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Modelling and Optimization of Heat Absorbed in the Evaporator of Low Temperature Cycle of Two-Step Cascade Refrigeration Systems

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Abstract
A single-stage refrigeration system has a low Coefficient of Performance (COP), thus it becomes paramount to have cascade refrigeration systems when there is need to have an evaporator temperature that is below -25 ^oC. Heat absorbed (QE) in the evaporator of low temperature cycle of two-step cascade refrigeration systems is one of the two parameters that determine the COP of the lower temperature cycle of the two-step refrigeration systems which is also a function of the COP of the cascade refrigeration systems. This research aimed at modelling and optimizing QE of the lower temperature cycle of two-step cascade refrigeration systems using eco-friendly refrigerants. Thermodynamic of the cascade refrigeration systems was performed by varying seven operating parameters using refrigerants R-134a in the High Temperature Cycle (HTC) and R-23 in the Low Temperature Cycle (LTC). Heat absorbed in the evaporator of the lower temperature cycle (QE[LTC]) of the refrigeration systems was optimized using Half Factorial Design of Design-Expert 12.0.1. The influence of the evaporating temperature ($T_{E,HTC}$), condensing temperature ($T_{C,HTC}$), cascade temperature difference ($\Delta T_{CAS,DIFF}$), evaporating temperature ($T_{E,LTC}$), superheating temperature ($T_{SUP,LTC}$), sub-cooling temperature ($T_{SUB,LTC}$), and refrigerant mass flow rate ($\dot{m}_{HTC}$) was investigated on the values of QE[LTC] of the refrigeration systems. The numerical QE[LTC] value is 14.183 while the measured value is 14.81.The study revealed that all the factors having interaction with TC[HTC] and TE[HTC] have a great influence on the value of QE[LTC].

Keywords: Heat absorbed, Coefficient of Performance, High Temperature Cycle, Low Temperature Cycle, Refrigerants, Cascade

1. Introduction
Refrigeration technology is widely used in our daily lives for comfort, commerce, and industrial production (Tsamos *et al*, 2016). Simple cycle refrigeration system consists of a unit compressor, expansion valve, condenser, and evaporator which is used in food storage, transportation, air conditioning, and refrigerator (Ogunsola *et al*, 2022a; Suman and Singh, 2020); but rapid freezing at a temperature range of -25 to -120 ^oC to safeguards against the effect of crystallization is still a challenge (Ogunsola *et al*, 2022a; Mishra, 2018; Dhumal and Dange, 2014). Therefore, there is intensive research into cascade refrigeration systems such as two-step refrigeration systems to achieve refrigeration temperatures below -25 ^oC that is widely used in cryogenics, hypothermal medicine, and cryopreservation for an instrument (Ogunsola *et al*, 2022a; Suresh *et al*, 2016). This system makes it possible to achieve lower evaporation temperature as well as moderate condensation pressure at ambient temperature. (Suresh *et al*, 2016; Mishra, 2017). However, Heat absorbed in the evaporator of low temperature cycle of two-step cascade refrigeration systems is one of the two parameters that determine the Coefficient of Performance (COP) of the lower temperature cycle of the two-step refrigeration systems that is a function of the COP of the cascade refrigeration systems (Ogunsola *et al*, 2022a).

Methodology

Performance Analysis

The two-step cascade refrigeration system was modelled by incorporating individual process of the cycle (Figure 1). Thermodynamic analysis was carried out and steady flow energy equation with the mass balanced equation were employed.

Selection of Refrigerants

Refrigerant R-134a was chosen for the high-temperature cycle (HTC) because of its energy-efficiency, cost effectiveness, environmentally friendliness, and exceptional thermodynamics and transport properties, while a lower boiling point refrigerant R-23 was chosen for the low-temperature cycle (LTC) because of its low critical pressure and availability.

Process Optimization of Two-Step Refrigeration Systems

Optimization of condensing temperature ($T_{C,HTC}$), evaporating temperature ($T_{E,HTC}$), cascade temperature difference ($\Delta T_{CAS,DIFF}$), evaporating temperature ($T_{E,LTC}$), superheating temperature ($T_{SUP,LTC}$), sub-cooling temperature ($T_{SUB,LTC}$), and refrigerant mass flow rate ($\dot{m}_{HTC}$) were conducted using Half Factorial Design (HFD) under the Factorial Design of the Design of Experiment (DOE) software (12.0.1), with its parameter levels stated in Table 1 that generated 30 experimental runs. Engineering Equation Solver (EES) was used to develop a model for the refrigeration systems and the effect of these seven parameters on the heat absorbed in the evaporator of the lower temperature cycle (QE[LTC]) was determined at optimum conditions. The numerical optimization chosen was based on the highest desirability (Ogunsola *et al.*, 2022a, b; Salman, 2014).

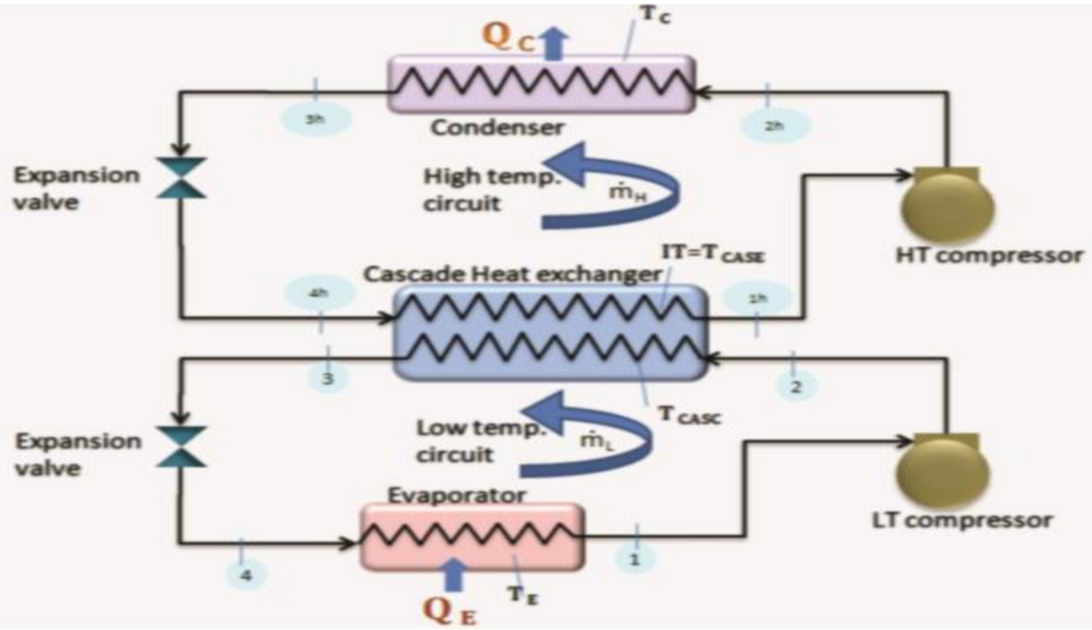


Figure 1: Schematic Diagram of a Cascade Refrigeration System

The percentage error between predicted and actual values was investigated to validate the experiments (equation 1).

