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Topic of Research: Analysis of Low-Grade Heat Source Driven Organic Rankine Cycle Integrated Refrigeration System

FINDINGS

The rising energy demand (in terms of power, heating, and cooling) throughout the world has put pressure on the fossil fuel reserves such as coal, petroleum products, natural gas, etc., which are depleting at a rapid rate. Moreover, the combustion of these fossil fuels led to environmental pollution such as global warming, acid rain, smog, etc. These issues have led researchers to explore alternative energy sources such as wind energy, hydro energy, low-grade thermal energy, etc. The sources of low-grade thermal energy are solar energy, geothermal energy, industrial waste heat, internal combustion engine waste heat, etc. and all of these sources are collectively called low-grade heat sources. Such availability of these sources has encouraged the researchers to analyze and design engineering systems that can be run on these alternative energy sources to generate power, cooling, or both.

In this study, an analysis of organic Rankine cycle integrated vapor-compression refrigeration system (ORC-VCR system) driven by low-grade heat sources is carried out. At first, analysis of the ORC-VCR system is carried out using Taguchi integrated grey relation analysis to determine optimal exergetic efficiency of the system and optimal compressor and expander pressure ratios. The optimal exergetic efficiency of the system, compressor pressure ratio, and expander pressure ratio are 39.86%, 9.8, and 4.4 respectively. Then, the ORC-VCR system of a fixed capacity of 66.67 kW as water chiller is analyzed for its exergetic, economic, and environmental performance. The working fluid, heat-source inlet temperature, cooling water temperature, cold fluid outlet temperature, and isentropic efficiencies of the compressor and the expander are taken as the input operating parameters. The optimal annual values of exergetic efficiency, total cost, and environmental cost are 28.4%, $69949, and $3491 respectively.

Then, an analysis is carried out to determine the impact of the zeotropic mixture as a working

fluid on the thermodynamic performance of the system. A flash tank is installed in the VCR cycle to minimize the exergy destruction associated with the single-stage expansion process executed by the expansion valve. The proposed system is called an organic Rankine cycle-driven flash tank integrated vapor compression refrigeration (ORC-FTVCR) system. The exergetic efficiency of ORC-VCR and ORC-FTVR systems are improved by 71.82% and 84.73% by using zeotropic mixtures whereas the incorporation of flash tank results in a 29% improvement in exergetic efficiency. Moreover, the exergy analysis by advanced means reveals that an appropriate selection of operating conditions for the system components can result in 32% improvement in endogenous exergetic performance of the system. Further, the hybrid system of solar collector and biomass burner is integrated with the ORC-VCR system, and its thermodynamic analysis is carried out to determine the most suitable fluid, which is found to be heptane among hexane, heptane, octane, nonane, decane. The exergetic efficiency and coefficient of performance of the system are just 4.21% and 0.551 respectively subjected to input operating conditions.

Finally, two evaporators are incorporated in the VCR cycle in place of just one to cater to the need for different cooling capacities at different temperatures. The proposed system performance is maximum at the mass fraction of 0.5 for zeotropic mixture (hexane/R245fa) and the corresponding exergetic efficiency and coefficient of performance of the system are 31.1% and 0.425. Therefore, the integration of the ORC with a VCR cycle provides with us a thermally activated system that can be run on a low-grade heat source and can be used for a wide range of applications such as heating, cooling, electricity, etc.

Keywords: Organic Rankine cycle, Vapor compression refrigeration, Low-grade heat source, Optimization, Sensitivity analysis, Thermo-economic analysis, Environmental analysis, Renewable energy.