



ISSN : 2321-9416

Indo - American Journal of Mechanical Engineering



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Prototype Characterization of a Linear Compressor-Based Energy-Efficient Vapor Compression Cycle

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Abstract

In this study, we create a working model of a VCC to test in the lab. Components of the VCC system include a high-efficiency 300W linear compressor with variable capacity control, an expansion valve, an air-cooled condenser, and an evaporator and condenser that are micro channel plate heat exchangers. Compressor capacity, evaporation temperature, and expansion valve opening position are all manipulated experimentally to see how they affect VCC performance. The prototype unit has a high COP of 4.5, which is really impressive. The experimental data is used to construct and verify models of the individual components and the refrigeration cycle. The suggested cycle model offers the knowledge necessary to direct the development and implementation of compact cooling systems that minimize energy consumption.

1. Introduction

Refrigeration and air conditioning systems, two of the most energy-hungry home equipment, rely heavily on vapor compression cycles (VCC). Air conditioners and refrigerators account for 13% and 16% of home power use, respectively. American in 2001 [1]. In addition, ACs account for up to 70% of UAE energy usage [2]. Because of this, more efficient cooling system designs are needed. Miniaturization is becoming standard in the electronics sector. Since these systems generate so much heat, they needed more efficient cooling. As a result, miniaturized vapor compression cycles are sought for use in highly portable electronic systems. Trutassanawin et al. [3] conducted research to design a miniaturized refrigeration system prototype for use in cooling electronics. With a COP ranging from 2.8 to 4.7 and a second-law efficiency of 33% to 52%, the cooling capacity of the system showed wide variation, sitting at 121 to 268 W. The thermal performance of a miniaturized VCC for electronic cooling has been investigated with the use of a test-

bed designed by Chang et al. [4]. The COP of the cycle has been analyzed in relation to the compressor speed and the expansion valve opening. Reducing the compressor's speed from 4200 to 3840 RPM enhanced condensation phenomena, the research found.

Experiments were conducted with evaporator and condenser temperatures ranging from -50 C to 0 C and 40 C to 55 C, respectively, as part of a comprehensive evaluation of a VCC test-bed conducted by Aurora and Kaushik [5]. Researchers found that a lower pressure ratio across the compressor resulted in less compression effort and a greater COP when the evaporator temperature was raised. Maintaining two-phase flow inside the evaporator improves refrigeration systems' coefficient of performance (COP). The coefficient for heat transmission decreased in the superheated region. As a result, a greater heat transfer coefficient [6] may be attained by the use of two-phase flow. Torrella et al.

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[7] performed a study, describing a generic technique for evaluating six VCC configurations. The researchers discovered that the COP rises with the degree of sub cooling because the difference in specific enthalpy throughout the evaporator becomes larger. On their research, Jensen and Skogestad [8] zeroed on on the optimum functioning of a basic VCC. Compressor power usage was studied in relation to sub-cooling and super-heating degrees. The research concluded that sub-cooling to some degree was preferable than super-heating. Aprea et al. [9] looked into the thermodynamic benefits of utilizing a suction-liquid heat exchanger to improve the efficiency of refrigeration systems. By exposing the refrigerant to sub-cool and super-heated temperatures, it demonstrated the recuperator's impact on COP improvement. Few mentions of creating VCCs using linear compressors and recuperates can be found in the aforementioned research. A linear compressor's intrinsic benefit in refrigeration applications is that its cooling capacity may be adjusted on the fly to meet changing needs. The study focuses on what happens to the system's COP when a fluid-to-fluid recuperate is added. Numerous parametric studies are carried out to examine how changing the operating circumstances of individual components affects the overall system performance. In addition, characterizations at the cycle and component levels are created so that the performance of the cycle under varying operational situations may be predicted. This research aids in the creation of a more compact vapor compression cycle that uses less energy. It also demonstrates the promise of small VCC systems for use in mobile cooling tasks, including as the cooling of electronics.

