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Energy Analysis Of Thermal Power Plant

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***Abstract*— the increased awareness that the world's energy resources are limited has caused many countries to reexamine their energy policies and take drastic measures in eliminating waste. It has also sparked interest in the scientific community to take a closer look at the energy conversion devices and to develop new techniques to better utilize the existing limited resources. The first law of thermodynamics deals with the quantity of energy and asserts that energy cannot be created or destroyed. This law merely serves as a necessary tool for the bookkeeping of energy during a process and offers no challenges to the engineer. The second law, however, deals with the quality of energy. More specifically, it is concerned with the degradation of energy during a process, the entropy generation, and the lost opportunities to do work and it offers plenty of room for improvement. The second law of thermodynamics has proved to be a very powerful tool in the optimization of complex thermodynamic systems. In this project we start our study with the introduction of Energy (also called availability), which is the maximum useful work that could be obtained from the system at a given state in a specified environment. And calculate exergy of different parts of power plant, and we continue with the reversible work, which is the maximum useful work that can be obtained as a system undergoes a process between two specified states of power plant system. Next we discuss and calculate the irreversibility (also called the energy destruction or lost work), which is the wasted work potential during a process as a result of irreversibility's, and we define a second-law efficiency.**

***Index Terms* - Energy analysis, Thermal Power Plant, Second law of thermodynamics, Reheat Rankin Cycle.**

I. INTRODUCTION

The Company was promoted by erstwhile Gujarat Electricity Board (GEB) as it's wholly owned subsidiary in the context of liberalization and as a part of efforts towards restructuring of the Power Sector. GSECL has initiated its activities in the field of Generation of Power. The Government of Gujarat (GoG) has also given to the GSECL the status of Independent Power Producer (IPP) with approval to undertake new power projects. The Company commenced its commercial operation in the year 1998. However, the operations of GSECL were limited to Power Stations units Gandhinagar #5, Wanakbori #7, Utran GBPS &Dhuvaran CCPP till the complete unbundling of erstwhile GEB was undertaken, i.e. up to 31st March. 2005.

Fig. 1 plant lay out

I. Background:

Sikka Thermal Power Station is located near Jamnagar, Which is the major industrial town in Gujarat. There are two units of 120MW capacity each. Commissioned in 1988 and 1993. In May 2015 GSECL said it was commissioning a feasibility study to replace the old, existing units with supercritical technology, extending their life and possibly their size (MW).

II. Proposed 500 MW expansions (Unit 3 and 4):

Gujarat State Electricity Corporation is pursuing an expansion of the station to Unit 3 and 4 – two new units of 250MW each. However, as of August 2014 the company still listed the data of commissioning as "2012 to 2013", just as it did in 2012.

Unit 3 was commissioned in April 2015, and Unit 4 was Described as "in an advanced stage of commissioning" and planned for financial year 2016.

III. Proposed 500 MW expansions (Unit 3 and 4):

Sponsor	Gujarat State Electricity Corporation
Location	Sikka village, Jamnagar district, Gujarat
Coordinates	22.42082767, 69.82759953 (exact)
Status	Operating (Unit 3), Construction (Unit 4)
Nameplate capacity	500MW (Unit-4: 250MW)
Employees	374
Type	Coal base Thermal power plant
Cola Source	all over India and Australia
Estimated annual CO_2 generation	2,956,850 tons
Source of financing	Government

Tab. 1.1. Project detail

II. Cycle Analysis and General Layout:

Thermal Power Plants are the main key element of electricity generation now a days as approx around 62% of electrical energy in the world is produced by using thermal power plant. Steam Planats are work on basis of Rankine cycle.

2.1 Rankine Cycle: The Rankine cycle is the ideal cycle for vapor power plants; it includes the following four reversible processes:

Process 1-2: Isentropic compression Water enters the pump as state 1 as saturated liquid and is compressed isentropically to the operating pressure of the boiler.

Process 2-3: Constant Pressure heat addition Saturated water enters the boiler and leaves it as superheated vapor at state 3

Process 3-4: Isentropic expansion Superheated vapor expands isentropically in turbine and produces work

Process 4-1: Constant Pressure heat rejection High quality steam is condensed in the condenser Main Title.

