SOLAR HETEROGENEOUS ORGANIC RANKINE CYCLE

By

Nora Hany Ibrahim Shaheen

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Chemical Engineering

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Title of Thesis:

Solar Heterogeneous Organic Rankine Cycle

Key Words:
Heterogeneous Binary Mixtures; Azeotropic Mixtures; Organic Rankine Cycle; Solar Energy; Hexane Water Mixtures

Summary:
The present thesis work studies the opportunities of performance improvement related to Solar Organic Rankine Cycle using heterogeneous organic working fluids, which are predicted to increase the thermal efficiency of the cycle from a thermodynamic point of view. This cycle is of critical importance since it can be integrated in multiple industrial plants helping in the waste heat recovery, which is a cost effective and environmentally friendly solution.

In the study, an investigation was carried out on three stages. The first stage was the selection of pure working fluids, which are suitable for cost efficient low temperature scale solar application. The second stage was a comparison between heterogeneous organic working fluid mixtures and pure working alternatives. Third, all the heterogeneous working mixture alternatives that did not achieve an increase in either thermal efficiency or savings were eliminated. Finally, the optimum alternatives of heterogeneous mixtures were indicated after multiple screening steps as water normal hexane and water cyclohexane mixtures, which showed promising results in terms of thermal efficiency increase taking into consideration cost savings and safety limitations.

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Dedication

This thesis is dedicated to the soul of my beloved father, my brave mother, my kind sisters and all the people who stood by my side in the journey.

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Nomenclature

Abbreviations

BIPV	Building Integrated Photovoltaic
CSP	Concentrated Solar Power
CPC	Compound Parabolic Collector
CPV	Concentrated Photo Voltaic
CSTP	Concentrated Solar Thermal Power
DVG	Direct Vapor Generation
DHI	Diffusion Horizontal Irradiance
DNI	Direct Normal Irradiance
EHE	External Heat Exchanger
EPA	Environmental Protection Agency
ETC	Evacuated Trough Collector
FPC	Flat Plate Collector
GHP	Global Horizontal Irradiance
GWP	Global Warming Potential
HPP	High Pressure Pump
HTF	Heat Transfer Fluid
IHE	Internal Heat Exchangers
kWh	Kilo Watt Hour
LFC	Linear Fresnel Collector
LFL	Lower Flammability Limit
MDM	Octamethyl trisiloxane
MM	Hexa methyl disiloxane
NBP	Normal Boiling Point
NFPA	National Fire protection Agency
ODP	Ozone Depletion Potential
ORC	Organic Rankine Cycle
PCM	Phase Change Material
PFC	Per Fluoro Carbons
PR	Peng Robinson
PTC	Parabolic Trough Collector
PV	Photovoltaic
RO	Reverse Osmosis
STPC	Solar Thermal Power Cycle
SWRO	Solar Water Reverse Osmosis
TES	Thermal Energy Storage

Greek Letter Symbols

μ	Viscosity	kg/m. sec
$\dot{W}$	Power Consumption	kW
λ	Latent Heat	kJ/kg
η_{Carnot}	Carnot Efficiency	
$\eta_{thermal}$	Thermal Efficiency	
η_{II}	Second law Efficiency	

Letter Symbols

Cp	Specific Heat	KJ/kg. K
$\dot{m}$	Mass flow Rate	kg/s
Q	Energy	kJ
H	Enthalpy	kJ/kg
K	Thermal Conductivity	W/mK
P	Pressure	bar
P	Pressure Ratio	
S	Entropy	kJ/ K
ΔS_{system}	Change of Entropy in System	kJ/ K
$\Delta S_{surroundings}$	Change of Entropy in Surroundings	kJ/ K
T	Temperature	°C
$T\ hot\ pp$	Pinch Point difference at Hot Side	°C
$T\ cold\ pp$	Pinch Point difference at cold Side	°C
T_H	Highest Temperature in the cycle	°C
T_L	Lowest Temperature in the Cycle	°C
T_{source}	Heat Source Temperature	°C
T_{sink}	Heat Sink Temperature	°C
T_o	Ambient Temperature	°C

Abstract

The current thesis is dealing with the application of solar thermal power generation that contributes to saving Earth; one of the merits of this application is its ability to be integrated within any process for variety of applications; one of which is the waste heat recovery. Generally, the solar thermal power generation plants consist of thermal energy storage (TES) systems and power generation cycles. Egypt has a high potential in solar energy utilization since it is located within the Sun Belt countries and has wide land area available for harnessing this energy resource.

The present work addresses improving the performance of Organic Rankine Cycle (ORC), this cycle can be a part of low temperature solar thermal electric generation plant. ORC produces power via the conversion of heat energy into mechanical energy. Although, heterogeneous organic working mixtures can be utilized in ORC for their potential to improve its thermal efficiency, no studies were published in this topic and that is where the novel impact of this investigation lies. Heterogeneous working fluids have higher vapor pressure at azeotropic compositions than their pure alternatives at the same working conditions, which can eventually lead to a significant improvement of the thermal efficiency of the cycle from a thermodynamic point of view using the proper temperature and pressure constraints.

The investigation to improve the ORC thermal efficiency was completed successfully in three main stages. The first stage is the development of a simulation model using Aspen plus Software in which suitable pure organic working fluids are used in ORC application using Direct Vapor Generation (DVG) Technology in low temperature scale within the temperature range between 30 °C - 200 °C .The heat collector used is of the Flat Plate Collector (FPC) type, which does not have complex tracking systems with relatively low cost. In the second stage, a comparison was performed between the thermodynamic calculations of pure and heterogeneous organic working mixtures. The third and final stage was the five steps of screening followed in order to identify the heterogeneous mixtures optimum alternatives.

The results are promising and they are covering all the stages followed in the calculations. From an engineering point of view, the two optimum heterogeneous organic mixtures are water/cyclo hexane and water/normal hexane mixtures. The Optimum mixtures are indicated based on their potential to achieve significant improvement in the performance of the ORC in terms of thermal efficiency taking into account the cost savings and safety limitations.