ARTICLE IN PRESS

Alexandria Engineering Journal (2016) xxx, xxx–xxx

HOSTED BY

ELSEVIER

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Gas turbine performance enhancement via utilizing different integrated turbine inlet cooling techniques

Alaa A. El-Shazly, Mohamed Elhelw, Medhat M. Sorour, Wael M. El-Maghlany *

Department of Mechanical Engineering, Faculty of Engineering, Alexandria University, Egypt

Received 15 June 2016; revised 14 July 2016; accepted 24 July 2016

KEYWORDS

Inlet-air cooling;
Absorption chiller;
Evaporative cooling;
Gas turbine

Abstract Regions that experience ambient temperatures rising during hot seasons have significant losses and impacts on both output power and efficiency of the gas turbine. When the ambient temperature increases, the air mass flow rate decreases, and hence leads to reduce the gas turbine produced power. Ambient air can be cooled by using either evaporative cooler or absorption chiller. Currently, the performance was simulated thermodynamically for a natural gas operated gas turbine. The performance was tested for the base case without any turbine inlet cooling (TIC) systems and compared with the performance for both evaporative cooler and absorption chiller separately in terms of output power, thermal efficiency, heat rate, specific fuel consumption, consumed fuel mass flow rate, and economics. Results showed that at air ambient temperature equals to 37 °C and after deducting all the associated auxiliaries power consumption for both evaporative cooler and absorption chiller, the absorption chiller with regenerator can achieve an augmentation of 25.47% in power and 33.66% in efficiency which provides a saving in average power price about 13%, while the evaporative cooler provides only an increase of 5.56% in power and 1.55% in efficiency, and a saving of 3% in average power price.

1. Introduction

For power production turbine, the inlet pressure shall be higher than that at the exit. The function of the compressor is to provide this increase in pressure. If air is compressed and discharged through the turbine, the energy expanded in the turbine will be less than that required to drive the compressor because of the losses occured in both the compressor and turbine, and the engine will barely rotate [1], but when adding energy to the discharged compressed air equals to the losses happened in both the turbine and compressor, and the produced power will be enough only to rotate the shaft without producing net output. Additional energy shall be added to the compressed air, which can be achieved by burning fuel in the combustion chamber positioned between compressor and turbine.

Gas turbines performance deteriorates badly when the ambient temperature increases. The significant influence of ambient temperature rise on power and thermal efficiency has been proven. Methods to improve gas turbine power at high ambient temperatures such as wet compression and water injection were developed. However, these methods lead to

* Corresponding author.
E-mail addresses: elmaghlany@alexu.edu.eg, elmaghlany@yahoo.com (W.M. El-Maghlany).

Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2016.07.036
1110-0168

Nomenclature

C_P	specific heat at constant pressure, kJ/kg K
C_{Pa}	air average specific heat at constant pressure across compressor, kJ/kg K
C_{Pg}	exhaust gases average specific heat at constant pressure across turbine, kJ/kg K
C_{Pw}	water specific heat at constant pressure, kJ/kg K
COP	coefficient of performance
h	enthalpy, kJ/kg
h_{fg}	specific enthalpy, kJ/kg_{vapor}
HR	heat rate, kJ/kW h
LHV	fuel lower heating value, kJ/kg
$\dot{m}_a$	air mass flow rate, kg/s
$\dot{m}_f$	fuel mass flow rate, kg/s
$\dot{m}_t$	exhaust gasses mass flow rate, kg/s
P	pressure, N/m^2
P_t	total pressure, N/m^2
P_v	vapor pressure, N/m^2
P_{vdb}	vapor pressure at dry bulb temperature, N/m^2
Q_a	absorber heat, kW
Q_{add}	heat added, kW
Q_C	condenser heat, kW
Q_e	evaporator heat, kW
Q_g	generator heat, kW
R	universal gas constant, kJ/kg K
r_p	pressure ratio
RH	relative humidity, %
SFC	specific fuel consumption, kg/kW h
T	temperature, K
$T_{cw\ in}$	chilled water inlet temperature, °C
$T_{cw\ out}$	chilled water outlet temperature, °C
T_{db}	dry bulb temperature, °C
T_w	water temperature, °C
T_{wb}	wet bulb temperature, °C
V	volumetric flow rate, m^3/s
W_C	compressor work, kW
W_{net}	net work, kW
W_P	pump work, kW
W_T	turbine work, kW

