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IDENTIFYING THE EFFECT OF REFRIGERANT LIQUID LEVEL IN RECEIVER ON ENERGY EFFICIENCY AND COOLING PERFORMANCE OF DOMESTIC FREEZERS

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This study investigates a domestic vapor-compression freezer system utilizing R404A refrigerant and a 0.75 kW-rated compressor, with a focus on the impact of different liquid refrigerant levels in the receiver on system performance and energy consumption. One major issue in household freezers is excessive energy use, particularly in systems lacking fluid regulation mechanisms such as a receiver. To explore this, an experimental setup was developed to test six operating conditions: one without a receiver and five with varying refrigerant fill levels in the receiver, ranging from less than 0% to over 60%. Experimental results showed that the freezer without a receiver recorded the highest Coefficient of Performance (COP) of 2.55 but also had the highest energy usage at 1.90 kWh. In contrast, the configuration with 30% refrigerant fill in the receiver demonstrated optimal performance, achieving a 47% reduction in compressor power, the lowest energy consumption (1.01 kWh), and an evaporator temperature reaching –31°C. These improvements are attributed to more stable refrigerant flow, enhanced subcooling, and better pressure regulation enabled by the receiver. The use of a liquid receiver allowed for smoother thermodynamic operation, minimizing energy loss through irregular phase distribution. The findings suggest that fine-tuning the refrigerant charge within the receiver can significantly improve the system's energy efficiency, without the need for extensive redesign of main components. This approach offers a simple, low-cost, and effective solution, especially relevant for household and small-scale commercial freezer applications where practicality and long-term savings are priorities

***Keywords:** refrigerant charge optimization, liquid receiver dynamics, subcooling efficiency, domestic freezer performance, R404A system behavior*

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1. Introduction

Improving energy efficiency in household refrigeration systems is an urgent priority in light of global energy challenges, increasing electricity costs, and growing concerns about environmental sustainability. Domestic refrigeration systems, including freezers, are among the most widely used household appliances and operate continuously throughout the year. As a result, even marginal improvements in their energy performance can yield substantial reductions in both household electricity consumption and national energy demand.

In modern conditions, advancing the efficiency of vapor-compression refrigeration systems aligns directly with international efforts to reduce greenhouse gas emissions and transition to low-carbon technologies. The vapor-compression cycle remains the dominant mechanism in household refrigeration, and optimizing its components offers a promising route for performance gains without the need for radical technological overhaul. As energy policies and efficiency standards become more stringent globally, the development of practical strategies to reduce energy consumption in refrigeration systems is of both economic and regulatory importance.

From a practical standpoint, improving freezer performance can directly benefit consumers by reducing utility costs and extending appliance lifespan through reduced compressor wear. In markets with high energy tariffs or unreliable power supplies, energy-efficient designs also contribute to system reliability and accessibility of cold storage for food preservation. Moreover, scalable and low-cost methods of improving system efficiency are especially important for widespread application in developing regions.

Therefore, studies that are devoted to enhancing the energy performance of domestic refrigeration systems through thermodynamically grounded yet economically feasible modifications such as refrigerant flow stabilization or passive charge control are of significant scientific relevance.

2. Literature review and problem statement

In many systems, the receiver helps ensure a continuous, stable supply of refrigerant to the expansion valve, which supports consistent evaporation and prevents performance fluctuations. However, little attention has been given to how the amount of refrigerant stored in the receiver (i.e., the refrigerant level) influences the overall cycle performance, particularly in domestic freezers. Existing research has primarily focused on optimizing the compressor or integrating new refrigerants, rather than adjusting fluid levels in the receiver [1, 2].

The refrigerant charge within the receiver has a direct impact on system thermodynamics by affecting pressure regulation, subcooling capacity, and refrigerant flow dynamics [3]. Overcharging or undercharging the receiver can lead to inefficiencies such as increased compressor load, poor cooling performance, or unstable operating conditions. While the receiver is standard in many commercial systems, its use has not been widely evaluated in smaller-scale applications like household freezers [4].

A previous study [5] presents results of a study on the use of environmentally friendly refrigerants (R32, R134a, R152a) in vapor-compression refrigeration systems. It was shown that the nature of the refrigerant significantly affects the energy efficiency and Coefficient of Performance (COP) of the system. However, there are questions left open regarding component-level optimization, particularly the dynamic behavior of the refrigerant fluid in storage components such as liquid receivers. This may be due to the intricacy in isolating the receiver effect within a total cycle system and the limitation in instrumentation in earlier experimental systems.

Yet another study [6] conducted a thermodynamic and exergy analysis of refrigeration systems and reiterated that enhanced understanding of internal energy losses can be a driving force behind system improvements. There are, however, a few gaps regarding refrigerant accumulation in the receiver and effects of liquid level fluctuation. These gaps may arise from inherent difficulties in obtaining high-accuracy real-time measurement of refrigerant levels.

A separate study [7, 8] found that incremental freezing during cooling stages can improve energy efficiency. There remain some outstanding issues to specifying the quantitative degree to which phase behavior of the refrigerant in receivers influences freezing rates and temperature uniformity. This could be due to the fundamental fact that observing phase transition in the internal component such as the receiver is difficult directly.