2. Experimental Test-bed

Compressor, condenser, evaporator, and expansion device make up the fundamental VCC. Adding an accumulator after the evaporator improves heat transmission since the evaporator outlet remains in the two-phase flow area [6]. Additionally, a heat exchanger may be installed within. The loop's temperature differential may be put to good use by

exchanging heat at the condenser and evaporator outlets. The VCC prototype we created is seen and described in Figure 1. A data gathering system is linked to every sensor. Accuracy is to within 0.7 OC for temperature, 0.15% of full scale for pressure, and 0.08% of measurement for mass flow rate. Lab VIEW is used to log the information into a computer. Read [10] for more explanation. As can be seen in Figure 1(b), everything is mounted on an aluminum frame and linked with copper piping and brass fittings. After the refrigeration loop has been constructed, it is inspected for leaks, insulated, and charged with R134a.

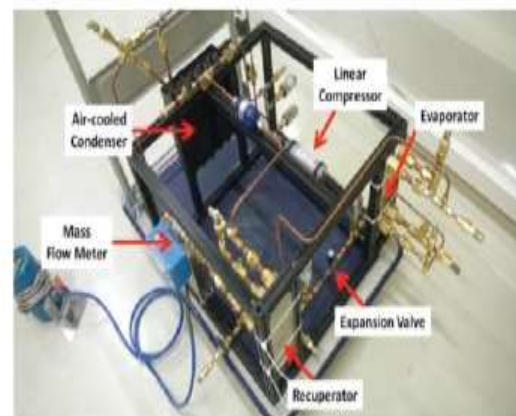
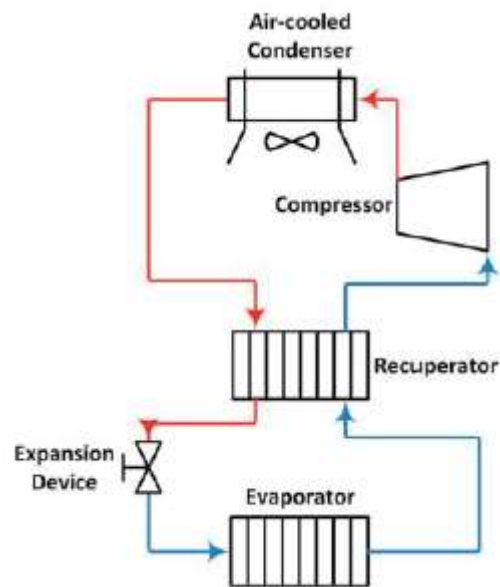
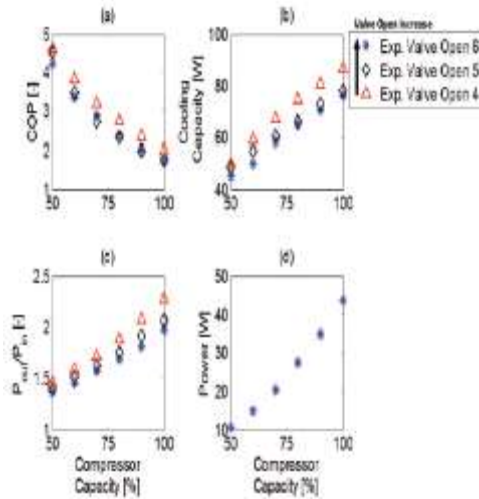


Fig. 1. Schematic diagram of VCC test-bed setup (left) and prototype photo before insulation (right)

3. Experimental Characterization

Compressor output, heat source temperature, and expansion valve opening are the tunable variables of a variable capacity compressor (VCC). The energy input of the compressor and evaporator, as well as the recuperate heat exchange rate and condenser heat rejection rate, are all affected by these variables. The compressor's capacity was raised from 50% to 100% in 10% increments, and the expansion valve was moved from its previous position of "open 4" to "open 6." Changes in the cycle's COP as a function of compressor capacity at various expansion valve openings are seen in Figure 2-a. Power consumption rises as the compressor's piston stroke lengthens with increased capacity, as seen in Figure 2-d. As can be seen in Figure 2-b, a larger evaporator cooling capacity is achieved by increasing the piston stroke length, which in turn raises the refrigerant mass flow rate. The evaporator's cooling capacity has increased, but the rise in power consumption has outpaced that growth. Therefore, increasing the capacity of the compressor results in a decreasing cycle COP. The impact on the pressure ratio across the compressor of varying compressor capacity is seen in Figure 2-c. When the compressor's capacity is raised, the outlet pressure rises as well [11], resulting in a greater pressure ratio across the compressor at a constant valve opening.



