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Review

Issues, comparisons, turbine selections and applications – An overview in organic Rankine cycle

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ABSTRACT

Waste heat accounts nearly 50% of the total energy used in the industries. This low grade thermal energy is mostly available in the temperature range of 120–650 °C, which can be effectively utilized to produce power by which the consumption of the fossil fuels can be mitigated to a certain extent. The total solar irradiance measured by satellite is roughly found to be 1361 W/m^2 which can be effectively utilised. The conversion of heat to electricity is often carried out by heat engines and thermodynamic cycles also play a major role in utilising waste heat effectively. Among the thermodynamic cycles, organic Rankine cycle (ORC) is considered to be an effective approach in harnessing low grade thermal energy. ORC is used in heat recovery of low-temperature sources such as biomass combustion, industrial waste heat, and geothermal heat. The efficient operation of ORC depends on the working fluid and expander employed which determines the efficiency and power output of the cycle. Compared to experimentation works, modeling works are mostly studied in the case of ORC. Current review predominantly focuses on the review of various thermodynamic cycles for power production, working fluids that can be employed in the cycle, turbine selection and applications of ORC by employing it as topping or bottoming cycle in other primary heat or power cycles.

1. Introduction

The environmental factors such as global warming, ozone depletion and atmospheric pollution unfolded the parameters to cease the dependency on fossil fuels. Fossil fuels still play a dominant role in energy resources as the energy demands keep raising. The rapid growth of industrialization, energy shortages and blackouts resulted in high energy demands accounting about 25% in 1978 to 33% in 2000, and 35–40% by 2020 (World Energy Balance, 1984) [1].The research interest gained considerable attention in utilizing the low-grade waste heat to minimize the energy losses. The priority in recovering waste heat is an initiative taken by worldwide governments to reduce the fuel consumption and thereby achieve higher energy conversion efficiencies. The current trends in climatic changes signify the importance of the optimization of existing conventional systems for power generation. Among the technologies available today such as organic Rankine cycle, Kalina cycle, Trilateral Flash cycle and Supercritical cycle, the organic Rankine Cycle (ORC) claims to produce 15–50% more power output for the same heat and is mainly suited for low-temperature heat recovery to generate power with low maintenance [24]. ORC is a boon in the sectors to which the energy consumption and energy demands can shortly be met shortly. The working phenomena of a steam cycle and ORC do not differ much except the working fluid used in the system. The ORC uses an organic fluid while the steam cycle uses water as working fluid to derive the mechanical power output which makes the ORC system to produce power from low heat sources, followed by the extraction of heat energy from solar and thermal energy from the oceans as an effective means to generate power output [1–3]. The advancements in ORC is progressed through applications in the field of thermoelectric generator [4], fuel cell [5,6], Diesel engine [7], microturbine [8], seawater desalination system [9], Brayton cycle [10] and cascade system [11,12]. The further progress in this field was extensively carried out by using ORC as prime movers in combined cooling and power system [13–15], CHP [16], micro CCHP, Vapor compression system [17], absorption cycle [18,19], additional electric energy storage [20] and steel processing plants [21] systems.

The important aspect that plays in the optimization of the working parameters is the selection of working fluid and selection of turbine as the prime mover. A summary of the selection of working fluids and design parameters of the turbine design is discussed to enlighten the design process in ORC setup. Throughout the literature study, numerous efforts were taken in recovering waste heat. Various thermodynamic cycles are used to efficiently convert the low-grade thermal energy (LGTE) to produce electricity such as organic Rankine Cycle

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Nomenclature

Abbreviations

ORC	Organic Rankine Cycle
CHP	Combined Heat and Power
CCHP	Combined Cooling Heat and Power
LGTE	Low-Grade Thermal Energy
SRC	Supercritical Rankine Cycle
KC	Kalina Cycle
TFC	Trilateral Flash Cycle
LNG	Liquefied Natural Gas
CSP	Concentrated Solar Power
EES	Engineering Equation Solver
TESS	Thermal Energy System Specialists
TRNSYS	Transient System Simulation Tool
TSORC	Two-Stage Serial Organic Rankine Cycle
OFC	Organic Flash Cycle
HRVG	Heat Recovery Vapor Generator
KPCC	Kalina Power-Cooling Cycle
KLACC	Kalina Lithium Bromide Absorption Chiller Cycle
TAE	Thermo-Acoustic Engine
IBC	Inverted Brayton Cycle
ODP	Ozone Depletion Potential
GWP	Global Warming Potential
HFC	Hydro Fluro Carbon
HFO	Hydro Fluro Olefins
CFD	Computational Fluid Dynamics
SORC	Small Scale Saturated Solar Organic Cycle
RO	Reverse Osmosis

