the potential savings in fuel, maintenance, and boiler room (Smith, 1981). The graphical representation will clearly give the information about fuel consumption, load condition, quantity of steam, exhaust gas losses, air ratio, fuel saving rate and flue gas temperature. The following are the performance characteristics that can be shown graphically based on the input obtained from the company.

- GCV of Coal v/s Quantity of Steam
- Exhaust Gas Losses v/s Air Ratio

Figure 1: Variation of Gross Calorific Value v/s Quantity of Steam

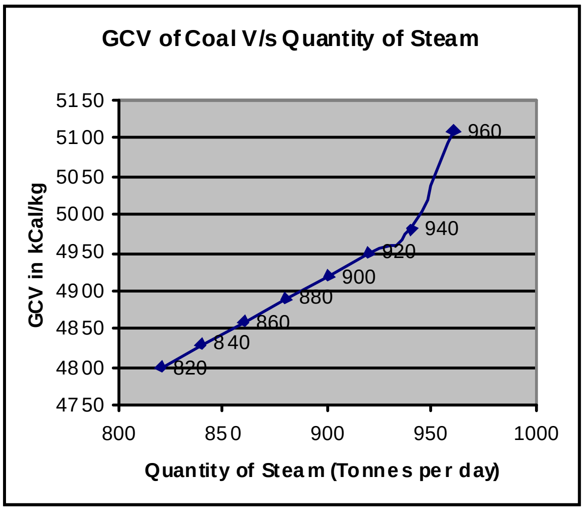


Figure 3: Variation of Fuel Saving Rate v/s Temperature

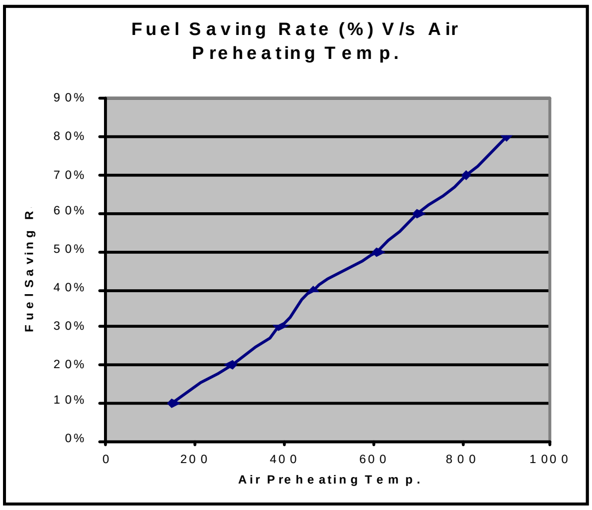


Figure 2: Variation of Exhaust Losses v/s Air Ratio

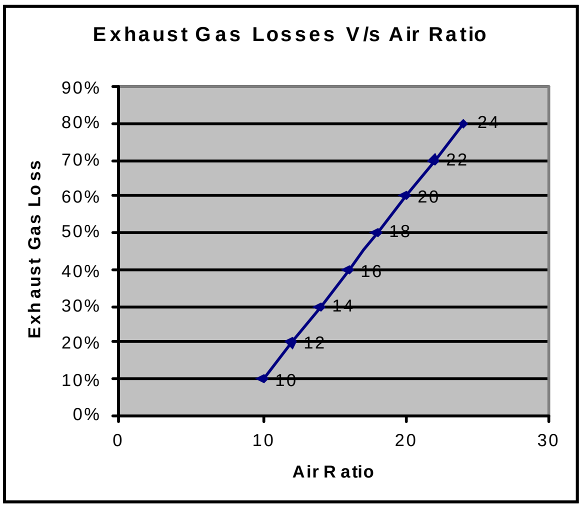
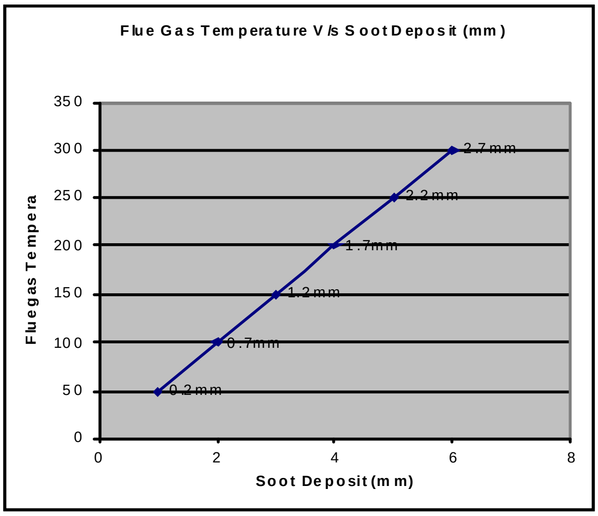


Figure 4: Variation of Flue Temperature v/s Soot



- Percentage Fuel Saving Rate v/s Air Preheating Temperature
- Flue Gas Temperature v/s Soot Deposit

In Figure 1, the curve shows that as there is increase in the quantity of steam, GCV of coal increases. In the company, variable GCV of the coal is maintained. The cogeneration plant uses 6000 kg/h (6 tonnes/h) maintaining variable GCV of the fuel. Figure 2 indicates that, when air fuel ratio increases, the percentage in exhaust gas losses also increases. In the company, they vary air fuel ratio from 8 to 18, depending on the requirement. The variation of air ratio and exhaust gas losses is always linear. In Figure 3, it is observed that, the air preheating temperature increases depending on the increase in fuel saving rate. For any company, analysis of fuel saving is done annually to know the energy saving potential. It is obvious that, if the percentage of fuel saving rate is more energy enhancement is possible. The soot deposit is a major problem in a boiler. A soot blower is properly equipped to collect soot at a considerable extent. The soot collected must be minimum depending on flue gas temperature. As flue gas temperature increases, soot deposit also increases. In the company, the values pertaining to soot deposit were collected with respect to the flue gas temperature. Figure 4 clearly indicates that, if flue gas temperature is very high the soot deposits in the boiler are more.

