Proceedings of "National Conference on Emerging Trends in Science and Advances in Engineering"
Organized by Phaltan Education Society's College of Engineering Phaltan,
www.coephaltan.edu.in
International Journal of Innovations in Engineering Research and Technology [IJIERT]
ISSN: 2394-3696, Website: www.ijiert.org, July, 2023

Optimizing Energy Resources: A Review of Waste Heat Recovery in Industrial Refrigeration Systems

Mr. Pramod Ladgaonkar·
Department of Mechanical Engineering, SBMSMP'S Ashokrao Mane Group of Institutions, vathar, Kolhapur,India.
pramod.ladgaonkar@gmail.com

DR. Laxman Waghmode
Department of Mechanical Engineering, Annasaheb Dange College of Engineering & Technology, Ashta, Sangali, India.
lyw_mech@adcet.in

Abstract- This paper explores the potential of heat recovery systems to enhance energy efficiency in dairy and industrial settings. Through a comprehensive literature review, various existing technologies and their effectiveness are examined. The results of the review indicate that heat recovery systems have the capability to improve the energy efficiency of refrigeration plants by minimizing energy losses and utilizing waste heat. Furthermore, the study highlights that the implementation of heat recovery systems may involve a significant initial capital investment. However, the long-term energy savings they offer can be substantial. This research demonstrates the potential of heat recovery systems to reduce energy costs and enhance overall energy efficiency in dairy and industrial applications.
The insights provided by this literature review are valuable in understanding the potential of heat recovery systems in the context of dairy and industrial settings. Additionally, the findings of this study lay the foundation for further investigations into the design and operation of energy-efficient refrigeration systems.

Keyword: heat recovery systems, effectiveness, efficient refrigeration systems

Introduction

The Indian economy has experienced rapid growth, resulting in an increased demand for energy. As a result, India has become the world's third-largest energy consumer, accounting for approximately 8.3% of global energy consumption in 2023, according to the International Energy Agency (IEA). In order to address this growing energy demand and reduce the carbon footprint, India has been focusing on energy efficiency solutions. One key approach to improving energy efficiency is the implementation of heat recovery systems.

This literature study focuses on different types of refrigeration systems used in industries, waste heat sources, and techniques employed for waste heat recovery. [6] Ammonia-based vapor compression refrigeration (VCR) systems and CO2-based VCRsystems are commonly utilized in industries due to their favorable thermal properties. The condenser, being a significant waste heat source, liberates a substantial amount of heat into the surroundings. Several techniques are discussed in this paper for recovering waste heat. A shell and coil type heat exchanger is designed and employed to recover waste heat during the condensation process. The study reveals that approximately 35% of latent heat can be recovered using this technique. Another approach mentioned is the use of ejector compression refrigeration, which involves the utilization of an internal heat exchanger and cooler to enhance waste heat recovery performance. In the context of a [6] dairy industry, a CO2 heat pump system with an integrated heat exchanger (IHX) is proposed for combined heat recovery and water heating applications. This system demonstrates a reduction in total fuel costs by 45.7% and a decrease in CO2 emissions by 33.8%.

Furthermore, [10] the study explores the integration of an Organic Rankine cycle, vapor compression cycle, and liquid desiccant technology to recover waste heat in an industrial setting. This integrated system shows promising results in terms of enhancing energy and exergy efficiencies. Additionally, the investigation focuses on the performance of a CO2 plant operating in hot climatic conditions. By coupling an ejector refrigeration cycle (ERC) to cool the CO_2 stream before entering the main compressor, the energy efficiency is found to increase by 40%, and the exergy efficiency rises by 63%.

In summary, this literature study highlights the importance of energy efficiency and waste heat recovery in industries. It discusses various techniques and systems employed for recovering waste heat in refrigeration systems, including shell and coil heat exchangers, ejector compression refrigeration, CO_2 heat pump systems with IHX, and integrated systems combining different cycles. The findings of this study provide valuable insights into the potential of waste heat recovery for improving energy efficiency and reducing environmental impact in different industrial applications.

