Energy 34 (2009) 1636–1641

Contents lists available at ScienceDirect

Energy

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

Performance analysis of an enhanced thermosyphon Rankine cycle using impulse turbine

B.M. Ziapour*

Department of Mechanical Engineering, University of Mohaghegh Ardabili, Ardabil, Iran

ARTICLE INFO

Article history:
Received 15 March 2009
Received in revised form
8 July 2009
Accepted 9 July 2009
Available online 3 August 2009

Keywords:
Electric power
Exergy
Impulse turbine
Low enthalpy
Thermosyphon

ABSTRACT

Thermosyphon Rankine cycle (TRC) is an environmentally friendly system for direct extraction of electrical power using low enthalpy heat sources. An enhanced design of the TRC system using impulse turbine was recommended, in this paper. Energy and exergy analysis of the TRC was formulated in order to estimate its optimum operating conditions. Also the data available in open literature were used to validate the TRC mathematical model. The results showed that the highest efficiency happens for the reaction turbine model at the turbine infinite speed; and for the impulse turbine at the turbine limited speed. The simulation results indicated that the present model can be able to increase the efficiency of the TRC system.

1. Introduction

Energy use continues to rise and with it the emissions of CO_2. In order to minimize emissions of pollutants, it is possible to use renewable energy. Renewable energies offer numerous advantages over non renewable, conventional energy sources in terms of environmental health and safety [1–4]. Thermosyphon Rankine engine turbine is a simple machine for direct extraction of electrical power using low enthalpy renewable heat sources such as geothermal energy, solar energy and waste heat [5].

According to Lund's report in 2005, the worldwide direct applications of geothermal energy projects had an estimated installed thermal capacity of 28,268 MW_t, indicating a 43% increase over 2000 [6]. Also according to Bertani's report, in 2005, the worldwide power generation from geothermal energy is approximately 8030 MW_e [7]. Experiments showed that thermosyphon was very suitable for extraction of geothermal energy, because of its independency to electric power [8,9].

The temperatures of the exhaust from most industrial processes and power plants are less than 370 °C(643.15 K). If this kind of waste heat is let into the environment directly, it would not only waste heat but also make heat pollution to the environment. Using conventional methods to recover energy from this kind of exhaust is economically infeasible. The thermosyphon Rankine cycle system exhibits great flexibility, high safety and low maintenance requirements in recovering this grade of waste heat.

Fig. 1 shows schematic of general thermosyphon Rankine engine. It is a vertical wickless heat pipe (i.e. one two-phase closed thermosyphon). The thermosyphon is a simple device which raises the kinetic energy of the working fluid as it flows in the vapor phase from the evaporator to the condenser. As shown in Fig. 1, an axial impulse vapor turbine has been installed between the adiabatic section and the condenser section and is capable of converting high kinetic energy of vapor in the pipe to electrical energy by using a directly coupled electrical generator. Nguyen et al. investigated performance of general thermosyphon Rankine engine [5]. In their work, two prototype axial impulse turbines were tested. According to their test results, the first and second prototype gave the efficiencies about $\eta_I = 0.1\%$ and $\eta_I = 0.21\%$ respectively. The measured power output is significantly different from the theoretical aspects.

Akbarzadeh et al. simulated the heat pipe turbine for production of power from renewable sources based on energy analysis [10]. They modeled a reaction turbine for power generation. In their design that was like to the schematic as shown in Fig. 1, water remains the preferred working fluid in term of safety, environmental acceptability and cost. Here, simulation results shown that, when the turbine rotates at infinite speed, then the maximized efficiency is delivered.

