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# Performance enhancement of combined cycle power plant using inlet air cooling by exhaust heat operated ammonia-water absorption refrigeration system

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## HIGHLIGHTS

- Overall performance can be improved by decreasing compressor inlet air temperature.
- Exhaust operated absorption cooling system is very much suitable for this purpose.
- With this system, the net power output increases by 9440 kW in summer season.
- In winter, the same system would further increase the power output by 400 kW.
- Variable to affect the performance of the system most is the condenser temperature.

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## ABSTRACT

Studies conducted on Brayton-Rankine combined cycle power plants have shown that the performance of its gas turbine unit and hence the overall performance of the plant can be improved by decreasing the compressor inlet air temperature. In these plants, a lot of low grade heat goes waste along with the exhaust gases. Absorption refrigeration systems always attract the users to utilize the low grade waste heat wherever it is available Therefore, in this work, a simulation model of an Indian combined cycle power plant coupled with exhaust heat operated ammonia-water absorption refrigeration system has been developed to investigate the performance of the combined system according to Indian atmospheric conditions which vary throughout the year. Energy and exergy analysis reveals that by having this arrangement, in summer season, an additional net power of 9440 kW is developed thereby increasing the thermal efficiency of the plant by 1.193% and the exergy efficiency by 1.133%. But, in winter, it would further increase the power output by 400 kW. As the North Indian atmospheric temperature varies from about 45 °C in summer to about 3 °C in winter, the variation of plant performance with the variation of ammonia condenser temperature has also been studied.



## 1. Introduction

Gas turbine power plants have gained wide popularity in recent times for large scale power generation due to their lower capital cost as compared to steam power plant, compactness, quick and easy starting, greater flexibility of operation, ability to meet the variable load demands quickly, lower environmental pollution, etc. The greatest disadvantage of the basic gas turbine cycle is that it has poor efficiency. A number of concepts have been introduced in these plants for improving efficiency. The power output and the efficiency of the gas turbine depend a great deal on the compressor inlet and turbine inlet temperatures. Low compressor inlet temperature and high turbine inlet temperature are desired to get high efficiency. The turbine inlet temperature cannot be kept very high due to metallurgical considerations and the possibility of $NO_x$ formation at high Temperature [1]. Lowering the compressor air inlet temperature does not pose any such problem and therefore, can be conveniently used. A number of researchers have conducted studies on different methods of inlet air cooling and on different system configurations. Ondryas et al. [2] proposed and studied the use of Lithium bromide-water absorption chiller, ammonia-water absorption chiller and mechanical vapour compression chiller for this purpose. Bassily [3] studied the performance of an intercooled reheat recuperated gas-turbine cycle with two stages of cooling in the intercooler and found that applying absorption inlet-cooling and evaporative after-cooling could increase the

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**Nomenclature**

| | |
|---|---|
| $cw_1, cw_2,\ldots, cw_6$ | nodal points in the cooling water line of condensers |
| $\bar{C}_p$ | isobaric molar specific heat (kJ/kmol K) |
| $\bar{C}^{\psi}_{p,j}$ | mean molar isobaric exergy capacity of jth component of air (kJ/kmol K) |
| $\dot{E}_C$ | rate of heat generated during combustion (kW) |
| $g_1, g_2,\ldots,g_{12}$ | nodal points in gas passage |
| h | specific enthalpy (kJ/kg) |
| $h_0$ | specific enthalpy at environmental state (kJ/kg) |
| $\bar{h}^0_d$ | standard molar specific enthalpy of devaluation (kJ/kmol) |
| $\Delta\bar{h}^0_f$ | standard molar enthalpy of combustion of fuel, i.e., enthalpy of combustion at 298.15 K and 0.101325 MPa (kJ/kmol of fuel) |
| $\dot{H}$ | enthalpy (kJ/s) |
| $\dot{I}$ | exergy destruction rate (kW) |
| $\dot{m}$ | mass flow rate (kg/s) |
| $\dot{n}$ | molar flow rate (kmol/s) |
| p | absolute pressure (Pa) |
| $p^0$ | standard environmental pressure (=101,325 Pa) |
| $p^{00}$ | standard partial pressure of a component, i.e., partial pressure of a component in standard environment (Pa) |
| $p_0$ | environmental pressure (Pa) |
| $\dot{Q}$ | heat transfer rate (kW) |
| $\bar{R}$ | universal gas constant (=8.31451 kJ/kmol-K) |
| RH | relative humidity |
| s | specific entropy (kJ/kg-K) |
| $s_0$ | specific entropy at environmental state (kJ/kg-K) |
| $\Delta\bar{s}^0_f$ | standard molar entropy of reaction of fuel (kJ/kmol-K) |
| T | absolute temperature (K) |
| $T_0$ | environmental temperature (K) |
| $T^0$ | standard temperature (=298.15 K) |
| $\dot{W}$ | work done rate (kW) |
| x | mole fraction |
| $\dot{X}$ | exergy flow rate (kW) |
| $\dot{X}_{heat}$ | net exergy transfer by heat (kW) |
| y | ammonia mass fraction |
| 1.2.3.4, etc. | nodal points |