2.2 Energy Analysis for the Cycle

All four components of the Rankine cycle are steady-state steady-flow devices. The potential and kinetic energy effects can be neglected. The first law per unit mass of steam can be written as:

Pump	$W_{pump} = h_2 – h_2$
Boiler	$Q_{in} = h_3 – h_2$
Turbine	$W_{turbine} = h_3 – h_4$
Condenser	$Q_{out} = h_4 – h_1$

Tab. 2.1. Energy analysis equations for Rankin cycle

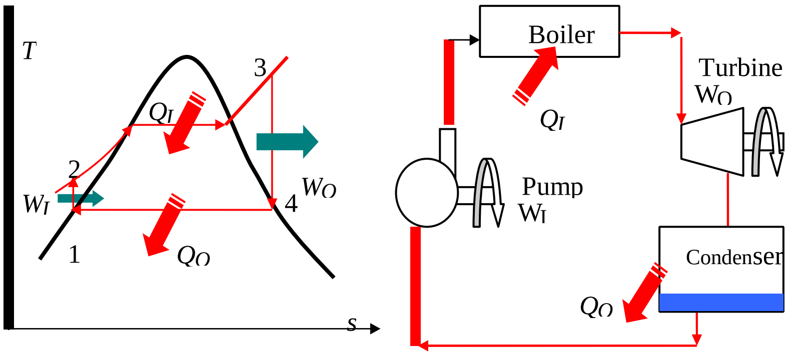


Fig 2.1 rankin cycle

The main title (on the first page) should begin 1-3/8 inches (3.49 cm) from the top edge of the page, centered, and in Times 14-point, boldface type. Capitalize the first letter of nouns, pronouns, verbs, adjectives, and adverbs; do not capitalize articles, coordinate conjunctions, or prepositions (unless the title begins with such a word). Leave two blank lines after the title.

1. Problem Specification:

Steam power plants are widely utilized throughout the world for electricity generation, and coal is often used to fuel these plants. Although the world's existing coal reserves are sufficient for about two centuries, the technology largely used today to produce electricity from coal causes significant negative environmental impacts. To utilize coal more effectively, efficiently and cleanly in electricity generation processes, efforts are often expended to improve the efficiency and performance of existing plants through modifications and retrofits, and to develop advanced coal utilization technologies.

Today, many electrical generating utilities are striving to improve the efficiency (or heat rate) at their existing thermal electric generating stations, many of which are over 25 years old. Often, a heat rate improvement of only a few percent appears desirable as it is thought that the costs and complexity of such measures may be more manageable than more expensive options.

To assist in improving the efficiencies of coal-to-electricity technologies, their thermodynamic performances are usually investigated. In general, energy technologies are normally examined using energy analysis. A better understanding is attained when a more complete thermodynamic view is taken, which uses the second law of thermodynamics in conjunction with energy analysis, via exergy methods.

Of the analysis techniques available, exergy analysis is perhaps the most important because it is a useful, convenient and straightforward method for assessing and improving thermal generating stations. The insights gained with exergy analysis into plant performance are informative (e.g., efficiencies are determined which measure the approach to ideality, and the causes and locations of losses in efficiency and electricity generation potential are accurately pinpointed). Exergy-analysis results can aid efforts to improve the efficiency, and possibly the economic and environmental performance, of thermal generating stations. Improvement, design and optimization efforts are likely to be more rational and comprehensive if exergy factors are considered. One reason is that exergy methods can prioritize the parts of a plant in terms of greatest margin for improvement – by focusing on plant components responsible for the largest exergy losses. For example, the authors previously showed that efficiency-improvement efforts for coal-fired electrical generation should focus on the steam generator (where large losses occur from combustion and heat transfer across large temperature differences), the turbines, the electrical generator and the transformer. In addition, however, other components should be considered where economically beneficial improvements can be identified even if they are small.

In most countries, numerous steam power plants driven by fossil fuels like oil, coal and natural gas or by other energy resources like uranium are in service today. During the past decade, many power generation companies have paid attention to process improvement in steam power plants by taking measures to improve the plant efficiencies and to minimize the environmental impact (e.g., by reducing the emissions of major air pollutants such as CO2, SO2 and NOx). Exergy analysis is a useful tool in such efforts.

2. Physical Exergy and Chemical Exergy:

The exergy associated with the mass flow is divided to the two types, Chemical exergy and
Physical exergy

Chemical exergy is given by,

The maximum work that could be obtain from a substance when it is brought from the environmental state to the dead state by means of processes involving interaction only with the environment.

