15TH IEA HEAT PUMP CONFERENCE
MAY 26–29, 2026 | HOFBURG
VIENNA 2026
DECARBONISATION THROUGH INNOVATION

Prediction of heat pump heat transfer rate and COP using a temperature–pressure based polynomial regression model

Min Seong Lee[a], Suk Min Seo[a], Se Hyun Noh[a], Tae Hyeon Park[a], Yun Ha Song[a], Yong Geun Kim[a], Duong Van Hau[b], Nguyen Thanh Phuong[b], Doan Quang Bao Phuc[b], Chan Woo Park[a,b*]

[a]Department of Mechanical Design Engineering , Jeonbuk National University, 567 Baekje-daero, Deokjin-gu, Jeonju-si, Jeonbuk State, Republic of Korea
[b]Department of Energy Storage/Conversion Engineering of Graduate School, Jeonbuk National University, 567 Baekje-daero, Deokjin-gu, Jeonju-si, Jeonbuk State, Republic of Korea

Abstract

Global efforts to mitigate greenhouse gas emissions require the replacement of fossil-fuel-based heating systems, among which heat pumps can play a key role. In industrial applications, heat pumps are attractive for recovering and upgrading waste heat streams; however, their performance is highly sensitive to operating temperatures. In this study, an experimental investigation was conducted on a water-to-water heat pump using the low-GWP refrigerant R1234ze(E), focusing on the recovery and reuse of waste heat under industrial conditions. The influence of the condenser- and evaporator-side inlet water temperatures on system performance was systematically examined. The experimental results show that changes in the heat-source and heat-sink temperatures lead to systematic variations in compressor suction and discharge pressures, and that these pressure conditions strongly govern the condensation and evaporation heat transfer rates as well as the coefficient of performance (COP). Based on this insight, a temperature/pressure-based polynomial regression model was developed, in which the condenser- and evaporator-side inlet water temperatures together with the compressor suction and discharge pressures were used as independent variables to predict the condensation and evaporation heat transfer rates and COP. For the lab-scale water-to-water heat pump, the proposed correlations achieve coefficients of determination (R^2) of 0.973, 0.954, and 0.989 for condensation heat transfer rate, evaporation heat transfer rate, and COP, respectively, demonstrating high predictive accuracy. When the same regression form is recalibrated using field data from an industrial water-to-water heat pump, the resulting correlations achieve R^2 values of 0.960, 0.917, and 0.965, confirming their applicability under real operating conditions. In addition, applying the same functional form to an air-to-air heat pump and re-estimating the coefficients yields an R^2 of 0.904 for the condensation heat transfer rate, indicating that the proposed approach can be extended to other types of heat pump systems.

Keywords: R1234ze(E); COP; Polynomial regression;

1. Introduction

In response to global climate change and the accelerating demand for greenhouse gas reduction, increasing attention has been directed toward technologies capable of replacing fossil-fuel-based systems in the heating, cooling, and process heat sectors.[1] In particular, the heating and process heat sectors, which have traditionally relied on boilers and direct combustion, account for a large share of energy consumption and CO_2 emissions; therefore, decarbonizing these sectors is recognized as an essential task for achieving national greenhouse gas

* Corresponding author. Tel.: +82-10-8776-9626
E-mail address: cw-park@chonbuk.ac.kr

reduction targets. In this context, vapor compression heat pumps, which can upgrade low- and medium-temperature heat sources to useful heat at relatively high temperatures, have emerged as a key alternative technology.

In industrial settings, numerous waste heat sources at or above ambient temperature—such as process cooling water, discharged water, and exhaust gases—are often available, and using heat pumps to recover and reuse this waste heat is highly promising in terms of improving energy efficiency and reducing greenhouse gas emissions.[2] However, the performance and efficiency of heat pumps are highly sensitive to the temperature conditions of the heat source and heat sink fluids; in particular, the inlet temperatures[3], which frequently fluctuate in industrial processes, become a critical factor in system design and in the formulation of operating strategies.

In this study, an experimental investigation was carried out on a water-to-water heat pump employing the low-GWP refrigerant R1234ze(E) under operating conditions representative of industrial waste heat recovery. The inlet water temperatures at the condenser and evaporator were treated as fixed control variables, and their influence on the compressor suction and discharge pressures, the condensation heat transfer rate, and the coefficient of performance (COP) was analysed. Based on the experimental data, polynomial regression models were then developed, in which the compressor suction and discharge pressures together with the condenser- and evaporator-side inlet water temperatures were used as independent variables to predict the heat transfer rate and COP. The proposed correlations are intended to serve as a simple and practical tool for performance estimation, preliminary design, and operational optimization of R1234ze(E)-based industrial heat pump systems.