An investigation into an energy audit [9, 10] tested energy losses in the main refrigeration components and found that efficiency of the compressor was the dominant factor in total energy consumption. It did not, however, isolate the impact of fluid control in the receiver. This may be due to cost and design limitations in the addition of fluid-level measuring systems to experimental equipment.

Experimental researches on refrigerant charging [11, 12] indicated that mischarged refrigerant has significant effects on pressure drops and cycling compressor behavior. However, post-condensation refrigerant distribution remains to be solved, especially for receiverless systems. The lack of focus on receivers in most experiments likely kept their potential influence from being detected.

A model study [13] put forth a semi-empirical model to predict performance under conditions of refrigerant flow fluctuations and proved improved system stability when buffer devices like accumulators or subcoolers are incorporated. However, empirical evaluation of liquid receivers has not been treated, most likely because test benches with real-time fluid-level control capabilities had limited access.

One way of avoiding these barriers is to create an experimental system where direct measurement and control of the refrigerant liquid levels within the receiver are possible with the other system parameters set as constants. This method was partially used in earlier cooling system studies [14, 15], where selective system modification allowed researchers to observe the effects of air parameters on refrigerating loads.

All this indicates that there is a necessity to carry out an experiment on the direct impact of liquid refrigerant levels in the receiver on the parameters of freezer performance, such as compressor power, internal temperature, energy consumption, and COP.

Thus, there is a clear need for scientific investigation into the role of refrigerant fluid levels in the receiver and their effect on compressor load, cooling efficiency, and energy consumption in freezer systems. Addressing this knowledge gap could provide practical design insights and contribute to low-cost energy optimization strategies for household refrigeration.

3. The aim and objectives of the study

The aim of this study is to identify the effect of refrigerant liquid level in the receiver on the thermodynamic performance and energy efficiency of a domestic freezer, in order to determine the optimal fill level for improved system operation.

Achieving this aim will allow the development of a practical, low-cost approach to enhancing freezer performance through passive refrigerant flow regulation, without the need for complex component redesign or control systems. To reach this aim, the following objectives were pursued:

– to compare the operational characteristics and energy consumption of a freezer system with and without a refrigerant receiver;

– to evaluate the impact of different refrigerant liquid levels in the receiver on the internal cabinet temperature during freezing;

– to determine the optimal liquid level in the receiver that provides the highest Coefficient of Performance (COP) and lowest compressor power consumption.

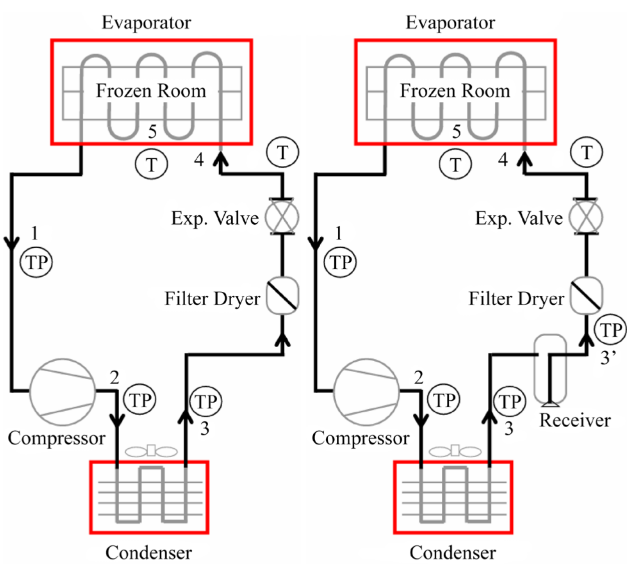
4. Materials and methods

The object of this study is a domestic vapor-compression freezer system, which was evaluated under laboratory conditions in two configurations: with and without a refrigerant receiver. The central hypothesis of the study is that the refrigerant level in the receiver plays a significant role in system thermodynamics, and that there exists an optimal fill level that enhances cooling capacity, reduces compressor workload, and improves the Coefficient of Performance (COP).

To support the experimental design and analysis, several assumptions were made. It was assumed that the expansion valve operates ideally, exhibiting negligible pressure loss, and that the heat transfer process within the refrigeration system remains stable and uniform throughout each test. The refrigerant used in all experiments (R404a) was assumed to follow ideal thermodynamic behavior based on its standard pressure-enthalpy (p-h) diagram. Additionally, each system was assumed to reach a quasi-steady operating state after an initial stabilization period.

To ensure a clear and focused comparison between cases, several simplifications were adopted. Only one refrigerant type (R404a) was used throughout all test cases to eliminate variability related to fluid properties. The physical design, geometry, and insulation of the freezer system were kept constant for all configurations. The receiver was treated as a passive component, with no active control of refrigerant flow, and the refrigerant liquid levels were manually adjusted and visually verified using a levelling device. These simplifications ensured that variations in performance could be attributed specifically to the presence and level of refrigerant in the receiver.

The experimental setup is illustrated in Fig. 1, which shows the system configuration with and without the receiver. The freezer system was instrumented with sensors at critical points along the refrigeration cycle to monitor temperature and pressure. These included the compressor inlet and outlet, condenser outlet, receiver outlet (where applicable), evaporator inlet, and the interior of the freezer compartment. Type-K thermocouples with an accuracy of ±0.5°C were used to record temperature, while analog pressure transmitters were used to measure refrigerant pressures.