Literature Review

qua ity of energy resources and their utilization. The The energy-intensive process of using bulk milkauthors discover that the exergetic COP of the system coolers to lower the temperature of milk from 350-410°C to prevent bacterial growth and maintain its quality has been inefficient, with a low coefficient of performance (COP) of approximately 3.0. Given the continuous increase in energy costs, researchers have conducted investigations to explore the potential for heat recovery from bulk milk coolers as an energy conservation solution to reduce water heating expenses in the dairy industry. This research paper aims to assess the feasibility of recovering waste heat from the condensation process using a shell and coil type heat exchanger. Previous studies have established that the heat dissipated during condensation comprises superheat, latent heat, and subcool heat of the refrigerant. While the recovery of superheat is well-established, the recovery of latent heat remains an ongoing research topic. This paper presents successful results in recovering the complete superheat and 35% of the latent heat from the condensation process. The heat recovery rate was observed to decrease as the cooling process advanced, with the highest recovery rate occurring when there were higher temperature differences across the heat exchanger. Additionally, the COP of the system increased from 3 to 4.8 with the incorporation of the heat recovery heat exchanger. The mass flow rate of water played a crucial role in waste heat recovery, as higher flow rates resulted in a lower exit temperature and vice versa. Furthermore, the temperature rise in the heat exchanger depended on the ratio of tube side to shell side mass flow rates, as well as the ratio of refrigerant inlet temperature to water inlet temperature. Overall, this paper demonstrates the significant energy savings potential in the dairy industry through the utilization of heat recovery from bulk milk coolers. The findings indicate that integrating a heat recovery system into the refrigeration process can considerably enhance the energy efficiency of the system and subsequently reduce energy costs. Therefore, it is recommended to implement such systems wherever feasible."

[2] The primary objective of this study is to conduct an exergy analysis of a waste heat recovery based ejector compression refrigeration system. This system combines the Rankine power cycle with the compression refrigeration cycle. Through a parametric study, the researchers examine the impact of exhaust gas inlet temperature, pinch point (PP), and evaporator temperature on both the energetic and exergetic coefficient of performance (COP) of the system. Additionally, the study investigates the exergy destruction occurring in each component.

This research surpasses previous works by incorporating exergy analysis, which is a crucial tool for evaluating theexperiences a significant decrease with higher exhaust gas temperature and PP, while the energetic COP shows a slight increase. Furthermore, the exergy destruction within the heat recovery steam generator rises as the exhaust gas temperature and PP increase. The study reveals that the most substantial exergy destruction occurs during the steam generation and condensation process, accounting for 65% of the total exergy destruction in the system, whereas the separator exhibits the least exergy destruction (0.3%).

In conclusion, this paper delivers valuable insights into the influence of exhaust gas temperature, PP of the heat recovery steam generator, and evaporator temperature on the performance of waste heat recovery based compression refrigeration from an exergy perspective. The findings from this study can be utilized to enhance the design, analysis, and overall performance of power and refrigeration systems.

[3] This research paper explores the utilization of Heat Recovery Loops (HRLs) as a means to indirectly integrate large industrial sites with low pinch temperatures, specifically focusing on dairy factories. The study investigates the dynamic operation of an industrial HRL and analyzes the impact of heat storage capacity and HRL temperature range on the amount of heat recovery achieved. To conduct the analysis, a model HRL based on variable industrial stream data is employed.

Previous studies have primarily concentrated on the potential of HRLs to decrease energy consumption, enhance thermal efficiency, and optimize heat recovery processes. Several investigations have been carried out to assess the effectiveness of HRLs in large industrial sites, including dairy factories. One study revealed that implementing an HRL resulted in a 15% reduction in energy consumption and improved overall energy efficiency. Another study indicated that HRLs could potentially lower energy consumption by up to 40% in large industrial settings.

In addition to considering the energy efficiency aspect, the dynamic nature of HRLs must be taken into consideration during the design and implementation stages. The researchers found that the temperature range of the HRL and a smaller heat storage volume can significantly enhance the amount of heat recovery achieved. They also discovered that the interface level of the storage tank depends on both the volume of the tank and the variability of the source and sink streams. Therefore, when selecting the hot and cold loop temperatures and determining the stratified tank volume, it is crucial to account for the nature of variability exhibited by these streams.

In conclusion, HRLs prove to be an effective solution for reducing energy consumption and improving thermal efficiency in large industrial sites, such as dairy factories. When implementing HRLs, it is important to consider the variability of the source and sink streams in order to select appropriate hot and cold loop temperatures and determine the optimal stratified tank volume. Moreover, effective control mechanisms must be implemented to ensure maximum utilization of the tank's storage capacity and efficient heat recovery.

[4] This paper introduces a novel design for an economizer specifically tailored for a pasteurized milk plant. The main concept involves dividing the hot exhaust gas into two channels, which flow upwards on the left and right sides, and then passing over aligned banks of tubes containing flowing water in a triple-pass arrangement. To evaluate the performance of the economizer, the authors developed three-dimensional models that incorporated heat transfer and fluid dynamics. Following the implementation of the economizer, noticeable changes were observed in both the water and exhaust gas temperatures. Simulation results demonstrate that the newly designed economizer can recover 38% of the heat loss and achieve a cost saving of 13%.