2. Methods

2.1. Experimental setup

Fig. 1 presents a schematic of the experimental apparatus used in this study.[4-5] The system was designed as a water-to-water heat pump configuration equipped with an internal heat exchanger, in which the condenser, evaporator, and internal heat exchanger were all implemented as plate heat exchangers (PHEs). The water circuits on the condenser and evaporator sides were arranged to allow independent control of inlet temperature and flow rate. The detailed specifications of the experimental apparatus are summarized in Table 1.

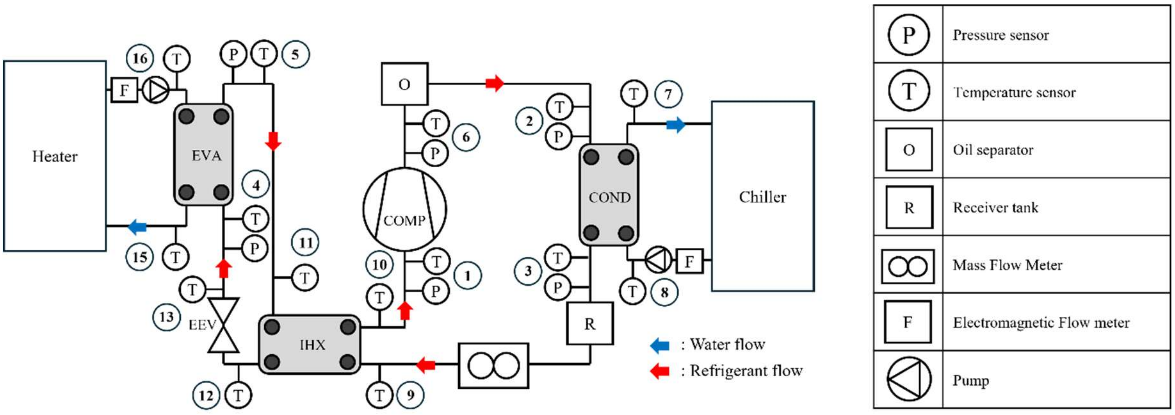

Figure 1. Schematic diagram of the experimental system

Table 1. Experimental device components

Components	Type	Company	Model
Compressor	Rotary	Samsung	UX5T250FNBJX
Receiver tank	3.6L	KYUNG THERMOTECH	OTA-RCV03-SG21
Compressor inverter	4.0kW	HITACHI	WJ200 040HF
Expansion valve	Electronic	DOTECH	EVC10B

Pump	Multistage	wilo	MHI202I
Oil separator	41bar	EMERSON	A-WZ 55824
Heat exchanger	Plate	SWEP	V20Hx12
Chiller	16A	CPT	C-RCH82
Water pump inverter	0.8kW	LS ELECTRIC	LSLV0008M100-1EOFNA
Refrigerant side flowmeter	Mass	TRICOR	TCM0650
waterflowmeter	Electric	ModMAG	M1000

2.2. Test procedure and control strategy

During the experiments, the compressor frequency and the opening of the expansion valve were kept constant, while the condenser- and evaporator-side water flow rates were maintained at prescribed set points by means of PID control. A heater and a chiller were installed in the respective water loops to adjust the inlet temperatures of the fluids entering the condenser and evaporator. By varying these inlet temperatures dynamically over time, the influence of the heat source and heat sink temperatures on the system performance was investigated.

The heat transfer rate and coefficient of performance (COP) of the heat pump were calculated from the measured operating conditions using Eq. (1) and (2). These performance indicators were evaluated for each test condition in order to quantify the effects of condenser- and evaporator-side inlet water temperatures on the heat transfer rate and overall efficiency of the R1234ze(E) water-to-water heat pump system.

$$\dot{Q}_{cond} = \dot{m}_h cp_{w,h}(T_{h,out} - T_{h,in}) \tag{1}$$

$$COP = \frac{\dot{Q}_{cond}}{\dot{W}} \tag{2}$$

2.3. Polynomial regression

Because the temperatures and pressures in the cycle are the key factors governing the heat pump performance and COP, linear regression correlations were developed that use the compressor suction and discharge pressures together with the condenser- and evaporator-side inlet water temperatures as independent variables.