Units

%	percentage
kW	kilo watt
˚C	temperature in degree celcius
W/m^2	watt per square meter
kg/s	kilogram per second
MW	mega watt
K	temperature in kelvin
kJ/kg	kilojoule per kilogram
MPa	mega pascal
Rpm	rotations per minute
$	American dollar
kWh	kilowatt hour

(ORC), supercritical Rankine Cycle (SRC), Kalina cycle (KC) and Trilateral Flash Cycle (TFC). The review work predominantly focuses on the derivatives of Rankine cycle (organic Rankine cycle and supercritical Rankine cycle) for efficient conversion of the waste heat or low-grade thermal energy (LGTE) in the temperature range of 120–350 ˚C. Detailed literature analysis is done on comparing organic Rankine Cycle (ORC) on par with other thermodynamic cycles such as supercritical Rankine Cycle (SRC), Kalina cycle (KC) and Trilateral Flash Cycle (TFC) and the same is presented in this paper.

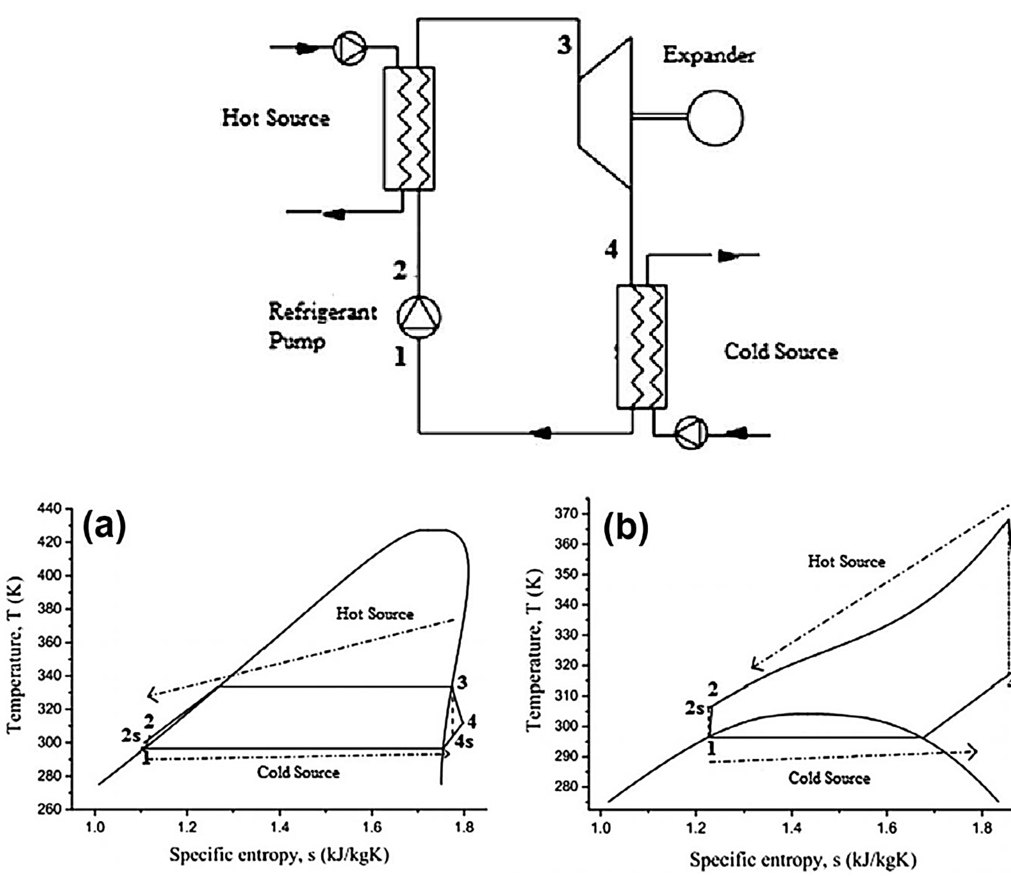

Fig. 1. ORC layout, T–s diagrams of subcritical (a) and transcritical (b) cycles [22].