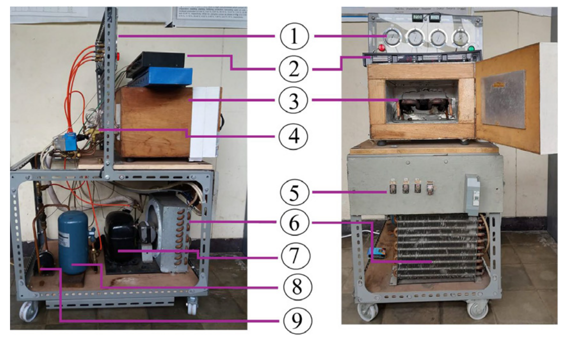


a *b*

Fig. 1. Schematic of freezer with refrigeration measurement points: *a* — without receiver; *b* — with receiver

The physical layout of the test bench is shown in Fig. 2. The system includes a compressor, evaporator, expansion valve, condenser, receiver, and associated controls and displays. Detailed component specifications are listed in Table 1. A digital watt meter with ± 1% accuracy was used to measure the compressor's electrical power draw, and a data logger recorded all operating parameters at 5-minute intervals throughout each 180-minute test run. These measurement intervals allowed for the tracking of dynamic changes in system behavior during steady-state operation.

Each test was performed with a fixed thermal load of 1 kg of water placed in the freezer compartment to simulate typical freezing conditions. A total of six test configurations were evaluated: one without a receiver and five with the receiver charged to different refrigerant levels (< 0%, 30%, 40%, 50%, and > 60%). All experiments were conducted under consistent laboratory conditions to ensure reliable comparison of results.



a *b*

Fig. 2. The experimental test bed: *a* — view from the left side; *b* — view from the front

Table 1

Freezer Specifications

Number	Component	Specifications
7	Compressor	Type; SC12CL, Code; 104L2623, 220-240V/50Hz, R-404A LBP
3	Evaporator	Type; touch plate (210 × 210 × 3) mm^3, Inner volume (148 × 251 × 251) mm^3, pipe diameter 5/8″, W 880 mm
4	Expansion valve	Danfoss TS2: Oriffice No. 02
6	Condenser	Type; Finned tube n 30, d 3/8″, L 10080 mm
	Refrigerants	R404a
1	Pressure gauge	Bourdon Barometer Type analog
2	Thermometer	Thermocouple digital type TC4Y Accuracy +2°C
8	Receiver	Brand: Airmender, A 127 mm, L 240 mm
5	Wattmeter	Multifunction Mini Ammeter D02A, Accuracy +1%

System performance was evaluated using the Coefficient of Performance (COP), calculated from enthalpy values derived from the R404A pressure-enthalpy diagram. The compressor work (W_k) was determined as the enthalpy difference between the compressor outlet and inlet, while the refrigeration effect (q_{RE}) was based on the enthalpy change across the evaporator. The COP was calculated as the ratio of q_{RE} to W_k, following standard thermodynamic relationships. These are expressed in equations (1) through (4) [16]:

$$w_k = (h_2 – h_1), \tag{1}$$

$$h_3 = h_4 \text{ (assumption) the expansion valve does not work,} \tag{2}$$

$$q_{RE} = (h_1 – h_4), \tag{3}$$

$$COP = \frac{q_{RE}}{w_K} = \frac{(h_1 - h_4)}{(h_2 - h_1)}. \tag{4}$$

Compressor electrical power (PEP) was measured directly using the wattmeter, and the total electrical energy consumption (EEE) over the test duration was calculated by summing the product of power and time for each interval, as shown in equation (5). Additionally, theoretical compressor power was estimated using equation (6), which accounts for refrigerant pressure, specific volume, and the polytropic exponent.

$$E=\sum P_{Ei}\left(\frac{\Delta t}{60.1000}\right)(\text{kWh}), \qquad (5)$$

$$PE=\frac{n}{n-1}p_1v_1\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}-1\right](\text{W}). \qquad (6)$$

After all data were collected, the results were analyzed to compare system performance across the various receiver configurations. Particular attention was given to COP, compressor power, internal cabinet temperature, and total energy consumption, allowing for the identification of performance trends and the determination of an optimal refrigerant liquid level in the receiver.

5. Research results effect of receiver and refrigerant fill level on freezer performance

5. 1. Comparison of freezer performance with and without receiver

Experiments were conducted using two freezer configurations: one without a receiver and one with a receiver. Performance data for both systems were collected over a 180-minute duration, with measurements taken at 5-minute intervals. The system without a receiver (Fig. 3, 4) and the one with a receiver containing < 0% refrigerant level (Fig. 5, 6) exhibited the highest compressor power and the lowest cooling performance.