The resulting correlations were formulated in the form of Eqs. (3), (4), and (5).

$$\dot{Q}_{cond} = C_1 + C_2T_{h,in} + C_3T_{c,in} + C_4P_{suc} + C_5P_{dis} + C_6T_{h,in}^2 + C_7T_{c,in}^2 + C_8P_{suc}^2 + C_9P_{suc}^2 + C_{10}T_{h,in}T_{c,in} + C_{11}T_{h,in}P_{suc} + C_{12}T_{h,in}P_{dis} + C_{13}T_{c,in}P_{suc} + C_{14}T_{c,in}P_{dis} + C_{15}P_{suc}P_{dis} \tag{3}$$

$$\dot{Q}_{eva} = C_1 + C_2T_{h,in} + C_3T_{c,in} + C_4P_{suc} + C_5P_{dis} + C_6T_{h,in}^2 + C_7T_{c,in}^2 + C_8P_{suc}^2 + C_9P_{suc}^2 + C_{10}T_{h,in}T_{c,in} + C_{11}T_{h,in}P_{suc} + C_{12}T_{h,in}P_{dis} + C_{13}T_{c,in}P_{suc} + C_{14}T_{c,in}P_{dis} + C_{15}P_{suc}P_{dis} \tag{4}$$

$$COP = C_1 + C_2T_{h,in} + C_3T_{c,in} + C_4P_{suc} + C_5P_{dis} + C_6T_{h,in}^2 + C_7T_{c,in}^2 + C_8P_{suc}^2 + C_9P_{suc}^2 + C_{10}T_{h,in}T_{c,in} + C_{11}T_{h,in}P_{suc} + C_{12}T_{h,in}P_{dis} + C_{13}T_{c,in}P_{suc} + C_{14}T_{c,in}P_{dis} + C_{15}P_{suc}P_{dis} \tag{5}$$

3. Results and Discussion

3.1. Analysis of Pressure and Heat Pump Performance/COP under Variations in Condenser/Evaporator Inlet Water Temperatures

The experiments showed that dynamic variations in the condenser- and evaporator-side inlet water temperatures led to systematic changes in the compressor suction and discharge pressures, accompanied by corresponding variations in the condensation and evaporation heat transfer rates and the COP. These observations quantitatively confirm that the heat-source and heat-sink temperatures govern heat pump performance and efficiency through their influence on the internal pressure conditions.

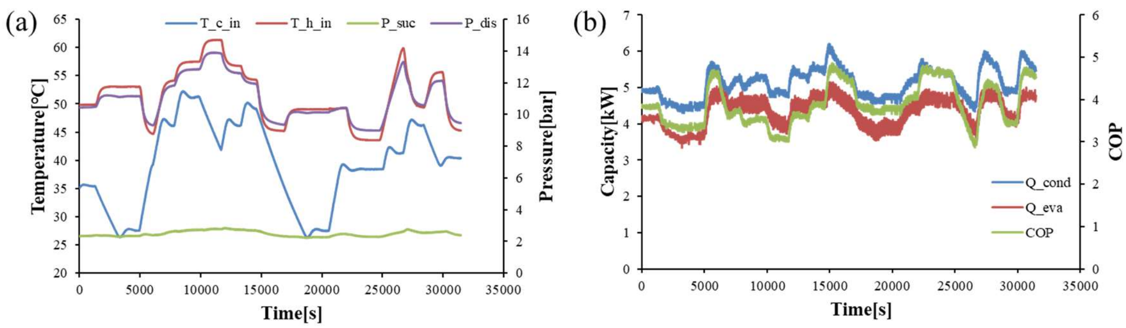

Figure 2 Time evolution of pressures and heat pump performance under condenser/evaporator inlet temperature variation

3.2. Performance Evaluation of the Regression Model Using Experimental Data

To evaluate the accuracy of the proposed regression model, experimental data obtained under dynamically varying condenser- and evaporator-side inlet water temperatures were used as inputs to the polynomial correlations. As a result, the coefficients of determination (R^2) for the condensation heat transfer rate, evaporation heat transfer rate, and COP were 0.973, 0.954, and 0.989, respectively, while the mean relative errors over the entire data set were as low as 1.04, 1.44, and 1.06%. These results confirm that the proposed regression model can reproduce the heat pump performance with high accuracy even under time-varying operating conditions.

