Energy Analysis of 135 MW Capacity of Reheating-Regenerative Steam Power Cycle using Irreversibility Approach

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Energy Analysis of 135 MW Capacity of Reheating-Regenerative Steam Power Cycle using Irreversibility Approach

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Abstract: The increased interest in energy efficiency and resourcefulness would help the adoption of power generation technology. The comprehensive energy analysis reveals the reasons of losses, as well as how to scale the process and rectify the thermal utilities. A thermodynamic analysis of a reheating- regeneration based 135 MW coal fired steam power plant is carried out in this research. The boiler, generators, Feed heaters, condenser, and pump have all been thoroughly analysed in terms team of energy use. The plant efficiency is 47%, the boiler unit efficiency is 70 % (Economizer. Super heater), the maximum heat consumed by the plant's economizer is 39 percent, and the steam quality is around 89-90% with 40 TPH of coal consumption, according to the thermodynamic study. To scale the operation, this study analyses the exergy destruction in various stages of the power generation system.

Keywords: Irreversibility Analysis, Re-Heating-Regeneration Rankine thermal power plant. Plant thermal efficiency

1. Introduction

Thermodynamics analysis is used to examine or evaluate how energy affects the performance of mechanical system. It uses mathematical models to determine the effects of different energy inputs and some of the energy output that results from a machine's operation. Which is used to develop models to illustrate the variables that have a direct impact on the system energy cycle. It is used to examine how energy moves through out a steam power plant which explains how that energy causes the system_steam to perform. So, this thermodynamics analysis real irreversible processes can be subjected and main goal is to find the efficiency of energy used that is also known as exergy efficiency and to shows in every step how much energy is wasted. Which wasted energy is again appointed in the power plant. Some of the recent thermal analysis of different type of power plant is studied or reviewed in the peer articles in different type of the power plant. There are different types of power plant in which there are different type of losses occurs which is analyses based on different literatures. For analysis of steam power plant there were considered challenges in which some challenges that are needed to see as first priorities in order to do thermodynamics analysis.

Zhang et. al. [1] Authors compares the nine power plants and did analysis of energy-exergy both and tries to improve the cycle efficiency as well as find losses in the component in the plant by which they can improve the plant component. Another study conducted analysed energy-exergy for thermal power plant that are in different thermodynamic performance factor [2,3].

Exergy research of a 240 MW coal-fired power station revealed that the main element of the most exergy degradation is the boiler in the total facility [4-6]. Exergy research on a 600 MW coal-fired power station revealed that the oxy combustion boiler are more efficient in comparison to the traditionally built combustion boiler [7-9]. Xiong et al. [10-13] conducted research on an 800 MW coal-fired power station, comparing the oxy combustion system to the traditional system and discovering that the oxy combustion system had a greater exergy efficiency [14] Yhang et al. [15] compare supercritical steam thermal power generations to existing subcritical steam thermal system using energy and exergy analysis to find exergy destruction and losses on a 660 MW coal-fired power station. Exergy and economic study of a 300 MW capacitive steam thermal power generation was carried out, and losses were discovered, as well as the induced malfunction assessment. Exergy cost analysis of steam thermal power generations was carried out using the thermo-economic Method [16], [17]. On a 660 MW steam thermal power generation, energy and exergy analyses were carried out, and the outcome discovered that the exergy destruction is highest for the boiler with zero energy loss in case of combustion processes [18]. On a 200