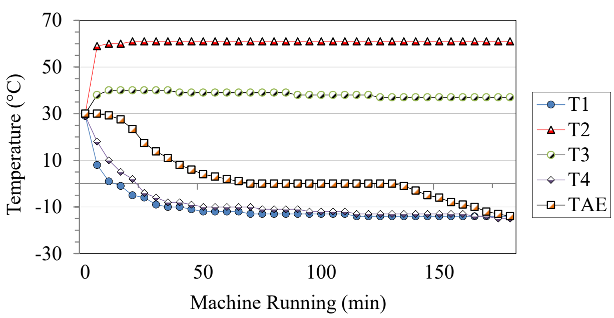


Fig. 3. The refrigeration temperature profile in freezer without receiver

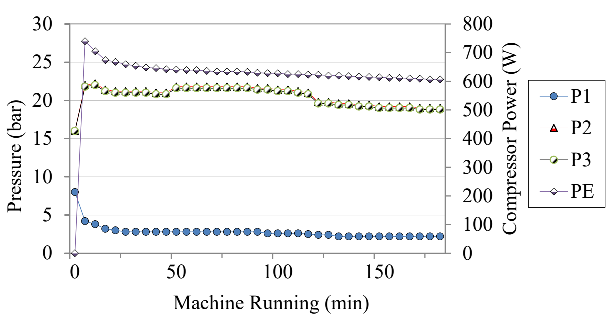


Fig. 4. The refrigeration pressure profile and compressor power in freezer without receiver

Fig. 3 shows fluctuating cooling temperatures, with slow declines and temperature instability, indicating a less efficient system in absorbing heat from the freezer chamber. Meanwhile, in Fig. 4 the system pressure is unstable, and the compressor power is relatively high all the time. This indicates a large compressor workload because there is no refrigerant flow stabilization.

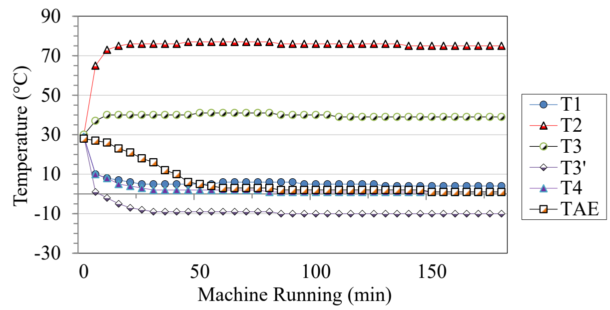


Fig. 5. The refrigeration temperature profile in freezer with a liquid level receiver < 0%

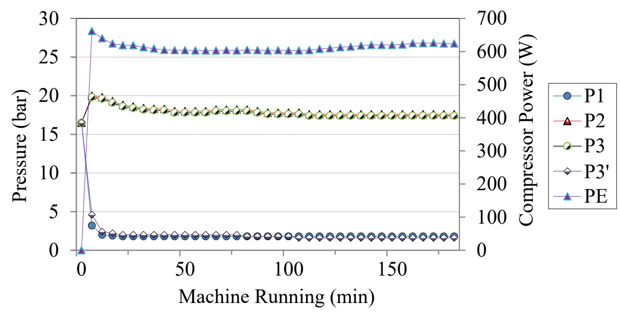


Fig. 6. The refrigeration pressure profile and compressor power in freezer with a liquid level receiver < 0%

In Fig. 5, the temperature did not drop significantly and was stable above 0°C which means the system failed to reach the freezing temperature, and is supported by Fig. 6 where the pressure remains high and the compressor power is close to power without a receiver.

In contrast, freezers equipped with 30% (Fig. 8, 9), 40% (Fig. 10, 11), and 50% (Fig. 12, 13) liquid levels in the receiver demonstrated improved performance.

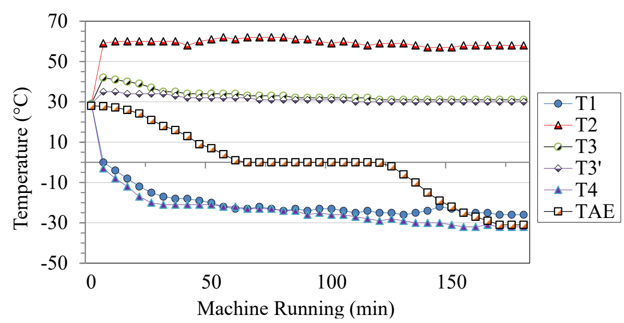


Fig. 7. The refrigeration temperature profile in freezer with a liquid level receiver of 30%

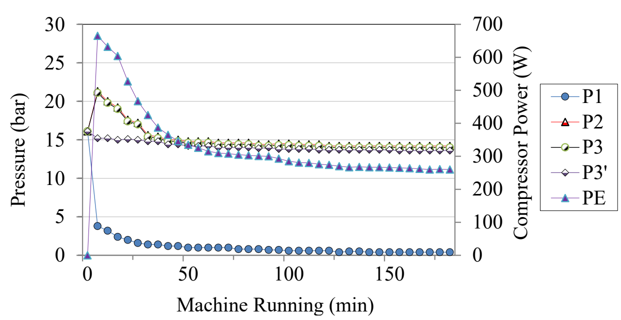


Fig. 8. The refrigeration pressure profile and compressor power in freezer with a liquid level receiver of 30%

The temperature decreased significantly to –31°C which indicates the optimal cooling performance in Fig. 7. While Fig. 8 the pressure becomes more stable and the compressor power is lower than the previous system.

The temperature drop pattern in the 40% liquid level test (Fig. 9) is similar to that of 30%, which also indicates excellent cooling performance. In Fig. 10, the pressure was also stable but the compressor power was slightly higher than in the test at the level of 30%.

