ISLAMIC UNIVERSITY OF TECHNOLOGY

*ORGANISATION OF ISLAMIC COOPERATION*

# EXERGY ANALYSIS OF 171 MW COMBINED CYCLE POWER PLANT IN BANGLADESH

FOR ATTAINMENT OF THE ACADEMIC DEGREE

**BACHELOR OF SCIENCE**
**IN**
**MECHANICAL ENGINEERING**

AUTHORED BY

**SYED MUSABBIR AL SIFAT**

STUDENT ID: 160011037

**MEHEDI HASAN PIASH**

STUDENT ID: 151447

**UNDER THE SUPERVISION OF**

**MR. MD. ABDUL KARIM MIAH**

**ASSISTANT PROFESSOR**

**DEPARTMENT OF MECHANICAL AND PRODUCTION ENGINEERING**

March, 2021

# CERTIFICATE OF RESEARCH:

The thesis title "**Exergy Analysis of 171 MW Combined Cycle Power Plant in Bangladesh,**" submitted by **Syed Musabbir Al Sifat (160011037)** and **Mehedi Hasan Piash (151447)**, has been accepted as satisfactory in fulfillment of the requirement for the Degree of Bachelor of Science in Mechanical and Production Engineering on March 2021.

Signature of the Supervisor

Mr. Md. Abdul Karim Miah

Department of Mechanical and Production Engineering

Islamic University of Technology

Gazipur, Dhaka

# DECLARATION

IT IS HEREBY DECLARED THAT THIS THESIS /PROJECT REPORT OR ANY PART OF IT HAS NOT BEEN SUBMITTED ELSEWHERE FOR THE AWARD OF ANY DEGREE.

**Syed Musabbir Al Sifat**

**Student ID: 160011037**

Piash

**Mehedi Hasan Piash**

**Student ID: 151447**

**Mr. Md. Abdul Karim Miah**

**Project Supervisor**

# ACKNOWLEDGEMENT:

We express our heartiest gratefulness to Almighty Allah for His divine blessings, which made us possible to complete this thesis successfully.

First and foremost, we feel grateful and acknowledge our profound indebtedness to Mr. Md. Abdul Karim Miah, Department of Mechanical and Production Engineering, IUT. His endless patience, scholarly guidance, continual encouragement, constant and energetic supervision, constructive criticism, valuable advice at all stages have made it possible to complete this project. We would also like to offer thanks to all who helped us in many ways during the project work. We acknowledge our sincere indebtedness and gratitude to our parents for their love.

We seek excuse for any errors that might be in this report despite our best efforts.

Syed Musabbir Al Sifat

Mehedi Hasan Piash

# Table of Contents

# List of Tables

# List of Figures

# ABSTRACT

The Kushiara Combined Cycle Cogeneration Plant is investigated in this research by energy and exergy analyses. Energy analysis using key operating conditions is used to evaluate the basic thermodynamic properties of the structures. To evaluate thermodynamic inefficiencies in the system and to direct potential changes in the facility, exergy destructions inside the system and exergy losses to the atmosphere are examined. The research included evaluating the thermodynamic properties of twenty-four node points in a thermal power plant unit, as well as measuring exergy values for each node. Exergies that were lost or destroyed were then measured. On the basis of the received data, the equipment and materials were compared on a table. In the boiler, the highest rate of exergy loss corresponded to 38.3 percent. The powerplant's average second law efficiency amounted to 50.7 percent. The method of measurement and the conclusions obtained are assumed to be applicable to other thermal power plants.

**Keywords**

Combined Cycle; Cogeneration; Thermal power plant; Exergy Analysis

# CHAPTER 1: INTRODUCTION

## 1.1 THE OBJECTIVES OF THE THESIS

Thermodynamics, heat transfer, fluid mechanics, manufacturing, and mechanical architecture are all concepts that are used in the design and study of thermal systems. The thermodynamics component of the design is studied in this research.

Energy consumption is the most important measure of a country's development stage and the quality of life in its populations. Population development, urbanization, industrialization, and technological advancement all lead to a rise in energy demand. Contamination and greenhouse effects are two major environmental issues that have arisen as a result of this strong upward trend. Today, fossil-fuel-fired thermal power plants (coal, gasoline, fuel-oil, natural gas) produce about 80% of the world's electricity, with renewable sources such as hydraulic, wind, solar, geothermal, and biogas supplying the remaining 20% [1]. Because of the rapid decline of fossil fuel sources, power plants must work as quickly as possible.

The overall energy supply and ecological circumstance requires an improved usage of fuel sources. Thus, the multifaceted nature of intensity producing units has expanded significantly. Plant proprietors are progressively demanding a strictly ensured performance. This requires thermodynamic computations of high accuracy. Accordingly, the use for thermodynamic figuring during plan and advancement has developed tremendously. Energy and exergy analysis has progressively pulled in the premium to accomplish the above objective. For the most part, the exhibition of thermal power plants is assessed through energetic performance criteria dependent on The First Law of Thermodynamics, including electrical power and thermal efficiency. In recent years, the exergetic analysis dependent on The Second Law of Thermodynamics has found as valuable strategy in the plan, assessment, streamlining and improvement of thermal power plants. The exergetic analysis cannot just decide extents, area and reasons for irreversibilities in the plants, yet in addition gives more significant evaluation of plant individual component effectiveness. These purposes of the exergetic analysis are the essential contrasts from lively performance analysis. Along these lines, it very well may be said that performing exergetic and energetic analyses together can give a total portrayal of system characteristics.

Total energy consists of available energy plus unavailable energy. Thinking about progressions of energy in a framework, total energy is simply called energy and available energy is called exergy. Exergy flows to and from components however do not balance indicating a disappearance or "consumption" of exergy. This disappearance is actually a conversion from available energy to unavailable energy. Utilization is an illustrative term demonstrating the loss of available energy. Components consume exergy by virtue of the ineffectiveness of their ability to transfer available energy. In order to analyze the quality degrees of different energy transporters, for example powers, it is important to decide the reciprocals of every energy amount at a specific evaluation level. This should be possible by utilizing exergy idea, which defeats the restrictions of the first law of thermodynamics; and depends on both The First and The Second Laws of thermodynamics.

Energy is constantly saved in each device or process. In contrast to energy, exergy isn't commonly conserved but is destroyed. Most of the reasons for thermodynamic flaw of thermal processes are not represented by energy or The First Law analysis. It is the exergy or second law analysis that accounts the irreversibilities like heat transfer through a finite temperature difference, chemical reactions, friction, mixing, and unrestrained expansion. The Second Law analysis of a power cycle empowers us to distinguish the significant sources of loss and shows roads for execution improvement. Practical devices including energy conversion and transfer consistently observe energy conservation law; however, the nature of energy corrupts for example work potential is lost or exergy is burned-through (i.e., destroyed). Degradation of energy is identical to the unrecoverable loss of exergy because of all real processes being irreversible. The loss of exergy or irreversibility gives a quantitative proportion of process inefficiency [2].

