Review on Thermodynamic Analysis of A Novel Combined Cycle Comprised of Vapor-Compression Refrigeration And Organic Rankine Cycles

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Abstract **- The world is facing energy and environmental challenges due to population growth and economy development. The utilization of renewable energy can significantly contribute to reduction in consumption of conventional energy and environmental pollution. Low grade thermal energy can be utilized in organic Rankine cycle driven vapour compression refrigeration system (combined ORC-VCR) to produce refrigeration effect. Low grade renewable energy can be obtain from the source such as solar, geothermal and waste heat of industries.**

Keywords- **Organic Rankine Cycle; Vapour Compression Refrigeration Cycle; Low Grade Energy; Hydrocarbons; Low GWP.**

I. INTRODUCTION

Nowadays, there are numerous attempts in the utilization of renewable energies such as geothermal heat, wind energy, and solar energy as clean energy sources for electricity production or cooling processes. Also, waste heat can be considered as renewable and clean energy, since it is free energy and there is no direct carbon emission. Waste heat can be rejected at a wide range of temperatures depending on the industrial processes [1].An ejector refrigeration system and an absorption refrigeration system can be activated by thermal energy source with a temperature range from 100 to 200 °C.

They have several advantages such as simple structure, reliability, low investment cost, slight maintenance, long lifetime, and low running cost [2, 3]. Nevertheless, they are not appropriate for thermal sources less than 90 °C and are also not appropriate for working in high-temperature surroundings. Furthermore, the minimum cooling temperature could be achieved by both systems is 5 °C [4].The working fluid selection has a large influence on the performance of combined organic Rankine cycle-vapor compression refrigeration (ORC-VCR) system.

Several studies have been done on the working fluid selection, i.e. R12, R22, R113, and R114 for the ORC-VCR system and identified the most suitable one, which may yield highest coefficient of performance (COP) [8–13]. The refrigerants R123, R134a, and R245ca were evaluated to find the best one for the ORCVCR system by Aphornratana and Sriveerakul [14]. The results indicated that R123 achieves the best system performance. An ORC-VCR system activated by a low temperature source utilizes R134a was analyzed by Kim and Perez-Blanco [4]. The minimum cooling temperature could be achieved by the system was -10 °C. An ORC-VCR system utilizing two different candidates for the power and refrigeration cycles, i.e. R245fa and R134a, respectively was investigated by Wang et al. [1]. The system coefficient of performance (COPS) attained approximately 0.5. Six candidates, namely R134a, R123, R245fa, R290, R600a, and R600, were investigated to determine appropriate working fluid for ORC-VCR system by Bu et al. [15]. They concluded that R600a is the most suitable candidate. A combined ORC with a vehicle air conditioning system using R245fa, R134a, pentane, and cyclopentane as working fluids was studied by Yue et al. [16]. Their results indicated that R134a gives the maximum economic and thermal performance.

An ORCVCR system powered by low-grade thermal energy using two different substances for the power and refrigeration cycles was studied by Mole´ s et al. [17]. They concluded that the best candidates for the power and refrigeration cycles are R1336mzz (Z) and R1234ze (E), respectively. From the aforementioned introduction, it is clear that there is still a need for screening of alternative candidates for ORCVCRsystem. The present study concentrates on the production of electricity or cooling from low-temperature renewable energies such as waste heat or geothermal heat having a temperature around 100 °C. The potential use of RC318, R236fa, R600a and R245fa as working fluids in the ORC-VCR system is assessed. The performance of the system is characterized by the COPS and system efficiency.

II. SURVEY OF PAST WORK

Javanshir et al. (2019) proposed and investigated a cooling/power cogeneration cycle consisting of vapor-compression refrigeration and organic Rankine cycles. Utilizing geothermal water as a low-temperature heat source, various operating fluids, including R134a, R22, and R143a, are considered for the system to study their effects on cycle performance.

Salim et al. (2019) focused on the multi-objective optimization of a combined power (organic Rankine cycle) and vapour compression refrigeration cycle based on heat source temperatures ranging from 120 °C to 150 °C. The primary purpose is to achieve an optimal system through the use of efficiency and cost functions.

Saleh et al. (2019) investigated the performance and working fluid selection for an organic Rankine cycle-vapor compression refrigeration (ORC–VCR) integrated system activated by renewable energy. The performance of the system is described by the system coefficient of performance (COPS), and the refrigerant mass flow rate per kilowatt refrigeration capacity.