$$Error = \frac{(Actual\ Value - Predicted\ Value)\ X\ 100}{Actual\ Value} \tag{1}$$

Table 1: Parameters Level Selected for Half Factorial Design (HFD) for Cascade Refrigeration System

	Units	Level	
		Low	High
HTC Condensing Temperature ($T_{C,HTC}$)	^oC	30	70
HTC Evaporating Temperature ($T_{E,HTC}$)	^oC	-20	-40
Cascade Temperature Difference ($\Delta T_{CAS,DIFF}$)	^oC	0	15
LTC Evaporating Temperature ($T_{E,LTC}$)	^oC	-50	-100
LTC Superheating Temperature ($T_{SUP,LTC}$)	^oC	0	20
LTC Sub cooling Temperature ($T_{SUB,LTC}$)	^oC	0	20
HTC Refrigerant Mass Flow Rate (M_{HTC})	kg/s	0.01	0.11

Results and discussion

Optimization of Cascade Refrigeration Systems with Refrigerants R-134a / R-23

The experimental design for the two-step cascade refrigeration systems with refrigerants R-134a/ R-23 (Table 2). The design generated thirty (30) experimental runs and run 4 (30 $T_{C,HTC}$ ^oC , -40 $T_{E,HTC}$ ^oC, 0 $\Delta T_{CAS,DIFF}$ ^oC, -50 $T_{E,LTC}$ ^oC, 0 $T_{SUP,LTC}$ ^oC, 0 $T_{SUB,LTC}$ ^oC and 0.11 $\dot{m}_{HTC}$ kg/s) has the highest value (14.81) of heat absorbed at the evaporator of lower temperature cycle (QE[LTC] of cascade refrigeration systems, while experimental run 5 (70 $T_{C,HTC}$ ^oC , -40 $T_{E,HTC}$ ^oC, 15 $\Delta T_{CAS,DIFF}$ ^oC, -100 $T_{E,LTC}$ ^oC, 20 $T_{SUP,LTC}$ ^oC, 0 $T_{SUB,LTC}$ ^oC and 0.01 $\dot{m}_{HTC}$ kg/s) has the least value (0.4881) of QE[LTC] (Table 2). The final tool factor interaction (2FI) empirical model in terms of coded factors for the QE[LTC] for both the significant and insignificant terms is expressed in equation 2.

$$
\begin{aligned}
QE[LTC] = 5.21 &- 1.25A - 0.1723B - 0.1599C + 0.8873D - 0.0808E + 0.2197F + 4.33G + 0.0464AB \\
&- 0.0274AC - 0.0074AF - 0.9760AG + 0.0647BC - 0.1064BD - 0.1091BE - 0.1769BG \\
&+ 0.0333CD - 0.0232CE + 0.0353CF - 0.1763DE + 0.6522DG + 0.1491EF - 0.1236EG \\
&+ 0.1935FG + 0.1964BCD \qquad (2)
\end{aligned}
$$

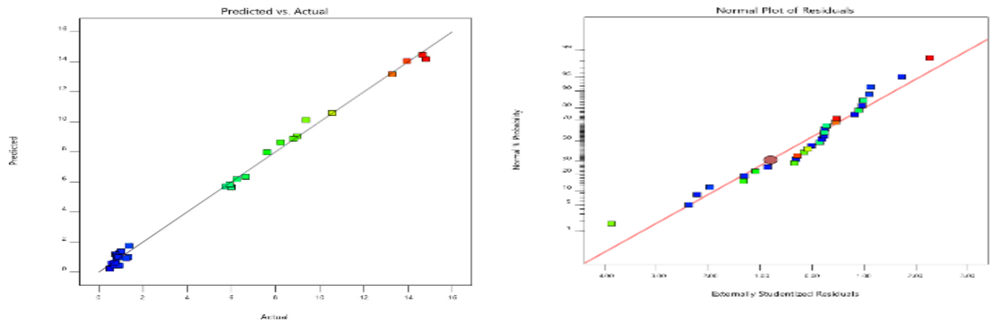
Where:

A= HTC Condensing Temperature [$T_{C,HTC}$] (^oC),
B = HTC Evaporating Temperature [$T_{E,HTC}$] (^oC),
C = Cascade Temperature Difference [$\Delta T_{CAS,DIFF}$] (^oC),
D = LTC Evaporating Temperature [$T_{E,LTC}$] (^oC),
E = LTC Superheating Temperature [$T_{SUP,LTC}$] (^oC),
F = LTC Sub cooling Temperature [$T_{SUB,LTC}$] (^oC), and
G = HTC Refrigerant Mass Flow Rate [$\dot{m}_{HTC}$] (kg/s).

The quality of the models developed was evaluated based on the R^2 value and the models developed seems to be the best at low standard deviation and high R^2 that is closer to unity thus making predicted value closer to the actual value of the response (Mohd *et al*., 2011). The value of R^2 for Eq. (2) as shown in Fig. 2a was 0.9960, Standard deviation value was 0.7515, mean value was 5.13, Coefficient of variation (C.V.) was 14.64, Adeq Precision was 20.7427, Adjusted (Adj) R^2 was 0.9765, and Predicted (Pred) R^2 was 0.8454. High value of R^2 for Eq. (2) was an indication that the predicted value for QE[LTC] is accurate and closer to its actual value (Montgomery, 2005). Figure 2b showed the effects of the model terms with respect to normal % probability.