The exergy utilization during a process is relative to entropy creation, which represents failures because of irreversibilities. The potential for development in a given part is controlled by its irreversibility rate under a given arrangement of conditions corresponding to the characteristic irreversibility rate inside the cutoff points powered by physical, innovative, financial and different imperatives. Consequently, exergy analysis is as significant as energy analysis for plan, activity and support of various hardware and frameworks of a power plant. An exergy analysis can distinguish areas of energy degradation and rank them regarding their criticalness. This information is valuable in coordinating the consideration of process design, researchers, and practicing engineers to those segments of the framework being investigated that offers the best opportunities for development [3].

The exergy consumption or order of destruction is a type of ecological damage. By safeguarding exergy through expanded proficiency (for example as little exergy as possible for a process), ecological damage is diminished [4]. Thusly, exergy analysis is as significant as energy analysis for plan, activity and support of various equipment and systems of a power plant. It is significant that the exhibition observing of a usable power station incorporates exergy analysis other than the ordinary energy analysis. In any case, expound exergy analysis has not yet been rehearsed generally in power stations due to an absence of plainly characterized codes and guidelines for this.

Among the thermal systems, combined cycle cogeneration systems are analyzed by exergy analysis. Exergy analysis, which is the combination of first law and second law of thermodynamics, helps to highlight the thermodynamic inefficiencies of a system. The main objective of this thesis was to perform an exergy analysis on the Kushiara 171 MW combined cycle power plant in Bangladesh and discuss the results and scope of further improvements.

## 1.2 LITERATURE REVIEW

Bejan, Tsatsaronis, and Moran (1996) published 'Thermal Design & Optimization', a detailed and systematic approach to thermal device design and optimization from a contemporary viewpoint. New developments in engineering thermodynamics, heat transfer, and engineering economics that are applicable to architecture are included in the text. Exergy analysis and entropy generation minimization was illustrated. There is also a comprehensive overview of engineering economics and thermoeconomics. Furthermore, a case study is used to keep the presentation consistent in the book. The construction of a gas turbine cogeneration device is the topic of the case study. [5]

Lazzaretto and Tsatsaronis' paper "On the Calculation of Efficiencies and Costs in Thermal Systems" (1999) is an expansion, generalization, and more formal presentation of the contents of the previous articles by the same authors. The SPECO method for measuring exergy-related costs in thermal systems is defined in this article. The auxiliary costing calculations are determined using general rules for describing fuel and commodity (based on the F and P rules). [6]

Tawney, Ehman, and Brown (2000) reflect on many sets of process steam flows and conditions in their paper "Choice of Cycle Configurations for Combined Cycle Cogeneration Power Plants," in order to provide a framework for comparing the most typical cycle configurations in combined cycle applications. The reliability and process steam flows specifications are used to determine plant architecture, cycle efficiency, and economics for each configuration. Instead of self-establishing energy balances, GE Enter Software, Inc.'s GateCycleTM Heat Balance software is used to build thermal models. In addition, an economic model for each cycle configuration is designed using a financial software tool created by Bechtel. The inference is that the type of cogeneration facility selected, as well as the economic criteria, are highly location specific and depend on a range of factors such as site environmental conditions, required power production and steam demand, capacity factor, durability, power purchase agreement and steam purchase agreement requirements, and the owner's economic parameters for return on equity. [7]

Huang (1996) identifies ten criteria for examining the efficiency of cogeneration systems in his paper "Performance Evaluation Parameters of a Cogeneration System." The utility of each parameter is often discussed. Finally, it is shown that the second-law efficiency (exergetic efficiency) and the power-to-heat ratio are the most suitable and useful metrics for a decision-maker to use when comparing the output of different designs. [8]

Bilgen (2000) discusses exergetic and engineering studies as well as a simulation of gas turbine-based cogeneration plants in his paper "Exergetic and Engineering Analyses of Gas Turbine Based Cogeneration Systems." Two cogeneration cycles have been examined, one with a gas turbine and the other with a gas turbine and a steam turbine. The conclusions were in fair agreement with the information presented. [9]

Habib (1994) provides a cogeneration system review in his article "First-and Second-Law Analysis of Steam-Turbine Cogeneration Processes." The study measures the irreversibilities of each plant's numerous components. The effect of the heat-to-power ratio and process pressure on thermal efficiency and utilization factor is also addressed. In contrast to a traditional farm, the overall irreversibility of the cogeneration plant is 38 percent less. This decline in irreversibility is followed by a 25% and 24% increase in thermal efficiency and utilization factor, respectively. The findings reveal that the boiler has the greatest exergy destruction. [10]

Huang and Naumowicz (1999) propose a framework for assessing the efficiency of a combined-cycle cogeneration system in their paper "Performance Evaluation of a Combined-Cycle Cogeneration System." This system's energy balances and performance evaluation metrics are given. The findings for a device like this that uses an advanced gas turbine as the prime mover demonstrate that it is a very flexible system. Over a wide range of process steam pressures, it can provide a high power-to-heat ratio as well as a high second-law efficiency. [11]

Karthikeyan et al. (1998) published a paper titled "Performance Simulation of Heat Recovery Steam Generators in a Cogeneration System," which includes energy balances for a single pressure stage heat recovery steam generator. Pinch and approach points' impact on steam generation as well as temperature profiles through heat recovery steam generators are studied. The effects of operating conditions on steam generation as well as the heat recovery steam generator's exit gas temperature are addressed. Low pinch point results in better heat recovery steam generator efficiency due to decreased irreversibilities, according to the findings. In addition, auxiliary firing increases steam efficiency. [12]

Boyce (2002) published the book "Handbook for Cogeneration and Combined Cycle Power Plants," which addresses all of the major aspects of power plant construction, operation, and maintenance. It includes technical information on sizing, plant configuration, fuel availability, drive modes, and performance characteristics of all major components in a cogeneration or combined cycle power plant. This book also includes a comparison of different energy technologies, the most recent cycles and power augmentation methods, evaluations and benefits of the most recent codes, thorough study of available facilities, techniques for enhancing plant stability and maintainability, monitoring and plant assessment techniques, and the benefits and drawbacks of gasoline. [13]

In 2019 Soonhu Soh et.al studied the operational efficiency of combined cycle power plants in Bangladesh and ranked them considering CCR, BCC and super efficiency model and considerable amount of waste has been found in the production process. [18]

In 2020 S. Hossain et.al analyzed the energy and exergy of Bangladesh's power generation sector. They found the exergy efficiencies between 35% to 39.2%. They found the hydro power plant more efficient than thermal power plant. [19]

In 2014 exergy analysis has been done of a 2000 MW power plant by Almutairi et.al and found that the combustion chamber is the main source of irreversibility and steam turbine is the lowest one. Also the temperature difference between the streams represents the major source of irreversibility in the HRSG. [20]

In 2014 a case study has been done on the prospect of combined cycle power plant in Bangladesh by Imtiaz Hossain et.al and found that this combined cycle can be introduced in Bangladesh. It is possible to produce more power using the same amount of gas in the single cycle [21].