The authors have accomplished an outstanding job in devising an innovative economizer design specifically tailored for pasteurized milk plants. This design not only effectively recovers heat loss but also provides significant cost savings. The inclusion of three- dimensional models incorporating heat transfer and fluid dynamics further enhances the accuracy of assessing the economizer's performance. Moreover, the authors have conducted an analysis of the internal rate of return for the economizer, demonstrating its potential for success.

Overall, this economizer design is highly commendable and is expected to be an invaluable asset to pasteurized milk plants. The authors' meticulous analysis of the economizer greatly contributes to its credibility and should be taken into account when designing similar economizers in the future.

[5] This research paper explores the potential of implementing a refrigeration heat recovery system on farm dairies with the objective of reducing water heating costs. The study begins with a theoretical energy balance analysis, which indicates that up to 60% of the water heating energy requirements could be recovered. Subsequent testing involved a tube-in-tube, counter-flow heat exchanger with fins on the refrigerant side and cores on the water side. The system was designed to provide

300 liters of water at 60°C, utilizing a 2.25 kW refrigeration system that cooled 2100 liters of milk per

day. The test results revealed that increasing the condenser pressure from 6.5 bar to 12 bar led to longer cooling times. However, the average coefficient of performance (COP) of the refrigerator decreased as the pressure increased, ranging from 3.0 to 2.3 over this pressure range for the water-cooled condenser system.

Furthermore, a study was conducted to investigate the impact of a heat recovery unit on the performance of a farm dairy vat refrigeration system. Simulated milk loads and conditions were used for a 210-cow dairy unit producing 10 liters of milk per cow per day, with an equivalent cooling load of 2000 liters of water. The COP of the refrigeration system exhibited significant variation with changing operating conditions. Increasing the condenser pressure from 6.5 bar to 12 bar resulted in a 23% reduction in COP due to increased compressor power consumption. The water-cooled system showed a
10 to 18% higher COP compared to the air-cooled system, depending on the condenser pressure, as a result of the power required to operate the fans. Altering the milk inlet or final temperature had no significant effect on the COP. The introduction of the heat recovery unit led to a reduction in COP values by approximately 0.1 (3 to 4%).

In conclusion, the findings of this study suggest that implementing a refrigeration heat recovery system on farm dairies can effectively reduce water heating costs. However, it is crucial to carefully monitor the system to ensure compliance with cooling regulations and operational requirements.

[6] This paper introduces a novel concept that utilizes waste heat from an ammonia-based milk refrigeration plant in northern India to pre-heat boiler feed water. The proposed system employs a trans-critical CO2 heat pump with an intermediate heat exchanger (IHX) to achieve this objective. A thermodynamic model of the refrigeration system is constructed and simulated using year-round field data, demonstrating that the heat pump can deliver heat at approximately 70°C for pre-heating the boiler feed water. The study's results indicate that implementing this system can lead to a reduction in CO2 emissions, as well as a significant decrease in total energy costs by approximately 45.7% and 33.8% respectively. Furthermore, the economic analysis reveals a payback period (PBP) of only 40 months.

This paper provides a comprehensive evaluation of a milk processing and refrigeration plant, focusing on energy efficiency, cost savings, and CO2 emission reduction. The authors conduct a thorough analysis of the system's performance through energy assessments, demonstrating that the deviation between the results obtained from thermodynamic modeling and field data is within ±15%. They also identify that the coefficient of performance (COP) of the system is influenced by various factors, including milk volume, ambient temperature, and total heat load.

The authors propose the utilization of heat rejected from the evaporative condenser of the ammonia-based refrigeration system for pre-heating the boiler feed water. They also propose the implementation of a trans- critical CO2 heat pump system with an intermediate heat exchanger to enhance the overall efficiency of the plant. The analysis results indicate that approximately 37 kW of recoverable heat can be obtained by employing the trans-critical heat pump system, resulting in a reduction of 5000 liters of groundwater consumption per week. Additionally, the system achieves a significant reduction in CO2 emissions (approximately 45.7%) and energy costs (approximately 33.8%).

Overall, this paper presents a compelling and detailed assessment of a milk processing and refrigeration plant in terms of energy efficiency, cost savings, and CO2 emission reduction. The authors propose a viable solution to increase system efficiency and save costs, and their findings hold promise for practical implementation.

[7] This paper introduces an innovative study focused on harnessing waste heat generated by a refrigeration system through the design of a helical coil tube-shell heat exchanger. The researchers employed two experimental variations of the helical coil heat exchanger, namely conventional and finned, to facilitate the absorption of the waste heat into tap water. The implementation of this system led to a notable enhancement in the coefficient of performance (COP) of the refrigeration cycle, with an increase of up to 40%. This improvement not only resulted in greater energy efficiency but also enabled the production of warm tap water at a temperature of 40°C, with a temperature difference of up to 10°C, at a flow rate of 2 liters per minute. As a consequence, the system became suitable for domestic purposes.

Furthermore, the study conducted a cost-benefit analysis, considering factors such as the net present value and the payback period (PP). The analysis demonstrated that the utilization of the designed heat recovery unit could lead to substantial electrical consumption savings. The payback period was estimated to be 11.7 months for the conventional heat exchanger and 17.5 months for the finned helical coil heat exchanger.

In conclusion, this paper presents an impressive study that explores the utilization of waste heat generated by a refrigeration system. The findings highlight the achievement of increased energy efficiency and the production of warm tap water through the innovative design of a helical coil tube-shell heat exchanger. This research contributes significantly to energy conservation efforts and the mitigation of thermal pollution.

This paper offers an analysis of the potential for energy recovery from refrigeration plants in the form of hot water or warm air. The study begins with a thermodynamic analysis to determine the optimal conditions for heat recovery, taking into account temperature requirements. A simulation model is then utilized to predict the system's performance under different temperature scenarios. The paper also includes the presentation of results obtained from an experimental unit, demonstrating significant reductions in energy consumption when heating and cooling loads are similar. It is emphasized that careful consideration must be given to the temperature requirements of the hot water, as a lower condensing temperature results in a higher Energy Coefficient of Performance (ECR).

Overall, the paper provides a comprehensive overview of the possibilities of recovering energy from refrigeration plants, considering the thermodynamic aspects and temperature requirements involved. However, it is noted that further research is necessary, particularly for systems with lower heating loads, in order to effectively meet the temperature requirements and optimize heat recovery.

[8] This paper introduces a novel hybrid refrigeration system that effectively utilizes industrial waste heat to generate both sensible and latent cooling effects. The integrated system comprises an Organic Rankine Cycle (ORC), a vapor compression cycle, and a liquid desiccant unit. Performance evaluations conducted on a 200 kWth industrial stack demonstrate that the system can produce 50 kW of sensible cooling and 132 kW of latent cooling when utilizing n-butane as the working fluid and setting the evaporating temperature at 140°C. The overall coefficient of performance (COP) of the system ranges from 0.8 to 0.96 when the ORC condensation temperature is set at 80°C.

The proposed hybrid refrigeration system holds great promise and can be applied in various industrial applications. It is characterized by its efficiency and cost-effectiveness, enabling the reduction of industrial waste heat, improved energy utilization efficiency, and decreased greenhouse gas emissions. The paper suggests the need for further research to explore the potential of this system in different industrial environments.

Overall, this paper presents a valuable contribution by introducing a novel hybrid refrigeration system that effectively harnesses industrial waste heat for cooling purposes. Its benefits include improved energy utilization and reduced environmental impact. The findings are significant for energy managers and stakeholders in various industries seeking to enhance their energy efficiency and sustainability.

[9] This paper introduces a novel integration of a supercritical CO2 cycle with an ejector refrigeration cycle (ERC) to enhance the performance of a CO2 plant operating in hot climatic conditions. The authors demonstrate that incorporating R717 as the refrigerant for the ERC leads to significantly improved energy and exergy efficiencies compared to a standalone CO2 cycle. Moreover, the integration results in an 18.3% reduction in the levelized cost of energy (LCOE). The study also includes a comprehensive sensitivity and parametric analysis to evaluate the impact of various operating and design parameters on the CO2/ERC plant's performance. Additionally, a multi-objective optimization study is conducted to determine the trade-off between exergy efficiency and cost-saving.

The results of this study highlight that the innovative integration of CO2 with ERC can substantially enhance the energy and exergy efficiencies of CO2 plants and lower the LCOE, particularly in hot climatic conditions where achieving the optimal minimum temperature of 31°C may not be feasible. The authors' comprehensive analysis offers valuable insights into the performance of CO2/ERC plants, and their optimization findings serve as a reference for future CO2/ERC plant designs.

Overall, this paper provides a comprehensive investigation into the performance of CO2/ERC plants and proposes a promising solution to enhance the performance of CO2 plants in hot climatic conditions. The findings are relevant for engineers and researchers interested in exploring the potential of integrating CO2 cycles and ERCs in power plants.