$E^{CH} = e^{ch}\, m/M$

Physical exergy is given by,

The maximum amount of work that could be obtain form the system at a given state in a specified environment.

Physical or thermo mechanical exergy is given by,

$E^{PH} = m\,\{(h - h_o) – T_o(S - S_o)\}$

And Total exergy is given by,

$E = E^{CH} + E^{PH}$

3. Materials and Tools required:

In case of Exergy analysis of GSECL thermal power plant (Sikka), we require some different document data and some other analysis tools as mention below,

Section	Mass flow Rate (T/hr.)	Temperature (ºC)	Pressure (kg/cm^2)	Vapor fraction
Steam generator				
Feed water in	367.4	228	151.4	0
Main steam out	383	540	136.4	1
Reheat Steam in	343	339	26.8	1
Reheat steam out	343	540	28.5	1
Steam Turbine				
High-pressure turbine inlet	383	540	127	1
High-pressure turbine outlet	343	339	26.8	1

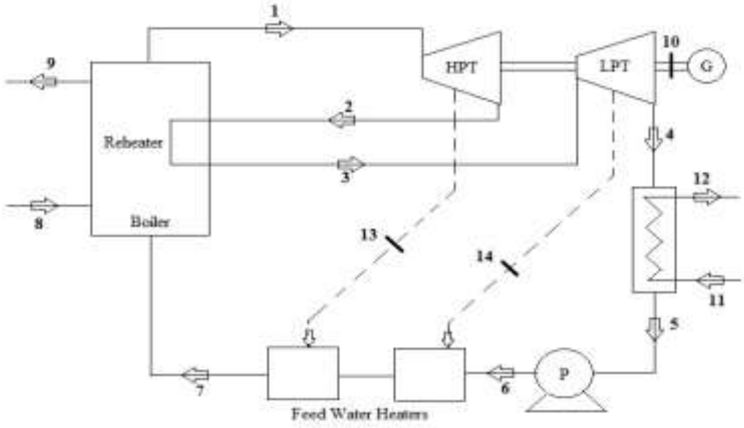
Low Pressure turbine inlet	343	540	26.4	1
Low-pressure turbine outlet	284.45	252.60	3.79	1
Condenser				
Condenser inlet	284.45	252.60	3.79	1
Condensate out	240	165	8	0
Cooling water in	17412.12	30		0
Cooling water out	17412.12	37		0
Pumps				
Boiler feed pump inlet	240	165	8	0
Boiler feed pump outlet	240	165	160	0
Feed Water Heater				
HPH-5				
Blead steam in	29	461.13		1
Feed water in	240	165	160	0
Feed water out		195	160	0
HPH-6				
Blead steam in	61.55	341.86		1
Feed water in		195	160	0
Feed water out	367.4	228	160	0

*A vapor fraction of 0 denotes a saturated or sub cooled liquid, and of 1 denotes a dry saturated or superheated vapor.

Tab. 1.2. Power plant working data

3. IMPLEMENTATION

3.1. Actual Cycle:- Actual cycle of Sikka TPP is as shown in below line



To take advantage of the increased efficiencies at higher boiler pressure without facing the excessive moisture at the final stages of the turbine, reheating is used. In the ideal reheating cycle, the expansion process takes place in two stages, i.e., the high-pressure and low-pressure turbines. The total heat input and total turbine work output for a reheat cycle become:

Pump	$W_{pump} = h_6 - h_5$
Boiler	$Q_{in} = Q_{boiler} + Q_{reheater} = (h_1 - h_6) + (h_3 - h_2)$
Turbine	$W_{turbine} = W_{HPT} + W_{LPT} = (h_1 - h_2) + (h_3 - h_4)$
Condenser	$Q_{out} = h_4 - h_5$

Tab. 3.1.Energy analysis equations for reheat cycle

And cycle efficiency is calculate by,
η_{reheat} = Net work done / Heat supply
$= (W_{HPT} + W_{LPT} - W_{pump}) / (Q_{boiler} + Q_{reheater})$
$\eta_{reheat} = (h_1 – h_2) + (h_3 – h_4) - (h_6 – h_5) \;/\; (h_1 – h_6) + (h_3 – h_2)$

The incorporation of the single reheat in a modern power plant improves the cycle efficiency by 4 to 5 percent by increasing the average temperature at which heat is transferred to the steam.