Table 2: Experimental Data for Refrigerants R – 134a / R – 23

Run	Parameters 1 A:TC[HTC] ^oC	Parameters 2 B:TE[HTC] ^oC	Parameters 3 C:TCAS [DIFF] ^oC	Parameters 4 D:TE[LTC] ^oC	Parameters 5 E:TSUP[LTC] ^oC	Parameters 6 F:TSUB [LTC] ^oC	Parameters 7 G:M[HTC] kg/s	Response QE[LTC] kW
1	70	-40	15	-50	0	0	0.01	0.7068
2	70	-20	0	-50	0	20	0.11	8.97
3	30	-20	0	-100	0	20	0.11	10.56
4	30	-40	0	-50	0	0	0.11	14.81
5	70	-40	15	-100	20	0	0.01	0.4881
6	70	-20	0	-100	20	20	0.11	6.646
7	70	-20	15	-50	20	20	0.11	8.23
8	30	-40	15	-100	0	0	0.11	9.381
9	70	-20	0	-50	0	0	0.01	0.798
10	70	-40	0	-100	0	20	0.11	6.23
11	30	-20	0	-50	20	20	0.01	1.334
12	70	-20	15	-100	0	20	0.11	5.754
13	30	-40	0	-50	20	20	0.11	14.65
14	30	-40	0	-50	0	20	0.01	1.354
15	70	-40	0	-100	20	0	0.11	5.992
16	30	-20	15	-100	20	20	0.01	0.8846
17	70	-20	0	-100	0	0	0.11	5.916
18	30	-20	0	-100	20	0	0.01	0.911
19	70	-40	15	-50	20	0	0.11	7.612
20	70	-20	0	-100	0	20	0.01	0.5788
21	70	-40	15	-50	20	20	0.01	0.7046
22	30	-20	15	-100	0	0	0.01	0.7746
23	30	-40	0	-100	20	20	0.01	1.001
24	30	-40	15	-50	20	0	0.01	1.221
25	70	-40	0	-50	20	0	0.01	0.749
26	30	-20	15	-50	0	0	0.11	13.29
27	30	-20	15	-100	20	0	0.11	8.814
28	30	-40	15	-50	0	20	0.11	13.95
29	70	-20	15	-50	20	0	0.01	0.7181
30	30	-40	15	-100	0	20	0.01	0.9096



a b

Figure 2

a: Graph of predicted QE[LTC] against its actual value
b: effect of the model terms with respect to normal % probability

The standard deviation value of 0.7515 for QE[LTC] indicated that the predicted value for the model correlated the data used in this study (Montgomery, 2005). Adeq Precision value obtained was 20.743 for the model to navigate the design space. The Model F-value of 51.30 (Table 3) implies the model is significant and that there is only 0.02% chance that Model F-Value could occur due to noise (Mohd *et al.*, 2011), thus A, D, G, AG and DG are significant model terms in this study.

Table 4 indicated diagnostics design between the actual value and residual value.
Figure 3a, d, g, and j, 4a, d, g, and j, 5a, d, g, and j, 6a, d, g, and j showed the factors interactions plots, Fig. 3b, e, h, and k, 4b, e, h, and k, 5b, e, h, and k, 6b, e, h, and k showed QE[LTC] value; while Fig. 3c, f, i, and l, 4c, f, i, and l, 5c, f, i, and l, 6c, f, i, and l showed the 3D factors interactions plots for the interactive effects among all the selected factors on the values of QE[LTC]. Figure 3a shows interaction of TC[HTC] and TE[HTC]. The value of QE[LTC] decreased as TC[HTC] and TE[HTC] values increased. Its QE[LTC] and 3D linear interaction is evident in Fig. 3b and c.
Similar trend was observed in the interaction between TC[HTC] and TCAS[DIFF] (Fig. 3d, e, and f), TC[HTC] and TSUB[LTC] (Fig. 3g, h, and i), TC[HTC] and ṁ[HTC] (Fig. 3j, k, and l), TE[HTC] and TCAS[DIFF] (Fig. 4a, b, and c), TE[HTC] and E[LTC] (Fig. 4d, e, and f), TE[HTC] and TSUP[LTC] (Fig. 4g, h, and i), TE[HTC] and ṁ[LTC] (Fig. 4j, k, and l), TCAS[DIFF] and TE[LTC] (Fig. 5a, b, and c), TCAS[DIFF] and TSUP[LTC] (Fig. 5d, e, and f), likewise TCAS[DIFF] and TSUB[LTC] (Fig. 5g, h, and i).
The interaction between TE[LTC] and TSUP[LTC] (Fig. 5j, k, and l), TE[LTC] and ṁ[HTC] (Fig. 6a, b, and c), TSUP[LTC] and TSUB[LTC] (Fig. 6d, e, and f), TSUP[LTC] and ṁ[HTC] (Fig. 6g, h, and i), as well as TSUB[LTC] and ṁ[HTC] (Fig. 6j, k, and l) showed a favourable increase in the value of QE[LTC].

Analysis of Variance (ANOVA) of QE[LTC]
The adequacy of the model was justified through analysis of variance (ANOVA). The value of QE[LTC] is therefore influenced by Condensing Temperature ($T_{C,HTC}$), Evaporating Temperature ($T_{E,HTC}$), Cascade Temperature Difference ($\Delta T_{CAS,DIFF}$), Evaporating Temperature ($T_{E,LTC}$), Superheating Temperature ($T_{SUP,LTC}$), Sub-cooling Te1perature ($T_{SUB,LTC}$), and Refrigerant Mass Flow Rate ($\dot{m}_{HTC}$). Figure 7 further indicates that the value of QE[LTC] is influenced by TC[HTC], TE[HTC] and TCAS[DIFF] while keeping the the TE[LTC] (-100 ^{o}C), TSUP[LTC] (0 ^{o}C), TSUB[LTC] (0 ^{o}C), and ṁ[HTC] (0.11 kg/s) constant.

