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A comprehensive review on the exergy analysis of combined cycle power plants

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ABSTRACT

The arriving optimum improvement of a thermodynamic system of energy conversion such as a combined cycle power plant (CCPP) is complicated due to the existence of different factors. Energy and exergy analysis is utilized as effective methods to determine both the quantity and quality of the energy sources. This paper reviews the latest thermodynamics analysis on each system components of a CCPP independently and determine the exergy destruction of the plant. A few layouts of the CCPP plant from different locations considered as case studies. In fact, the most energy losses occurred in the condenser compared with the plant components. It found that in the combustion chamber (CC) the highest exergy destruction occurred. The ambient temperature causes an evident decrement in the power production by the gas turbine (GT). The result has proved that besides energy, exergy analysis is an efficient way to the assessment of the performance of the CCPP by recommending a more advantageous configuration of the CCPP plant, which would lead to reductions in fuel required and emissions of air pollutants.

1. Introduction

World's population growth and substantial global economic development are causing the increase in demand for energy dramatically. The energy supply has undergone a shock due to the economic crisis that has inflicted the global market. The gap between energy supply and demand has risen continuously. Studies have determined that there was an approximate 6% average annual growth in the electricity demand for the world [1]. Further, increase in demand for the energy expected for the next few years.

In general, there are many resources from which energy can be generated, including the conventional resources of fossil fuels, nuclear and renewable energy resources. The most common fuels used to generate energy are natural gas, coal and petroleum. Among the fossil fuels, coal has been one of the most abundant resources used for generating the electricity worldwide. In fact, the world energy demand greatly sustained by the combustion of fossil fuel [2]. According to International Energy Agency (2010), by the year 2030 the coal consumption rate will be more than 6000 million tonnes of carbon equivalents, and across the globe, 42% of electricity supply mainly comes from the coal power plants.

Technically, the operation of a thermal plant that generates electricity using combustion of fossil fuel is much more complicated as compared to a hydroelectric plant. It required flowing fluids to work under extremely high temperature and pressure [3]. Moreover, continuous supervision and maintenance on the complex automatic control units and operating conditions of the thermal power plants are necessary to ensure the power plant operating efficiently and produce maximum power [3–5].

To protection the mother nature and reduce the energy wasted, growing awareness was focused recently to the on more-efficient power generation system and generates power depend on the renewable

Abbreviations: BFW, Boiler feed water; CC, Combustion chamber; GT, Gas turbine; LHV, Low heating value; HHV, High heating value; HP, High pressure; LP, Low pressure; IP, Intermediate pressure; HRSG, Heat recovery steam generator; ST, Steam turbine; CCPP, Combined cycle power plant; BFP, Boiler feed water pump; SH, Superheater; RH, Reheater; DeSH, Desuperheater; Eco, Economizer; Eva, Evaporator; CEP, Condensate Extraction Pump; N_2, Nitrogen; O_2, Oxygen; CO_2, Carbon dioxide; H_2O, Water

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List of symbols

e	Specific exergy [kJ/kg]
Ex	Exergy [kJ]
$\dot{E}x$	Exergy flow rate [kW]
h	Specific enthalpy [kJ/kg]
$\dot{m}$	Mass flow rate [kg/s]
P	Pressure [kPa]
$\dot{Q}$	Heat rate [kW]
R	Gas constant [kJ/kmol K]
s	Specific entropy [kJ/kg K]
T	Temperature [°C]
y	Molar fraction
$\dot{W}$	Work [kW]
$\dot{E}$	Energy [kW]
$\dot{I}$	Exergy Destruction Rate [kW]
c	Specific heat capacity [kJ/kg K]
r	Pressure ratio
k	Heat ratio

List of subscripts

f	Fuel
Dest	Destruction
i	Initial
T	Turbine
in	Inlet
out	Outlet
P	Pump
a	Air
c	Compressor
g	Combustion gas
x	Exergy
w	Work
0	Ambient condition
AC	Air compressor
Cond	Condenser

List of superscripts & greek letter

T	Temperature
P	Pressure
ch	Chemical exergy
ph	Physical exergy
η	Efficiency
λ	Air-fuel ratio
ξ	Ratio of chemical exergy to LHV of fuel

resources energy [6,7]. Many latest policies of the energy encourage researchers to boost the dependent on the sources of the renewable energy, to help in reducing environmental issues and enhance the energy security of the regions which depend on the use the fossil fuel [8–10].