3.2. Calculation

State: 1
Substance: Superheated steam
Pressure: 136.4 kg/cm^2 = 134 bar
Temperature: 540 °C = 813 °K
Mass flow rate: 383 T/hr. = 106.3889kg/s
Composition: $H_2O_{(g)}$ = 100%
$E_{PH} = m\,[(h_1 – h_o) – T_o(S_1 - S_o)]$
= 106.3889[(3440.93 – 104.8) – 298.15(6.55 – 0.367)]
= 158.8034 MW
$E_{CH} = 0$ (chemical exergy of steam is zero as it is working fluid)
So, $E_{TOTAL} = E_{PH} + E_{CH}$
E_T = 158.8034 + 0
E_1 = 158.8034 MW

State: 2
Substance: Superheated steam
Pressure: 26.8 kg/cm^2 = 26.2908 bar
Temperature: 339 °C
Mass flow rate: 343 T/hr. = 95.2778 kg/s
Composition: $H_2O_{(g)}$ = 100%

$E_{PH} = m\,[(h_2– h_o) – T_o(S_2 - S_o)]$
= 95.2778[(3098.71 – 104.8) – 298.15(6.77 – 0.367)]
= 103.3627 MW
$E_{CH} = 0$ (chemical exergy of steam is zero as it is working fluid)
So, $E_{TOTAL} = E_{PH} + E_{CH}$
E_T = 103.3627 + 0
E_2 = 103.3627 MW
Further, Calculation of exergy at each state is done by use of MATLAB program.

States	Physical Exergy in MW	Chemical Exergy in MW	Total Exergy in MW
State 1	158.8034	0	158.8034
State 2	103.3627	0	103.3627
State 3	128.9370	0	128.9370
State 4	19.5957	0	19.5957
State 5	7.2462	0	7.2462
State 6	8.2177	0	8.2177
State 7	23.0023	0	23.0023
State 8	0	183.3333	183.3333
State 9	4.3670	0.366	4.7330
State 10	120	0	120
State 11	0.1570	0	0.1570
State 12	4.8172	0	4.8172
State 13	9.2851	0	9.2851
State 14	19.9030	0	19.9030

Tab. 3.2 mat lab data

3.3. Exergy Destruction:

Pump: $Ed_{pump} = E6 – E5 + W_{pump}$
And W_{pump} = m (h6 – h5) = 66.6667 (706 – 697.39)
= 0.574 MW
And Ed_{pump} = 8.2177 –7.2462 +0.574
= 1.5455 MW
Condenser: Ed_{con} = (E4 – E5) – (E12 – E11)
= (19.5957 – 7.2462) – (4.8172 – 0.15698)
= 7.6893MW

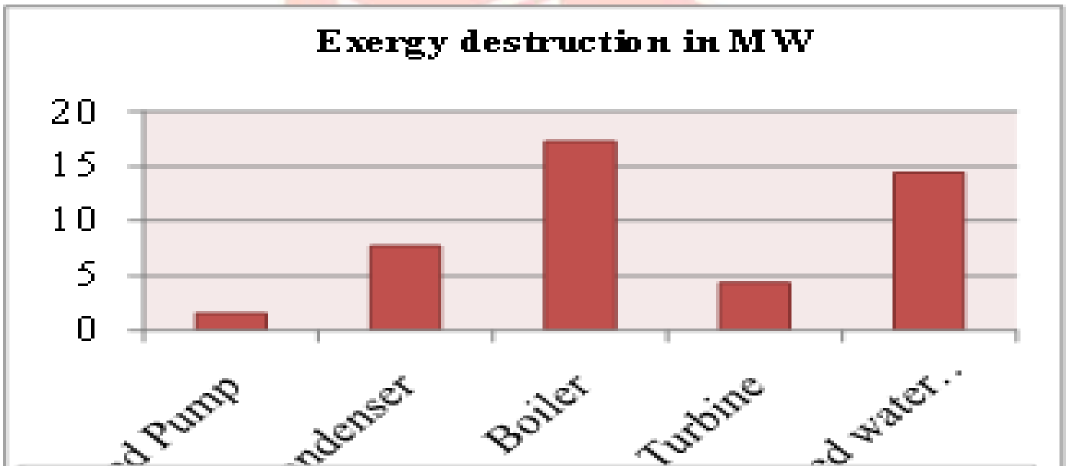
Boiler: $Ed_{boiler} = Ed_b + Ed_{reheater}$
$= E8 + E7 + E2 – (E1 + E3 + E9)$
$= 183.3333 + 23.0023 + 103.3627 – (158.8034 + 128.9370 + 4.7330)$
$= 17.2246$ MW