In 2008, Ameri et al. Investigated Neka Combined cycle power plant in Iran and evaluated irreversibility of every equipment. The main sources of irreversibility are the combustion chamber, gas turbine, duct burner, and heat recovery steam generator (HRSG). The combustion chamber is where the most exergy is lost in a gas turbine. Usage of duct burner increases the overall power output by 7.38%. [22]

In 2020, Ferdushi et al. measured performance of power plants in Sylhet for 24 months. In this study gross electricity generation is considered as output. Average efficiency of the two plants was 90% and 78% respectively at the start of the study. The result shows that efficiency decreases over time. [23]

In 2017, Unal Fatih performed thermodynamic and exergoecoomic analysis on a combined cycle power plant in Turkey. The equipments were compared with each other. The maximum rate of exergy loss and cost of exergy destruction were calculated. [24]

Okoroigwe et al. investigated the progress of ST-ISCCS development (Solar Tower- Integrated Solar Combined Cycle System). It has been discovered that much research attention has been given to ST technology, with some commercial ST power plants operating in various parts of the world [25]. Aliyu et al. carried out detailed energy, exergy, and parametric analyses of a triple pressure combined cycle power plant while taking into account the exhaust gasses of the gas turbine used in the Rankine cycle. The findings of such a study will provide power plant designers, engineers, and operators with useful information and guidelines [26]. Abuelnuor et al. evaluated performance of Garri "2" CCPP on the basis of second-law of thermodynamics via exergy analysis. In order to improve performance of Garri "2" every individual process are examined for exergy destruction and exergetic efficiency [27]. Colpan et al. quantified exergy destructions within the power plant and exergy losses to the surroundings, applied performance assessment variables to the plant, determined product costs, and identified cost formation within the system [28]. Prakash et al. investigated a combined cycle power plant equipped with a carbon capture system, which was then converted into methane and used in the additional gas turbine unit for energy enhancement, while the remaining part was sent for CO2 storage. The total exhaust from the additional gas turbine is also used to amplify steam generation in the heat recovery steam generator, increase steam turbine efficiency and work output, and capture carbon dioxide from it. Exergy analysis is performed to estimate the exergy destruction and exergetic efficiency of key components in the customized cycle configuration of a gas/steam combined cycle power plant [29]. Ibrahim et al. evaluated a combined cycle power plant and found that the most energy loss occurs in the condenser and the most exergy destruction occurs in the combustion chamber. They concluded that exergy analysis is a better method at measuring the performance of a combined cycle power plant.[6] Zhu et al. conducted energy and exergy analysis on combined cycle power plant on board ships. They concluded that adjustment of turbocharger can reduce exergy destruction. Amount of load affects the performance of the power plant [30]. Kaviri et al. studied a combined cycle power plant with dual pressure and supplementary firing. They discussed how the HRSG inlet temperature affects the steam cycle efficiency. Optimum temperature for the HRSG is $650^0$C [31]. Ali et al performed thermodynamic analysis on the combined cycle power plant having triple pressure HRSG at Guddu in Pakistan. Energy loss and exergy destruction of each component was calculated. Total power output and energy and exergy efficiency was also calculated [32].

## 1.3 COMBINED CYCLE COGENERATION SYSTEMS

### 1.3.1 Cogeneration

The development of electrical energy and usable thermal energy from the same energy supply is known as cogeneration. Only a small portion of the fuel energy is converted into electricity in traditional electricity generation, and the rest is lost as waste heat. Cogeneration helps to mitigate this depletion by restoring a portion of it. Industrial sites, district heating, and houses are some of the most common uses for cogeneration.

The prime movers in cogeneration schemes are classified in general. Steam turbines, gas turbines, hybrid cycle engines, and reciprocating engines are also currently viable systems. New developments are already projected to become commercially viable over the next ten years. Fuel cells, Stirling motors, and micro-turbines are among them. [14]

### 1.3.2 Combined Cycle Cogeneration Systems

Prime movers such as gas turbines and steam turbines are used in the most common combined cycle system. In both systems, the topping cycle (gas turbine) generates electricity while refusing heat, while the bottoming cycle (steam turbine) recovers and utilizes excess heat to generate electricity and process heat.

Combining the Diesel and Rankine cycles is also feasible. The only distinction is that a diesel engine replaces the gas turbine. The extension of the Rankine cycle to medium to high-power engines could be economically feasible. [15]

### 1.3.3 CONFIGURATIONS

Cogeneration systems based on the combined cycle can be very complicated, as there are several implementations that can be chosen and configured to provide the owner with the necessary consistency, stability, and rate of return. [7]. The use of various models of steam turbines and heat recovery steam generators causes major configuration variations.

Condensing or back-pressure (non-condensing) steam turbines are available. Water leaves a backpressure steam engine at a pressure greater than or equal to ambient pressure, with the pressure differing based on the thermal load. Steam for the thermal load is extracted from one or more intermediate levels at the required pressure and temperature in condensing steam turbines. At the condenser's load, the remaining steam is drained. The condensing method has a higher fixed cost and, in general, a lower overall performance than the back-pressure system. However, by properly regulating the steam flow rate through the turbine, it can regulate the electrical power independently of the thermal load to some degree. [15]

The circulation type, number of pressure levels, and supplementary firing are the key distinctions between heat recovery steam generators. HRSGs may have a natural or forced circulation design, depending on the circulation type. HRSGs are vertical in forced circulation systems. The drums are supported by the HRSG's steel frame. Pumps are used to circulate the water through tubing. Pumps are not necessary in a natural circulation system. HRSGs are of the horizontal variety. The density differential between the down comer and riser circuits, as well as their hydraulic resistances, determine circulation. HRSGs may be single-pressure or multi-pressure based on their pressure conditions. Using a multi-pressure level increases the use of electricity from a gas turbine's exhaust gas, lowering energy loss in the device. HRSGs may be unfired, supplementary-fired, or exhaust-fired, depending on the steam specifications. The energy from the exhaust is used in unfired HRSGs, while additional fuel is applied to the exhaust gas to improve steam generation in supplementary-fired and exhaust-fired HRSGs. [13]

# CHAPTER 2: Methodology

## 2.1 General Description

Kushiara combined cycle cogeneration plant is located in Fenchuganj, within the Sylhet division of Bangladesh. A gas turbine system, a heat recovery steam generator (HRSG), a steam turbine with related generator, and a main steam condenser are all part of the facility. Auxiliary devices that are typical to the combined cycle are also available. Figure 1 shows a schematic sketch of the farm. A dump steam condenser is also present, which is required during the unit's start-up and shut-down, as well as in the event of a steam turbine failure.

Natural gas provided by a nearby supplier acts as the plant's steam. In dedicated separators, natural gas is isolated from oil and humidity before being compressed by electrically operated natural gas compressors.

The municipality provides raw water. It's used to make up the condensate that's left over from the process. It is also delivered to the cooling tower basin.