Table 3: ANOVA for selected factorial model for QE[LTC]

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	695.22	24	28.97	51.30	0.0002	*
A	23.55	1	23.55	41.70	0.0013	*
B	0.6629	1	0.6629	1.17	0.3280	
C	0.3234	1	0.3234	0.5726	0.4833	
D	16.09	1	16.09	28.50	0.0031	*
E	0.1498	1	0.1498	0.2653	0.6284	
F	0.7209	1	0.7209	1.28	0.3098	
G	462.30	1	462.30	818.67	< 0.0001	*
AB	0.0418	1	0.0418	0.0740	0.7965	
AC	0.0158	1	0.0158	0.0280	0.8737	
AF	0.0011	1	0.0011	0.0020	0.9658	
AG	14.37	1	14.37	25.45	0.0040	*
BC	0.1053	1	0.1053	0.1865	0.6838	
BD	0.2498	1	0.2498	0.4423	0.5355	
BE	0.1471	1	0.1471	0.2605	0.6315	
BG	0.4125	1	0.4125	0.7304	0.4318	
CD	0.0267	1	0.0267	0.0473	0.8365	
CE	0.0116	1	0.0116	0.0206	0.8916	
CF	0.0275	1	0.0275	0.0487	0.8340	
DE	0.4100	1	0.4100	0.7260	0.4331	
DG	5.25	1	5.25	9.30	0.0284	*
EF	0.5139	1	0.5139	0.9100	0.3839	
EG	0.3373	1	0.3373	0.5974	0.4745	
FG	0.8102	1	0.8102	1.43	0.2847	
BCD	0.4009	1	0.4009	0.7099	0.4379	
Residual	2.82	5	0.5647			
Cor Total	698.05	29				

***** Significant at $p < 0.05$, R^2 is 0.9960, A-TC[HTC], B-TE[HTC], C-TCAS[DIFF], D-TE[LTC], E-TSUP[LTC], F-TSUB[LTC], G-M[HTC]

Table 4: Diagnostics design between the actual value and residual value

Run Order	Actual Value	Predicted Value	Residual
1	0.7068	0.6252	0.0816
2	8.97	9.03	-0.0647
3	10.56	10.59	-0.0287
4	14.81	14.18	0.6267
5	0.4881	0.2278	0.2603
6	6.65	6.35	0.3006
7	8.23	8.64	-0.4079
8	9.38	10.12	-0.7395
9	0.7980	1.06	-0.2669
10	6.23	6.19	0.0435
11	1.33	1.00	0.3316
12	5.75	5.69	0.0663
13	14.65	14.46	0.1929
14	1.35	1.74	-0.3894
15	5.99	5.65	0.3382
16	0.8846	0.9864	-0.1018
17	5.92	5.83	0.0836
18	0.9110	1.26	-0.3514
19	7.61	7.97	-0.3597
20	0.5788	0.5830	-0.0042
21	0.7046	0.6383	0.0663
22	0.7746	0.6750	0.0996
23	1.00	1.38	-0.3817
24	1.22	0.9071	0.3139
25	0.7490	1.18	-0.4302
26	13.29	13.18	0.1148
27	8.81	8.88	-0.0642
28	13.95	14.05	-0.1021
29	0.7181	0.4250	0.2931
30	0.9096	0.4304	0.4792

TE[LTC] (-50 ^{o}C), TSUP[LTC] (0 ^{o}C), TSUB[LTC] (0 ^{o}C), and ṁ[HTC] (0.11 kg/s)