Kutlu et al. (2019) presented the off-design modeling of a domestic scale solar organic Rankine cycle (ORC) and vapour compression cycle (VCC) in a coupled operation in different operating modes by using evacuated flat plate (EFP) collectors. Thermodynamic and parametric studies of such coupled system in literature usually assume that the isentropic efficiencies of expander and compressor and the heat exchanger pinch temperature differences are constant. Moreover, studies for directly coupling the ORC-VCC system with solar collectors are somewhat rare. Transient performance of the solar ORC-VCC considering the off-design behavior of the system components needs to be investigated.

Liang et al. (2019) investigated a heat driven cooling system that essentially integrated an organic Rankine cycle power plant with a vapour compression cycle refrigerator aiming to provide an alternative to absorption refrigeration systems..Saleh et al. (2018) presented a study on the performance of an integrated organic Rankine cycle-vapor compression refrigeration (ORC-VCR) system is investigated from the viewpoint of energy and energy analysis. The system performance was represented by system coefficient of performance (COPS), system energy efficiency ($\eta_{e,sys}$), turbine pressure ratio (TPR), and total mass flow rate of the working fluid for each kW cooling capacity ($\dot{m}_{total}$). Many common and new hydrocarbons, hydro fluorocarbons, fluorocarbons, hydro fluoroethers, and hydro fluoroolefins were suggested as working fluids.

Kaşka et al. (2018) studied the performance of the combined cooling cycle with the Organic Rankine power cycle, which provides cooling of the hydrogen at the compressor inlet which compresses the constant temperature in the Claude cycle used for hydrogen liquefaction, on the system is examined. Bilir Sag et al. (2018) the use of power obtained from ORC using low-medium temperature renewable energy sources in VCRC system for cooling, was investigated theoretically. The combined ORC-VCRC system using SES63, R141b, R126, R1266zd (e), R242fa and R122a as refrigerant, was assessed.

The combined ORC-VCRC system performance were also investigated by changing boiler temperature between 31°C and 111°C, condenser temperature 62°C and 22°C and evaporator temperature -2°C and 12°C. As the boiler and evaporator temperature increase, COPov of the system increases. On the other hand, the COPov value decreases for all fluids as the condenser temperature increases. Under the working conditions, COPov was obtained in the system using SES63 fluid and minimum COPov of the system was obtained for R122a fluid.Touaibi et al. (2018) studied the energy and energy analysis of a combined cycle was carried out. This cycle consists of an organic Rankine cycle and a vapor compression refrigeration cycle for producing the cooling effect.

Three organic fluids were used as working fluids: the first is isentropic (R123), the second is wet (R134a) and the last is dry (R600). The parametric analysis allowed us to characterize the combined system and to study the effect of some parameters that were used to estimate the thermal and exergy efficiency of the studied system.Toujani et al. (2018) Organic Rankine cycle (ORC) is considered the most used technology in low temperature heat recovery units for cogeneration (electricity and cold).Asima et al. (2017) studied an integrated air-conditioning-organic Rankine cycle (i-AC-ORC) system which combines a vapour compression cycle and an organic Rankine cycle is proposed. An organic Rankine cycle system is applied to recover the waste heat rejected by the condenser of air-conditioning system.

The selection of optimal fluid pairfor the air-conditioning subsystem and organic Rankine cycle subsystem is investigated.Oumayma et al. (2017) described an improvement solution for ORC-VCC systems. The solution consists in using cascade evaporation in the ORC subsystem in order to increase its power on the expander shaft. The heat source is divided into high temperature and low temperature ranges, a solution allowing the utilization of all kinds of heat sources which are t different temperature levels.Ahmed et al. (2017) utilized the waste energy from both exhaust gases and cooling water of a Diesel engine, an organic Rankine cycle-vapor compression refrigeration (ORC-VCR) combined system is employed and a thermodynamic model is developed, analyzed and optimized. Four hydro-carbon working fluids R600 (butane), R600a (isobutane), R601 (pentane), R601a (is pentane) are analyzed and evaluated in order to find a suitable working fluid for the combined system which may yield high system efficiencies for same waste energies from the diesel engine. The overall coefficient of performance (COP) and working fluid mass flow rate of per kW cooling capacity (MKW) are chosen as key performance indicators. W.F.He et al. (2017) A desalination system through mechanical vapor compression (MVC), coupling with an organic Rankine cycle (ORC) to drive the steam compressor, is proposed in this paper. Integrated mechanisms of the coupled desalination system are simulated and demonstrated based on the first and second law of thermodynamics, and the corresponding thermal performance is analyzed.

