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# Performance of an R-134a Two-Stage Vapor Compression Refrigeration System

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Two-stage vapor compression refrigeration systems (TSVCRS) have gained significant attention from researchers due to their effectiveness in situations where the pressure ratio across the compressor in a single-stage vapor compression refrigeration system (VCRS) exceeds a range of 4 to 5.[1] When a single-stage VCRS is used for low-temperature applications, typically between –30ºC (–22ºF) and –100ºC (–148ºF),[2] it results in challenges such as high compressor work, elevated discharge temperatures and reduced volumetric efficiency.

To address these issues, TSVCRSs are increasingly used in various sectors, including supermarkets, pharmaceuticals, beverage, petroleum and chemical industries for low-temperature applications. Getu and Bansal[3] have conducted thermodynamic analysis on TSVCRSs operating on carbon dioxide (R-744) and ammonia (R-717) as a refrigerant to optimize system design and operating parameters. These parameters include condensation, subcooling, evaporation and superheating temperatures in the high-temperature ammonia circuit; temperature differences in the two-stage heat exchanger; and evaporation, superheating, condensation and subcooling in the low-temperature $CO_2$ circuit.

Using multilinear regression analysis (MRA), mathematical expressions were developed for the maximum coefficient of performance (COP), the optimal temperature for the evaporation of R-717 and the optimal mass flow ratio of R-717 to R-744 in the cascade refrigeration system. The refrigerants chosen for a system, whether they are pure or mixed, depend on the specific application. Refrigerants with high-boiling points face limitations due to their large suction volume and extremely low evaporative pressure. Meanwhile, refrigerants with low-boiling points are restricted by their high condenser pressure. Therefore, low-boiling point refrigerants are preferred for LTCs, and high-boiling point refrigerants are recommended for HTC within the cascade refrigeration system.

Researchers have shown that various environmentally friendly refrigerants such as R-744, R-717 and hydrocarbons have zero ozone depletion potential (ODP) and low global warming potential (GWP).[4 – 6] Massuchetto et al.,[7] examined the theoretical performance of different refrigerants, highlighting superiority of the R-744/RE170 with the highest COP and the lower discharge temperature and condensation pressure. Logesh et al.,[8] observed that R-134a/R-170 pair had the highest COP in a TSVCRS.

Kilicarslan[9] conducted experimental and theoretical studies on a TSVCRS that uses R-134. This study aimed to evaluate the performance of the TSVCRS by comparing it with two single-stage vapor compression systems.

In their research paper, Bhattacharyya et al.,[10] examined a two-stage vapor compression cycle that is endo-reversible in nature. The aim was to find the optimal intermediate temperature that would result in maximum exergy and refrigeration effect. To validate their theoretical results, the researchers developed an extensive numerical model of a transcritical $CO_2$-$C_3H_8$ cascade system. Similarly, Lee et al.,[11] performed a study on a cascade refrigeration system that used $CO_2$ and ammonia. They were focused on finding the optimal condensation temperature for the cascade condenser. The goal was to achieve the highest possible COP while minimizing the amount of exergy destruction.

Agnew et al.,[12] examined the performance of three-stage vapor compression refrigeration systems with environmentally friendly refrigerants, focusing on the combination that minimizes power consumption for a given refrigeration rate, taking into account overlap temperature and compression process efficiency.

Bhattacharyya et al.,[13] investigated the performance and optimization of a heat pump-cascade refrigeration system containing both internal and external irreversibilities while considering the allotment of heat exchanger inventories.

Dopazo and Fernandez-Seara[14] experimentally evaluated a TSVCRS having refrigerants $NH_3$ and $CO_2$, specially designed to provide a 9 kW (30709.28 Btu/h) refrigeration capacity horizontal plate freezer at –50ºC (–58ºF). Bingming et al.,[15] provided experimental data on a cascade refrigeration system using $CO_2$-$NH_3$ and screw compressors. Rezayan and Behbahaninia[16] reported exergy and thermoeconomic optimization analysis of a $CO_2/NH_3$ TSVCR cycle.

Economic considerations are also crucial in conjunction with thermodynamic and safety analyses. Singh et al.,[17] conducted a comparative energy, exergy and economic analysis of a TSVCRS using the R-717/R-290 refrigerant pair. This study found a maximum COP of 1.917, a second-law efficiency of 39.14% and a total annualized cost of $836,395/yr. Mosaffa et al.,[18] proposed an optimization study of an R-744/R-717 TSVCRS, achieving a second-law efficiency of 45.89% having a total cost rate of $0.01099/s on a 50 kW (170607.12 Btu/h) cooling capacity TSVCRS. Patel et al.,[19] compared R-744 in a LTC, and R-290 and R-717 refrigerants in a HTC, finding that R-290 had a 5.33% lower cost but 6.42% higher destruction of exergy compared to R-717.

Researchers, including Bhattacharyya et al.,[13] have delved into the economic aspects of TSVCRS, emphasizing the importance of thermal inventory parameters for heat exchangers. The thermal inventory parameter, defined as the product of the external fluid capacitance rate and its effectiveness, significantly impacts heat exchanger efficiency. Increasing the size of heat exchangers can enhance system performance but also escalate system costs, as more efficient systems tend to be more expensive. Therefore, a balance must be struck between system investment cost and thermodynamic performance.

In response to these challenges, researchers have used multiobjective optimization approaches to identify the optimal design conditions for TSVCRS. Aminyavari et al.,[20] conducted multiobjective optimization based on exergetic, economic, energetic and $CO_2$ viewpoints, while Asgari et al.,[21] reported on multiobjective optimization using exergoeconomic analyses and advanced exergy for an internal auto TSVCRS. Jain et al.,[22] conducted the multiobjective optimization of TSVCRS considering its risk analysis. Several researchers[23 – 24] proposed the cascading of VCRSs with absorption refrigeration system to achieve high energy efficiency.

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