A hybrid cooling tower system, which functions as a wet/dry cooling tower all year, offers cooling water for steam condensing and machinery cooling. A cooling tower, divided into two cells, a cooling tower basin, which gathers cooled water from the towers, and cooling tower circulation pumps, which supply cooling water to the steam condenser and other users, are the main components of this system. The atmospheric air, which serves as cooling air, is pushed via the dry and wet parts in parallel flows through the induced draught fans.

Steam is either exclusively from the intermediate pressure steam generator (in the absence of steam turbine extraction) or a combination of steam from the intermediate pressure steam generator and steam from the steam turbine's regulated extraction.

## 2.2 Schematic Diagram

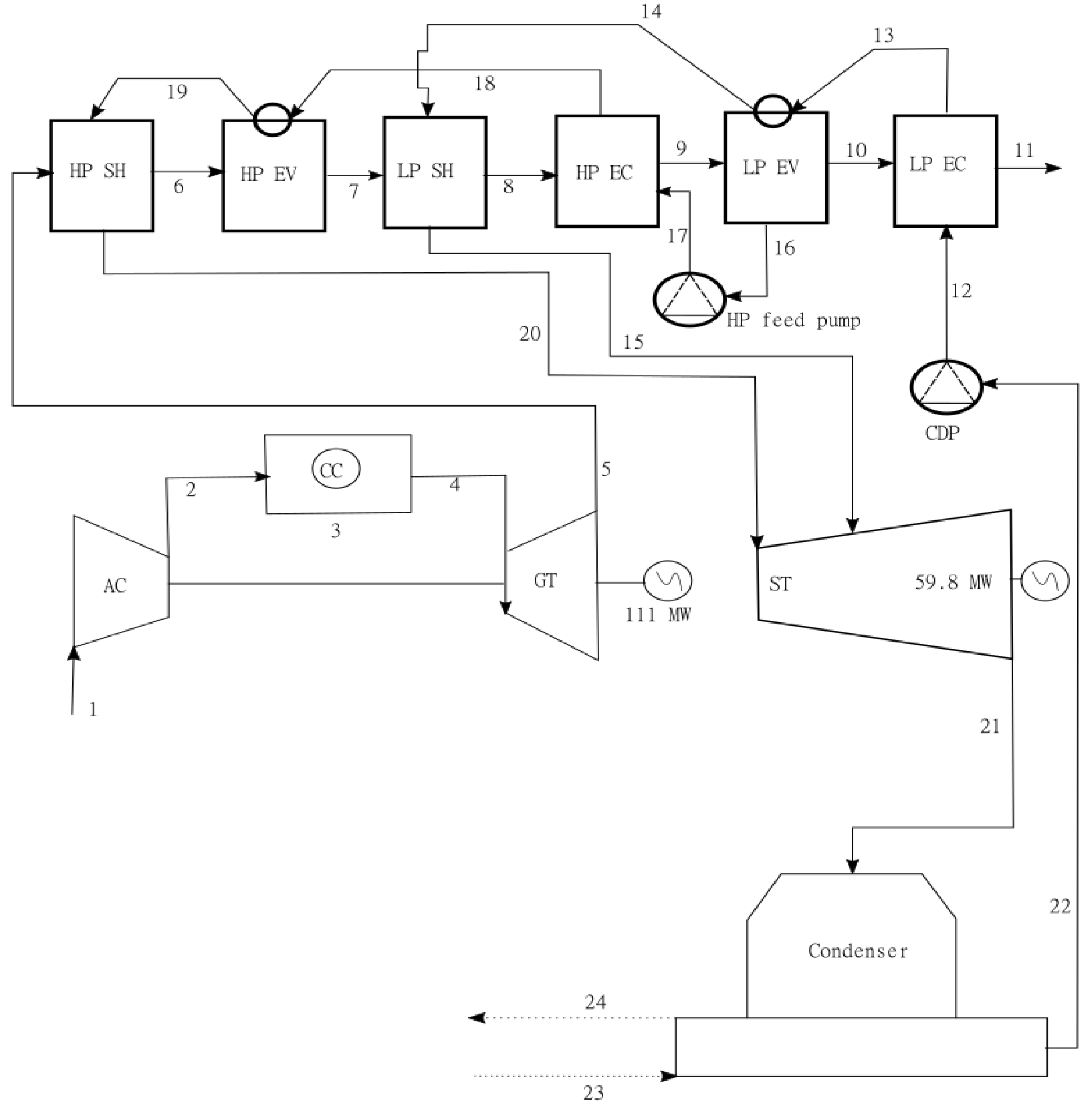

**Figure 1:** Schematic diagram of Kushiara Combined Cycle Cogeneration Plant

## 2.3 Process Description

This section addresses the Kushiara power plant's electricity generation operation. Natural gas is used to power the air compressor. The gas turbine compresses air and combines it with heavily heated gasoline. The gas turbine blades rotate as the hot air-fuel mixture flows through them. The turbine spins quickly, powering a generator that generates 111 megawatts of electricity. The gas that emerges through the exhaust pipe is already very hot. The exhaust heat from the gas turbine is absorbed by a Heat Recovery Steam Generator (HRSG), which would otherwise escape through the exhaust stack. The HRSG converts the heat from the gas turbine exhaust into steam, which is then delivered to the steam turbine. The energy from the steam engine is transferred to the generator drive shaft, where it is transformed into another 59.8 MW of electricity.

## 2.4 Exergy Analysis

Exergy is the overall amount of work that can be accomplished by putting a system into equilibrium with its surroundings. Every system that is not in equilibrium with its environment has any amount of exergy, while a system that is in equilibrium with its environment has zero exergy by necessity so it cannot do work with respect to its environment. [16]

Exergy analysis is a tool for evaluating, modeling, and developing energy systems that incorporates the conservation of mass and energy values with the second law of thermodynamics. The exergy approach is a valuable instrument for advancing the target of more effective energy resource usage since it allows for the determination of wastes and losses' positions, forms, and true magnitudes. Many engineers and scientists agree that conducting an exergy analysis in addition to or instead of standard energy analysis is the better way to measure a process's thermodynamic output because exergy analysis tends to have further insights and be more effective in furthering efficiency enhancement efforts than energy analysis. [17]

### 2.4.1 Mathematical Equations

Mass balance across the components: $\Sigma m_{in} - \Sigma m_{out} = 0$

Exergy of Components: $X = m(h-h_o) - T_o(s-s_o)$

Exergy equation: $\Sigma X_{in} - \Sigma X_{out} + W_{in} = 0$

$$X_{expanded} = (1 - T_o/T_s) * Q_{in} + W_{in}$$

Exergy destruction: $X_{dest} = \Sigma m(\Delta X)$

For 2nd law efficiency: $n_{II} = \left(1 - \frac{X_{dest}}{X_{expanded}}\right) * 100\%$

