INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Programme of Study	:	**Ph.D.**

Thesis Title: **Thermoeconomic optimization studies of the refrigeration systems using metaheuristic techniques**

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Thesis Submitted to the Department/ Center	:	**Chemical Engineering**
Date of completion of Thesis Viva-Voce Exam	:	**04/10/2023**
Key words for description of Thesis Work	:	Refrigeration systems; Thermoeconomic optimization; Performance optimization; Metaheuristic techniques; Exergy and energy efficiency;

SHORT ABSTRACT

Refrigeration systems play a crucial role in maintaining thermal comfort by removing excess heat from enclosed spaces. These systems are vital for various applications, from cooling buildings to preserving perishable goods. The primary goal is to provide a cooling load to the evaporator through chilled water to maintain a specific temperature within the enclosed space. Among the various refrigeration systems, the vapor compression refrigeration system (VCRS) stands as the most widespread choice due to its high coefficient of performance (COP). However, VCRS consumes a significant amount of electricity because of its compressor, contributing indirectly to substantial CO_2 emissions. To address the issues of energy consumption and CO_2 emissions, researchers have turned their attention to refrigeration systems driven by alternative low-grade energy sources, such as vapor absorption refrigeration systems (VARS) and vapor adsorption refrigeration systems. Unfortunately, these sorption technologies tend to suffer from lower efficiency compared to conventional VCRS.

In response to these challenges, a solution has been proposed: the cascaded refrigeration system, which integrates conventional VCRS and VARS. This integration aims to reduce energy consumption and enhance overall system efficiency. Optimization techniques have been instrumental in achieving these objectives while ensuring that the system is not overdesigned. Optimization plays a crucial role in system analysis, design, modeling, and performance improvement. A thermoeconomic optimization approach has been developed, combining thermodynamic and

economic parameters within a single framework. This approach can be solved using various metaheuristic algorithms, offering flexibility in finding optimal solutions. Both single and multi-objective thermoeconomic optimization studies have been conducted to determine optimal values for objectives such as total annual cost, exergy destruction, exergy efficiency, COP, and other decision variables like temperatures and mass flow rates. Literature shows that the optimization of these systems has been studied using genetic algorithm (GA) and particle swarm optimization (PSO). However, according to the No Free Lunch theorem, no optimization algorithm can determine the optimal solutions for all problems. Therefore, the thermoeconomic optimization of the studied systems is done using the recently proposed metaheuristic techniques. These optimizations have been applied to standalone and cascaded refrigeration systems using recently proposed metaheuristic techniques. These studies employ various single and multi-objective metaheuristic algorithms to find optimal solutions. The following sections will delve deeper into the specific aspects of each optimization study.

Optimization of Vapor Absorption Refrigeration Systems (VARS and MVARS): In this research, the governing equations of energy, exergy, mass, and component balance are solved to determine various parameters for the entire system. The thermophysical properties of the refrigerant are obtained from REFPROP 9.0 software, while equations from the literature are used for the absorbent/salt. A modified VARS is proposed to improve its performance, and a multi-objective thermoeconomic optimization study is conducted. This study focuses on minimizing the total annual cost of the systems and reducing the total exergy destruction. Different metaheuristic techniques, including the multi-objective genetic algorithm (MOGA), multi-objective particle swarm optimization (MOPSO), and multi-objective sanitized teaching learning-based optimization (MOsTLBO), are employed. Two models, VARS and MVARS, are studied with MOGA determining the minimum annual cost for both models, MOPSO reporting the minimum exergy destruction. The results yield Pareto points that offer optimal solutions based on specific requirements. MVARS excels from an exergy perspective, while VARS is favored economically. MVARS exhibits approximately 17% less exergy destruction but incurs a 0.9% higher total annual cost compared to conventional VARS.

