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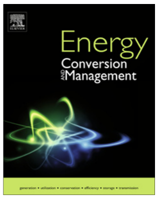

Energy-exergy analysis of compressor pressure ratio effects on thermodynamic performance of ammonia water combined cycle

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ABSTRACT

The purpose of this study is to investigate the effect of compressor pressure ratio (RP) on the thermodynamic performances of ammonia-water combined cycle through energy and exergy destruction, enthalpy temperature, yields, and flow velocity. The energy-exergy analysis is conducted on the ammonia water combined cycle and the Rankine cycle, respectively. Engineering Equation Solver (EES) software is utilized to perform the detailed analyses. Values and ratios regarding heat drop and exergy loss are presented in separate tables for different equipments. The results obtained by the energy-exergy analysis indicate that by increasing the pressure ratio compressor, exergy destruction of high-pressure compressors, intercooler, gas turbine and the special produced work of gas turbine cycle constantly increase and the exergy destruction of recuperator, in contrast, decreases continuously. In addition, the least amount of input fuel into the combined cycle is observed when the pressure ratio is no less than 7.5. Subsequently, the efficiency of the cycle in gas turbine and combined cycle is reduced because the fuel input into the combined cycle is increased.

1. Introduction

Gas turbines have been used to operate mechanical equipment such as pumps, compressors, and small power generators [1], especially to meet peak, middle, and part loads [2–6]. In industrial fields, gas turbines have also been widely used in combined power plant cycles [7–9], which show low efficiency [10]. Those power plants are made up of gas and steam turbines [11–14]. The gas turbine power plants are smaller and lighter than the steam power plants [15]. The cost of each unit is less, and the required time to deliver the gas turbine is also relatively shorter. The operation of gas turbine power plants is rapid, and can be performed through the remote control. Liquid and gaseous fuels like synthetic fuels, which include low calorific value gas, can be used in the gas turbines [16–20]. Gas turbines in comparison with the other major system productions have fewer environmental restrictions. Low efficiency can also be removed by using gas turbines in the combined cycle. As a result, load power supply is used. Besides, the other benefits like rapid and flexible operations can be utilized in a wide range of loads.

Gas turbines have uniaxial or biaxial arrangement [21,22]. Recently, biaxial arrangement rotated by different rates is used. Compression and supported compression of the turbine are located on one axis while turbine power and the external load are placed on the other axis. High-pressure compressors and turbines may also be used on an axis, while low-pressure compressor, turbine, and external load are placed on the other axis. In any arrangement, the gas generator is a part of the system that includes the compressor, combustion chamber, and high-pressure turbine. The variable speed is feasible in the biaxial orientation and this property is suitable for numerous industrial applications.

In addition, the energy-exergy analysis method can be conducted on different heat resources [23], refrigerator cycles [24], solid cells [25], congregation of heat and power [26], Organic Rankine Cycle (ORC) [27–30], and geothermal systems [31]. Minimizing exergy destruction that results from the temperature variation in heat recovery steam generators plays a significant role in increasing the overall efficiency of a combined cycle [32]. Thermodynamic calculations indicate that the overall efficiency will be improved by increasing the steam pressure. Doubling the steam pressure in the cycle improves the efficiency by 4%, but only about 2% improvement is achieved when adding triple pressure [33]. When the temperature of the compressor drops, the performance of the system and economic benefits increases, since less power is consumed in the compressor [34].

In recent years, there is a research boom in the analysis of various combined cycles in order to obtain better optimization. Zare

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Nomenclature

R	gas constant
P	pressure
T	temperature
Q	heat transmitted (kW)
Q_r	total wasted heat from combustion chamber
x_i	mole fraction of components
a_i	activity of reaction component
a	mole ratio of air to fuel
E	total energy in each components
$\dot{E}x_{D,i}$	exergy total in points i
$\dot{E}x_i$	total exergy
$\dot{E}x^{ph}$	physical exergy
$\dot{E}x^{ch}$	chemical exergy
$\dot{E}x^{tot}$	total exergy
n_e	free electrons in a hydrogen molecule for reaction with oxygen
$\Delta\bar{h}_f^0$	enthalpy reaction changes in standard mode
$\Delta\bar{s}_f^0$	entropy reaction changes in standard mode
U	internal energy
h	enthalpy
s	entropy
PR	external reformer
AB	after burner combustion chamber
ε	coefficient of the thermal heat exchanger
IC	inter cooler
HX	thermal heat exchanger
m	mass flow rate (g)
M	molar mass (g/mol)
q_{max}	possible highest transferred heat in HX
q_{act}	transferred heat from each fluid
LHV	lower heating value
C	thermal capacity
L	low heat value of fuel
EPC	exergy performance coefficient
$\dot{W}$	produced power
$\dot{W}_{net}$	pure power combined cycle
c	compressor
comp1	high-pressure compressor
comp2	low-pressure compressor
rec	recuperator
GT	gas turbine
cond	condenser