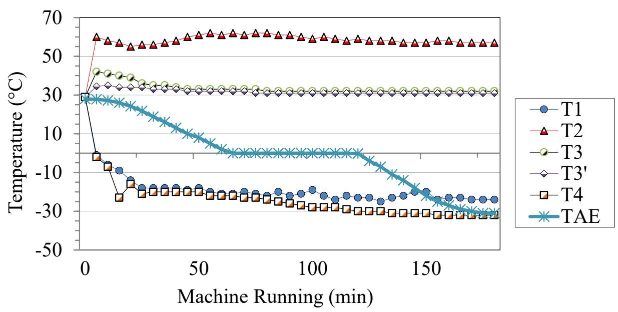


Fig. 9. The refrigeration temperature profile in freezer with a liquid level receiver of 40%

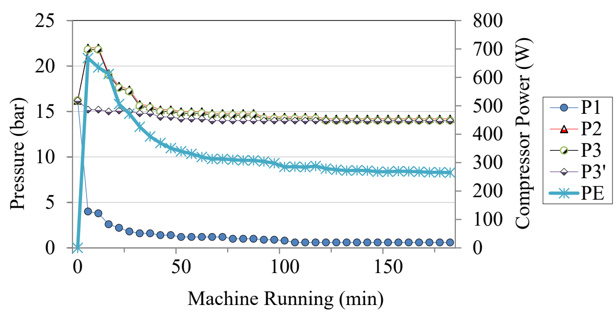


Fig. 10. The refrigeration pressure profile and compressor power in freezer with a liquid level receiver of 40%

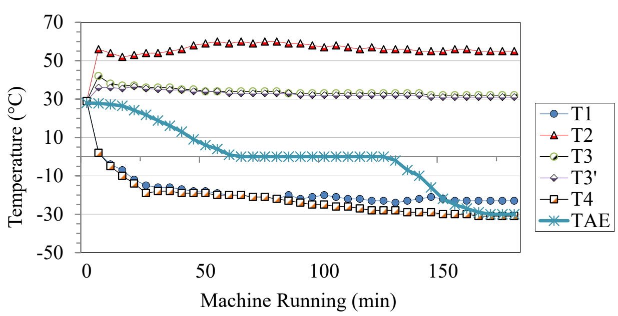


Fig. 11. The refrigeration temperature profile in freezer with a liquid level receiver of 50%

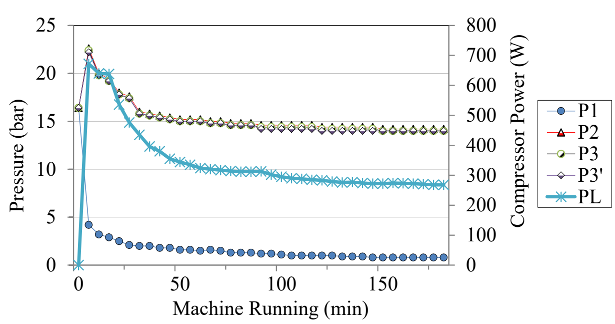


Fig. 12. The refrigeration pressure profile and compressor power in freezer with a liquid level receiver of 50%

When compared to the tests at the 30% and 40% levels, the freezer temperature at the 50% test was slightly higher (Fig. 11), with higher compressor power seen in Fig. 12 indicating an increase in workload when the refrigerant volume was larger.

The system with a refrigerant level greater than 60% (Fig. 13, 14) experienced compressor failure due to overpressure after the 20th minute, preventing further analysis.

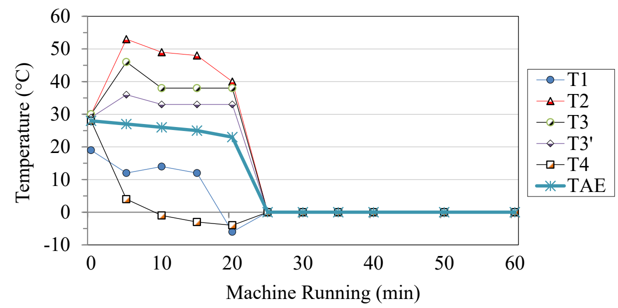


Fig. 13. The refrigeration temperature profile in freezer with a liquid level receiver > 60

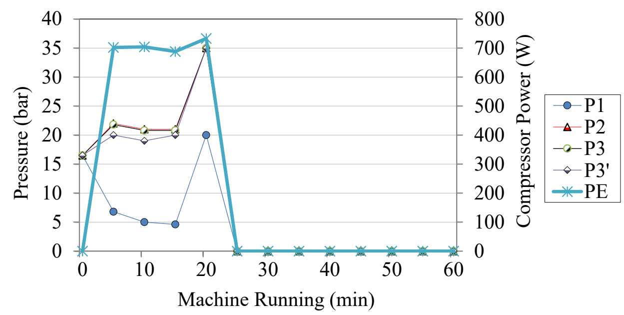


Fig. 14. The refrigeration pressure profile and compressor power in freezer with a liquid level receiver > 60%

The data in Fig. 14 of the ≥ 60% test was only recorded up to the twentieth minute due to system failure due to too high pressure. In Fig. 15, there is a very large surge in pressure and compressor power before the system shutdown, this indicates overpressure.

5. 2. Evaluation of water-ice temperature performance

Water-ice temperatures were used to assess the effectiveness of the freezer system in maintaining low internal cabinet temperatures.