Compressor power consumption (d), pressure ratio across the compressor (c), cooling capacity (b), and coefficient of performance (a) as a function of compressor capacity

4. VCC Modeling

Evaporator and recuperate plate heat exchangers and condenser fin-tube heat exchangers are discussed in Section 4.1. The refrigerant absorbs heat from the heat source fluid in the evaporator. Coolant goes in and out of the phase transition in an evaporator. Figure 3-a depicts the evaporator's singular flow zone. The following equations must be solved to simulate the heat transport in the evaporator in order to estimate the evaporator outlet condition:

$$\left[\dot{m}_{\text{evap}} (\bar{T}_{\text{sat}} - T_w) p_w L_p \right]_{\text{evap}} = \left[\dot{m}_{\text{air}} (\bar{T}_{\text{sat}} - T_w) p_w L_p \right]_{\text{air}} + \left[\dot{m}_{\text{air}} (A_s + \pi D_h) (\bar{T}_{\text{sat}} - T_w) \right]_{\text{amb}} \quad (1)$$

The temperature differential between the condenser outlet and the evaporator outlet causes the heat to be transferred from one to the other via the recuperate. A two-phase fluid from the condenser side of the system enters the recuperate and departs as a sub-cooled liquid. To the contrary, after passing through the evaporator, the refrigerant goes into the recuperate, where it undergoes further heating before emerging as a superheated gas. Given that we have no idea how these two fluids would react to one another, we have assumed the recuperate may be divided into three flow zones, as seen in Figure 3-b. Solving heat balancing equations between the condenser and the refrigerant, the heat exchanger wall, and the evaporator and the refrigerant is necessary for modeling the heat transfer in the recuperate.

$$\begin{aligned} \left[\dot{m}_{\text{cond}} L1 (\bar{T}_{\text{cond}} - T_w) p_w L_{TP} \right]_{\text{cond}} &= \left[\dot{m}_{\text{cond}} L1 (\bar{T}_{\text{cond}} - T_w) \right]_{\text{cond}} \\ \left[\dot{m}_{\text{evap}} L2 (\bar{T}_{\text{evap}} - T_w) p_w L_p \right]_{\text{evap}} &= \left[\dot{m}_{\text{evap}} L2 (\bar{T}_{\text{evap}} - T_w) \right]_{\text{evap}} \\ \left[\dot{m}_{\text{evap}} L3 (\bar{T}_{\text{evap}} - T_w) p_w L_p \right]_{\text{evap}} &= \left[\dot{m}_{\text{evap}} L3 (\bar{T}_{\text{evap}} - T_w) \right]_{\text{evap}} \end{aligned} \quad (2)$$

Solving heat balances between the condenser's refrigerant, pipe wall, and air flow across each zone allows one to estimate the condenser's output state. As can be seen in Figure 3-c, the flow within the condenser is separated into two distinct zones.

$$\begin{aligned} \left[\dot{m}_{\text{cond}} L1 (\bar{T}_{\text{cond}} - T_w) p_w L_{TP} \right]_{\text{cond}} &= \left[\dot{m}_{\text{air}} L1 (\bar{T}_{\text{cond}} - T_{\text{amb}}) A_{s(p+r)} \right]_{\text{amb}} \\ \left[\dot{m}_{\text{cond}} L2 (\bar{T}_{\text{cond}} - T_w) p_w L_p \right]_{\text{cond}} &= \left[\dot{m}_{\text{air}} L2 (\bar{T}_{\text{cond}} - T_{\text{amb}}) A_{s(p+r)} \right]_{\text{amb}} \end{aligned} \quad (3)$$