COST ESTIMATION OF THE COGENERATION PLANT

For any company, Cost Benefit Analysis is an exceptionally important factor. Any energy conservation measure involves an investment. It could be for minor modification of equipment, or a capital investment for buying a new one. The anticipated benefits from this, however, are expected to accrue in the future. The value of money, measured in terms of what it can buy, changes with time due to a variety of reasons. It is the inflation rate almost inevitable in present day economy. There is the interest rate or the discount rate, which the client may have earned on the money that he has been asked to invest in the energy conservation measures. The client will compare the present worth of the future expected savings with his present expense involved before making a decision (Arora and Domkundwar, 1975).

The following data was considered to correctly achieve the cost economics of Steam Turbine based Cogeneration Plant:

- Capacity of Steam Turbine generator = 6 MW = 6000 kW
- Average load = 0.9 × 6000 = 5400 kW
- Plant operating hours per annum = 8000 hours
- Plant Load Factor = 90%
- Heat rate as per standard given by Steam Turbine supplier = 3200 kcal/kWh
- Fuel used – Highly Volatile Bituminous Coal
- Calorific Value of Coal = 5000 kcal/kg
- 1 ton or 1000 kg of Coal = 3600 Rupees (including Transportation) as per July 2010 statistics
- Capital Investment for total cogeneration plant = 35 crores (For 1 MW = 5.5 Crores as per government standard)
- Quantity of coal consumed per hour = 6000 kg

Cost Estimation of the Cogeneration Plant

1. Energy consumed per annum =

   Plant Load Factor x Plant Capacity x No. of operation hours

   = 0.9 × 6000 × 8000 = 432 × 10^5 kWh per annum

2. Heat input to generate above calculated units = Units (kWh) x heat rate

   = 432 × 10^5 × 3200 = 1382400 × 10^5 kcal

3. Cost of fuel per annum = Annual Coal consumption x Price

   = Rs. 99,532,800 nearly 10 crores.

5. Cost of capital and operation charges/ annum = Rs. 11,050,000

6. Overall cost of power from cogeneration plant = Rs. 110,582,800 or 11 crores
7. Power consumption at 90% load factor = 0.9 × 6000 = 5400 kW
8. Total Generation cost in units per year= 0.9 × 6000 × 8000 = 432 × 10^5 Units/year
9. Cost of power per unit in the company = Rs. 3.70
10. Annual Generation Cost = 432 × 10^5 × Rs. 3.70 = Rs. 159,840,000
11. Power selling cost per unit = Rs. 5
12. Annual power selling cost = 432 × 10^5 × 5 = Rs. 216,000,000
13. Profit/year = 216,000,000 – 159,840,000 = Rs.56, 160,000
14. Payback Period = 6 years

MAJOR OBSERVATIONS AND RECOMMENDATIONS

During the pulverization process, it was observed that, the coal obtained after the process was not proportionate in size. The better suggestion is to use accurate sized crusher with screen, which is capable of achieving complete pulverization action. Some pipe lines or channels that facilitate steam or water were reaching the stage of deterioration. This may lead to major technical problems. This should be given emphasis. Hence replacement of the pipes must be done by using high quality steel. It was observed that the economizer is not very perfect and effective, as the economizer tubes might have been choked due to the continuous use of raw water leading to precipitation and hence scaling. Subject to the condition of the economizer tubes being normal, its performance can be improved by a thorough and physical cleaning of the tubes inside and outside. In the laboratory, it was clearly noticed that, ultimate analysis of coal in not at all done. The ultimate analysis of coal will give the most accurate information about the estimation of heat losses, beneficial for the tabulation of energy balance sheet and correct determination of efficiency of boiler using indirect method. Thus it was recommended to perform ultimate analysis of coal compulsorily. It was necessary to correctly maintain the percentage of moisture content in the coal, which will be responsible for the increase in GCV of coal and energy efficiency. In the company, it was made mandatory to have online air monitoring system from the pollution control board to control air flow in the boiler for enhancement of energy efficiency.

CONCLUSION

The cogeneration plant of the company meets the requirements satisfactorily. The company is aiming its best to supply steam to the processing units continuously from cogeneration plant for the continuous and increased production of tyres (Dryden, 1982). Before the installation of Cogeneration plant, the production rate of tyres was moderate. Cogeneration unit in the company has increased the production of tyres by 20%. The paper provides the recommendations for the enhancement of energy efficiency of 6 MW cogeneration plant. It is a unique opportunity to make investigation in Cogeneration division for the thorough performance assessment, thermodynamic parameters and studying the energy conservation opportunities of boilers. The thermal analysis and energy audit done for the existing power boiler in the

Cogeneration plant can be considered for the future study (American Gas Association). The thermal analysis carried out in the project using the principles of Thermodynamics and Heat Transfer, will help the company to know the different thermodynamic aspects of a boiler. The energy auditing for a boiler will help to know the heat losses, energy savings and cost benefits (Thumann, 1988). The thermal analysis done theoretically can be compared using any modeling approach to obtain the results easily by the company. The concise energy audit report will help the company to carry out detailed energy auditing in the future.

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