As shown in Fig. 15 the temperature line for liquid levels of 30% and 40% is the lowest and stable at –31°C when compared to without a receiver which only reaches –14°C. Receiver < 0% fails to freeze and survives at 1°C temperature illustrates armpit efficiency.

5. 3. Determination of optimal refrigerant liquid level

Among the various liquid levels tested, the 30% receiver fill demonstrated the best overall performance. As shown in Fig. 16 and Table 2, it yielded the lowest compressor power consumption (335.7 W) and the lowest energy consumption (1.01 kWh), while achieving a low cabinet temperature and maintaining a competitive COP. Configurations with higher fill levels (40% and 50%) also performed well, but did not show significant advantages over the 30% level.

COP trends across different configurations over the entire 180-minute cycle are presented in Fig. 17, while compressor power variations are detailed in Fig. 19.

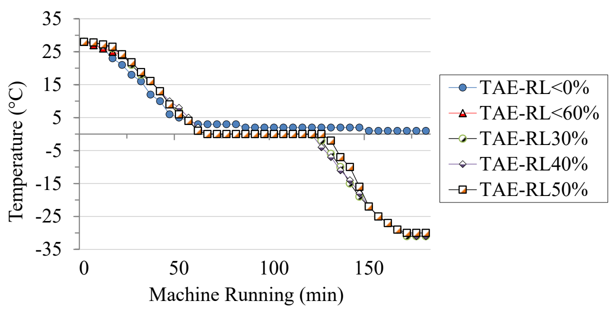


Fig. 15. The air-ice product temperature for each measurement period against the operating time of freezer: TAE-RL < 0% : water-ice temperature of liquid refrigerant in receiver < 0%; TAE-RL30% : water-ice temperature of liquid refrigerant in receiver 30%; TAE-RL40% : water-ice temperature of liquid refrigerant in receiver 40%; TAE-RL50% : water-ice temperature of liquid refrigerant in receiver 50%; TAE-RL > 60% : water-ice temperature of liquid refrigerant in receiver > 60%; TEA-TR : water-ice temperature of freezer without receiver

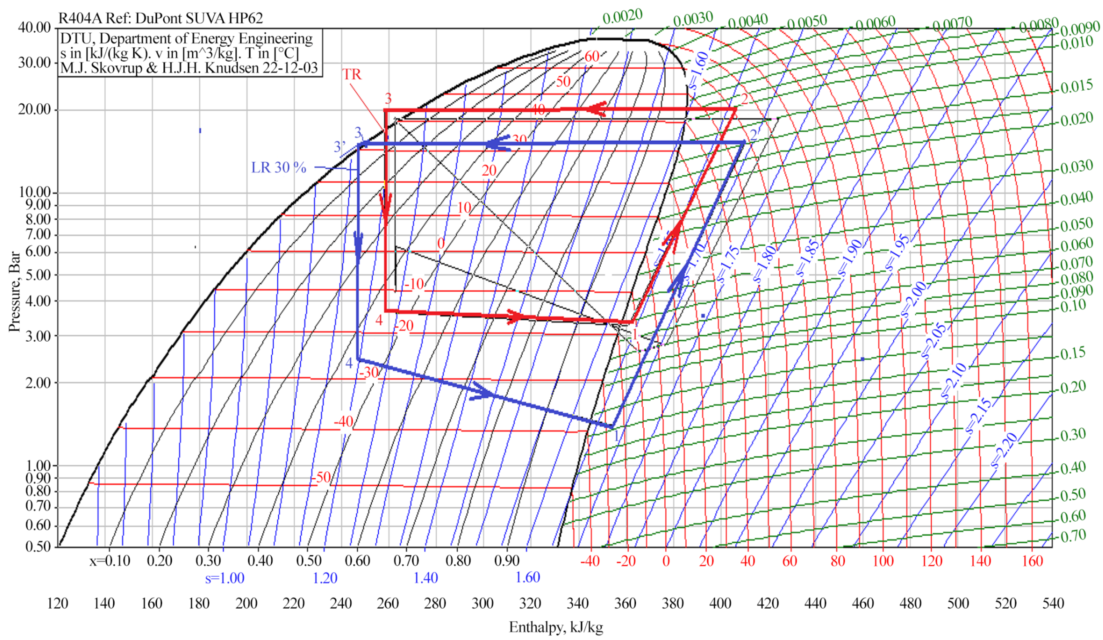


Fig. 16. Two cycles of p-h diagrams of sample experimental data when the machine operates for 180 minutes, the machine uses receiver (LR 30%) and without receiver (TR)

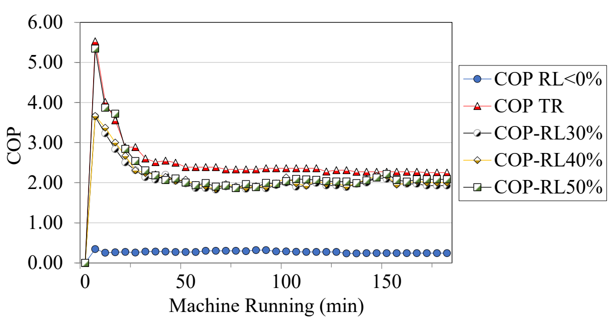


Fig. 17. Coefficient of Performance of all types of experiments for each measurement period against the operating time of freezer

The system without a receiver (TEA-TR in Fig. 18) recorded only –14°C, while the configuration with < 0% refrigerant level (TAE-LR< 0% in Fig. 18) failed to freeze the load, stabilizing at 1°C.