MW capacitive coal-fired power station, an energy and exergy study revealed that the condenser was the most energy-wasting equipment, while the boiler was the most exergy-wasting component [19]. On a 150 MW steam thermal power generation, energy, exergy, and economic analyses were carried out on the thermal utilities of the plant, and it was discovered that the boiler has the maximum exergy destruction while the condenser exhibits the lowest exergy destruction when compared to the other thermal utilities, and an economic analysis is needed for plant improvement [20]. When energy and exergy analyses were done on a 348.5 MW steam thermal power generation, it was discovered that the condenser has the most energy losses and the boiler has the highest exergy losses when compared to the other thermal utilities [21]. On a 315 MW steam thermal power generation, energy and exergy study revealed that the turbine had the most irreversibility, as well as the highest exergy destruction and energy losses [22]. Energy and exergy analyses were conducted between steam thermal power generations and nuclear power plants, with the capacity of both facilities set at 500 MW [23]. Exergy, energy, and economic analyses were conducted on a 435 MW gas-fired power station. This multi-objective performance is carried out as a result of the plant's optimization and the discovery of the optimal design variable [24]. On a 100 KW gas-fired power plant, energy and exergy analyses were carried out under three distinct situations in order to determine which state was best for the plant, i.e., a trade-off in the operating condition [25]. Anozie et al. [26] conducted an exergy and economic study on a 100 MW plant and discovered that the thermal plant is mostly dependent on three factors: temperature, boiler efficiencies, and condenser efficiencies. Energy and exergy analysis of gas fired power generation was performed, with a comparison between a simple gas turbine and an intercooled gas turbine [27]. It was discovered that the performance effectiveness of intercooled gas turbine is greater when compared to the basic gas cycle, however the exergy distruction is less than the basic gas turbine. Exergy research was performed on a 150 MW capacitive gas fuelled power station, and it was shown that the combustor destroys the most exergy due to chemical reactions [28]. An energy and exergy study of a gas-fired power plant revealed that the combustion chamber had the highest exergy destruction compared to the other plant thermal utilities [29]. Exergy research of a 150 MW capacitive gas fuelled power plant revealed that the combustion chamber's exergy efficiency, or second law efficiency, is significantly low in comparison to other thermal utilities [30]. Combustor was the most inefficient component in comparison to other thermal utilities, and it had the highest exergy destruction in comparison to other thermal utilities, according to an energy and exergy study done on a 146.2 MW capacitive gas fuelled power plant [31]. It was evaluated on the exergo-economic analysis and optimization of combined heat and power production [32]. Exergy and economic analysis were done on combined cycle power plants. Exergy, energy, and economic analyses of combined power plants were carried out and applied to a biomass integrated post-firing combined-cycle power plant [33, 34]. They conducted an energy and exergy analysis in which they compared the efficiency of an intercooled combustion turbine-based combined power plant to that of a simple combined power plant and discovered that the efficiency of an intercooled combustion turbine is higher than that of a simple combined power plant [35]. Exergy study of a 420 MW combined power plant revealed that the heat recovery steam generator had the greatest exergy loss, and the combustion chamber of the combined power plant had a substantially worse efficiency than the gas turbine cycle [36] An energy and exergy study of a combined power plant was conducted, and it was discovered that in a combined cooling, heating, and power production system, exergy destruction in the combustor was the highest in comparison to other thermal utilities [37]. Exergo-economic analysis was conducted for an externally fired combined power plant to determine if exergy destruction was preventable or unavoidable, as well as investment costs for each component [38]. The influence of compressor and gas turbine efficiencies on the most favourable exergy output rate and exergy efficiency performance has been discussed at integrated cooling, heating, and power processes [39-40]. Exergy was studied for all thermal utilities of a 420 MW capacitive combined cycle power plant to determine sensitivity of the whole component of the combined cycle power plant [41]. Energy and exergy analyses were carried out on a combined cycle power plant, namely a gas–turbine combined cycle, which was entirely focused on the examination of reforming processes and the component energy and exergy efficiency of the combined cycle [42]. Using both traditional and advanced exergetic analysis, an exergy study of a combined cycle power plant revealed that the combustion chamber had the most exergy destruction [43]. Highest energy loss, i.e., exergy distraction in the gasification process, and thermal efficiency will be high at an ideal gas cycle at a particular temperature ratio in an integrated gasification combined cycle power plant [44].Highest energy loss, i.e., exergy distraction in the gasification process, and thermal efficiency will be high at an ideal gas cycle at a particular temperature ratio in an integrated gasification combined cycle power plant [40-44]. On a 420 MW capacitive mixed Brayton/Rankine power cycle, half of the total exergy destruction in the combustion chamber, which is a component of the Brayton cycle, was conducted during the reheating phase [45]. We can double the efficiency of the cycle by employing solid oxide fuel, hence this fuel is used in gas turbine plants [46]. The working fluid in this cycle was an ammonia-water combination [47]. It was a combined cycle in which power and cooling were produced concurrently with just one heat source. Utilizing the facility's data, an energy and exergy study for a solar integrated combined cycle was conducted. The heating-cogeneration and trigeneration examples of an integrated organic Rankine cycle were shown to be less sensitive to temperature and pressure changes than the electrical power and cooling-cogeneration instances. An energy and exergy research was conducted on a heat-matched biogas-based cogeneration facility in order to assess overall and component efficiency, identify and calculate thermodynamic losses, and detect and measure energy consumption. An 11.52 MW diesel engine-based cogeneration power plant underwent an exergy analysis, and it was concluded that the diesel engine's maximum exergy destruction was primarily due to the diesel engine's mostly irreversible combustion process, as well as heat loss from the engine and friction.