## Table 1 : Mass flow rate and thermodynamic properties of Kushiara plant

| Stream | Mass flow rate (kg/s) | Pressure (bar) | Temperature (°C) | Enthalpy, h (kJ/kg) | Entropy, s (kJ/kg.k) | $e^{total}$ (kJ/kg) |
|---|---|---|---|---|---|---|
| 1 | 382 | 1.013 | 27 | 300.613101 | 6.87096875 | 0 |
| 2 | 382 | 11 | 368 | 651.3736 | 6.96528 | 322.2 |
| 3 | 6.8 | 25 | 34 | -3.289355 | -1.651544 | 52000 |
| 4 | 388.8 | 10 | 1108 | 1025.091 | 7.684 | 895 |
| 5 | 388.8 | 1.04 | 560 | 859.701 | 7.927776 | 241.7 |
| 6 | 388.8 | 1.032 | 475 | 766.3756 | 7.810796 | 187 |
| 7 | 388.8 | 1.025 | 318 | 598.6254875 | 7.5597062 | 91 |
| 8 | 388.8 | 1.022 | 312 | 592.283516 | 7.5498535 | 87.6 |
| 9 | 388.8 | 1.018 | 236 | 513.295262 | 7.4031965 | 51.7 |
| 10 | 388.8 | 1.014 | 186.5 | 462.229111 | 7.3015985 | 32 |
| 11 | 388.8 | 1.013 | 110 | 384.35844 | 7.116092 | 10 |
| 12 | 60.8 | 22 | 43 | 182 | 0.6113 | 90.91 |
| 13 | 60.8 | 18 | 168 | 710.3 | 2.02 | 196.6 |
| 14 | 10.4 | 7.92 | 169 | 2767 | 6.67 | 858.3 |
| 15 | 10.4 | 6.05 | 269 | 2997.3 | 7.254 | 913.4 |
| 16 | 50.4 | 7.92 | 169 | 716 | 2.03 | 200.2 |
| 17 | 50.4 | 141 | 171 | 730.95 | 2.0351 | 212.72 |
| 18 | 50.4 | 110 | 304 | 1370 | 3.30 | 472.3 |
| 19 | 50.4 | 97.8 | 310 | 2728 | 5.624 | 1132.9 |
| 20 | 50.4 | 91 | 528.6 | 3459 | 6.75 | 1526.3 |
| 21 | 60.8 | 0.1 | 45 | 2382 | 7.5158 | 219.56 |
| 22 | 60.8 | 0.1 | 42.8 | 179.24 | 0.60963 | 88.65 |
| 23 | 3070 | 2.65 | 27.5 | 115.53 | 0.402 | 87.23 |
| 24 | 3070 | 1.08 | 38 | 159.16 | 0.5456 | 87.78 |

# CHAPTER 3: RESULTS AND DISCUSSIONS

## 3.1 Exergy Destruction

Exergy destruction in each component is calculated using the mathematical equations stated in section 2.4.1. It was found that the maximum amount of exergy was destroyed in the combustion chamber.

**Table 2: Exergy destroyed in each component**

| Components | Exergy Destroyed (MJ/s) |
|---|---|
| Compressor | 11.464 |
| Combustion Chamber | 128.7 |
| Gas Turbine | 8.62 |
| HP SH | 2.01 |
| HP EV | 4.031 |
| LP SH | 0.749 |
| HP EC | 0.878 |
| LP EV | 1.256 |
| LP EC | 2.13 |
| Steam Turbine | 12.516 |
| Condenser | 6.27 |
| HP Feed Pump | 0.209 |
| Condensate Pump | 0.03045 |

