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ScienceDirect
Applied Energy 84 (2007) 16–28
APPLIED ENERGY
www.elsevier.com/locate/apenergy

Potential of regenerative gas-turbine systems with high fogging compression

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Available online 19 June 2006

Abstract

The study of evaporatively-cooled cycles is of interest because of the prospect of enhanced efficiencies and conceptual simplicity that can lead to low capital costs. This work focuses on a cycle that relies on continuous cooling of the air under compression, followed by recuperation of residual exhaust heat, combustion and expansion. Ideal gases are modeled, with realistic values of efficiencies, air-to-fuel ratios and turbine-inlet temperatures. As the amount of water injected in the compressor increases, the efficiency of the cycle peaks at progressively higher pressure-ratios. The pressure ratio and the recuperator effectiveness are important parameters for cycle efficiency. Compared to a dry cycle with no recuperation with a pressure ratio of 25, the efficiency can increase from 45% to 51.5% and the specific work from 410 kJ/kg to 680 kJ/kg when compression cooling and recuperation are implemented.

Keywords: Water injection; Droplet evaporation; Wet compression; Gas-turbine cycle; Regenerative Brayton-cycle; Compressor cooling

1. Introduction

A constant search for enhanced capacity and efficiency of power-generation cycles has led many researchers to consider evaporative cooled compression [1]. The main driver

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0306-2619/$ - see front matter
doi:10.1016/j.apenergy.2006.04.008

Nomenclature

a	number of carbon atoms in fuel molecule
A	specific heat molar coefficient (J/kmol K)
A_{tot}	total surface area of liquid water droplets (m^2/kg)
b	number of hydrogen atoms in fuel molecule
B	mass of dry air per mole of fuel (kg/kmol)
c	water stoichiometric coefficient at combustor inlet
C	compression rate $= (1/P)(dP/dt)$ (s^{-1})
C_p	specific heat (J/kg)
COT	compressor-outlet temperature (°C)
D_v	diffusion coefficient (m^2/s)
f_l	water injection rate per unit mass of dry air (%), kg/kg of air
h	enthalpy (J/kg)
h_{fg}	enthalpy of vaporization (J/kg)
I	vapor mass flux (m^2/s)
k	thermal conductivity (W/m^2K)
M	molecular weight (kg/kmol)
n	number of droplets per unit mass of dry air (kg^{-1})
P	pressure (Pa)
q	heat flux (W/m^2)
R	gas constant (J/kgK) or droplet radius (μm)
R_1	initial radius of droplet (μm)
R_p	pressure ratio
RH	relative humidity (%)
t	time (s)
T	temperature (K)
TIT	turbine's inlet-temperature
α	species mass fraction, dry air basis
β	mass of fuel per mass of dry air
γ	mass of carbon dioxide per mass of dry air
δ	mass of water per mass of dry air
ε	temperature effectiveness of regenerator
ζ	mass of oxygen per mass of dry air
η	polytropic efficiency
v	specific volume of humid air (m^3/kg)
λ	excess air coefficient
ρ	density (kg/m^3)
ω	specific humidity (kg/kg)

Subscripts

0	reference condition for enthalpy
1	compressor inlet
2	compressor outlet
3	turbine inlet
4	turbine outlet