2. Thermodynamics analysis of present thermal model

The first and second laws of thermodynamics are basic approaches to, and properties of, all analytical equations. A straightforward mathematical model of the basic principles of thermodynamics is used in the study. Mass and energy balance equations have been applied in all thermal utilities 1,4). In order to make the analysis more straightforward, the following assumptions are made:

1. The thermal process established a stable flow and system while taking into account the control volume.
2. The mass condition at each state inside the control surface of control volume does not change over time.
3. The rate of mass flow into and out of the control volume remains constant across time.
4. Isentropic efficiencies to be assumed for both turbine and pump analysis

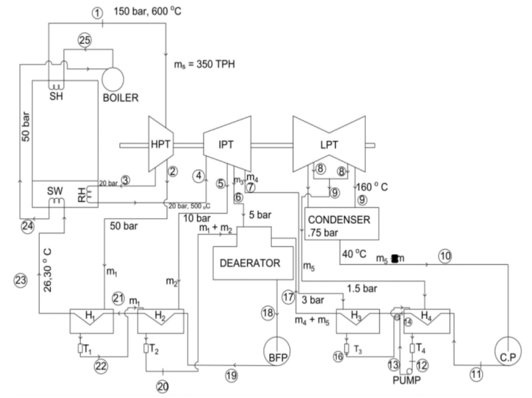

Fig. 1: Plant Schematic

The thermodynamic equations and relation are following. Equations adopted from ref. no 52). Proposed plant schematic Fig. 1, referred from reference no 52).

$S_g = S_f + xS_{fg}$ (1)

Where $S_{fg} = S_g - S_f$ (2)

Enthalpy expression as follows

$h_g = h_f + xh_{fg}$ (3)

Where $h_{fg} = (h_g - h_f)$ (4)

h11 = h10+ sp. Vol. * P (5)

$T_{11}/T_{12} = (P_{11}/P_{12})^{((\gamma-1)/\gamma)}$ (6)

The steam generation unit's inlet feed water temperature is T23.

the following heater heat equations

Heater 1: m1 = m steam (h23 - h21) (h2 - h22) (7)

Heater 2: m steam = m2 (h5-h20) + m1 (h22-h20) (h21-h19) (8)

Heater 3 (Dearator): (m steam - m steam - m1 - m2 - m3) = (m steam - m steam - m1 - m2 - m3) (h18 – h17) (9)

Heater 4 m4 = (m steam- m1- m2- m3) (h7-h16) (h17 – h15) (10)

Heater 5

Using the formula: m5 (h8 - h12) + m4 (h16 - h12) = (m steam -m1 -m2 -m3 -m4 -m5) (h14 –h11) (11)

High Pressure Turbine Work (HPT) is equal to m steam (h1 - h2) plus m steam (m1 - m1) (h2 -h3) (12)

HPT + (m steam -m1) (h4-h5) + (m steam -m1 -m2) (h5-h6) + (m steam -m1 -m2 -m3) (h6-h7) + (m steam -m1 -m2 -m3 -m4) (h7 –h8) (13)

HPT Work + IPT + (m steam -m1 -m2 -m3 -m4 -m5) = Low Pressure Turbine Work (h8 –h9) (14)

Assume that 1% of the pump's effort, Wnet, is equal to 132.6 or 132 M WATER (Plant Generation)

Boiler Heat Increase

Q A is equal to m steam (h1 - h23) plus m steam (m1) (h4 –h3) (15)

Cycle efficiency = W net/Q (16)

Water economizer temperature (T24) T 24/T 3 =(P 24/P 3)((-1)/) (17)

Consumption of coal m coal* C.V = Q1 (18)

Q eco = m steam (h24 - h23)/mc (19)

m steam(h25 - h24)/mc = Q boiler (20)

Qs.h = m_steam(h1 –h25)/mc (21)

Qr.h = m_steam (h2 –h3)/mc (22)

Percentage of heat absorbed by economiser = (h_24- h 23)/(h 1-h 12) (23)

Boiler heat absorption rate = (h 25-h 24)/(h 1-h 12) (24)