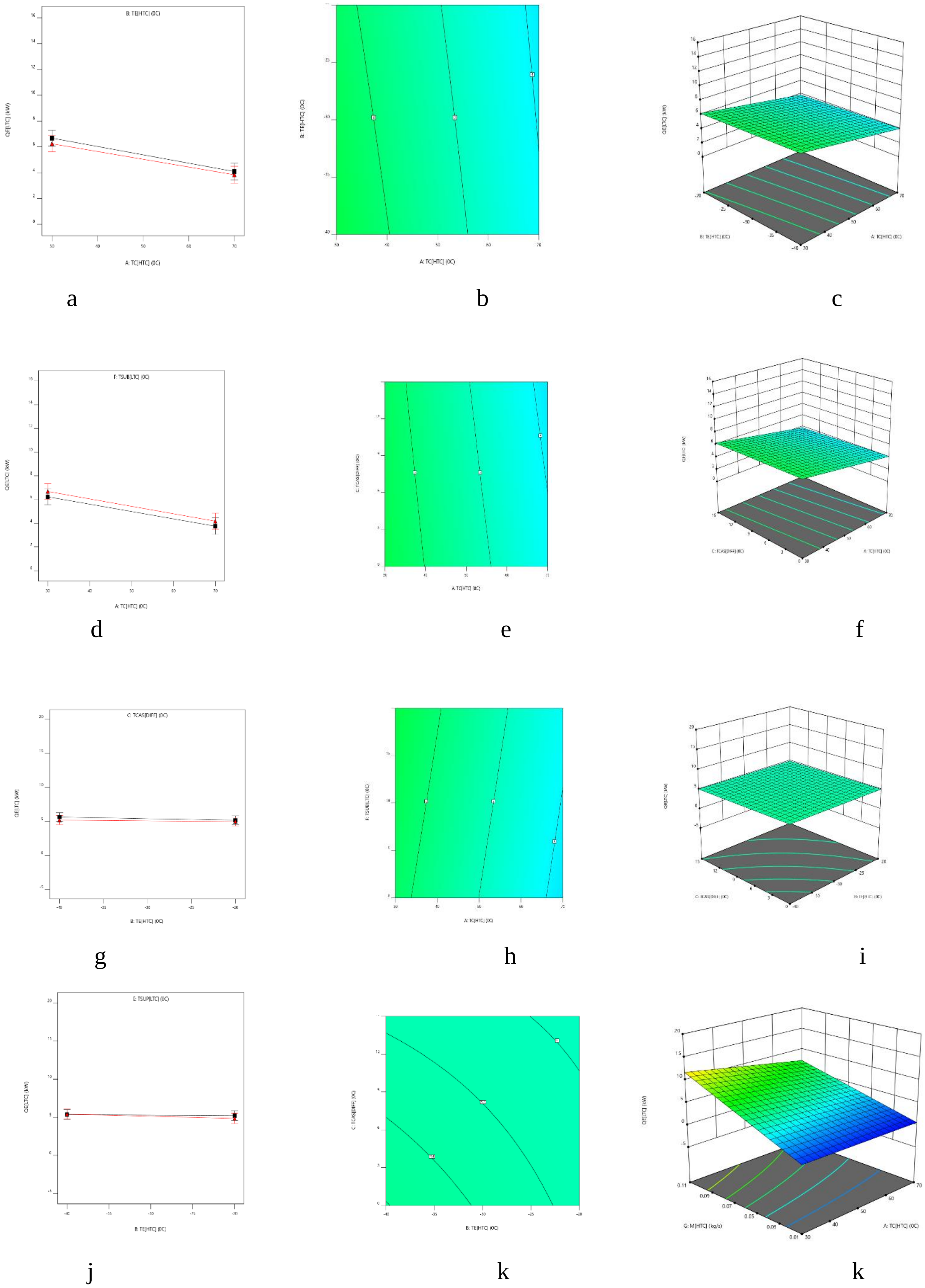


Figure 3: (a) Interaction, (b) QE[LTC] and (c) 3D surface plot of TC[HTC] against TE[HTC] on QE[LTC] (d) Interaction, (e) QE[LTC] and (f) 3D surface plot of TC[HTC] against TCAS[DIFF] on QE[LTC] (g) Interaction, (h) QE[LTC] and (i) 3D surface plot of TC[HTC] against TSUB[LTC] on QE[LTC] (j) Interaction, (k) QE[LTC] and (l) 3D surface plot of TC[HTC] against M[HTC] on QE[LTC]

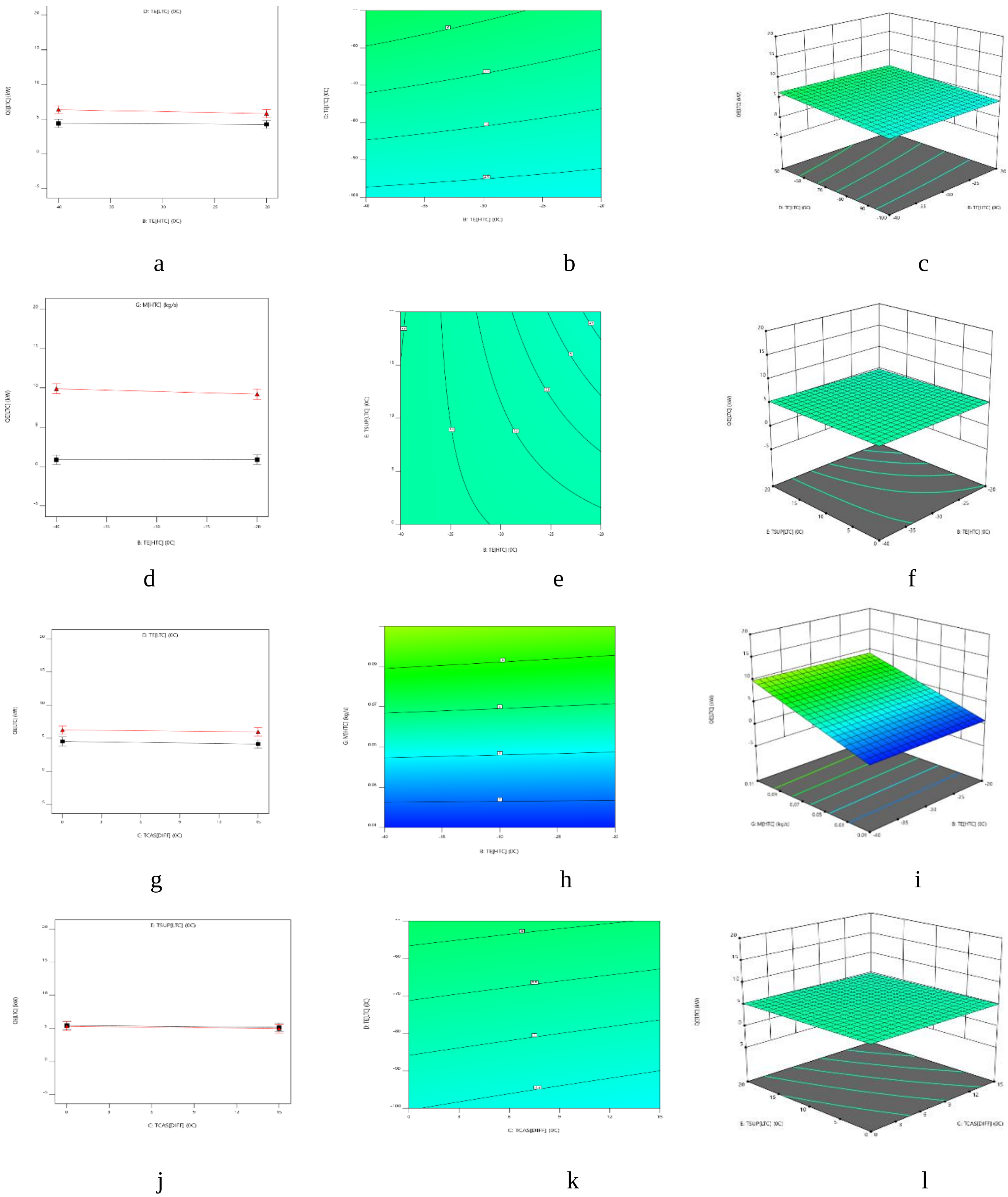


Figure 4: (a) Interaction, (b) QE[LTC] and (c) 3D surface plot of TE[HTC] against TCAS[DIFF] on QE[LTC] (d) Interaction, (e) QE[LTC] and (f) 3D surface plot of TE[HTC] against TE[LTC] on QE[LTC] (g) Interaction, (h) QE[LTC] and (i) 3D surface plot of TE[HTC] against TSUP[LTC] on QE[LTC] (j) Interaction, (k) QE[LTC] and (l) 3D surface plot of TE[HTC] against M[HTC] on QE[LTC]