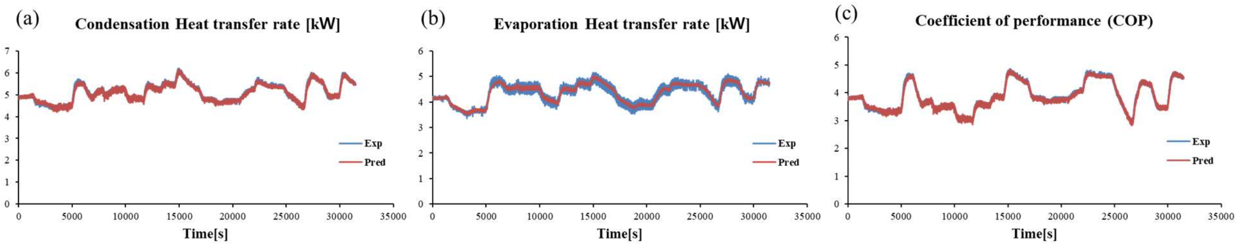

Figure 3. Comparison of measured and predicted results over time for the experimental heat pump: (a) condensation heat transfer rate, (b) evaporation heat transfer rate, (c) COP

Table 2. Performance metrics of the regression model for the lab-scale heat pump

Elements	R^2	MAE	ERR_avg(%)
Condensation heat transfer rate	0.973	0.0527	1.038
Evaporation heat transfer rate	0.954	0.0624	1.436
Coefficient of performance	0.989	0.0399	1.058

3.3. Performance Evaluation of the Regression Model Using Field Data

For the field validation, the same polynomial regression form as that used for the lab-scale tests was applied to an industrial water-to-water heat pump, while the regression coefficients were recalibrated using the site measurement data. In the field, the inlet water temperatures on the condenser and evaporator sides fluctuate irregularly over time. These time-varying inputs were directly fed into the regression model, and the predicted values were compared with the measured performance. The results show that the coefficients of determination (R^2) for the condensation heat transfer rate, evaporation heat transfer rate, and COP are 0.961, 0.917, and 0.965, respectively, while the corresponding average relative errors are limited to 3.26%, 6.78%, and 4.79%. These findings demonstrate that the proposed temperature/pressure-based regression model can accurately reproduce heat pump performance even under dynamic and irregular real-world operating conditions, thereby confirming its applicability to field systems.

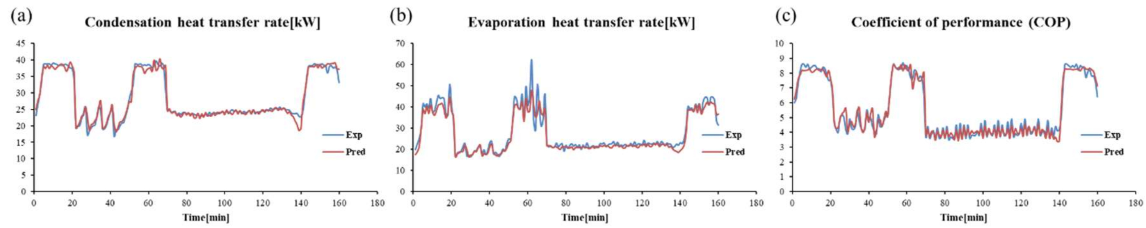

Figure 4. Comparison of measured and predicted values over time for the field heat pump: (a) condensation heat transfer rate, (b) evaporation heat transfer rate, (c) COP

Table 3. Performance metrics of the regression model for the field heat pump

Elements	R^2	MAE	ERR_avg(%)
Condensation heat transfer rate	0.961	0.909	3.265
Evaporation heat transfer rate	0.917	1.902	6.779
Coefficient of performance	0.965	0.254	4.786

3.4. Performance Evaluation of the Regression Model Using Air-to-Air Heat Pump Data

For further validation, the same functional form of the polynomial regression model was applied to an air-to-air heat pump, and the regression coefficients were recalibrated using the measured data from this unit. Due to limitations in the instrumentation, only the evaporation heat transfer rate could be evaluated directly, and the dataset included both normal heating and defrost operation, leading to highly transient and rapidly varying operating conditions. Despite these challenges, the proposed regression model achieved an R^2 of 0.905 and an average relative error of 6.49% for the evaporation heat transfer rate, indicating good predictive performance over the entire operating period, including defrost cycles. These results demonstrate that the functional structure of the temperature/pressure-based correlation developed in this study possesses sufficient generality to be applied to other types of heat pump systems, such as air-to-air units.

