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Feasibility of electrical power generation using thermoelectric modules via solar pond heat extraction

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ABSTRACT

Solar pond undoubtedly has been a reliable source of low grade heat supply by acting as both collector and storage for the incoming solar radiation. The thermal efficiency of the solar ponds is between 15 and 25% of the incoming horizontal solar radiation. Meanwhile, the thermoelectric technology enables the conversion of heat into electricity using thermoelectric modules. In this paper, the feasibility of the system by combining solar pond and thermoelectric modules is presented. This system can be achieved by using a thermoelectric modules-embedded heat exchanger module that will able to extract the heat available from the lower convective zone of the solar pond. The analysis in this paper was conducted by investigating the solar ponds operating in different climate conditions, which are Group A (Kuala Lumpur), Group B (Riyadh) and Group C (Melbourne and Granada) base on Köppen climate classification. The theoretical feasibility draws the limit on the performance and cost of the solar pond-thermoelectric system under commercially available thermoelectric technology at the present state. Later, the result was contrasted against the performance of the power generation units operate under realisable operating condition with solar pond. The result in this study revealed that, under ideal condition, the system is at least 10 times costly compared to other renewable energy sources like off-grid solar photovoltaic system with storage. Meanwhile, at its best operating climate, this system will be able to achieve annual carbon dioxide reduction of 2.38 kg/m^2-year in a practical case.

1. Introduction

As emphasised by Bell [1] in his review on thermoelectric systems, if the high *ZT* material for thermoelectric is obtained, a society with gas emission free environment could be realised with a reduction in both fuel consumption and CO$_2$ emissions. Also, vigorous research and development of renewable energy resources will shape the renewable energy into the main source of energy supply in the future [2].

A solar pond (Fig. 1) consists of three distinct zones, upper convective zone (UCZ), non-convective zone (NCZ) and lower convective zone (LCZ). The solar pond (SP) has its coolest zone at the UCZ and the hottest zone at LCZ. Across the NCZ from top to bottom, the salinity and temperature gradually increases until it reach LCZ which consists of saturated salt solution (typically NaCl).

Over the past few decades, solar ponds have been a good source of low grade heat [3] in the range of 40–80 °C for industry such as salt production, food processing and water supply. This is possible due to the cheap cost of the land i and availability of high solar radiation throughout the year. The conventional electric power generation from the SP is achieved via organic Rankine cycle (ORC) [4] using an organic refrigerant that boils at lower temperature such as R134a as illustrated in Fig. 2. Typical thickness of UCZ is around 0.15–0.4 m, the UCZ serves as the heat sink for the SP-ORC system as well as the thermal insulator for the LCZ. Meanwhile, the NCZ with a typical thickness between 1.0 and 1.5 m. It acts as a thick insulator that only transfers the heat via conduction mode. In turn, the LCZ (around 1.0–3.0 m) possesses highest temperature in the form of saturated brine, providing the heat needed to boil the organic refrigerant into vapour that subsequently drives the turbine. Table 1 shows the SP coupled with ORC for electric power generation.

The operation of ORC is dependent on the temperature of the LCZ. During winter, the LCZ temperature will reduce to temperature as low as 40 °C and the operation of ORC comes to a halt.

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Nomenclature

A	area (m^2)
c	specific heat capacity (J/kg°C)
d	gap width (m)
Δ	difference
$\overline{H}$	solar radiation (W/m^2)
K	thermal conductivity (W/m°C)
LCZ	lower convective zone
$\dot{m}$	mass flow rate (kg/s)
N	number of
NCZ	non-convective zone
ORC	organic Rankine cycle
$\dot{Q}$	heat transfer (W)
R	resistance (°C /W)
r	efficiency ratio/fraction of Carnot
SP	solar pond
T	temperature (°C)
TE	thermoelectric
TEM	thermoelectric module
U	overall heat transfer coefficient (W/m^2°C)
UCZ	upper convective zone
$\dot{V}$	volume flow rate (m^3/s)
$\dot{W}$	electrical power (W)
x	thickness (m)
ZT	figure of merit
γ	heat extraction percentage (%)
η	efficiency (%)

Subscript

am	ambient
C	Carnot
c	cold
e	electrical
HX	heat exchanger
h	hot
L	lower convective zone, LCZ
lmtd	log mean temperature difference
re	solar radiation to electricity
t	thermal

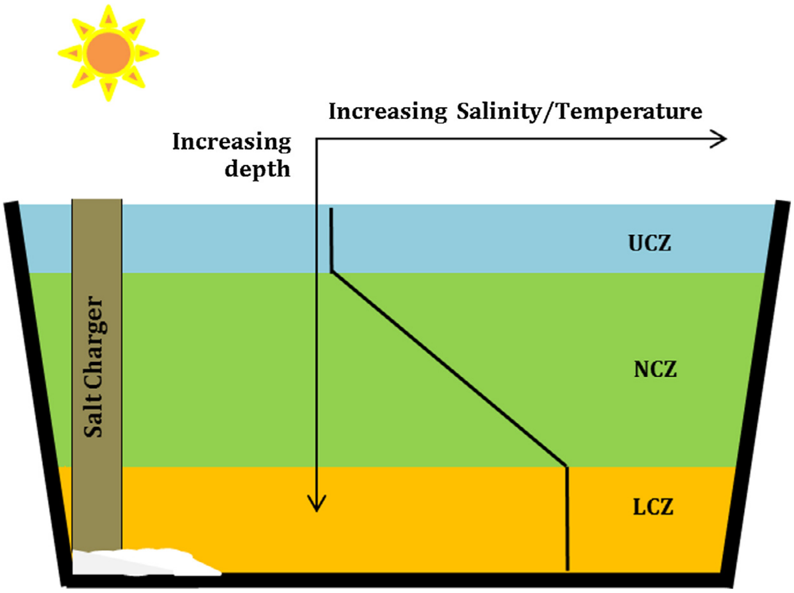

Fig. 1. The SP with the salinity and temperature gradient in the SP.

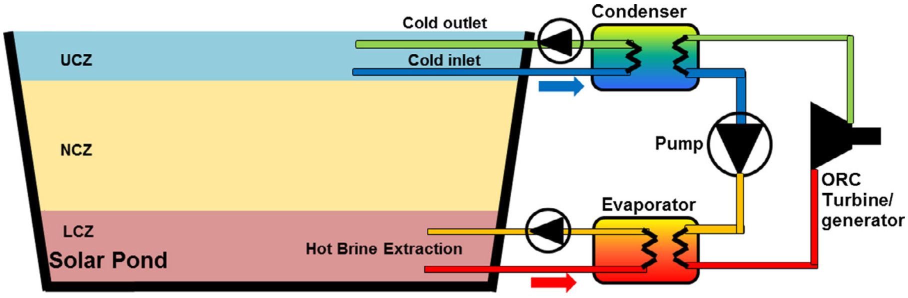

Fig. 2. Conventional electric power generation from SP using ORC.