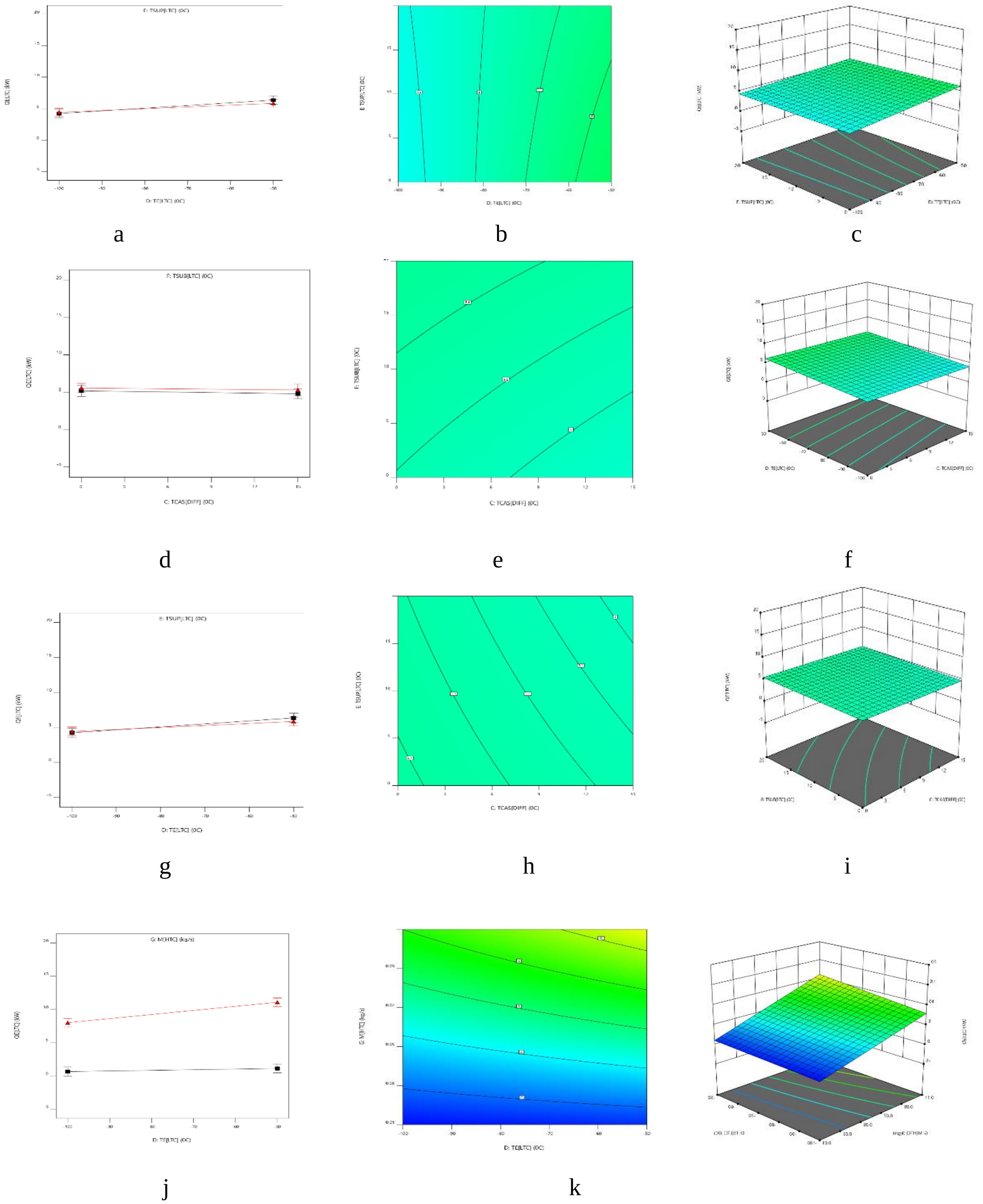


Figure 5: (a) Interaction, (b) QE[LTC] and (c) 3D surface plot of TCAS[DIFF] against TSUP[LTC] on QE[LTC] (d) Interaction, (e) QE[LTC] and (f) 3D surface plot of TCAS[DIFF] against TSUB[LTC] on QE[LTC] (g) Interaction, (h) QE[LTC] and (i) 3D surface plot of TE[LTC] against TSUP[LTC] on QE[LTC] (j) Interaction, (k) QE[LTC] and (l) 3D surface plot of TE[LTC] against TSUP[LTC] on QE[LTC]

