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Theoretical Analysis for Solar Driven Mechanical Refrigeration Systems

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Abstract

Organic Rankine Cycle has become attractive due to the possibility of using low heat energies potential. Such a renewable source is solar energy. This paper presents a first law thermodynamic analysis of solar Rankine cooling system. It is analyzed the choosing of working fluids, depending on their thermodynamic properties, and the influence of generation and condensing temperatures on the overall efficiency of combined cycle. There were analyzed two working fluids: R 245fa and R 134a. The performed thermodynamic analysis showed that the thermodynamic performance R245fa performs better than R134a.

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Keywords: Organic Rankine Cycle, solar cooling, thermodynamic analysis, R 245fa, R 134a

1. Introduction

Solar energy is one of renewable energies with an important impact in the reduction of fossil fuel consumption and helping to reduce the negative effects of certain forms of pollution of the environment. In the same time, solar cooling is an attractive application of solar energy, because the need for cooling has the maximum value in maximum insolation period of the day

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Nomenclature

ORC	organic Rankine cycle
VCC	vapor compression cooling
COP_s	overall performance of the ORC/VCC
COP_c	coefficient of performance of the mechanical cooling system
η_p	efficiency of the Organic Rankine Cycle
ξ	the slope of entropy in T-s diagram
p_e	evaporating pressure
p_c	condensing pressure
p_g	generating pressure
T_e	evaporating temperature
T_c	condensing temperature
T_g	generating temperature

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The most promising cooling systems that use solar energy as an energy source are [1]: absorption systems, systems that use a Rankine cycle to drive the compressor and systems that use electricity produced by photovoltaic panels. Despite the thermal activated refrigeration systems have experienced rapid growth, vapor compression cooling systems (VCC) are most used in this moment [4, 6]. There are two ways to activate this type of cooling system using the sun:

- Using photovoltaic panels, to produce energy by coupling an electric motor directly to the compressor shaft;
- Using solar thermal collectors, to produce thermal energy for a fluid heat engine, the mechanical work produced will activate the compressor. Recent researches have shown that there are two types of thermal engines with development opportunities for achieving solar cooling systems.

In the first thermal engine, the working fluid changes phase during the cycle. The most used cycle for this type of heat engine is Rankine cycle. In the second one, the working fluid remains in gaseous phase. The most used cycles for this type of heat engine are Brayton cycle and Stirling cycle. For applications that involve low thermal energies input, Rankine cycle engine is preferable to use. When using the cycle for solar applications, the organic Rankine cycle (ORC) is preferred instead water Rankine cycle, because the liquid-vapor phase change occurs at a lower temperature than the water-steam phase change.

A good solution is to use the same working fluid in both Organic Rankine Cycle and Vapor Compression Cycle. In this way, a common condenser should be used and elimination of the special seals to maintain fluid separation in the expander-compressor unit.

2. Solar Rankine cooling system (ORC/VCC) analysis

2.1. System design

In figure 1 the solar Rankine cooling system is presented. The H outline represents the Organic Rankine heat engine while the C outline represents the mechanical compression cooling system. The Organic Rankine heat engine (ORC) is composed of solar collector (generator) G, expender E, condenser K1 and pump P. The mechanical compression cooling system (VCC) is composed of evaporator E, mechanical compressor C, condenser K2 and throttle valve VL. If the working fluid is the same in both circuits, there is just one condenser K.

The T-s diagram of ORC/VCC cycle is presented in figure 2.

There are three different pressures in the system: