

Abstract

Rising electricity prices and environmental regulations make it increasingly economically justified to utilize low-temperature waste heat generated as a by-product of many technological processes. One of the potential applications to convert waste heat into cooling capacity using an ejector refrigeration system. Despite numerous descriptions in the literature, such systems have not found industrial applications up to date. In order to implement this technology in industry, a number of tests are needed, including those involving the operation of the ejector refrigeration systems under real conditions of industrial waste heat supply. Practical tools for the design of the devices in question must be also developed. This study delves into the development and validation of a comprehensive mathematical model for an ejector refrigeration system, specifically focusing on the design and selection of components for efficient operation.

The research involved developing a 0-D ejector and plate heat exchanger models, incorporating key parameters such as geometry, fluid properties, and efficiencies to predict performance under various operating conditions. The model was rigorously tested and validated against experimental data from two first commercial prototype systems driven by the waste heat of 200 kW and 600 kW built and tested under real industrial conditions. These prototypes utilized the low GWP and low-pressure HFO refrigerant R1233zd(E) for waste heat recovery, showcasing the feasibility of this environmentally friendly refrigerant in the ejector refrigeration systems, especially for high-temperature cooling. The well-calibrated ejector model, along with the plate heat exchanger models, which are the most important components of the ejector cooling system, confirmed their accuracy and usefulness for design purposes. The ejector component characteristic efficiencies were optimized for the ejector calculation model, and ejector key performance parameters were estimated to be highly accurate. The average relative error in the estimation was 5.0%, 5.6%, and 15.6% for the mass entrainment ratio, pressure ratio, and ejector total efficiency, respectively. The ejector model accuracy was highly sensitive to the correct estimation of the mixing loss coefficient. The research also highlighted the importance of utilizing experimental data from similar superheat conditions to accurately estimate fixed ejector coefficients during the design process. Also, the plate heat exchanger models were considered accurate, giving the relative error of estimation of the outlet temperatures and heat transfer rates below 10% for most cases. The resulting accuracy is sufficient from the perspective of refrigeration system design.

The study revealed significant challenges associated with using the low-pressure

R1233zd(E) refrigerant, specifically the sensitivity of the system performance to pressure drops. Given this fact, several measures to reduce pressure losses were taken, and several refrigeration system configurations were tested. A refrigeration system operating with R1233zd(E) was also compared with high-pressure R1234ze(E).

The satisfying performance of the refrigeration system using R1233zd(E) was confirmed for high-temperature cooling conditions, equivalent to the glycol temperature of 16°C/19°C (outlet/inlet of the evaporator), where the COP was 0.25 under critical operating parameters. However, using this refrigerant requires several steps to reduce the minimum pressure loss in the refrigeration system. For standard cooling conditions, equivalent to the glycol temperature of 6°C/12°C (outlet/inlet of the evaporator) requiring higher pressure ratios, the system operating with R1234ze(E) refrigerant achieved better performance, where COP reached 0.25.