Heat absorbed by r.h as a percentage is (h 2-h 3)/(h 1-h 12) (25)

Heat absorbed by s.h as a percentage is (h 1-h 25)/(h 1-h 12) (26)

Stream rate equals m steam/W_ (27)

Heat rate = Q1/W_ (28)

Efficiency of steam generation $=(m_s (h_1-h_{23}))/(m_c \times c.v)$ (29)

Work ratio = wnet/wt (30)

Condenser flow (condition for LPT)

$= m_{steam} - \sum_1^5 m$

Cooling tower water floe rate

$m\_steam(cp\Delta t + L.H)cond = m\_water(cp\Delta t)c.t$ side (31)

Exergy of Boiler

Exergy (∈) $=m\times c\_p\times T\_o\ (T\_b\ )/T\_o -1-\ln (T\_b\ )/T\_o\ )$ (32)

Where Tb = boiler temperature

To = Atmosphere temperature

$\Delta s=c\_p \ln(〖\Delta T〗\_out ∣ 〖\Delta T〗\_in)$ (33)

$Irr = To\sum \Delta s$ (34)

Exergy decrement rate = ∈_output-∈_input (35)

Steam exergy loss rate = ∈ ∈_in/ _out (36)

Exergy destruction ratio = T0Δs/Q_boiler (37)

Exergy efficiency = 1- EDD (38)

Steam exergy increment rate = m_steam h1-h23-T0(s1-s23)) (39)

Rate of exergy increases in steam minus rate of exergy decreases equals exergy destruction in the boiler. (40)

Condenser

Exergy (∈) $=m\times c\_p\times T\_o\ (T\_b\ )/T\_o -1-\ln (T\_b\ )/T\_o\ )$ (41)

$Irr = To\sum \Delta s$ (42)

Rate of exergy decrease = ∈_output-∈_input (43)

EDD ratio = T0Δs/Q_boiler (44)

Exergetic efficiency = 1-EDD (45)

Exergy rise rate in stream = m steam h9-h10-T0(s1-s9) (46)

3. Result and Discussion

There was a detailed investigation of the thermal facility. Calculations are made about the first and second laws' efficacy, inlet-outlet temperatures, inlet-outlet exergy, mass flow rates for each component, and exergy destruction in the boiler and condenser. It was determined that the boiler destroys more energy than the condenser. The results are shown in table-1, as may be seen below, in a tabular manner.

Table 1. Compare result of different component

Thermal utilities	mfr (kg/s)	Work (M_WATER)	Tin (0c)	Tout (0c)	Exergy output (MW)	Exergy input	Exergy destruction (MW)
Boiler	97.6	-	263	600	49.589	12.284	71.873
Heater1	16.3	-	190.611	263	1.9	1.083	-
Heater2	0.07	--	156.365	190.611	0.004	0.00311	-
Heater 3	2.21	-	111	135.131	0.071	0.045	-
Heater 4	6.029	-	45	91	0.076	0.0077	-
Deaerator	24.86	-	135.131	156.365	1.105	0.813	-
H.P.T	97.6	56	600	437	29.861	49.589	6.642
I.P.T	81.3	112.042	500	225	7.622	30.986	2.645
L.P.T	54.16	134	300	160	2.557	8.666	6.496
condenser	47.5	-	160	40	2.157	0.048	30.995

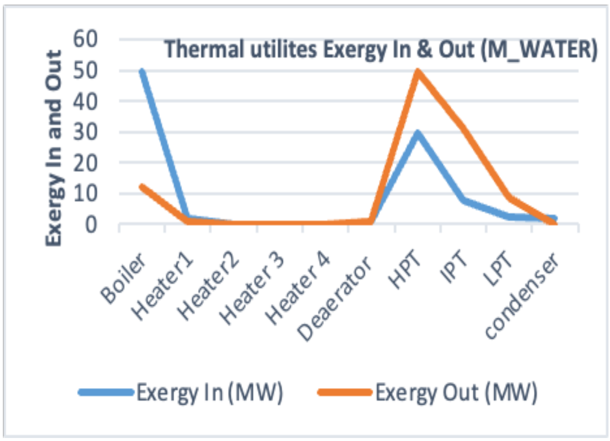

Fig. 2: Plant component exergy output & input

There are various graphs drawn between thermal utilities of thermal power plant vs. Exergy input & output, Exergy loss, Thermal utilities heat absorbed and heat loss rate respectively.