Greek symbols

ρ	density, kg/m^3
ω	moisture content, kg_{vapor}/kg_{air}
ω_{db}	moisture content at dry bulb temperature, kg_{vapor}/kg_{air}
$\eta_{C,isen}$	isentropic efficiency of the compressor.
$\eta_{C,m}$	mechanical efficiency of the compressor
$\eta_{T,isen}$	isentropic efficiency of the turbine
$\eta_{T,m}$	mechanical efficiency of the turbine
$\eta_{,cc}$	combustion efficiency
η_{th}	thermal efficiency
ΔP_{inlet}	inlet pressure loss, N/m^2
ΔP_{cc}	pressure drop through combustion chamber, N/m^2
$\varepsilon_{he,LT}$	low temperature generator effectiveness
$\varepsilon_{he,HT}$	high temperature generator effectiveness
ε_{evap}	evaporative cooler effectiveness
ε_{reg}	regenerative effectiveness
γ	specific heat ratio
λ	circulation ratio
$\frac{A}{F}$	Air to Fuel ratio.

Subscripts

a	actual temperature
reg	regenerator

Abbreviations

TIC	turbine inlet cooling
ISO	International Organization for Standardization
EOH	equivalent operating hours

some defects such as shorten equipment lifetime and increase maintenance costs. The inlet air to the compressor can be cooled, thereby boosting the output power at high ambient temperatures which is called turbine inlet cooling. Several types of research have extensively studied the different turbine inlet cooling methods to enhance gas turbine performance. Al-Ibrahim and Varnham [2] reported that refrigeration systems could be whether absorption or mechanical compression. Running costs for mechanical chillers are less expensive than those for absorption chillers, but initial costs and auxiliaries' power consumption are extremely higher which may reach about 30% of the produced power. In addition, Jaber et al. [3] studied the effect of cooling gas turbine intake air by using the evaporative and cooling coil. The results showed output power is similar for both evaporative cooling and chiller system which is about 1.0–1.5 MW, but the power consumed by mechanical chiller auxiliaries is higher, and hence the overall output decreases. Moreover, Alhazmy and Najjar [4] reported that the spray coolers are cheaper than chiller coils. However, they are directly limited by ambient temperature and relative humidity. Spray cooler is able to reduce air ambient temperature by 3–15 °C, increasing power by 1–7%, and efficiency by 3%, while chiller coils provide complete control for air temperature, despite the higher power consumption which is subtracted from the output power. On the other hand Nasser and El-Kalay [5] recommended the use of a single effect water-lithium bromide absorption chiller system in Bahrain for cooling intake air of gas turbine, which is capable of increasing power output by 20% in summer. Lowering air temperature by 10 °C at 40 °C ambient condition leads to increase power by 10%. In addition, Hosseini et al. [6] studied the performance of evaporative cooler system on gas turbines installed in Fars power plant in Iran. The results showed that the output power increases by 11 MW at 38 °C ambient temperatures and 8% relative humidity, and a reduction of 19 °C in inlet air temperature can be achieved by evaporative cooling. The payback period is about four years considering a gain of 5280 MW h and the selling price of 2.5 Cents/kW h. On the other hand, Ameri and Hegazi [8] used a steam absorption chiller with air cooler in order to cool intake air of

Please cite this article in press as: A.A. El-Shazly et al., Gas turbine performance enhancement via utilizing different integrated turbine inlet cooling techniques, Alexandria Eng. J. (2016), http://dx.doi.org/10.1016/j.aej.2016.07.036