*Greek letters*

| | |
|---|---|
| $\psi$ | specific exergy (kJ/kg) |
| $\psi_{Ph}$ | specific physical exergy (kJ/kg) |
| $\psi_{Ch}$ | specific chemical exergy (kJ/kg) |
| $\bar{\psi}$ | molar specific exergy (kJ/kmol) |
| $\bar{\psi}_{Ph}$ | molar specific physical exergy (kJ/kmol) |
| $\bar{\psi}_{Ch}$ | molar specific chemical exergy (kJ/kmol) |
| $\bar{\psi}^0_{Ch}$ | standard molar specific chemical exergy (kJ/kmol) |
| $\eta_{ex}$ | exergy efficiency |
| $\eta_{Th}$ | thermal efficiency |
| $\Delta$ | used for a change in any parameter |

*Subscripts*

| | |
|---|---|
| a | air |
| A | absorber |
| ACS | absorption cooling system |
| BRC | Brayton-Rankine combined cycle |
| c | for condenser cooling water pumps and cooling tower fans of combined cycle |
| C | for condenser of absorption cooling system |
| C1 | compressor No. 1 |
| C2 | compressor No. 2 |
| CEP | condensate extraction pump |
| COP | coefficient of performance |
| CPCP | condensate preheater circulation pump |
| E | evaporator |
| f | fuel |
| G | generator |
| GT1 | gas turbine No. 1 |
| GT2 | gas turbine No. 2 |
| HPFP | high pressure feed pump |
| j | component of air |
| LPFP | low pressure feed pump |
| P | product |
| p | pump |
| R | reactant |
| S | strong solution |
| SHE | solution heat exchanger |
| ST | steam turbine |
| T | thermostatic expansion valve |
| V | pressure reducing valve |
| W | weak solution |
| 0 | for environmental state |

*Superscripts*

| | |
|---|---|
| 0 | For standard state |

optimum efficiency of the cycle by 3.5%. Farzaneh-Gord and Deymi-Dashtebayaz [4] conducted the case study of the Khangiran refinery and proposed a new approach to improve performance of the refinery's gas turbines by cooling inlet air of the gas turbines by potential cooling capacity of the refinery natural-gas pressure drop station. Yang et al. [5] studied the economic aspects of inlet air cooling for gas–steam combined cycle power plant and presented an analytical method to evaluate the applicability of inlet air chilling with Li Br-Water absorption chiller and inlet fogging with evaporative cooler in terms of parameters such as efficiency ratio, profit ratio and relative payback period and found that inlet fogging is superior in power efficiency for ambient temperature 15–20 °C while the absorption chiller is preferable in the zones with ambient temperature greater than 25 °C and Relative Humidity greater than 40%. Khaliq and Dincer [6] carried out the theoretical energetic and exergetic analyses of a proposed gas turbine cycle cogeneration equipped with inlet air cooling and evaporative after-cooling of the compressor discharge and concluded that the global thermal efficiency of the system can be improved mainly by reducing the local irreversibility rates in the combustion chamber. The combination of evaporative after-cooling and absorption inlet cooling would result in higher values of optimum pressure ratios. Barigozzi et al. [7] carried out the techno-economical analysis of an indirect system for cooling the inlet air to the gas turbine unit of combined cycle power plant for three different climatic conditions, i.e., at Phoenix (USA), New Orleans (USA) and Abu Dhabi (UAE). In the proposed cooling system, water is cooled in night time by mechanical chillers and the chilled water is used in the hot day hours to cool the inlet air to the compressor. The parametric analysis showed that the important and key parameter that affects the economical revenue is the size of the cooling storage. Burno et al. [8] integrated an exhaust heat operated absorption cooling system with biogas-fired micro gas turbine (MGT) of a sewage treatment cogeneration plant and studied the effect on the performance of the plant. Moya et al. [9] experimentally determined the efficiency and viability of the performance of a trigeneration system consisting of a micro gas turbine in which the exhaust gas heat was utilized to produce cooling with an air cooled