Fig. 19 shows the total energy consumption for 180 minutes. The graph shows the highest consumption in systems without receivers and the lowest in the use of liquid receiver level 30%. This trend shows that the use of receivers, especially at the liquid level of 30–50%, significantly lowers energy requirements.

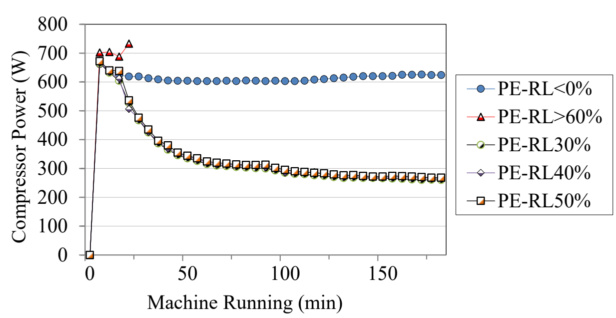


Fig. 18. The compressor power for each measurement period against the operating time of freezer: PE-RL< 0% : compressor power of liquid refrigerant in receiver < 0%; PE-RL30% : compressor power of liquid refrigerant in receiver 30%; PE-RL 40% : compressor power of liquid refrigerant in receiver 40%; PE-RL 50% : compressor power of liquid refrigerant in receiver 50%; PE-RL> 60% : compressor power of liquid refrigerant in receiver > 60%; PE-TR : compressor power of freezer without receiver

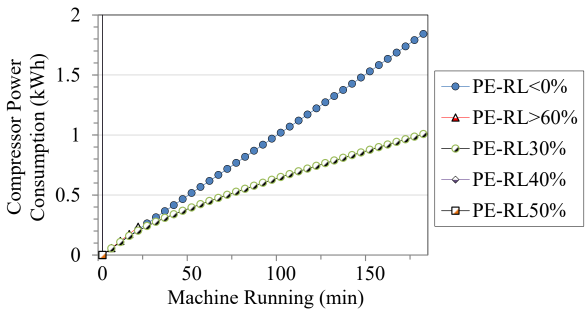


Fig. 19. The electric energy consumption for compressor power in freezer experiment with various variations of refrigeration fluid levels in receiver: PE-RL< 0% : compressor power of liquid refrigerant in receiver < 0%; PE-RL 30% : compressor power of liquid refrigerant in receiver 30%; PE-RL 40% : compressor power of liquid refrigerant in receiver 40%; PE-RL 50% : compressor power of liquid refrigerant in receiver 50%; PE-RL > 60% : compressor power of liquid refrigerant in receiver > 60%; PE-TR : compressor power of freezer without receiver

Table 2 provides a summary of COP, indicating that its average value for freezer experiment when sorted from highest to lowest is TR, LR 50%, LR 40%, LR 30%, and LR < 0%. The product temperature (water-ice) that can be achieved when sorted from the coldest to the warmest temperature was LR 30%, LR 40%, LR 50%, TR, and LR < 0%. On the other hand, the average compressor power when sorted from largest to smallest was TR, LR < 0%, LR50%, LR40%, and LR30%. The consumption of electrical energy by the compressor when sorted from the highest to the lowest was TR, LR < 0%, LR 50%, LR 40%, and LR 30%.

Table 2

Summary of study results during the trial time of each freezer operating for 180 minutes

Freezer operates for 180 minutes (Experimental type)	COP average	Ice-water product temperature (°C)	Average compressor power (W)	Electrical energy consumption (kWh)
TR	2.55	–14	634.4	1.90
LR < 0%	0.27	1	614.1	1.84
LR 30%	2.09	–31	335.7	1.01
LR 40%	2.15	–31	339.7	1.02
LR 50%	2.27	–30	345.4	1.04

Users without freezer receiver consumed the highest amount of electricity at 1.90 kWh. It was observed that for freezer with refrigeration liquid levels in receiver, the consumption rates decreased. For example, at < 0%, 1.84 kWh was consumed, while the freezer with levels of 50%, 40%, and 30% consumed 1.04 kWh, 1.02 kWh, and 1.01 kWh, respectively. The lowest electricity consumption was recorded for freezer with a refrigeration liquid level of 30%. In terms of electricity consumption, freezer with receiver is more energy-efficient than without. Specifically, the freezing machine equipped with a receiver consumed 47% less energy (1.01 kWh) compared to freezer without a receiver (1.90 kWh). It is important to note that the experimental results were recorded for 180 minutes.

6. Discussion of the influence of receiver liquid levels on freezer system performance

As shown in Fig. 4, 5, the freezer without a receiver exhibited unstable refrigeration temperatures and high compressor power usage. The temperature profile (Fig. 4) shows delayed and inconsistent cooling, while pressure and compressor power readings (Fig. 5) indicate significant cycling and energy demand. This is attributed to the lack of a buffer for refrigerant flow, leading to irregular expansion valve feeding and pressure fluctuations.