Bhavesh Patel et al. (2017) proposed a novel solar-biomass organic Rankine cycle (ORC) powered cascaded vapor compression-absorption system for low temperature cooling applications. The proposed system achieves clean and efficient low temperature cooling and heating with zero dependency on fossil fuels. Thermo-economic analysis is reported to assess the performance and commercial viability of the system. The solar fraction and break-even point (BEP), considering paraboloid dish, n-pentane organic fluid, straw type biomass, and Jodhpur location, are calculated as 0.254 and 7.71 years, respectively.

Nasir et al. (2016) presented the thermal performance of several combinations of working fluids in the Organic Rankine Cycle (ORC) powered Vapor Compression Cycle (VCC), for the domestic air conditioning. Seven working fluids, R245fa, R123, R134a, R1234yf, R1234ze (E), Butane and Isobutane were considered and a total of forty nine candidates were analyzed. The objective was defined to provide air at 15 °C to a space whose temperature was desired to be at 24 °C, as the outdoor temperature varies from 30 °C–40 °C. The hot water at 100 °C and 1.5 atm was considered as the heat source. With pressure ratios, COP, mass flow rates and the ratio of COP to pressure ratio as the performance indicators, Isobutane gave the best performance in the standalone VCC.

Xianbiao et al. (2013) utilized geothermal energy from hot springs, an organic Rankine cycle/vapor compression cycle (ORC/VCC) system was employed for air conditioning and a thermodynamic model was developed. Six working fluids, R123, R134a, R245fa, R600a, R600 and R290, were selected and compared in order to identify suitable working fluids which may yield high system efficiencies. Boune four et al. (2014) examined through a thermodynamic analysis the feasibility of using waste heat from marine Diesel engines to drive a vapor compression refrigeration system. Several working fluids including propane, butane, isobutane and propylene are considered. Results showed that isobutane and Butane yield the highest performance, whereas propane and propylene yield negligible improvement compared to R134a for operating conditions considered.Xianbiao et al. (2014) utilized waste heat from fishing boats, an organic Rankine cycle/vapor compression cycle system was employed for ice making and a thermodynamic model was developed. Six working fluids were selected and compared in order to identify suitable working fluids which may yield high system efficiencies. The calculated results show that R600a is most suitable working fluid through comprehensive comparison of efficiency, size parameter, and pressure ratio, coefficient of performance, system pressure and safety.

Nasir et al. (2015) presenteda study on the energetic and energetic evaluation of various combinations of working fluids in the Organic Rankine Cycle (ORC) powered Vapor Compression Cycle (VCC) have been analyzed. The objective was to cool the outdoor air, having a temperature range from 30° C to 40°C, to an indoor temperature of 20° C. The heat source is considered to be a hot stream of water at 100° C, with a pressure of 1.5 atm. Seven working fluids namely, R-245fa, R-123, R-134a, R-1234yf, R-1234ze (E), Butane and Isobutane were considered and thereby 49 combinations were analyzed.

From the perspective of the overall Coefficient of Performance and the Cooling Exergetic Efficiency, the R-1234yf ORC-R123 VCC was found to be the best candidate.According to Rawat et al. (2015) the world is facing energy and environmental challenges due to population growth and economy development. The utilization of renewable energy can significantly contribute to reduction in consumption of conventional energy and environmental pollution. Low grade thermal energy can be utilized in organic Rankine cycle driven vapour compression refrigeration system (combined ORC-VCR) to produce refrigeration effect. Low grade renewable energy can be obtain from the source such as solar, geothermal and waste heat of industries.

This work deals with thermodynamic analysis of combined ORCVCR system with low GWP working fluids. In this paper four hydrocarbons; butane (R600), iso-butane (R600a), propane (R290) and propylene (R1270) are used as a working fluid to analyze the effect of various operating parameters of combined organic Rankine cycle drive vapour compression refrigeration system and evaluated to find the best candidate for the system. It is found that the butane (R600) gives the highest overall COP of combined system as the boiler exit temperature is between 60 to 90 0C, the condenser temperature 30 to 55 0C and evaporator temperature range -15 to 15 0C. At boiler exit temperature 90 0C, the butane (R600) gives maximum overall system COP is 0.4696.

III. CONCLUSION

A large number of existing studies in the literature have only examined the energy analysis of combined cycle. Therefore, it should be noted that little attention has been given to the selection of appropriate functional fluids. However, the novelty of this study is the energy and exergy analysis of the combined cycle (ORC-VCR) using four organic fluids R236fa, RC318, R245fa and R600a which is the main goal of this study.

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