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Condenser-side integration of a simple solar-type waste heat recovery device in a thermal plant

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ABSTRACT

In this paper, the integration and applicability of solar thermal technology with a thermal plant condenser is examined. This is proposed as a heat transfer enhancement measure in improving the thermal efficiency of power generating plants. Equally, a thermodynamic investigation into the rankine plant is undertaken, in addition to evaluating the heat transfer performance of a novel dual plate flow-directional absorber (DPFA), which is coupled to the condenser. The major benefit of the DFPA over other absorber designs is that it has simultaneous serial and counter-flow functionality (with different flow configurations in different operational modes): this is particularly useful in absorbing radiation from twin sources simultaneously and independently, while generating additional work for other thermal applications. Results confirm considerable exergy destruction in the plant in varying operating conditions, and significant waste heat recovery prospect.

1. Introduction

In a thermal plant, the condenser is one of the principal heat transfer components and also a major source of energy losses. The energy losses in a power plant can be particularly high and recoverable for additional work. Globally, the energy demand grows with growing population, accentuating the need for innovative energy technology. It is estimated that the global population will grow by nearly a quarter in 2030 (Facts and Figures, 2012). Particularly, an estimated 20% of the global population has inadequate or no energy/power provisions (Facts and Figures, 2012): in sub-Saharan Africa alone, about 45% of the population have no access to grid power (Energy for All, 2011). By the current growth rate, energy demand will steadily increase in the foreseeable future; and meeting the energy demand becomes a technological and economic challenge, especially with respect to design, operation and maintenance of existing and futuristic thermal plants.

Notably, there has been a range of studies into different energy recovery technologies in power plants; in the following work by Badr et al. (1985) on the performance of Rankine-cycle power-plants which used steam as the working fluid, a BASIC programme was developed to facilitate the prediction and optimal design of Rankine-plants in varying operating environments. Kumar Kapooria et al., (2008) conducted a study into a rankine cycle plant, and observed that the efficiency can be improved by using intermediate reheat cycle. Tony et al., (2012) compared the Organic Flash Cycle (OFC) to other advanced vapor cycles for intermediate and high temperature waste heat reclamation and solar thermal energy applications, and found that aromatic hydrocarbons are better suited as working fluids in Organic Rankine Cycles (ORC) and OFC due to their higher power output and it requires less complex turbine designs. Huijuan et al. (2010) reviewed the Rankine and supercritical Rankine cycles for the conversion of low-grade heat into electrical power, and concluded that the thermodynamic and physical properties, stability, environmental impacts, safety, compatibility, availability and cost are important considerations for selecting a working fluid. Ankur and Khandwawala (2013) obtained correction curves for power output on account of conflicts between actual and predicted output value for a 120 MW thermal power plant. Also, Nouman (2012) conducted a comparative study into working fluids of Organic Rankine Cycles – ORC. It was determined that the temperature profile in the evaporator and condenser is of key importance to the exergy losses and best energy utilization. Wang et al. (2011) reviewed various designs of the Rankine cycle, its thermodynamic principles towards achieving high efficiency, and the selection of the working fluids, the results gave an insight into

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Nomenclature

A	Area (m^2)
Q	Heat (KJ/kg)
h	Enthalpy (KJ/kg)
P_t	Turbine (Generated) Power (W)
W	Work (KJ/kg)
E	Power (W)
s	Entropy (KJ/kg)
P	Pressure (Pa)
T	Temperature (W)
υ	Specific volume (m^3/kg)
W	Work (KJ/kg)
E	Power (W)
s	Entropy (KJ/kg)
S_{gen}	Entropy generation (KJ/kgK)
m	Mass fraction
$\dot{m}$	Mass flow rate (Kg/s)
ΔE_{system}	Energy difference (KJ/kg)
Δke_s	Potential Energy difference (KJ/Kg)
U_{pf}	Overall heat loss conductance W/m^2
σ	Stefan-Boltzmann constant (W/m^4K)

Subscripts

a	ambient
boil.	boiler
cond.	condenser
dest	destroyed
p	pump
t	turbine
out	outlet
source	pump
sink	pump
e	Temperature (W)
in	in
i	Intermediate
reg.	regenerator
s	solar
c	condenser
sup.	superheater

Symbols

0	destroyed
η	Efficiency
b, in	system boundary, in
b, out	system boundary, out

the Rankine cycle (RC) as being the most favourable basic working cycle for thermodynamic exhaust heat recovery (EHR).