Greek symbols

η	efficiency
$\eta 1$	first low efficient
$\eta 2$	second low efficiency
η_{th}	combined cycle thermodynamic efficiency
ψ	specific exergy (kW/kg)
Δ	reaction changes

Subscripts and superscripts

i	components
D	destruction
Ph	physical
Ch	chemical
e	free electrons

et al. [35] used the wasted heat to achieve the first and the second efficiency laws in the ammonia-water combined cycle, respectively. By examining the benefits of ammonia water taken as the fluid in the combined cycle power plant, Dejfors et al. [36] achieved greater efficiency compared with the Rankine cycle. Ricardo et al. [37] examined the parametric effects on the Rankine power generation combined cycle and compared it with the ammonia absorption cycle. Zhi et al. [38] analyzed the influence of inlet temperatures of both heat resource and cooling water on system efficiencies based on the first and the second laws of thermodynamics. The results showed that the indexes of the power recovery and the exergy efficiencies of the KC (Kalina cycle) were 18.2% and 41.9%, respectively, while the composite power recovery efficiency and the composite exergy efficiency of AWRC (ammonia-water Rankine cycle) were 21.1% and 43.0%. Ahmadi and Toghrai [39–41] investigated steam cycle of a power plant with an individual unit capacity of 200 MW by considering mass, energy, and exergy balance equations through the EES software. Their results revealed that the biggest waste, which is 69.8% of the total energy, is consumed by the condenser. And the biggest exergy lost (around 85.66% of the total energy) is done by the boiler.

In this paper, we assume that the ammonia-water is implemented as a binary mixture of a combined cycle. The energy-exergy analysis for each part is then conducted. EES software is used to perform the analysis. For verification and comparison, the Rankine cycle is chosen and the same process is conducted on this cycle. The purpose is to examine the effect of compressor pressure ratio (RP), as one of the most important effected factors, on thermodynamic performances of ammonia-water combined cycle. Results of the compressor pressure ratio effects on the thermodynamic performance are investigated through energy and exergy destruction, enthalpy, temperature, yields, and velocity, etc.

2. Methodology

In this study, the ammonia-water combined cycle as shown in Fig. 1 and the Rankin combined cycle as shown in Fig. 2 are examined and analyzed for detailed comparisons. It should be noted that the indices of equations are chosen with correspondence to notations in Figs. 1 and 2. In order to analyze the thermal cycles, each equation is written separately for each component. Then, those equations are solved together in a system with temperature, pressure, and flow variables at every point.

In general, the energy equation is assumed to be the volume control for each component and can be written as follows

$$\dot{Q} + \dot{n}_i\bar{h}_i = \dot{W} + \dot{n}_e\bar{h}_e. \tag{1}$$

Exergy balance equation for each component is given by

$$\dot{E}_{in} + \sum \dot{Q}_i\left(1 - \frac{T_0}{T_i}\right) = \dot{E}_{out} + \dot{W} + \dot{E}_D, \tag{2}$$

where E is the total exergy at each point and includes the sum of physical and chemical exergies of components at each considered point.

Physical exergy of a thermodynamic system is consisted of mechanical and thermal exergy. Mechanical exergy is a function of the pressure in the thermodynamic system, while the thermal exergy is a function of the temperature in the thermodynamic system. Physical exergy can be expressed by

$$\dot{E}x^{ph} = \sum\{n_i[(h - h_0) - T_0(s - s_0)]\}. \tag{3}$$

Chemical exergy is equal to the maximum of produced works, while chemical species of the thermodynamic system can mix and react with the species available in the environment. Those