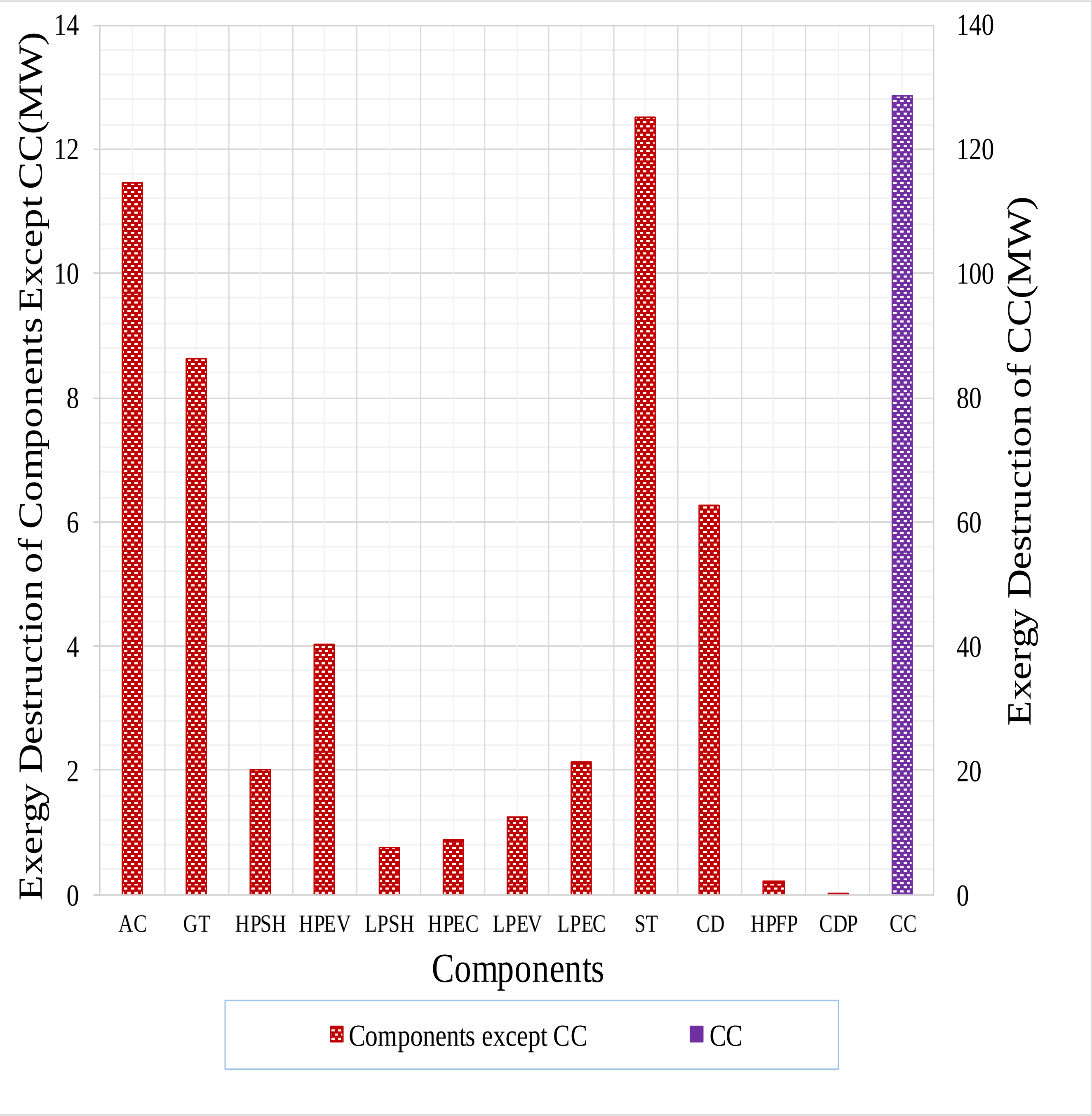

**Figure 2: Exergy destruction in each component**

Exergy destruction in each component is illustrated using bar charts in figure 2. In this figure, the destruction of exergy was measured in the unit of Mega Watt, where it can be seen that the combustion chamber has exergy destruction of approximately 128 MW, which is the maximum compared to other components. The condensate pump has the least amount of exergy destruction, approximately 2 MW. There are some other components like an air compressor, gas turbine, high-pressure superheater, high-pressure evaporator, low-pressure superheater, high-pressure economizer, Low-pressure evaporator, Low-pressure economizer, steam turbine, condenser, high-pressure feed pump; exergy destruction of these components are as follow 11 MW, 9 MW, 2 MW, 4 MW, 1 MW, 1.2 MW, 1.5 MW, 2.1 MW, 12.7 MW and 0.5 MW. From these data, it can be determined which of these components has the better efficiency. For calculating the second law of efficiency, the exergy recovered from each component have to be measured. Then the second law efficiency can be determined. As the exergy destruction is explained in this figure, the second law efficiency can be determined easily from this data.

The combustion chamber has the most exergy destruction as most of the heat generated is difficult to use to increase efficiency. As a result, the exergy destruction in this component is so high compare to other components. Then moving forward, some other components also have a different level of destruction of exergy. Steam turbine has the destruction of exergy of 12.7 MW, which is the indicator that the steam turbine also has a significant amount of exergy destruction due to super-heated steam and some other parameters. Air compressor also has the exergy destruction of 11 MW due to its low efficiency. One of the important component condensers has exergy destruction of 6.2 MW due to its low second law efficiency. The condensate pump has the lowest exergy destruction 0.5 MW, due to its efficiency in recovering the entropy inside the process. Many parameters were introduced here to explained the destruction of the exergy here in this figure. Exergy destruction of the components gives the exact idea of the second law efficiency, whether the second law efficiency will be low or high of these components. Furthermore, the efficiency of all components and other aspects like improving these components in the sense of the destruction of the energy and other aspects like efficiency can take ideas from this figure.

## 3.2 Second Law Efficiency

The second law efficiency of each component was calculated following the calculation of exergy destruction in each component. It was found that the gas turbine is the most efficient, and the condenser is the least efficient among the components.

Table 3: Second law efficiency of each component

| **Components** | **Second law efficiency (%)** |
|---|---|
| Compressor | 91 |
| Combustion Chamber | 64 |
| Gas Turbine | 97 |
| HP SH | 91 |
| HP EV | 89 |
| LP SH | 43 |
| HP EC | 94 |
| LP EV | 85 |
| LP EC | 75 |
| Steam Turbine | 83 |
| Condenser | 21 |
| HP Feed Pump | 77 |
| Condensate Pump | 82 |

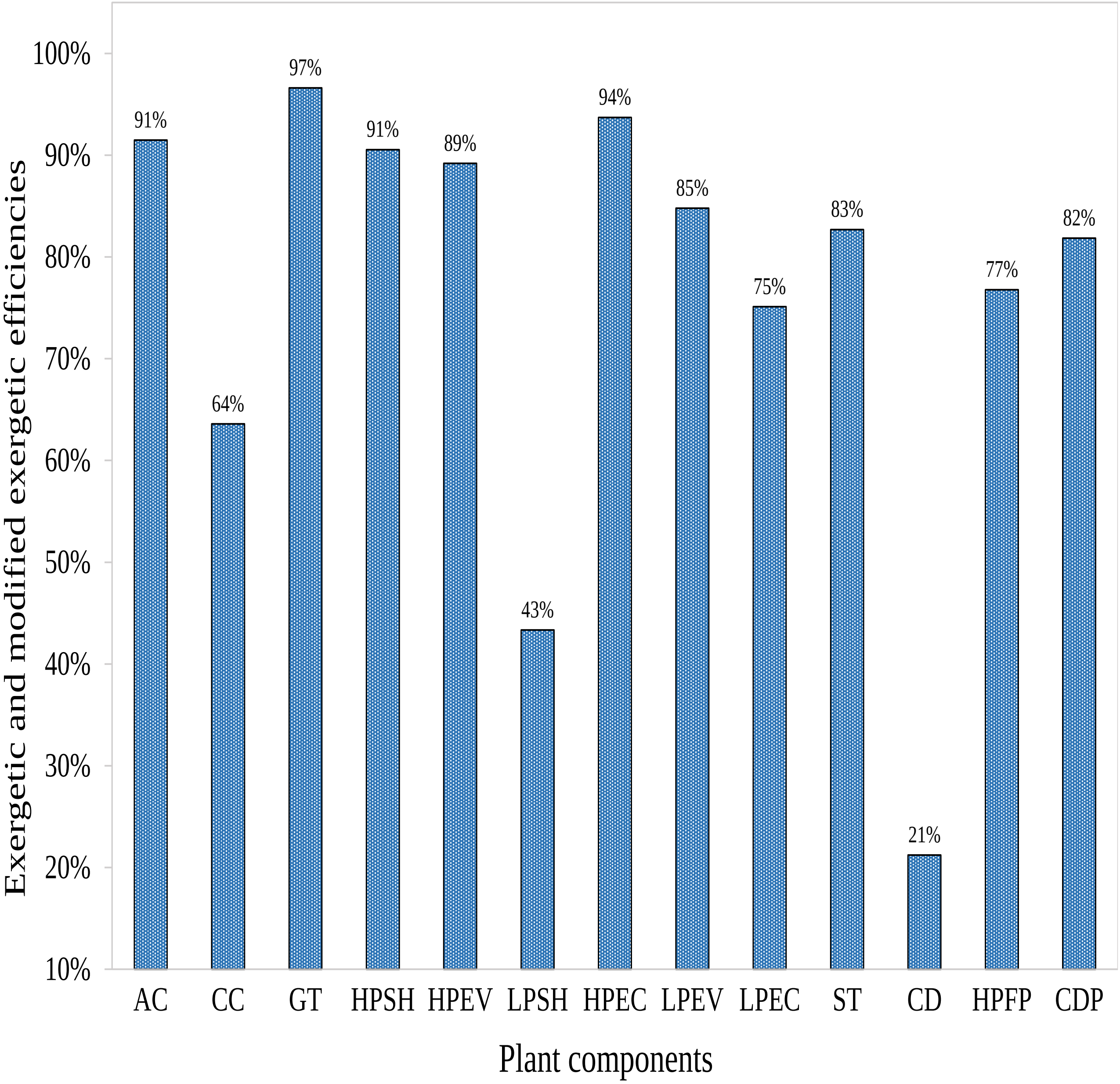

**Figure 3: Second law efficiency of each component**

The second law efficiency of each component is illustrated using a bar chart in figure 3. This figure gives a clear idea of all the components of how efficient they are regarding delivering maximum output, consider the input energy delivering. The second law efficiency calculate based on how much exergy one component can utilize to work output. It is visible that the gas turbine has the most efficient among all the components. After that, there are other components as follow as Air compressor (91%), Combustion chamber (64%), High-pressure superheater (91%), High-pressure evaporator (89%), Low-pressure superheater (43%), High-pressure economizer (94%), Low-pressure evaporator (85%), Low pressure economizer (75%), Steam turbine (83%), Condenser (21%), High pressure feed pump (77%), Condensate pump (82%). All these components have different types of efficiency, which will impact the overall performance of the power plant. The lowest efficiency can be seen in the condenser (21%), which means this component cannot maximize the exergy delivered in the input section.  The Air compressor has an efficiency of 91%, which indicates a convincing performance. The combustion chamber was the component in the previous figure, which was the top of exergy destruction with a second law efficiency of 64%; this indicates that the exergy recovery has been pretty good, and thus the kind of performance provided.