Despite the various studies into waste heat recovery devices in thermal plants, there has rarely been studies directed towards twin extraction of heat from the condenser with a potential for integration of solar energy technology. In this work therefore, an integrated waste heat recovery device coupled to a solar energy absorptive device is evaluated as a route towards improved waste heat recovery and throughput. The dual plate flow-directional absorber (DPFA) employed here consists of a novel (patentable) absorber design which can be coupled to a condenser operating in ambient conditions. The dual plate flow-directional absorber incorporates a dual plate absorber which can absorb radiant heat from dual heat sources - emitted radiation from the condenser as well as incident solar radiation. The top and the rear absorbers when operated in typical ambient conditions can absorb radiant heat from a condenser, as well as incident solar radiation. One of the absorbers can serve as a preheater and the other, the main heater of the working fluid thereby increasing the energy gain of the fluid with savings in space and costs. The major benefit of the DFPA over other absorbers is that it has a simultaneous serial and counter-flow functionality (with different flow configurations in different operational modes); this is particularly useful in absorbing radiation from twin heat sources simultaneously and independently, while generating additional work for other thermal applications with significant environmental benefits.

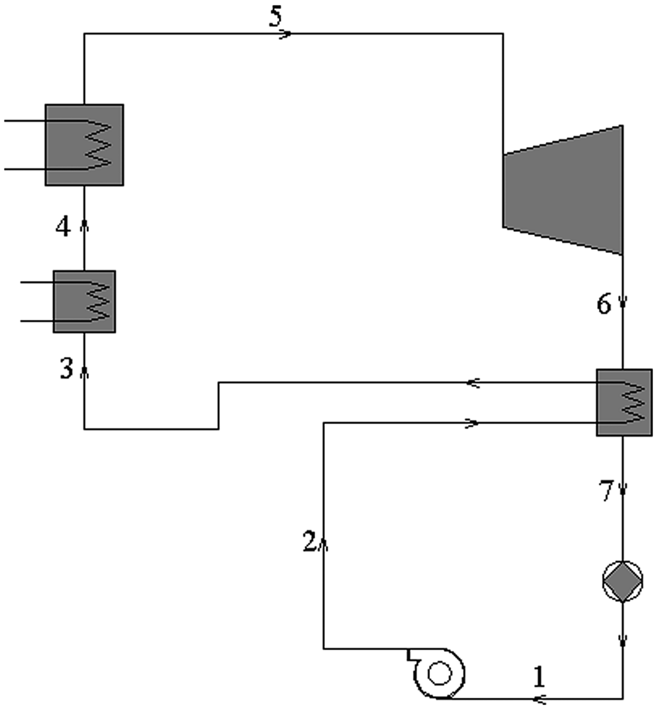

Fig. 1. Thermodynamic process diagram of the regenerative rankine power plants.

2. Cycle description

In Fig. 1, the regenerative rankine plant is shown schematically, considering the stand-alone operation in which there is no axillary heat input - an operational mode in which the energy input to the boiler is supplied by means of a gas heating or concentrated solar power (CSP) technology. Fig. 2 shows the thermodynamic cycle of the plant, the temperature-entropy (T-s) diagram of the regenerative rankine cycle. The main components of the plant consist of a boiler/vaporizer, the superheater, turbine, condenser, regenerator and a pump.

3. Thermodynamic analysis

The rankine plant is analyzed as a steady state flow process (Yunus and Michael, 2006). The changes in kinetic and potential energy are negligible in the steam relative to the work and heat