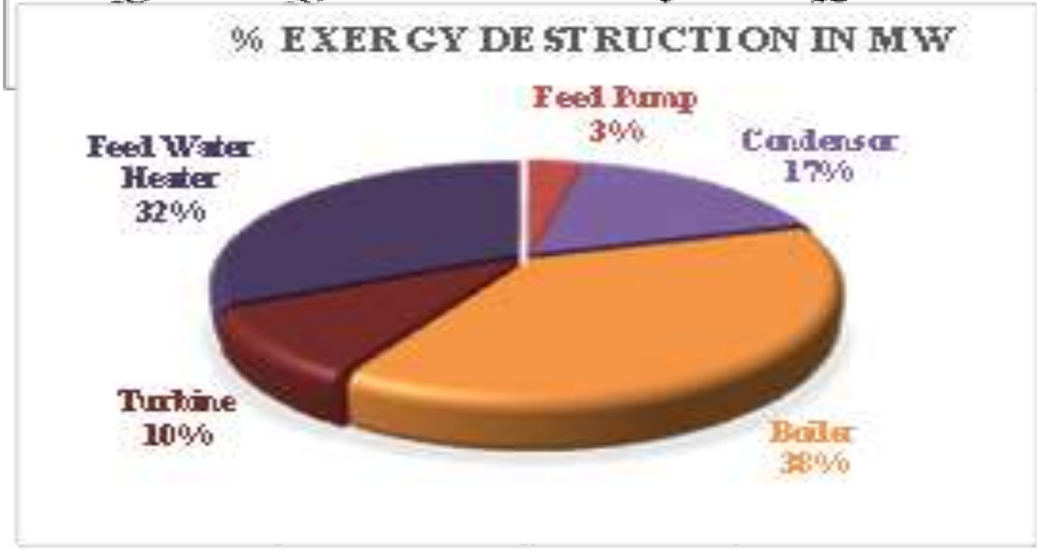
Turbine: $Ed_{turbine} = Ed_{HPT} + Ed_{LPT}$
$= (E1 – E2 – E13) + (E3 – E4 – E14) – (W_G) + (W_{pump})$
$= (158.8034 – 103.3627 – 9.2851) + (128.9370 – 19.5957 – 19.9030) - 120 + 0.574$
$= 4.314$ MW

Feed Water Heater: $Ed_{fwh} = Ed_{hph} + Ed_{lph}$
$= E13 + E14 + E6 – E7$
$= 9.2851 + 19.9030 + 8.2177 – 23.0023$
$= 14.4035$ MW

Component	**Exergy destruction rate in MW**	**% Total exergy destruction rate**	**% exergy rate entering the system**
Pump	1.5455	3.4210%	0.8430%
Condenser	7.6893	17.0204%	4.1942%
Boiler	17.2246	38.1270%	9.3952%
Turbine	4.314	9.5491%	2.3531%
Feed water heaters	14.4035	31.7233%	7.8565%
Cumulative	*45.1769*	*100%*	*24.6420%*

Tab. 3.3. Exergy destruction data of each component





4. CONCLUSION

Exergy analysis indicates that the waste-heat emissions from the condenser, although great in quantity, are low in quality (i.e., have little exergy) because their temperatures are near to that of the environment. Therefore, condenser improvements can typically yield only slight increases in plant exergy efficiency.

Second, it can be seen from Table 3.3 that most (approximately 70%) of the total exergy destruction occurs in the boiler and feed water heater, while the remainder occurs in other devices (approximately 10% in the turbine, 17% in the condenser, 3% in the feed pump). Steam generator and Feed water heater are thus the most inefficient plant device. As a result, significant potential exists for improving plant efficiency by reducing steam-generator irreversibility, by modifying the combustion and/or heat-transfer processes occurring within it.

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