Optimization of Cascaded Refrigeration Systems (CRS): A single-objective thermoeconomic optimization of CRS with various absorbent-refrigerant combinations is conducted. Metaheuristic techniques, such as sanitized Teaching Learning Based Optimization (sTLBO), Atom Search

Optimization (ASO), Coyote Optimization Algorithm (COA), Yin-Yang Pair Optimization (YYPO), and Tree Growth Algorithm (TGA), are utilized to optimize the total annual cost. The objective function is based on energy, exergy, economic, and environmental performance criteria. Decision variables include cascade, evaporator, absorber, generator, condenser, overlap temperatures, and the effectiveness of the solution heat exchanger. COA reports the minimum total annual cost for all considered absorbent-refrigerant combinations, with the lowest total annual cost achieved for ($CaCl_2$-LiBr-$LiNO_3$)-H_2O-R290 combination at 13164.76 US $/year.

Optimization of Subcooler Integrated Systems (SCRS): To compare the advantages and disadvantages of subcooler-integrated vapor compression absorption refrigeration systems (SCRS) with standalone CRS, single-objective thermoeconomic optimization of SCRS with various absorbent-refrigerant combinations is performed. The total annual cost of the system is formulated using energy, exergy, and economic performance criteria and minimized using metaheuristic algorithms (sTLBO, ASO, COA, YYPO, TGA). R290 combined with all absorbent solution/solution mixtures-water combinations yields the optimal total annual cost for both standalone and subcooled systems. R290 combined with ($CaCl_2$-LiBr-$LiNO_3$)-H_2O provides the minimum total annual cost at 13164.8 US $/year and 15401.9 US $/year for standalone and subcooled systems, respectively. While the COP of the optimal subcooled system is approximately 250% higher than its standalone counterpart, the higher compressor work results in a penalty cost nearly 190% higher for the subcooled system. Both COA and sTLBO report quick convergence to the optimal fitness function for all refrigerant-absorbent combinations.

Optimization of Vapor Recompression-Absorption Refrigeration Systems (VRARS): The multi-objective thermoeconomic optimization of VRARS with LiBr-H_2O and ($CaCl_2$-LiBr-$LiNO_3$)-H_2O as working fluids is investigated using metaheuristic techniques (MOGA, MOPSO, MOsTLBO). This system utilizes the rejected heat from the condenser to heat the absorbent-refrigerant mixture in the generator and pressurize the superheated refrigerant in the compressor. The optimization aims to achieve maximum exergy efficiency and minimum total annual cost. Two cases are studied with different sets of decision variables, including temperatures, compression ratio, mass flow rate of the absorber coolant, and the effectiveness of the solution heat exchanger. MOPSO determines the minimum total annual cost, while MOsTLBO focuses on maximizing exergy efficiency. The results indicate that LiBr-H_2O exhibits higher exergy efficiency (~8% higher) than ($CaCl_2$-LiBr-$LiNO_3$)-H_2O, while ($CaCl_2$-LiBr-$LiNO_3$)-H_2O incurs a lower total annual cost (~3% less) than LiBr-H_2O for

Case 1. For Case 2, the exergy efficiency remains the same for both working pairs, but the total annual cost for ($CaCl_2$-LiBr-$LiNO_3$)-H_2O is approximately 5% less than LiBr-H_2O. MOsTLBO outperforms MOGA and MOPSO based on the inverted generational distance for both cases. Moreover, the maximum exergy efficiency and minimum total annual cost are improved by approximately 36% and 41%, respectively, for Case 2 compared to Case 1.

In summary, the optimization of refrigeration systems, whether standalone or cascaded, holds significant promise for minimizing energy consumption, reducing CO_2 emissions, and achieving cost-effective operation. The choice of refrigerant-absorbent combinations and system configurations plays a crucial role in determining the optimal performance. By utilizing advanced metaheuristic algorithms, researchers can uncover Pareto-optimal solutions that balance conflicting objectives and guide the selection of the most suitable refrigeration system for specific requirements.