Applied Energy 197 (2017) 83–99

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Recuperators for micro gas turbines: A review

Gang Xiao [a], Tianfeng Yang [a], Huanlei Liu [a], Dong Ni [b], Mario Luigi Ferrari [c], Mingchun Li [a], Zhongyang Luo [a], Kefa Cen [a], Mingjiang Ni [a,*]

[a] State Key Laboratory of Clean Energy Utilization, Zhejiang University, 38 Zheda Road, Hangzhou 310027, China
[b] State Key Laboratory of Industrial Control Technology, Zhejiang University, 38 Zheda Road, Hangzhou 310027, China
[c] Thermochemical Power Group (TPG) – DIME, Università di Genova, via Montallegro 1, Genova 16145, Italy

HIGHLIGHTS

- A review on recuperators for micro gas turbines is presented.
- Different types of recuperators and material selection are given and compared.
- Research on heat transfer and pressure drop characteristics is summarized.
- Optimization methods used to improve recuperator performance are reviewed.
- Future development of recuperators is discussed.

ARTICLE INFO

Article history:
Received 28 October 2016
Received in revised form 19 March 2017
Accepted 22 March 2017
Available online xxxx

Keywords:
Micro gas turbine
Recuperator
Material selection and manufacturing
Heat transfer effectiveness
Pressure drop loss
Optimization

ABSTRACT

Micro gas turbines are a promising technology for distributed power generation because of their compact size, low emissions, low maintenance, low noise, high reliability and multi-fuel capability. Recuperators preheat compressed air by recovering heat from exhaust gas of turbines, thus reducing fuel consumption and improving the system efficiency, typically from 16–20% to ~30%. A recuperator with high effectiveness and low pressure loss is mandatory for a good performance. This work aims to provide a comprehensive understanding about recuperators, covering fundamental principles (types, material selection and manufacturing), operating characteristics (heat transfer and pressure loss), optimization methods, as well as research hotspots and suggestions. It is revealed that primary-surface recuperator is prior to plate-fin and tubular ones. Ceramic recuperators outperform metallic recuperators in terms of high-temperature mechanical and corrosion properties, being expected to facilitate the overall efficiency approaching 40%. Heat transfer and pressure drop characteristics are crucial for designing a desired recuperator, and more experimental and simulation studies are necessary to obtain accurate empirical correlations for optimizing configurations of heat transfer surfaces with high ratios of Nusselt number to friction factor. Optimization methods are summarized and discussed, considering complicated relationships among pressure loss, heat transfer effectiveness, compactness and cost, and it is noted that multi-objective optimization methods are worthy of attention. Moreover, 3D printing and printed circuit heat exchanger technologies deserve more research on manufacturing of recuperators. Generally, a metallic cost-effective primary-surface recuperator with high effectiveness and low pressure drop is a currently optimal option for a micro gas turbine of an efficiency of ~30%, while a ceramic recuperator is suggested for a high efficiency micro gas turbine (e.g. 40%).

Contents

* Corresponding author.
E-mail address: ceu_ni@zju.edu.cn (M. Ni).

http://dx.doi.org/10.1016/j.apenergy.2017.03.095
0306-2619/

Nomenclature

A	heat transfer surface area (m^2)
A_0	wavy fin amplitude (mm)
b_c	mean spacing between plates (mm)
C	heat capacity rate ratio
CC	cross-corrugated
CFD	computational fluid dynamics
CU	corrugated-undulated
CW	cross-wavy
C_{max}	larger of the two heat capacity rates (W/K)
C_{min}	smaller of the two heat capacity rates (W/K)
Comp	compactness (m^2/m^3)
c_p	specific heat (J/(kg K))
DNS	direct numerical simulation
d_h	hydraulic diameter (mm)
ECS	energy conversion system
EGT	exhaust gas temperature (K)
e	scale height (mm)
f	friction factor
GA	genetic algorithm
H	height (mm)
H_i	channel internal height (mm)
h	heat transfer coefficient (W/(m^2 K))
h_f	fin height (mm)
j	Colburn factor
k	over heat transfer coefficient (W/(m^2 K))
L	length (mm)
L_c	flow length of flow channel (mm)
LES	large eddy simulation
LMTD	logarithmic mean temperature difference
LOM	laminated object manufacturing
l	fin length (mm)
MOGA	multi-objective genetic algorithm
$\dot{m}$	mass flow rate (kg/s)
Nu	Nusselt number
NPGA	Niched-Pareto genetic algorithm
NSGA	nondominated sorting genetic algorithm
NTU	number of transfer unit
P	pressure (Pa)
P_{air}	inlet pressure of air side (Pa)
P_{gas}	inlet pressure of gas side (Pa)
PAES	Pareto archived evolution strategy
PCHE	printed circuit heat exchanger
Pr	Prandtl number
PSO	particle swarm optimization
q_w	heat flux (W/m^2)
Re	Reynolds number
RH	relative humidity
RNG	renormalized group
RSM	Reynolds stress model
SLM	selective laser melting
s	fin pitch (mm)
t	fin thickness (mm)
T	temperature (K)
TIT	turbine inlet temperature (K)
U	average velocity (m/s)
W	width (mm)

Greek symbols

α	s/h_f
γ	t/s
ΔP	pressure drop (Pa)
ΔP_{air}	pressure drops of air side (Pa)
ΔP_{gas}	pressure drops of gas side (Pa)
δ	plate thickness (mm)
δ_0	t/l
ε	effectiveness
θ	corrugation angle
θ_0	intersection angle
λ	thermal conductivity (W/(m K))
μ	dynamic viscosity (N s/m^2)
ρ	fluid density (kg/m^3)

Subscripts

b	bulk value
f	fluid
in	inlet
max	maximum
min	minimum
out	outlet
w	wall condition