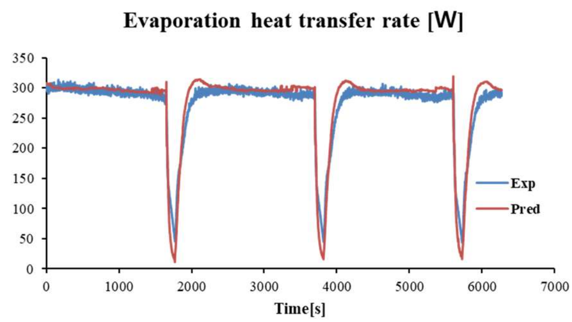

Figure 5. Comparison of measured and predicted evaporation heat transfer rate over time for the Air-to-Air heat pump

Table 4. Performance metrics of the regression model for the Air-to-Air heat pump

Elements	R^2	MAE	ERR_avg(%)
Evaporation heat transfer rate	0.905	11.825	6.494

4. Conclusion

This study experimentally investigated a water-to-water heat pump using the low-GWP refrigerant R1234ze(E) under industrial waste-heat recovery conditions and developed temperature/pressure-based polynomial regression correlations for predicting its performance. The main findings can be summarized as follows:

- Dynamic tests with varying condenser- and evaporator-side inlet water temperatures showed that these temperatures induce systematic changes in compressor suction and discharge pressures, accompanied by corresponding variations in the condensation and evaporation heat transfer rates and the COP, quantitatively confirming that heat-source and heat-sink temperatures govern heat pump performance via their influence on internal pressure conditions.
- A polynomial regression model was formulated using the condenser- and evaporator-side inlet water temperatures and the compressor suction and discharge pressures as independent variables, and the condensation heat transfer rate, evaporation heat transfer rate, and COP as outputs; validation against lab-scale data yielded R^2 values of 0.973, 0.954, and 0.989 and mean relative errors of 1.04%, 1.44%, and 1.06%, demonstrating high predictive accuracy.
- Using the same functional form and recalibrating the regression coefficients with field data from an industrial water-to-water heat pump, the model achieved R^2 values of 0.961, 0.917, and 0.965 with average relative errors of 3.26%, 6.78%, and 4.79% for condensation heat transfer rate, evaporation heat transfer rate, and COP, respectively, confirming that the temperature/pressure-based correlations remain valid under irregular, time-varying real operating conditions.
- When the same regression structure was applied to an air-to-air heat pump and recalibrated using its measurement data, only the evaporation heat transfer rate could be evaluated, yet the model still achieved an R^2 of 0.905 and a mean relative error of 6.49%, indicating that the proposed correlation form has sufficient generality to be extended beyond the specific water-to-water system to other heat pump configurations.

Overall, the proposed temperature/pressure-based polynomial regression framework provides a simple yet robust tool for predicting heat pump performance, and it can be used to support performance estimation, preliminary design, and operational optimization of industrial heat pump systems using R1234ze(E) and potentially other working fluids.

Acknowledgements

The authors would like to thank the research funds for their support with this project. This research was supported by the NRF (National Research Foundation of Korea, grant No RS-2023–00209123). The authors also acknowledge the Korea Institute of Energy Technology Evaluation and Planning (KETEP, grant no RS-2024–00422116, RS-2024–00432255). And this work was also supported by the Technology Innovation Program (20018237, RS-2024–00441989, and RS-2025–04332968) funded by the Ministry of Trade, Industry & Energy (MOTIE, Korea).

References

[1] Gerard F, Guevara Opinska L, Smit T, Rademaekers K. Trinomics. Policy support for heating and cooling decarbonisation. 2021.
[2] Wesseling JH, Lechtenböhmer S, Åhman M, Nilsson LJ, Worrell E, Coenen L. The transition of energy-intensive processing industries towards deep decarbonization: Characteristics and implications for future research. Renew Sustain Energy Rev 2017;79:1303–13.
[3] Alarnaot-Alarnaout G, Navarro-Esbrí J, Barragán-Cervera Á, Mota-Babiloni A. Energy, exergy, economic, and environmental (4E) assessment of an experimental moderately-high-temperature heat pump for district heating and cooling networks. Energy Conversion and Management 2025;325:119346.
[4] Devecioğlu AG, Oruç V. Improvement on the energy performance of a refrigeration system adapting a plate-type heat exchanger and low-GWP refrigerants as alternatives to R134a. Energy 2018;155:105–16.
[5] Mota-Babiloni A, Navarro-Esbrí J, Barragán-Cervera Á, Molés F, Peris B. Drop-in analysis of an internal heat exchanger in a vapour compression system using R1234ze(E) and R450A as alternatives for R134a. Energy 2015;90:1636–44.