. Numerous thermodynamic power cycles have been established and studied for the past few years [11,12]. Some of these new cycles are found to handle the system that utilizes the heat sources with low or medium temperatures, as well as, the theoretical and experiments investigations have confirmed their capabilities [13–15]. The combined cycle consist from the Brayton and Rankine thermodynamic cycle as shown in Fig. 1 [16]. The increase in the CCPP efficiency required to implement the suitable working fluid such as binary mixture [17,18]. The increase of the boiling temperature in the Heat recovery steam generator (HRSG), gives the ability to produce a high thermal exchange between the working fluid and the sources of the heat under variable temperature [19,20]. Therefore, the more heat exchange will decrease the losses of irreversibility in the process of heat addition [21,22].

Fig. 2 shows studies that have been conducted on energy and exergy of the CCPP most of them during the last forty years. At the same time, by the use of power output of the plant, researchers can improve thermodynamics performance. Thus, CCPP performance can be maintained to operate at an optimum level. For this reason, this paper takes a review of the energy and exergy analysis of CCPP. Fig. 2 included the published articles from the year 1976 to the year 2017, it is clear to note that, the number of the published article was increased to arrive the maximum number in 2017. These increases show the interested of the researcher to use the exergy analysis of the CCPP.

This paper reviews the combination of an available literature in the area of the combined cycle power plant. The general aspects of the different configuration of the combined cycle power plant, its improvement, modelling, and simulation are discussed. Additionally, the analysis of the each component is carried out based on the energy, exergy and exergy destruction and made suggestions improvement. Finally, one can make a decision to use current combined cycle power plant to produce innovative more effective outputs. This study divided into four main parts including the introduction. Thermodynamics analysis of the combined cycle power plant deals with a literature review of the thermodynamics analysis of the combined cycle power plant. A summary of the most important findings of the works related to the present study given. These include comparison of an ideal and actual cycle, energy and exergy analysis of the advanced combined cycle systems. The third part discusses three case studies and shows how they performed the exergy analysis. The last part states the conclusions of the literature work and provides recommendations for future work.

2. Thermodynamics analysis of the combined cycle power plant: a review

The CCPP plant introduced with the cogeneration technology that utilizes both power and heat from one single primary fuel or energy source simultaneously, able to provide a more efficient power generation system [23,24]. Heat recovery steam generator (HRSG) detain the heat rejected from GT and make use of it to increase the temperature of the steam (working fluid) in Rankine cycle (steam cycle) [25,26].

The improvement the exploitation of the energy resources required efficient methods to the analysis of the performance of power generation cycles. Commonly, to analysis, the process of energy conversion, the first law of thermodynamics is applied in the methodology for

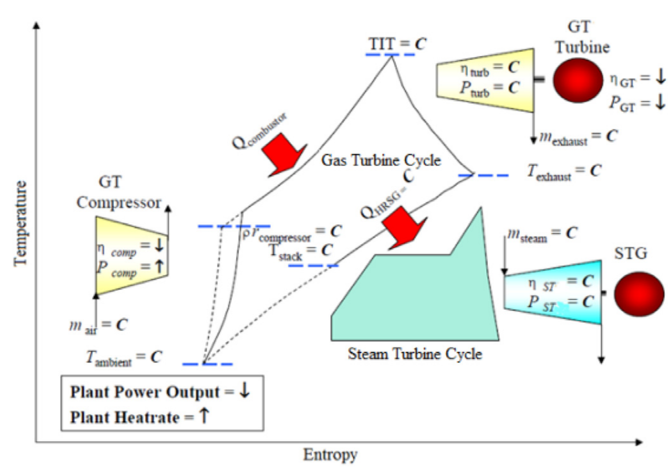

Fig. 1. Entropy-temperature of the CCPP cycle [16].