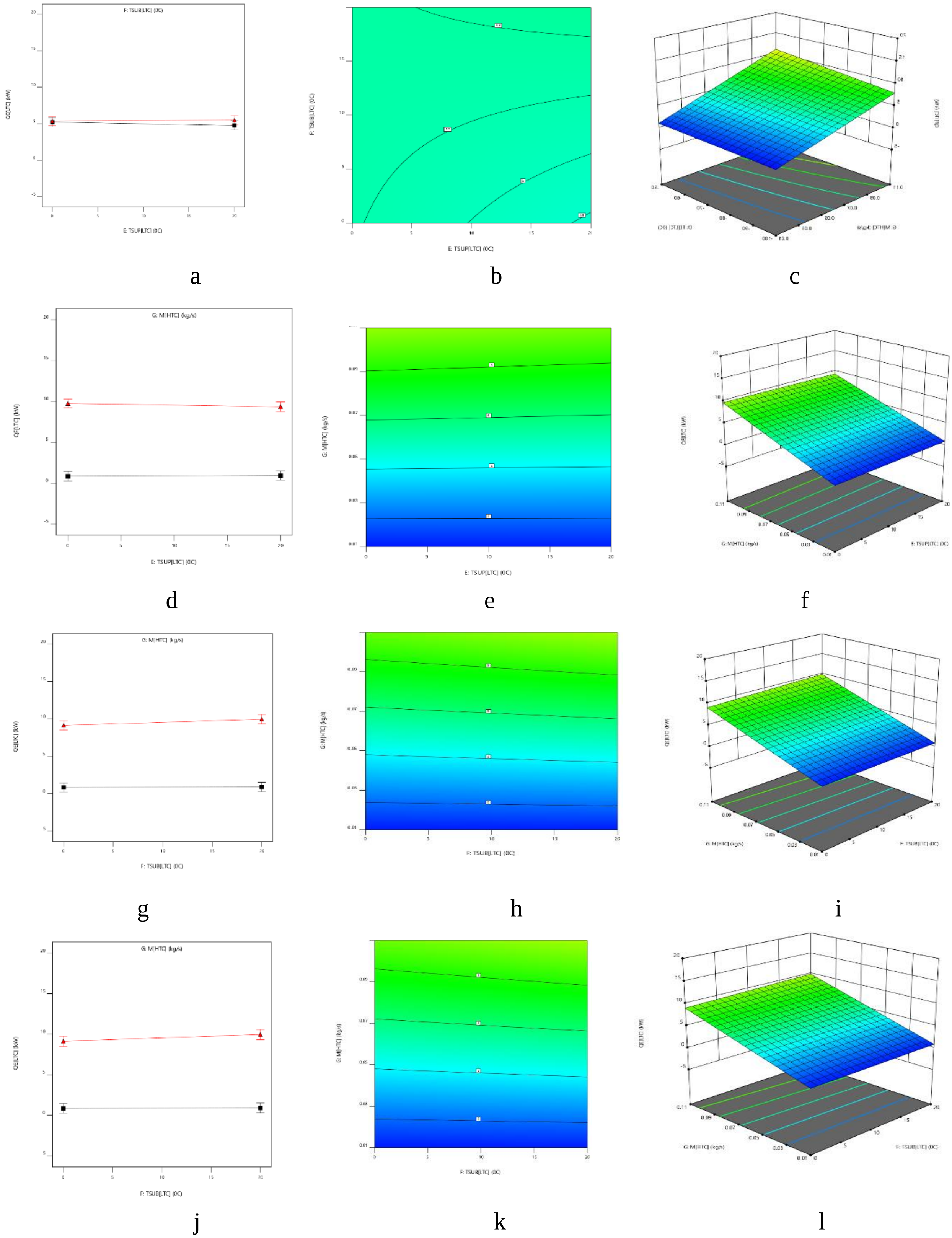


Figure 6: (a) Interaction, (b) QE[LTC] and (c) 3D surface plot of TE[LTC] against M[HTC] on QE[LTC] (e) Interaction, (f) QE[LTC] and (f) 3D surface plot of TSUP[LTC] against TSUB[LTC] on QE[LTC] (g) Interaction, (h) QE[LTC] and (i) 3D surface plot of TSUP[LTC] against M[HTC] on QE[LTC] (j) Interaction, (k) QE[LTC] and (l) 3D surface plot of TSUB[LTC] against M[HTC] on QE[LTC]

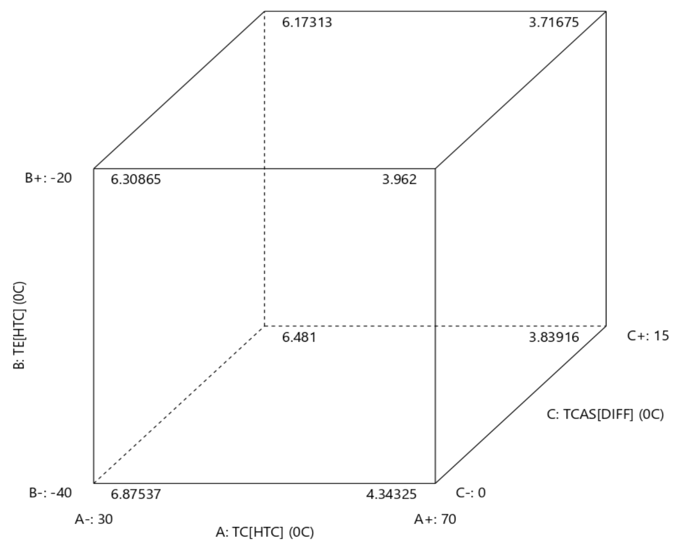
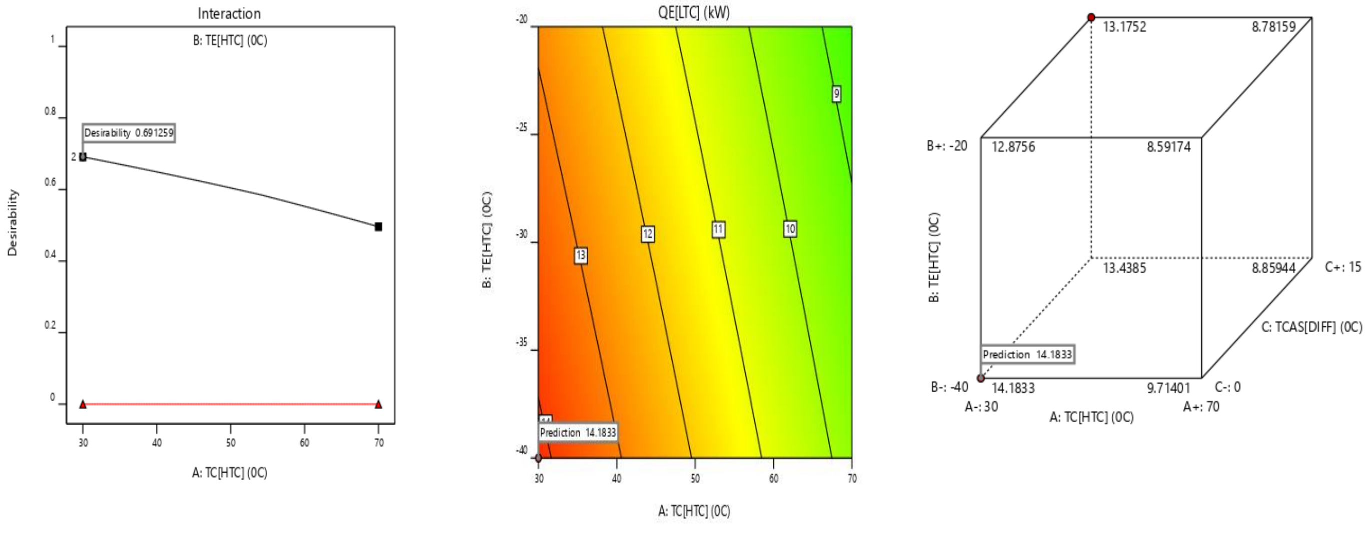


Figure 7: Cube Graph of Interaction of Important Factors on QE[LTC]

3.3 Numerical Optimization Studies of QE[LTC]

In this study, the highest desirability was 0.691 while the optimum value suggested for TC[HTC], TE[HTC], TCAS[DIFF], TE[LTC], TSUP[LTC], TSUB[LTC], and ṁ[HTC] are 30 ^{o}C, -40 ^{o}C, 0 ^{o}C, -50 ^{o}C, 0 ^{o}C, 0 ^{o}C, and 0.11 kg/s (Fig. 8), compared to 30 ^{o}C, -40 ^{o}C, 0 ^{o}C, -50 ^{o}C, 0 ^{o}C, 0 ^{o}C, and 0.11 kg/s, obtained from the study. The numerical QE[LTC] value is 14.183 while the measured value is 14.81. The percentage error difference was 0.04% (Table 5), thus indicated that no significant difference and level of acceptability of the study (Ogunsola *et al.*, 2022a, b).



a b c

Figure 8: (a) Numerical interaction desirability, (b) Predicted desirability and (c) Cube graph of interaction of important factors on desirability

Table 5: Values of Experimental, Numerical Optimization and Percentage Difference

	A:TC[HTC] °C	B:TE[HTC] °C	C:TCAS [DIFF] °C	D:TE[LTC] °C	:TSUP[LTC] °C	F:TSUB [LTC] °C	G:M[HTC] kg/s	QE[LTC] kW
Experimental	30	-40	0	-50	0	0	0.11	14.81
Numerical Optimization	30	-40	0	-50	0	0	0.11	14.183
% Different								0.04%

Conclusion

The measured value of QE[LTC] is 14.81, while its numerical value is 14.183 with percentage error difference of 0.04%, thus indicating high level of acceptability of the experiment.