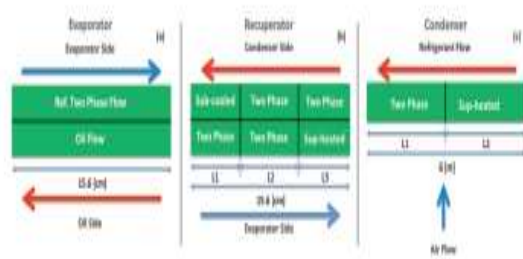


Fig. 3. (a) Evaporator has single flow zone (b) Recuperate has three flow zones (c) Condenser has two flow zones

4.2. Linear Compressor and Expansion Valve

In this project, a piston-cylinder compressor was employed; the piston was powered by a linear motor. The compressor may be modeled using the governing equation, where ρ is the density, V is the compression volume, ω is the frequency, and η_v is the volumetric efficiency. In terms of the differential pressure across the compressor. Depending on the cross sectional area, fluid specifications, and pressure ratio, the expansion valve's flow coefficient determines the mass flow rate through the valve.

5. Model Validation

To accurately forecast input and output circumstances, all component models have been verified using experimental data. The impact of varying compressor capacity on recuperate zone lengths is seen in Figure 4-a. Heat transmission in the recuperate increases with compressor capacity. Also rises when the temperature differential between the recuperate plates becomes larger. At larger compressor capacities, the two-phase zone of the recuperate is influenced by the increased superheating and sub-cooling of the refrigerants. The VCC test-bed's P-h diagram is shown in Figure 4-b for a range of compressor loads. The graph clearly demonstrates that the experimental data agrees extremely well with the predictions of the component model.

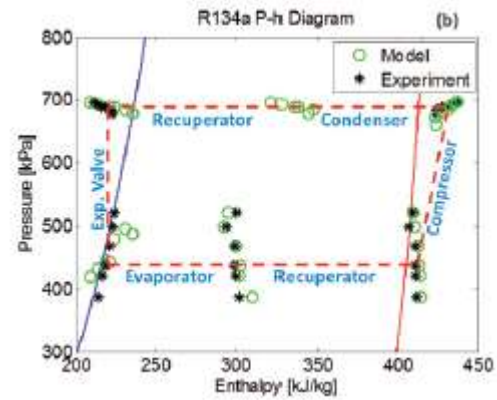
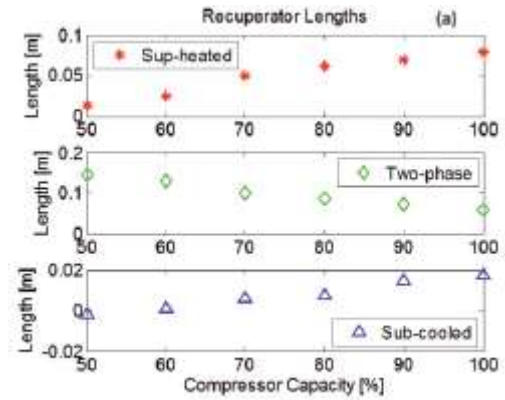
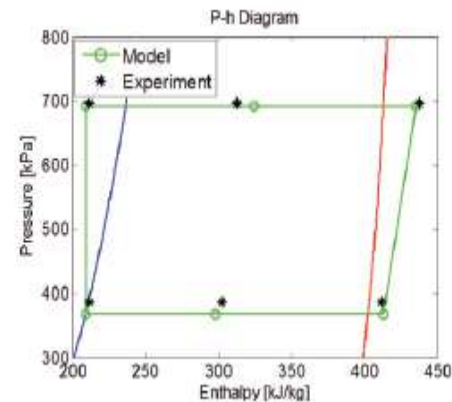
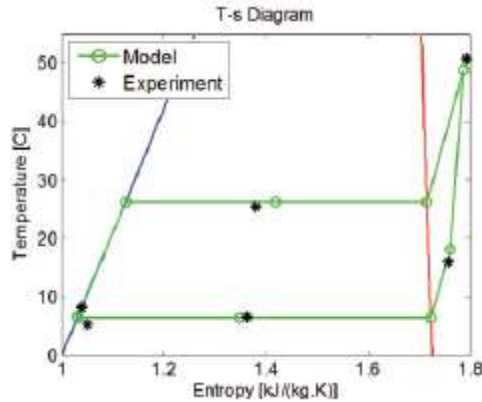