A similar performance was observed in the system with a receiver charged at < 0% (Fig. 6, 7), which functionally behaved like a system without a receiver due to insufficient refrigerant mass. Fig. 6 shows that the temperature never dropped below 0°C, failing to achieve freezing, while Fig. 7 shows persistently high compressor power. These results confirm that an inadequately charged receiver does not contribute positively to system stability or efficiency, supporting the findings from Fig. 19 (high compressor load) and Fig. 17 (low COP). The water temperature in this case (Fig. 16) remained at 1°C throughout the test period, demonstrating a failure in thermal performance.

The introduction of a receiver filled to 30%, 40%, and 50% (Fig. 8–13) significantly improved freezer operation. As shown in Fig. 8, the system with a 30% receiver fill reached –31°C rapidly and remained stable, indicating optimal evaporator performance. Fig. 9 further supports this, with lower and stable compressor power and pressure readings. Similar trends were observed at 40% (Fig. 10, 11) and 50% (Fig. 12, 13) fill levels, although a slight increase in compressor power was noted as the fill level increased, likely due to increased refrigerant volume increasing system pressure slightly. Nevertheless, the systems maintained high thermal performance with cabinet temperatures at or below –30°C, as confirmed in Fig. 16.

However, the 60% fill level exceeded system safety margins, resulting in compressor shutdown (Fig. 14, 15). Fig. 14 shows a steep pressure and power surge, followed by failure at the 20th minute. This highlights the thermodynamic limit beyond which overcharging leads to overpressure, endangering component integrity.

As seen in Fig. 16, the systems with 30% and 40% receiver levels maintained the lowest and most consistent water temperatures at –31°C. These results reflect effective and sustained refrigeration throughout the 180-minute cycle. The system without a receiver (TEA-TR) reached only –14°C, and the < 0% case never achieved freezing, further confirming the necessity of adequate refrigerant buffering.

This is consistent with COP data in Fig. 18, where the highest average COP values were found in the 30–50% receiver range. Fig. 19 also reveals that compressor power dropped significantly in those cases, confirming reduced energy demand. As summarized in Fig. 20, the total energy consumption for the 30% fill level was the lowest (1.01 kWh), compared to 1.90 kWh in the system without a receiver. These findings clearly illustrate the energy-saving potential of correctly filled receivers.

Based on the results in Fig. 17 (p-h diagram), Fig. 18 (COP trend), and Table 2, the 30% fill level achieved the best overall performance, balancing high COP (2.09), low compressor power (335.7 W), and the coldest cabinet temperature (–31°C). The 40% and 50% levels also performed well but with slightly higher compressor workloads and energy usage. Beyond 50%, system performance declined and at > 60%, failure occurred.

These findings demonstrate that the 30% refrigerant level offers the best thermodynamic stability, subcooling capacity, and mass flow regulation. Unlike prior studies that focused on refrigerant type [5] or general charge behavior [11, 13], this study highlights the specific contribution of the receiver and its fill level as a passive but effective performance control mechanism.

This research adds a novel dimension to existing studies. Unlike paper [5], in which evaluated alternative refrigerants, or paper [13], in which modeled flow fluctuations, this study provides empirical validation of receiver fill level as a critical design parameter. In paper [11] identified the effects of incorrect refrigerant charge but did not explore how intermediate storage could mitigate such inefficiencies.

Nonetheless, the study has limitations. All tests were conducted under controlled lab conditions, which may not fully reflect real-world performance under varying ambient temperatures, intermittent loads, or long-term cycling. The inability to extend testing beyond the 60% fill level also limited the analysis of upper operational thresholds. Practical application in mass-produced systems may require the integration of reliable, low-cost liquid level indicators and pressure relief mechanisms to avoid system overpressure.

The findings show that tuning receiver fill level is a low-cost, effective method to enhance energy efficiency in domestic freezers. Future work could investigate dynamic receiver level control, explore the impact of different receiver geometries, and test system behavior under fluctuating ambient conditions. The development of compact sensors for real-time refrigerant level monitoring and the validation of results in real-use conditions are recommended steps to bridge the gap between laboratory performance and commercial application.

7. Conclusions

1. The integration of a receiver into the freezer system significantly reduced energy consumption. The freezer without a receiver consumed 1.90 kWh over the test period, while the system with a 30% receiver level used only 1.01 kWh, representing an energy saving of approximately 47%. This improvement is primarily attributed to enhanced refrigerant flow stability and subcooling.

2. Freezers equipped with a receiver demonstrated superior cooling performance compared to the system without one. The minimum product temperature reached with the 30% and 40% liquid levels was –31°C, compared to only –14°C for the freezer without a receiver. This result confirms the receiver's role in maintaining consistent evaporator conditions and improving thermal transfer.

3. Among the tested configurations, the 30% refrigerant fill level in the receiver yielded the most efficient system performance. It achieved the lowest energy usage (1.01 kWh), the lowest average compressor power (335.7 W), and the lowest cabinet temperature (–31°C). These results indicate that a 30% fill level offers an optimal balance between refrigerant mass, pressure control, and heat exchange, setting it apart from both undercharged and overfilled conditions.

Conflict of interest

The authors declare that have no known competing financial interest or personal relationship that could have appeared to influence that work reported in this paper.

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Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors have used artificial intelligence technologies within acceptable limits to provide their own verified data, which is described in the research methodology section.

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