References

Bhattacharyya S., Mukhopadhyay S., Kumar A., Khurana R.K., Sarkar J., (2005). Optimization of a CO_2-C_3H_8 cascade system for refrigeration and heating. *Int. J. Refrigeration* 28 (8), 1284–129

Cengel, Y.A.; Boles, M.A. (2006). Thermodynamics: An Engineering Approach, 5th Ed. pp. 616–620, USA, McGraw-Hil

Dhumal, A.H. and Dange, H.M. (2014). Investigation of influence of the various expansion devices on the performance of a refrigerator using R407C refrigerant. *Journal of Advanced Engineering Technology*. 5(2):96-99. International Institute of Refrigeration (IIR) 2015-2019

Kim, D.H., Park, H.M. and Kim, M.S. (2012). Characteristic of R134a/R410A cascade heat pump and optimization. Purdue, International Refrigeration and Air Conditioning Conference. Pp. 1-7.

Kshetri, K. R. (2015). Parametric Study of R744-R717 Cascade Refrigeration System. Design And Development Of Cascade Refrigeration System, 2349-7610.

Kumar, A. and Agrawal, A.B. (2015). Performance analysis of ozone layer friendly refrigerant as a posible replacement of R-22 in vafour compression refrigeration system. *Journal of Engineering Science and Research Technology*. 4(6):292-301

Lee, T.S; Liu C.H and Chen T.W (2006). Thermodynamic analysis of optimal condensing temperature of cascade-condenser in CO2/NH3 cascade refrigeration systems. *Int. J.* Ref. 29 1100-1108.

Madhu, S.E; Ranendra, R. and Bijar K.M (2017). Development of refrigerants: Indian Journal of Scientific Research 14(2):175-1

Mishra, R.S. (2017). Thermal Performance of HFO refrigerants in two stages cascade refrigeration systems for replacing r-134a. *Journal of Research in Engineering and Innovation*. 1(6): 153-156.

Mishra, R.S. (2018). Performance analysis of vapour compression refrigeration systems using eighteen ecofriendly and other CFC refrigerants. *Journal of Research in Engineering and Innovation.* 2(4): 349-359.

Mohd, N.I., Zainal, A.A., Mohd, A.A., Nazwin, A., Shamsul, K.S. (2011). Optimization of process variables for malachite green dye removal using rubber seed coat based activated carbon. *Journal of Engineering and Technology IJET-IJENS, 11(1):234-239*

Montgomery, D.C. (2005). Design and analysis of experiments (6^{th} Ed.). John Wiley and Sons. Singapore (SG): *Pp. 101*

Nicola, G.D; Giuliani, G; Polonara, F; Stryjek, R. (2005). Blends of carbon dioxide and HFCs as working fluids for the low temperature circuit in cascade refrigeration systems. *International Journal of Refrigeration*. 28. pp. 130-140.

Ogunsola, A.D., Durowoju, M.O., Alade, A.O., Jekayinfa, S.O., Ogunkunle, O. (2022)b. Modelling and optimization of two-step shea butter oil biodiesel synthesis using snail shells as heterogeneous base catalysts. *Journal of Energy Advances.* Doi: 10.1039/d1ya00042. Pp. 1-16

Ogunsola, A.D., Kolawole, M.Y., Aderibigbe, A.A., Olaogun, O., Adeyi, A.J., Adeyi, O., Ibiwoye, M.O. and Adetunji, M.O. (2022)a. Modelling and optimization of coefficient of performance of lower temperature cycle of two-step refrigeration systems. *LAUTECH Journal of Engineering and Technology*. 16(2):31-53.

Padalkar, A.S. and Kadam, A.D. (2010). Carbon dioxide as natural refrigerant. *Journal of Applied Engineering Research*. 1(2):261-272.

Parekh, A.D. (2014). Analysis of heat exchanger area of two stage cascade refrigeration system using taguchi. *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*. 8(9):1652-1658

Parekh, A.D., Tailor, P.R. and Jivanramajiwala, H.R. (2010). Optimization of R507A-R23 cascade refrigeration system using genetic algorithm. *Journal of Mechanical and Mechatronics Engineering*. 4(10):915-919.

Ronald, F. (1921). “The Correlation between Relatives on the Supposition of Mendelian Inheritance. Published article on Application of Analysis of Variance.

Salman, J. (2014). Optimization of preparation conditions for activated carbon from palm oil fronds using response surface methodology on removal of pesticides from aqueous solution. *Journal of Chemistry, 7:101-108*.

Singh, M. and Somvanshi, P. (2014). Thermodynamic analysis of vapour compression system using alternative refrigerant. *Journal of Mechanical and Civil Engineering*. 11(1):81-89.

Suman, S. and Singh, S. K. (2020). Comparative thermodynamic performance analysis of a cascade system using different refrigerant couples. Journal of Engineering Science and Research Technology. 9(2).pp. 17-32.

Suresh, B; Venkatesh, G; Jayasimha, R. K. and Surendra, R. M. (2016). Comparing the performance of domestic refrigerator by changing the design of condenser and by using refrigerant R-600a. J*ournal of Current Engineering and Technology*. 6(5). P-ISSN 2347-5161.

Tsamos, K.M., Ge, Y.T., Santosa, I.D.M.C. and Tassou, S.A. (2016). Experimental Investigation of a gas cooler/condenser designs and effects on a CO_2 booster system. *Journal of Applied Energy*. pp 1-10. doi: org/10.1016/j.apenergy.2016.03.00