On the other hand, condensate pump was the lowest in the previous figure in terms of destruction of the exergy and has a second law efficiency of 82%, as expected. Other component's efficiency was understandable as their destruction of the exergy was not large enough. This second law efficiency can be affected due to many parameters. These parameters can be addressed as overheated and other environmental effects also. If all of the reasons are considered, then the second law of efficiency can be understood accordingly in this figure. This figure is the overview of the plant, how much efficient was the power plant and how to improved it.

Furthermore, this figure indicates what amount of the exergy can be extracted from each component that will help improve the power plant and exactly where the improvement is needed. With the help of this figure, future work of this project can be drawn, and the improvement of the plant can also be made.

### 3.3 Exergy Distribution

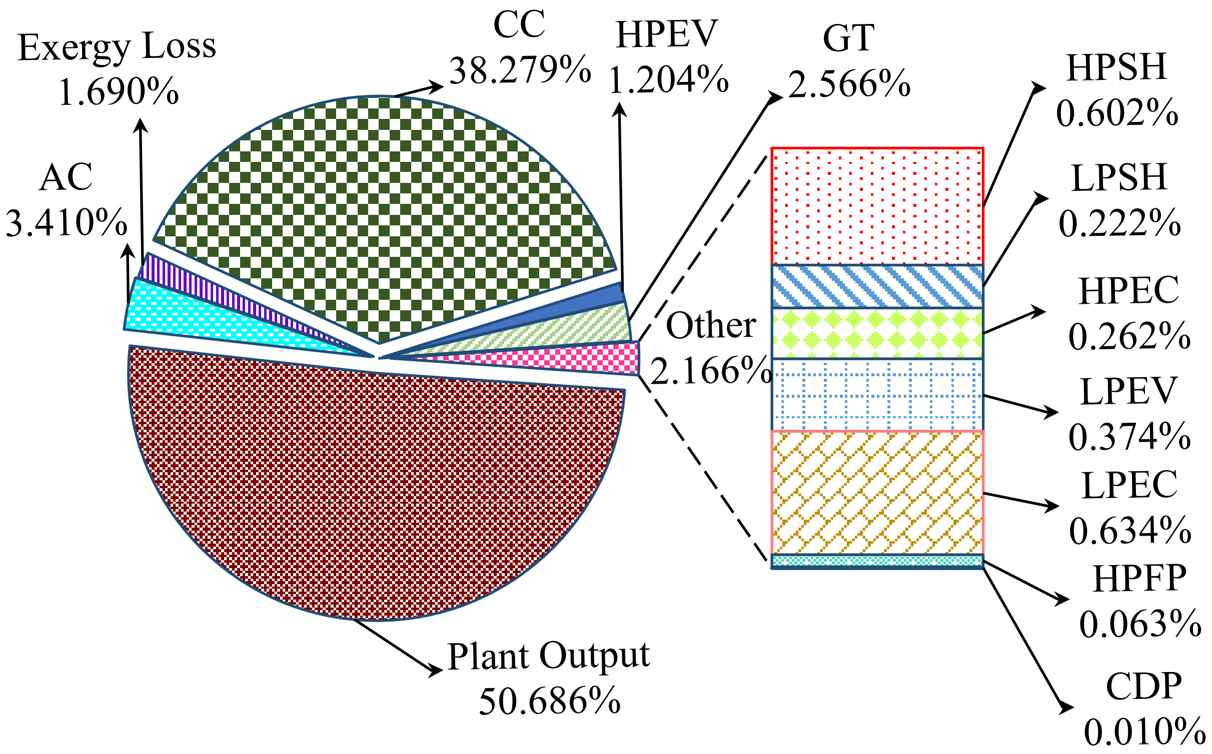

**Figure 4: Exergy distribution in the plant**

In figure 4, exergy distribution in the plant is illustrated using a pie chart. From the figure, it was observed that the plant output is 50.7%. The other 49.3% of exergy is being destroyed or lost. The maximum exergy destruction occurs in the combustion chamber. More than 38% of total exergy is destroyed in the combustion chamber.

The other components contribute about 10.7% in exergy destruction. The air compressor has a significant amount of exergy destroyed, 3.41% of the total plant. Percentage of exergy destruction in air compressor (3.41%) and gas turbine (2.57%) are also noteworthy. The remaining components have very insignificant amount of exergy destruction. It is also notable that there is 1.69% exergy loss in the power plant.

This figure is a summary of the whole investigation of the Kushiara combined cycle power plant. It helps us understand where improvement is needed most. It also gives a clear understanding about the plant's overall performance.

## 3.4 Recommendations and Further Works

In this chapter, some recommendations on performance improvement of Kushiara combined cycle power plant are discussed. From the results section, it was observed that the combustion chamber has the maximum rate of exergy destruction. Thus, it is necessary to first consider the boiler in the planned improvements. It is also necessary to thoroughly analyze factors that cause exergy losses in the boilers. The reason for the exergy loss in the boilers corresponds to the energy types with an irregular combustion phenomenon such as chemical energy, heat energy, and internal energy. These energy sources lose excessive amounts of energy during conversion. The high efficiency of the boiler is a significant factor that influences the performance of the system. In order to reduce energy losses in the boiler, it is necessary to prevent the formation of layers on the inner and outer surfaces of the pipes that obstruct heat transfer to prevent the discharge of the obtained heat through the flue gas. A factor that directly affects the efficiency of the boiler corresponds to the amount of air necessary for combustion. It is important to determine the optimal value of the air excess co-efficient during ignition. Therefore, it is essential to revise fresh air fans and to consider an automatic control technique. The loss of exergy in the turbine group is very low when compared to that of the boiler. Improvements to the turbine group will increase turbine efficiency, increase the availability of intermediate steam from the turbine stages, and increase the efficiency of the front heaters. However, it should be noted that the exergoeconomic factor of the turbine group is significantly high when compared with that of other equipment. Improvements in the turbine group will improve the performance of the equipment and will increase the cost of the system. Therefore, it is possible to optimize the intermediate steam obtained from the best improvement turbine without increasing the turbine cost and to thereby increase system efficiency. The situation is different for condensers that play a substantial role in conversion. They are characterized by irreversibility and high energy losses. Additionally, the exergoeconomic factor can reach a minimum of 9%, and this indicates that improvements that are considered for the condenser may not significantly increase investment costs of the system. The energy and exergy loss-related shares of other equipment within the system are low, and thus improvements applied to these types of equipment will not significantly contribute to system performance and could lead to an increase in the costs.