Conclusion

In conclusion, the discussions and insights provided in this paper have shed light on the importance of waste heat recovery and energy efficiency in various industrial applications. The presented literature review and research findings highlight the potential of different techniques and systems for recovering waste heat and improving overall energy performance.

The utilization of heat recovery systems in refrigeration plants has been recognized as a promising approach to enhance energy efficiency. The studies mentioned in the conversation have demonstrated the effectiveness of techniques such as [7] shell and coil heat exchangers, ejector compression refrigeration, [6]CO_2 heat pump systems with integrated heat exchangers (IHx), and integrated systems combining different cycles. These approaches have shown significant energy savings, reduction in fuel costs, and decreased CO2 emissions.

Moreover, [10] the research conducted on hybrid refrigeration systems and the integration of various cycles, such as the Organic Rankine cycle and vapor compression cycle, has demonstrated improved energy and exergy efficiencies. These findings provide a foundation for further exploration and optimization of waste heat recovery systems in industrial settings.

The insights of papers highlight the growing importance of energy efficiency and waste heat recovery in addressing the rising energy demands and environmental concerns, particularly in countries like India experiencing rapid economic growth. By implementing heat recovery systems, industries can reduce energy consumption, minimize greenhouse gas emissions, and achieve long-term cost savings.

In conclusion, the literature study and research findings discussed today underscore the significant potential of waste heat recovery systems in improving energy efficiency and reducing environmental impact in various industrial applications. Further research and development in this field will continue to advance the design and operation of energy-efficient refrigeration systems, ultimately contributing to a more sustainable and greener future.

References

[1] S. N. Sapali, S. M. Pise, A. T. Pise, and D. V. Ghewade, "Investigations of waste heat recovery from bulk milk cooler," *Case Stud. Therm. Eng.*, vol. 4, pp. 136–143, Nov. 2014, doi: 10.1016/j.csite.2014.09.003.

[2] R. Kumar and A. Khaliq, "Exergy analysis of industrial waste heat recovery based ejector vapour compression refrigeration system," *J. Energy Inst.*, vol. 84, no. 4, pp. 192–199, Nov. 2011, doi: 10.1179/174396711X13050315650958.

[3] M. J. Atkins, M. R. W. Walmsley, and J. R. Neale, "Process integration between individual plants at a large dairy factory by the application of heat recovery loops and transient stream analysis," *J. Clean. Prod.*, vol. 34, pp. 21–28, Oct. 2012, doi: 10.1016/j.jclepro.2012.01.026.

[4] S. Niamsuwan, P. Kittisupakorn, and I. M. Mujtaba, "A newly designed economizer to improve waste heat recovery: A case study in a pasteurized milk plant," *Appl. Therm. Eng.*, vol. 60, no. 1–2, pp. 188–199, 2013, doi: 10.1016/j.applthermaleng.2013.06.056.

[5] G. E. Stinson, C. J. Studman, and ; D J Warburton, "A Dairy Refrigeration Heat Recovery Unit and Its Effects on Refrigeration Operation," 1987.

[6] S. Singh and M. S. Dasgupta, "CO2 heat pump for waste heat recovery and utilization in dairy industry with ammonia based refrigeration," *Int.*

J. Refrig., vol. 78, pp. 108–120, Jun. 2017, doi: 10.1016/j.ijrefrig.2017.03.009.

[7] B. K. Roomi and M. A. Theeb, "Experimental and theoretical study of waste heat recovery from a refrigeration system using a finned helical coil heat exchanger," *Heat Transf.*, vol. 49, no. 6, pp. 3560–3574, 2020, doi: 10.1002/htj.21788.

[8] T. B. Herbas, E. A. Daivi, and J. A. R. Parise, "Heat recovery from refrigeration plants: Meeting load and temperature requirements*," 1990.

[9] Y. Lu, A. P. Roskilly, R. Huang, and X. Yu, "Study of a novel hybrid refrigeration system for industrial waste heat recovery," in *Energy Procedia*, Elsevier Ltd, 2019, pp. 2196–2201. doi: 10.1016/j.egypro.2019.01.620.

[10] R. H. Mohammed, N. A. A. Qasem, and S. M. Zubair, "Enhancing the thermal and economic performance of supercritical CO2 plant by waste heat recovery using an ejector refrigeration cycle," *Energy Convers. Manag.*, vol. 224, Nov. 2020, doi: 10.1016/j.enconman.2020.113340.