Figure 4: (a) Validation of the VCC component model; (b) impact of compressor capacity change on recuperate zone length





Recuperate-integrated refrigeration cycle pressure-enthalpy and temperature-entropy graphs at 100% compressor capacity

It is expected that the cycle model can stand on its own, with the only external factor being the boundary conditions. Condenser side conditions include air velocity and ambient temperature, whereas evaporator side parameters include oil mass flow rate and intake temperature. Models of individual stages are built up and blended to form the whole cycle model. At an evaporation temperature of 25 oC and a compressor capacity of 100%, the cycle model is validated as shown in Figure 5. The cycle model also accurately predicted the mass flow rate of the refrigerant to within 9.27%. Excellent concordances can be shown between the cycle model and the experimental data across all plots and calculations.

6. Conclusion and Future Work

The concept for a portable VCC was created. In-depth parametric studies were conducted to learn more about the system's behavior in various settings. In order to determine the impact of changing the operating conditions on the recuperate and condenser, moving boundary models were built. Depending on the state of these heat exchangers. At varying loads, the recuperate model accurately predicted the super-heat and sub-cooled degrees supplied to the refrigerant. The model is combined with others of its kind to provide a more comprehensive representation of a cycle. Experimental findings confirmed the validity of the suggested components and cycle models. The predictions of the model's components and cycle closely match the available experimental data.

References

- [1] C. Berry, End-use consumption of electricity (2001 (accessed February 27, 2014)). URL <http://www.eia.gov>
- [2] Air conditioning (2013 (accessed May 15, 2014)). URL <http://www.powerwise.gov.ae>
- [3] S. Trutassanawin, E. A. Groll, S. V. Garimella, L. Cremaschi, Experimental investigation of a miniature-scale refrigerationsystem for electronics cooling, *IEEE Transactions on Components and Packaging Technologies* 29 (3) (2006) 678-687.
- [4] C. Chang, N. Liang, S. Chen, Miniature vapor compressor refrigeration system for electronic cooling, *IEEE Transactions onComponents and Packaging Technologies* 33 (4) (2010) 794-800.
- [5] A. Arora, S. C. Kaushik, Theoretical analysis of a vapour compression refrigeration system with R502, R404A and R507A, *International Journal of Refrigeration* 31 (6) (2008) 998-1005.
- [6] J. Catano, T. J. Zhang, J. T. Wen, M. K. Jensen, Y. Peles, Vapor compression refrigeration cycle for electronics cooling partI: Dynamic modeling and experimental validation, *International Journal of Heat and Mass Transfer* 66 (2013) 911-921.
- [7] E. Torrella, J. A. Larumbe, R. Cabello, R. Llopis, D. Sanchez, A general methodology for energy comparison ofintermediate con gurations in two-stage vapour compression refrigeration systems, *Energy* 36 (7) (2011) 4119-4124.
- [8] J. B. Jensen, S. Skogestad, Optimal operation of simple refrigeration cycles part I: Degrees of freedom and optimality ofsub-cooling, *Computers and Chemical Engineering* 31 (5-6) (2007) 712-721.
- [9] C. Aprea, M. Ascani, F. d. Rossi, A criterion for predicting the possible advantage of adopting a suction/liquid heatexchanger in refrigerating system, *Applied Thermal Engineering* 19 (4) (1999) 329-336.
- [10] M. Alzoubi, Development of a high-performance compact refrigeration cooling prototype, Master thesis, Masdar Instituteof Science and Technology (2014).
- [11] M. Alzoubi, G. Li, T. J. Zhang, First-principle dynamic modeling of a linear micro-compressor, *International MechanicalEngineering Congress and Exposition* 6B (2013) 12-17, IMECE 2013 – San Diego.