In the study, the results of energy and exergy analyses indicate that improvements with respect to a power plant increase performance and decrease the amount of fuel required. This eliminates the degree of environmental pollution caused by hazardous gases released due to burning. Analyses also underline that if in thermal power plants costs are examined in improvements will be beneficial in increasing the efficiency in plants. Hence, it is necessary to perform exergy analyses in planned power plants and to increase the performance of the power plant to optimal values in order to decrease operational costs of thermal power plants and eliminate environmentally hazardous gas emissions.

Advanced exergy analysis can be the next step of this research. In advanced exergy analysis, exergy destruction is split into two parts, avoidable and unavoidable. By conducting advanced exergy analysis, real potential for thermodynamic improvements of the system can be identified. This will be an indication of how much exergy destruction can be avoided with the best possible technologies in next decade.

# Nomenclature:

| | |
|---|---|
| m | Mass flow rate (kg/s) |
| X | Exergy flow rate (KW) |
| e | Specific exergy (KJ/kg) |
| h | Specific enthalpy (KJ/kg) |
| s | Specific entropy (KJ/kg.k) |
| Abbreviations | |
| AC | Air compressor |
| GT | Gas turbine |
| CC | Combustion chamber |
| HPSH | High pressure superheater |
| HPEV | High pressure evaporator |
| LPSH | Low pressure superheater |
| HPEC | High pressure economizer |
| LPEV | Low pressure evaporator |
| LPEC | Low pressure economizer |
| ST | Steam turbine |
| CD | Condenser |
| HPFP | High pressure feed pump |
| CDP | Condensate pump |

# REFERENCES:

[1] Nazrul I, Farhana A, *Energy and Exergy Analysis of a Coal Fired Thermal Power Plant with Varying Load Conditions,* 2017

[2] Kiran B, *Performance Optimization of Steam Power Plant through Energy and Exergy Analysis*, 2012

[3] Kotas T, *The Exergy Method of Thermal Plant Analysis, 1st Edition,* 1985

[4] Ibrahim D, Marc A, *Thermal Energy Storage: Systems and Applications,* 2002

[5] Bejan, A., Tsatsaronis G., Moran M., *Thermal design and optimization,* John Wiley and Sons Inc., U.S.A., 1996

[6] Lazzaretto, A., Tsatsaronis, G., *On the calculation of efficiencies and costs in thermal systems*, In: Proceedings of the ASME Advanced Energy Systems Division, AES-Vol.39, 1999

[7] Tawney, Ehman, Brown, *Selection of Cycle Configurations for Combined Cycle Cogeneration Power Plants,* 2000

[8] Huang, *Performance Assessment Parameters of a Cogeneration System,*1996

[9] Bilgen, *Exergetic and Engineering Analyses of Gas Turbine Based Cogeneration Systems,* 2000

[10] Habib*, First-and Second-Law Analysis of Steam-Turbine Cogeneration Systems,* 1994

[11] Huang, Naumowicz*, Performance Evaluation of a Combined-Cycle Cogeneration System,* 1999

[12] Karthikeyan, R., Hussain, M.A., Reddy, B.V., Nag, P.K., *Performance simulation of heat recovery steam generators in a cogeneration system*. International Journal of Energy Research 1998; 22:399-410

[13] Boyce, *Handbook for Cogeneration and Combined Cycle Power Plants,* 2002

[14] EDUCOGEN, *A guide to cogeneration*, March 2001

[15] EDUCOGEN, *The European educational tool on cogeneration*, second edition, December 2001

[16] Cownden, R., Nahon, M., Rosen, M., *Exergy analysis of a fuel cell power system for transportation applications,* Exergy Int. J. 1(2) (2001):112-121

[17] Dincer, I., *The role of exergy in energy policy making*, Energy Policy, Vol.30, pp.137-149, 2002

[18] Soh, S., Parves MDT., *An efficiency analysis of combined cycle power plants using dea models: a case study in Bangladesh,* 2019

[19] Hossain, S., *Energy, exergy and sustainability analyses of Bangladesh's power generation sector, 2020*

[20] Almutairi, A., Pilidis, P. *Energetic and Exergetic Analysis of Combined Cycle Power Plant: Part-1 Operation and Performance, 2014*

[21] Hossain, I., Khan, M., *Prospect of Combined Cycle Power Plant over Conventional Single Cycle Power Plants in Bangladesh: A Case Study, 2014*

[22] Ameri, M., Ahmadi, P., *Exergy analysis of a 420MW combined cycle power plant,* 2008

[23] Ferdushi, F., Kamil, A., *The Measures of Efficiency of Power Generation Plants in Sylhet of Bangladesh,* 2020

[24] Unal, F., Ozkan, D., *Application Of Exergoeconomic Analysis For Power Plants,* 2017

[25] E. Okoroigwe and A. Madhlopa, "An integrated combined cycle system driven by a solar tower: A review," *Renew. Sustain. Energy Rev.*, vol. 57, pp. 337–350, 2016.

[26] M. Aliyu, A. B. AlQudaihi, S. A. M. Said, and M. A. Habib, "Energy, exergy and parametric analysis of a combined cycle power plant," *Therm. Sci. Eng. Prog.*, vol. 15, p. 100450, 2020.

[27] A. A. A. Abuelnuor, K. M. Saqr, S. A. A. Mohieldein, K. A. Dafallah, M. M. Abdullah, and Y. A. M. Nogoud, "Exergy analysis of Garri' 2' 180 MW combined cycle power plant," *Renew. Sustain. Energy Rev.*, vol. 79, no. May, pp. 960–969, 2017.

[28] C. O. Colpan and T. Yeşin, "Energetic, exergetic and thermoeconomic analysis of Bilkent combined cycle cogeneration plant," *Int. J. Energy Res.*, vol. 30, no. 11, pp. 875–894, 2006.

[29] D. Prakash and O. Singh, "Exergy analysis of combined cycle power plant with carbon capture and utilization," *Energy Sources, Part A Recover. Util. Environ. Eff.*, vol. 00, no. 00, pp. 1–22, 2020.

[30] T. K. Ibrahim *et al.*, "A comprehensive review on the exergy analysis of combined cycle power plants," *Renew. Sustain. Energy Rev.*, vol. 90, no. March, pp. 835–850, 2018.

[31] A. G. Kaviri, M. N. M. Jaafar, T. M. Lazim, and H. Barzegaravval, "Exergoenvironmental optimization of Heat Recovery Steam Generators in combined cycle power plant through energy and exergy analysis," *Energy Convers. Manag.*, vol. 67, pp. 27–33, 2013.

[32] M. S. Ali, Q. N. Shafique, D. Kumar, S. Kumar, and S. Kumar, *Energy and exergy analysis of a 747-MW combined cycle power plant Guddu*, vol. 41, no. 13. Taylor & Francis, 2020.