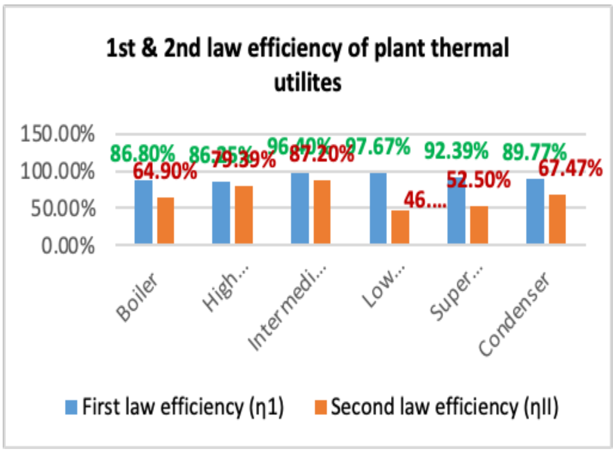

Fig. 3: Plant component 1st and 2nd law efficiency

Figure 2 represents the graph between exergy output and various component of power plant which clearly showed that H.P.T turbine has maximum exergy output. Graph between exergy input and various thermal utilities of power plant and shows that boiler has maximum exergy input. Fig. 3, clearly explains the 1st and 2nd law efficiencies of proposed plant components. It signifies the actual useful work and energy loss. It compares the ideal and actual thermodynamic cycle.

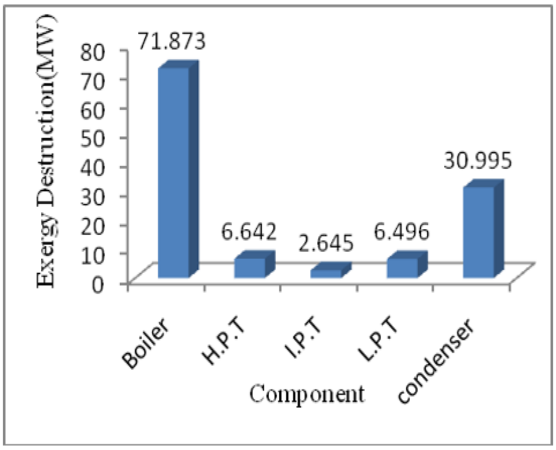

Fig. 4: Exergy loss in plant thermal utilities

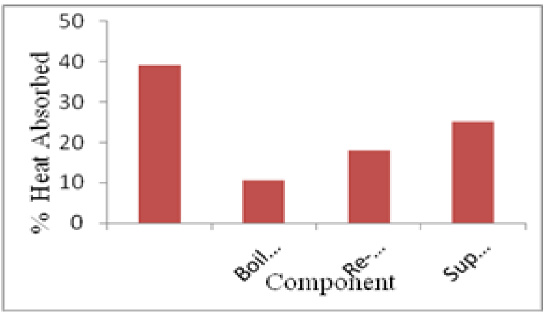

Fig. 5: Heat absorb by plant thermal utilities

Boiler exergy destruction is highest in comparison to the condenser and turbine, in Fig. 4 between exergy destruction and component of power plant.

The Fig. 5 between heaters used in power plant and percentage heat absorbed in the cycle and shows that economised absorbed maximum heat with respect to another component.

4. Conclusion

The concept behind thermodynamics analysis is to find irreversibility present in any plant and by using that concept irreversibility can be reduced. Any plant or component of a plant can be improved using one of four different types of thermodynamics analysis: energy analysis, exergy analysis, economic analysis, and exergo-economic analysis. The report's main goal is to use data to determine the combined power plant's energy and exergy efficiency. In context to the objective many literature reviews are been done that consist of term thermal analysis of different type of power plant. For this goal, four different types of power plants—thermal power plants that burn coal and gas, combined power plants, and cogeneration power plants—are explored. According to the calculation, there is a comparison between the energy and exergy efficiencies of the plant and its individual components, and it is discovered that the process of heat supply has the greatest exergy destruction and the process of heat removal, or condensation, has the greatest energy destruction. These processes are, respectively, the combustion chamber or the boiler and the condenser. As per the literature review and data procured from the plant, calculation of thermodynamics analysis is done via help of energy and efficiency of the plant. The 1st and 2nd law thermodynamic efficiency represent real beneficial work as well as energy waste. It compares and contrasts the ideal and real thermodynamic cycles.

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