* Tel.: +98 451 5512910; fax: +981 451 5512904.
E-mail address: behrooz_m_ziapour@yahoo.com

0360-5442/$ – see front matter
doi:10.1016/j.energy.2009.07.012

Nomenclature

A	area, m^2
H	liquid feeding tube height, m
$\dot{I}$	exergy destruction rate, kJ/s
k	ratio speed
$N_{limited}$	turbine limited speed, rpm
$\dot{m}$	mass flow rate of working fluid, kg/s
P	pressure, kpa
$\dot{Q}$	heat transfer rate, kJ/s
R	radius, m
s	specific entropy, kJ/kg K
T	temperature, K
V	speed
$\dot{W}$	shaft work, kJ/s
α	inlet blade angle
γ	outlet blade angle
ρ	density, kg/m^3

Subscripts

0	reference environment
1,2,...	cycle state points
B	blade
C	condenser
E	evaporator
i, in	inlet
isen	isentropic
I	first law
II	second law
o, out	output
P	preheater
R	relative, Turbine blade radius
Rankine	Rankine cycle
S	source
T	turbine
tot	total
u	useful work

In order to improve the performance of the system that uses a low-grade heat source, Takahisa et al. designed and tested the organic Rankin cycle (ORC) with HCFC-123 as working fluid; and then the thermal efficiency obtained about 1.25% [11].

The exergy analysis of cycles based on second law of thermodynamics calculates exergy destruction of processes and has important role in energy conversion systems. Some investigators have been done exergy analysis of ORC systems [12–14]. It has been proven that in the cases of low power output the use of screw motors is very common for expansion, because turbines have in small power range high gap losses.

This paper proposes an enhanced design of the thermosyphon Rankine cycle (TRC) and presents its energy and exergy analysis based on the first and second laws of thermodynamics.

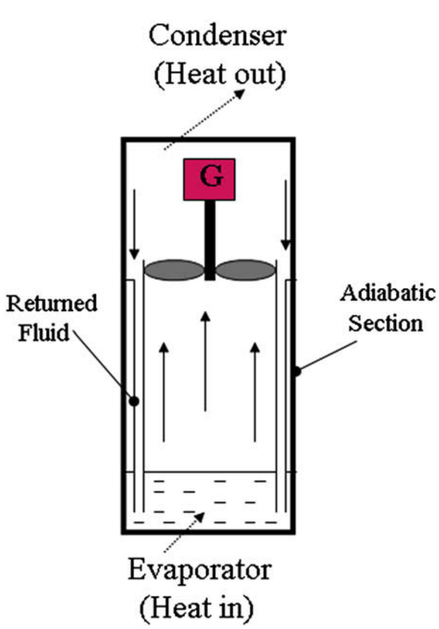

Fig. 1. Schematic presentation of general thermosyphon Rankine engine.

2. Proposed design

In a conventional thermosyphon consisting of a single tube, thermal performance is restricted by entrainment and flooding phenomena. Furthermore, it is difficult to maintain a uniform liquid film which causes the heat transfer performance to deteriorate [9]. In order to improve the performance of a TRC system, we have developed a loop type where vapor and liquid flow passages are separated by installing liquid feeding tube with showering nozzle, as shown in Fig. 2. The working fluid used in this study is water. Also T-s diagram of Cycle has been presented in Fig. 3. According to these figures, the following processes make the TRC system operation:

- *1–2* line: The sequence of the preheater and pipe make elevation H. Thus, pressure difference is produced between inlet and outlet process. Therefore it acts as a pump. Also heat rate $\dot{Q}_P$ is added by preheater within the water reserve tank.
- *2–3* line: This is an absorbing heat ($\dot{Q}_S$) process in evaporator at mean saturated temperature.
- *3–4* line: This is a work process in an impulse turbine. Raised steam from evaporator is entered to the convergent-divergent nuzzle of the impulse turbine. For decreasing irreversibility, top of the thermosyphon has been formed as convergent–divergent nuzzle.
- *4–1* line: This is a rejecting heat ($\dot{Q}_C$) process at ambient mean temperature in the condenser.

3. Formulation

3.1. Energy and exergy formulation

An energy balance for new design cycle (Fig. 2) based on the first law of thermodynamics, gives following equation:

$$\dot{Q} = \dot{W}_u - \dot{Q}_C \quad (1)$$

where $\dot{Q}$ is the total added heat($\dot{Q}_S + \dot{Q}_P$), $\dot{W}_u$ is the useful work in turbine and $\dot{Q}_C$ is the rejected heat in condenser. Therefore the first law efficiency η_I may be regulated as follows: