Springer Proceedings in Energy

Prashant V. Baredar
Srinivas Tangellapalli
Chetan Singh Solanki *Editors*

Advances in Clean Energy Technologies

Select Proceedings of ICET 2020

Springer

Springer Proceedings in Energy

The series Springer Proceedings in Energy covers a broad range of multidisciplinary subjects in those research fields closely related to present and future forms of energy as a resource for human societies. Typically based on material presented at conferences, workshops and similar scientific meetings, volumes published in this series will constitute comprehensive state-of-the-art references on energy-related science and technology studies. The subjects of these conferences will fall typically within these broad categories:

- Energy Efficiency
- Fossil Fuels
- Nuclear Energy
- Policy, Economics, Management & Transport
- Renewable and Green Energy
- Systems, Storage and Harvesting
- Materials for Energy

eBook Volumes in the Springer Proceedings in Energy will be available online in the world's most extensive eBook collection, as part of the Springer Energy eBook Collection. Please send your proposals/inquiry to Dr. Loyola DSilva, Senior Publishing Editor, Springer (loyola.dsilva@springer.com)

More information about this series at http://www.springer.com/series/13370

Prashant V. Baredar · Srinivas Tangellapalli ·
Chetan Singh Solanki
Editors

Advances in Clean Energy Technologies

Select Proceedings of ICET 2020

Springer

Editors
Prashant V. Baredar
Department of Energy
Energy Centre, Maulana Azad National
Institute of Technology
Bhopal, Madhya Pradesh, India

Srinivas Tangellapalli
Department of Mechanical Engineering
Dr. B. R. Ambedkar National Institute
of Technology Jalandhar
Jalandhar, Punjab, India

Chetan Singh Solanki
Department of Energy Science
and Engineering
Indian Institute of Technology Bombay
Mumbai, Maharashtra, India

ISSN 2352-2534 ISSN 2352-2542 (electronic)
Springer Proceedings in Energy
ISBN 978-981-16-0234-4 ISBN 978-981-16-0235-1 (eBook)
https://doi.org/10.1007/978-981-16-0235-1

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

This book presents a pool of research and review articles on different aspects of engineering design from the 1st International Conference on Innovations in Clean Energy Technologies (ICET), which was organized by Energy Centre, Maulana Azad National Institute of Technology, Bhopal, Madhya Pradesh, India, from August 27 to 28, 2020.

The conference aims to provide a platform for academicians, scientists, and researchers across the globe to share their scientific ideas and vision in the areas of smart technologies based products, energy-efficient systems, solar and wind energy, carbon sequestration, green transportation, green buildings, energy materials, bio-energy, smart cities, and other related fields of energy. The ICET-2020 conference played a key role in setting up a bridge between academicians and industries.

Due to the COVID-19 outbreak around the world, the meetings and gatherings were banned, besides strict immigration policy. Based on most authors' appeal and health considerations, after careful discussion, the conference committee changed this event to an online conference.

The conference presented more than 200 participants to interchange scientific ideas. During the two-day conference, researchers from academics and industries offered the most recent cutting-edge findings, went through several scientific brainstorming sessions, and exchanged ideas on practical socio-economic topics. This conference also provided an opportunity to establish a network for collaboration between academician and industry. The major emphasis was given on the recent developments and innovations in various fields of energy and clean technologies through plenary lectures. This book presents various chapters addressing the science and engineering of various clean technologies in the form of mathematical- and computer-based methods and models for designing, analyzing, and measuring the cleanliness of products and processes. This book brings together different aspects of engineering design and will be useful for researchers and professionals working in this field.

We would like to acknowledge all the participants who have contributed to this volume. We also deeply express our gratitude to the generous support provided by, MANIT, Bhopal. We also thank the publishers and every staff and student volunteer of the department and institute who has directly or indirectly assisted in accomplishing

this goal. Finally, we would also like to express our gratitude to the Respected Director of MANIT, Dr. N. S. Raghuwanshi, for providing all kinds of support and blessings.

Despite sincere care, there might be typos and always a space for improvement. We would appreciate any suggestions from the reader for further improvements to this book.

Bhopal, India Dr. Prashant V. Baredar
Jalandhar, India Dr. Srinivas Tangellapalli
Mumbai, India Dr. Chetan Singh Solanki
October 2020

About This Book

Innovation, technology, material, resources, and various other factors have an important role in the design of a component. This book presents various chapters addressing the science and engineering of various clean technologies in the form of mathematical- and computer-based methods and models for designing, analyzing, and measuring the cleanliness of products and processes. Experimental, computational, and analytical aspects in the field of design are discussed in various chapters in this book. This book brings together different aspects of engineering design and will be useful for researchers and professionals working in this field.

ICET-2020 was held at MANIT, Bhopal, India, in August 2020. Numerous scientists, researchers, and industry experts presented the future aspects of process/product design and papers on the latest researches and technologies. This conference provided a forum for research scholars, scientists, undergraduate, postgraduate, and industry experts to discuss the latest challenges and future needs in the areas of design and development of innovative clean technologies.

Contents

About the Editors

Dr. Prashant V. Baredar besides being the Chairman and Professor at the Department of Energy, Energy Centre MANIT, Bhopal, is also an educator, innovator, researcher, and author. He did his Ph.D. in Thermal Engineering, Integrated Energy System. He has successfully led 8 projects which involves sensitivity analysis and optimization of hybrid system of solar, wind and biomass' and evaluated downdraft gasifier in RGPV Campus using different biomass briquettes for electricity generation for Madhya Pradesh Council of Science and Technology (MPCST). He carried out electricity generation project entirely based on captivating wind power for Ministry of New and Renewable Energy (MNRE). His constant and unfailing devotion earned him best faculty award in 2010 by honorable Chairman BOG and Best Researcher award in 2017 by CRS Education Expo NCR Noida. He has also published over 100 research papers in reputed international and national journals and conferences; authored five books and three books chapter on mechanical engineering, biodiesel and renewable energy resources. He also has two patents to his credit. He has also guided 43 M.Tech. Theses and eight Ph.D. theses so far. He has done several sponsored and consultancy projects in energy sector for Madhya Pradesh Urja Vikas Nigam, NHDC and Municipal Corporation.

Dr. Srinivas Tangellapalli besides being an Associate Professor at Department of Mechanical Engineering in Dr. B. R. Ambedkar NIT Jalandhar, is also an educator, researcher and author. He received his Ph.D. from JNT University College of Engineering, Hyderabad, in 2008 and was a Postdoctoral fellow at University of Ontario Institute of Technology (UOIT), Canada, in 2010 and 2013. He has completed various research projects funded by CSIR, SERB and NSERC. He has four patents and one copyright to his credit. He has authored three books, ten book chapters, 100 journal publications, and 85 conference proceedings. His current areas of research are solar poly-generation, combined power and cooling systems, Kalina power systems, combined cycle power generation and solar-biomass hybrid systems. He has given 60 invited lectures and has supervised five Ph.D. students, 29 M.Tech. thesis and 35 UGC projects. He also has an industrial experience of 3 years and 9 months in a machine tool company.

Dr. Chetan Singh Solanki besides being a Professor at the Department of Energy Science and Engineering, IIT Bombay, is also an educator, innovator, researcher, entrepreneur, author and philosopher. He received his Ph.D. from IMEC (Ketholik University) Leuven, Belgium, a leading R&D and innovation hub in micro and nano-electronics. Dr. Solanki has done remarkable work in the solar sector and being one of the Principal Investigators at The National Center for Photovoltaic Research and Education (NCPRE) is currently leading two projects of national importance on the dissemination of affordable solar technology. This project aims to provide R&D and education support for India's ambitious 100 GW solar mission. He also fathers the Solar Urja through Localization for Sustainability (SoULS) project at IIT Bombay, which aims to provide solar study lamp to every child in rural India as part of its 'Right to Light' mission. He has also won the European Material Research Society's young scientist award in 2003 and IIT Bombay's Young Investigator Award in 2009. He has published over 100 research papers in reputed international journals, authored 4 books on solar and renewable energy and received first prize from the Ministry of New and Renewable Energy (MNRE), Govt. of India in 2011 for his book, 'Renewable Energy Technologies—A Practical Guide for Beginners' (Hindi). He also has four US patents to his credit. Being an active member of several national committees related to Solar Technology he still finds time to practice yoga, breathing exercises and meditation for physical and mental well-being and promotes "being happy under all situations".

Chapter 1
Experimental Investigation of Domestic Refrigerator Used as an Air Conditioner by Augmentation Method

Pankaj P. Gohil and Altafhusen Saiyed

Abstract Human comfort demand is raised day to day due to climate change, global warming and other environmental issues. Conventional air conditioners provide the human comfort; however, other side it consumes high electricity. So, main objective of the study is to reduce the power consumption. In this study, the domestic refrigerator compressor is interconnected with separate indoor unit of air conditioner. In addition, also one more capillary tube is augmented with the existing refrigeration unit with air conditioner indoor unit. An attempt has been made to investigate the performance parameters for both cases with four different coiling cabinet volumes of 44.4, 3.41, 2.25 and 1.5 m^3. The results showed that more refrigeration effect is achieved with augmented one capillary tube in second case condition and the temperature and relative humidity have obtained as 23 °C and 50%, respectively. The power consumption compared to same capacity of existing air conditioner is obtained with 1/3rd times of power for small cooling cabinet area.

Keywords Vapor compression refrigeration cycle · Air conditioner · Refrigerator · Augmentation method · Power consumption · Refrigeration effect

Nomenclatures

TR	Tons of refrigeration
h_{eo}	Enthalpy at evaporator outlet in kJ/kg
h_{ei}	Enthalpy at evaporator inlet in kJ/kg
h_{co}	Enthalpy at compressor outlet in kJ/kg
h_{ci}	Enthalpy at compressor inlet in kJ/kg

P. P. Gohil (✉)
Mechanical Engineering Department, Sarvajanik College of Engineering and Technology, Surat, India
e-mail: pankaj.gohil@scet.ac.in

A. Saiyed
Mechanical Engineering Department, Vidhyadeep Institute of Engineering and Technology, Surat, India

P. V. Baredar et al. (eds.), *Advances in Clean Energy Technologies*,
Springer Proceedings in Energy, https://doi.org/10.1007/978-981-16-0235-1_1

1.1 Introduction

Human comfort demand is raised day to day due to the global warming, climate change and others. Main factors affecting to the human comfort areas; air temperature, humidity, circulation and hygiene. These requirements of human can be fulfilled by air conditioner [1]. Power consumption and environmental imbalance are main critical issues in the field of air conditioner. Total electricity produced all over the world is consumed for the refrigeration and air conditioning purpose of about 30% [2]. Normally, the power consumption of 1 tons of refrigeration (TR) of split air conditioner is around 1 kWh; it shows that every hour one unit of electricity is consumed. And other side, domestic refrigerator units are typically characterized by low cooling capacities (50–250 W) and low quantities of charge (20–200 g) considered. A conventional domestic refrigerator runs on vapor compression refrigeration (VCR) cycle. It comprises main four components viz. compressor, condenser, capillary tube and evaporator, and accessory part is used as dryer. The similar components are also used in a domestic air conditioner system. In addition, accumulator is provided in the air conditioner for better performance. Rather than, there is vast difference in design of cooling load, capacity and size of component and also in types of refrigerant. The geometrical parameters of the components of refrigerator system are also considered other main factors to affect the performance value. The schematic diagram of vapor compression refrigeration cycle is illustrated in Fig. 1.1, which commonly used in both domestic refrigerator and air conditioner.

In the past, many of researchers were carried out the studies on the subjects of optimization, effectiveness and performance of the individual refrigerator and air conditioner systems. Moreover, the researchers also made efforts to run the air

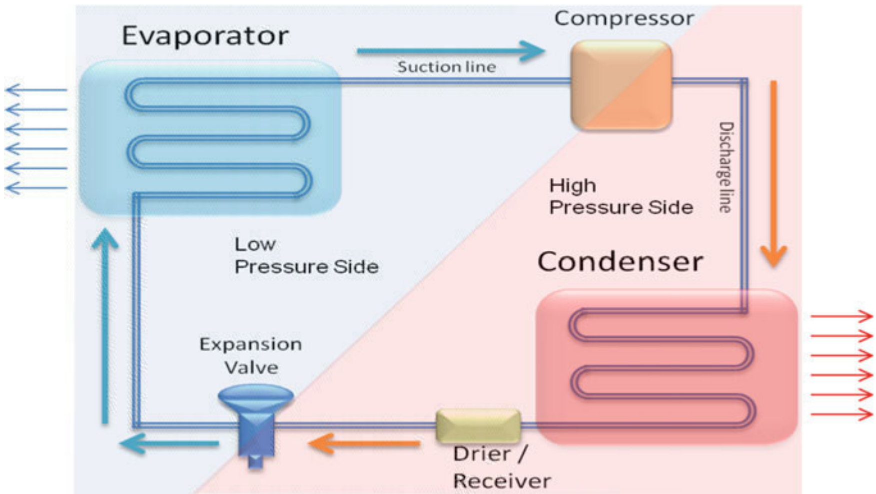

Fig. 1.1 Schematic diagram of VCR cycle [2]

conditioner by using different source of energy, i.e., energy available in exhaust gases [3, 4]. Among few researchers worked on the combined system, these studies are mostly on conservation and utilization of cooling and heating of the system.

Himanshu et al. attempted the feasibility study of refrigerator cum air conditioner and conserved the excessive cooling of defrosting unit of refrigerator area and utilized it in conditioning of air, where water is circulated and this circulation pipe takes place in the freezer tray [5]. In addition, an experimental study was performed by Kongre et al. [1] air conditioner cum water dispenser and investigated the performance of the water and air/water cycle running on the system. It was found that room temperature decreased from 28 to 20 °C, and hot water temperature increased from 28 to 58 °C. Moreover, cold water temperature decreased from 30 to 5 °C which maintains the COP in between 4 and 5. In the same line of work, the heat exchanger is used in between compressor and condenser [6]. The result showed that water enters as water refrigerant heat exchanger, and it was heated up to 50 to 55 °C within 2 min and leads to save energy. The study of intercooler is also used in between refrigerator and air conditioner was investigated by Doyong and Jeong [7].

The adoption of diffuse and sub cooling techniques leads to increase in the COP of the system [8]. In this study, analytical method was attempted, and the results showed that improvement in the COP of the system obtained by 27.58%. Shashank et al. [9] discussed the different parameters, such as capillary tube length, bore diameter, coil pitch, number of twist and twist angle. It was found that pitch and diameter did not create any effect in case of helical coiled capillary tube. While, in case of serpentine coiled tube, pitch and diameter affected performance of the system. One relevant study was also carried out with different tube parameters by Nishant et al. [10] and showed there is a possibility to improve COP of the system. The ellipse shaped vapor coil was also used to increase the heat transfer rate [11]. This result showed that there was a minor decrease in system pressure, and COP was also improved. Researchers have been investigated the capillary tube at specific condition of adiabatic [12–14].

Al-Rashed [15] carried out the study on the investigation of performance by different refrigerants. Various other parameters, such as expansion device capacity, quantity of charge and ambient temperature were also examined [16]. Basha [17] studied the optimum condenser length for 165 L domestic refrigerator for different size condenser by experimental method. The result discussed that the COP found was 8.298 and 8.890 for condenser lengths of 6.1 m and 7.01 m, respectively. The maximum COP obtained was 8.51 at condenser length of 7.01 m.

Researches carried out the work mainly on to optimize the units of refrigerator and air conditioner which would overcome the problem of electricity consumption as well as environmental balance. It is toward the reduction in power consumption of the system [2].

Based on the reports shown that in actual working of refrigerator, compressor shuts off as the desired temperature is obtained by the system. The compressor of the refrigerator in the night period almost remains in non-working condition, and air conditioner is mostly used in the same time period. It is, therefore, the compressor can be utilized for the air conditioning purpose, and power consumption could be minimized.

The paper presents an attempt to investigate the power consumption of an air conditioner by using the compressor of refrigerator and analyze the power consumption of multifunctional systems.

1.2 Experimental Methodology

In order to investigate the performance parameter of an air conditioner running on a compressor of refrigerator with necessary modifications, the experimentation has been carried out. The experiments were conducted under two different cases: (i) Case-I: Existing refrigerator with indoor unit of air conditioner, and (ii) Case-II: Augmenting capillary unit with case-I.

In order to perform the investigation of performance parameters of the multifunctional systems, a refrigerator of 165 L capacity made by Voltas and air conditioner unit having capacity of 0.8 TR are selected. The compressor used is low capacity hermetically sealed refrigerator compressor. The detail specification of both units is provided in Table 1.1.

The mathematical expressions are used in calculation of performance parameters for both cases, and the detail of same is provided as [18].

$$\text{Mass flow rate} = 210/\text{RE} \tag{1.1}$$

$$\text{Refrigeration effect (RE)} = \text{Enthalpy difference of evaporator inlet and outlet,}$$
$$h_{eo} - h_{ei} \tag{1.2}$$

$$\text{Compressor work (Wc)} = \text{Enthalpy difference of compressor suction and discharge}$$
$$hc_{eo} - h_{ci} \tag{1.3}$$

Table 1.1 Detail of considered refrigerator and indoor unit of air conditioner for the study

Refrigerator	
Volume	165 L
Compressor input current	1.2 A
Compressor input voltage	230 V
Length of evaporator	381 mm
Length of condenser	660 mm
Indoor unit of air conditioner	
Capacity	0.8 TR
Length of evaporator	1270 mm
Blower motor rating	75 W
Air flow volume	16.5 m^3/h

1.2.1 Experimental Setup for Case-1

First, the performance test has been carried out on a single compartment refrigerator of 165 L volume with refrigerant R-12. And an indoor unit of air conditioner of 0.8 TR capacity is combined with the same. The concept of use of only indoor unit of air conditioner as available and the schematic diagram of case-1 is shown in Fig. 1.2.

The experimental setup was prepared in the laboratory, and the same picture is illustrated in Fig. 1.3.

It is clearly seen from Figs. 1.2 and 1.3, the experimental setup in which evaporator of air conditioner is connected parallel with refrigerator's evaporator by using only one capillary of refrigerator having 2743 mm length and 0.635 mm bore. Among four valves, two valves are provided at the ends of both evaporators 1 and 2 to separate systems for individual running. A cycle with capillary tube and evaporator-1 is for the refrigeration purpose and capillary and evaporator-2 is for air conditioning. If the system works as an air conditioner, the valves of evaporator-1 remain closed, and when it works as the refrigerator, the valves of evaporator-2 will remain closed.

After the completion of fabrication of system, it is evacuated and filled with refrigerant R-134a and observed the performance readings of pressure, temperature and air flow from constructed setup with four different considered cooling cabinet volumes of 44.4, 3.41, 2.25 and 1.15 m^3.

In order to implement the augmentation method with the case-1 system, one capillary tube is added with the same system and observed all same readings are considered as case-2.

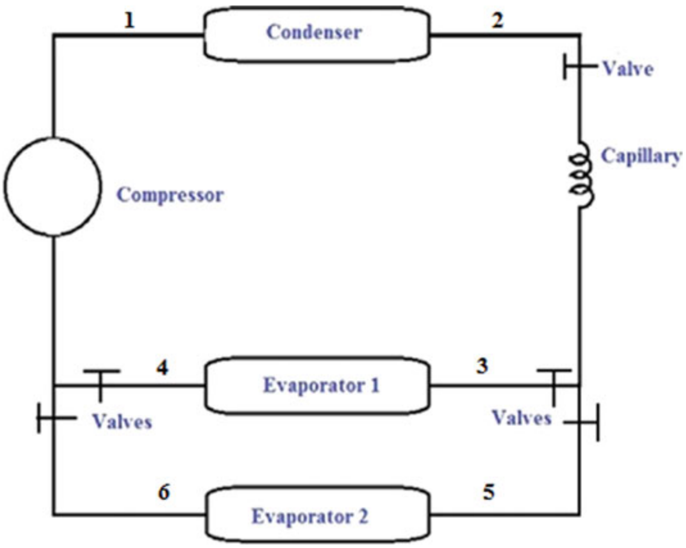

Fig. 1.2 Schematic diagram of system for case-1

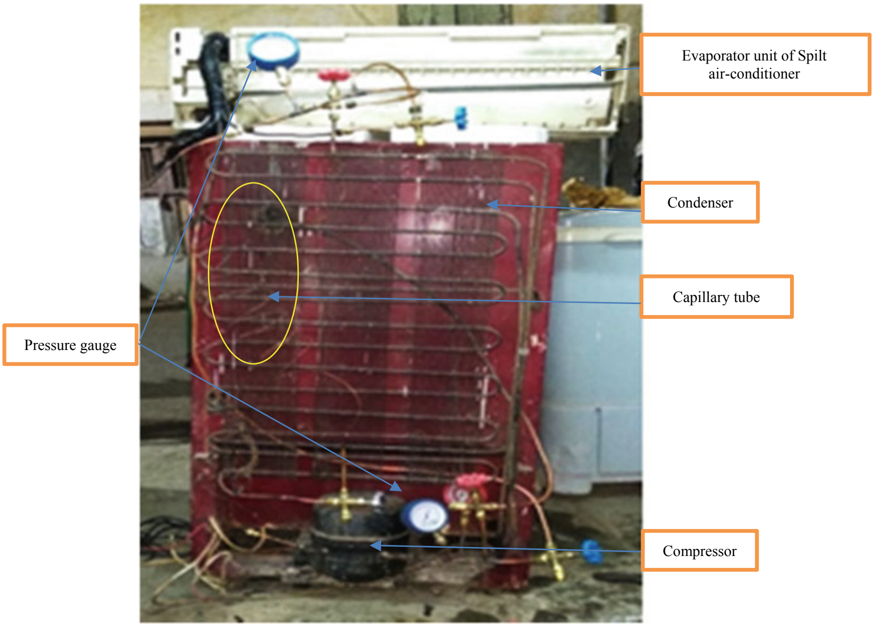

Fig. 1.3 Picture of complete experimental setup of case-1

1.2.2 Experimental Setup for Case-2

The schematic diagram of the case-2 is illustrated in Fig. 1.4. In this cycle, there are single compressor, single condenser, two capillary tubes and two evaporators. Additional capillary tube having 914 mm long and 1.397 mm bore is provided with existing capillary-1 of refrigerator. It also contains four valves at the inlet of capillary tube and at the inlet and outlet of both evaporators 1 and 2.

Moreover, the performance readings of pressure, temperature and air flow from constructed setup with four different control volumes of 44.4, 3.41, 2.25 and 1.5 m^3 have been observed. The photograph of capillary tube is used for case-2 is shown in Fig. 1.5.

The performance analysis and calculations were performed to investigate all the parameters of performance for the both case I and II conditions.

1.3 Result and Discussion

As a first step, the procedure of observation of reading was initiated with measurement of power consumption and other parameters of existing considered refrigerator of

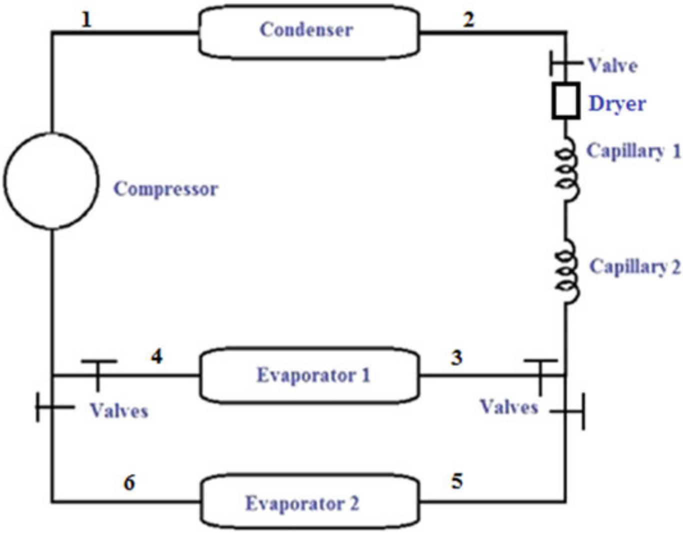

Fig. 1.4 Schematic diagram of system for case-2

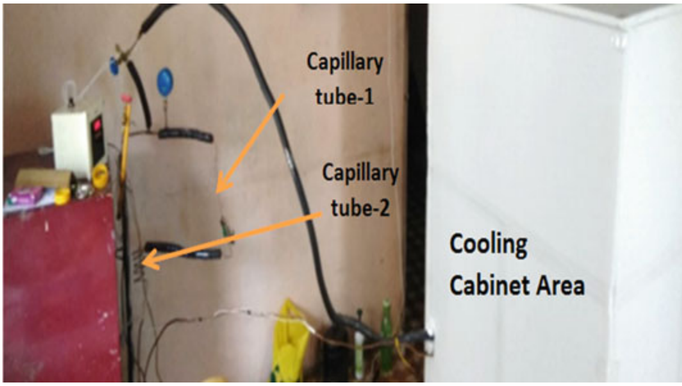

Fig. 1.5 Picture of complete experimental setup of Case-2

capacity 165 L. It has found that compressor requires 1.2 A and 230 V power. The primary readings were taken before the starting of experiment for two cases 1 and 2.

In first case, by considering the average load for two persons as 76.2 W and in volume of system is 44.4 m^3, an experiment was performed. In this case, two types of readings were taken, one is when the blower is OFF and other is with blower ON, and the readings were recorded after running of blower for 10 min. The summary of results case-1 is shown in Table 1.2.

Table 1.2 Summary results for case-1

S. No.	Parameters	Blower off	Blower on
1	Compressor suction pressure, P_1	207 kPa	341 kPa
2	Compressor discharge pressure, P_2	2034 kPa	2206 kPa
3	Evaporator inlet pressure, P_3	221 kPa	248 kPa
4	Atmosphere temperature, T_a	32 °C	32 °C
5	Condenser inlet temperature, T_1	87.5 °C	91.6 °C
6	Condenser outlet temperature, T_2	63.9 °C	67.5 °C
7	Refrigerator evaporator inlet temperature, T_3	6.6 °C	9.8 °C
8	Refrigerator evaporator outlet temperature, T_4	15.5 °C	10.3 °C
9	Air conditioner evaporator inlet temperature, T_5	6.8 °C	8.8 °C
10	Air conditioner evaporator outlet temperature, T_6	20.6 °C	35.5 °C

Based on the results measured, the obtained value of temperature at inlet of evaporator of air conditioner is 6.8 and 8.8 °C, when the blower is OFF and ON, respectively. Finally, it is concluded that the power consumption of compressor with case-I condition is current of 1.35 A and voltage of 230 V, i.e., 310.5 W h. It is slightly higher than the existing refrigerator consumption of 276 W h; however, it is 1/3rd times lesser compared to 0.8 TR air conditioner consumption.

The same procedure was adopted, and the readings were recorded for the case-2 condition. The summary of the results is provided in Table 1.3.

It is apparent from Tables 1.2 and 1.3 that suction and discharge of compressor as well as evaporator pressures were significantly noticed lower in case-2 than that of case-1 in the same atmospheric temperature. Addition of capillary tube also reduced temperature of condenser and temperature of both evaporators on both ends. The power consumption is found to be with case-2 condition is 315 W h. It is

Table 1.3 Summary result for case-2

S. No.	Parameters	Blower off	Blower on
1	Compressor suction pressure, P_1	124 kPa	172 kPa
2	Compressor discharge pressure, P_2	1703 kPa	1930 kPa
3	Evaporator inlet pressure, P_3	138 kPa	193 kPa
4	Atmosphere temperature, T_a	32 °C	32 °C
5	Condenser inlet temperature, T_1	73.9 °C	82.1 °C
6	Condenser outlet temperature, T_2	59.4 °C	64.1 °C
7	Refrigerator evaporator inlet temperature, T_3	1.5 °C	4.6 °C
8	Refrigerator evaporator outlet temperature, T_4	16.1 °C	30.4 °C
9	Air conditioner evaporator inlet temperature, T_5	2 °C	3.5 °C
10	Air conditioner evaporator outlet temperature, T_6	22 °C	34 °C

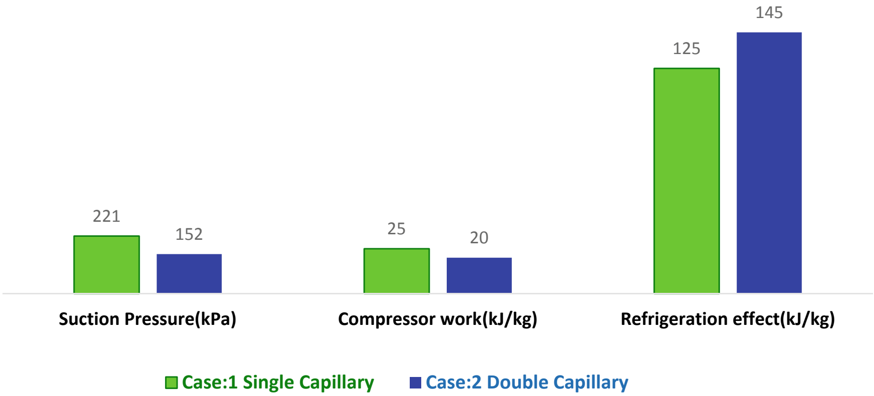

Fig. 1.6 Comparison between Case-1 and Case-2 for different parameters

minimum difference in value with case-1 condition. It leads to more refrigeration effects achieved with case-2 with the same power utilization.

Moreover, the similar sets of readings were also measured for the other cooling volumes as 3.41, 2.25 and 1.5 m^3. Figure 1.6 illustrates the comparison of results of suction pressure, theoretical compressor work and refrigeration effect for case-1 and case-2 condition. It is clearly shown in Fig. 1.6 that the suction pressure and theoretical compressor work are found to be less for case-2 compared with case-1. To achieve the same temperature across the evaporator, compressor consumes comparatively less work as additional capillary tube is provided. The refrigeration effect is found more to be 145 kJ/kg for case-2 compared to 125 kJ/kg of case-1. It may be due to augmented additional specific length of capillary tube with the case-1, and it leads to decrease the temperature. The percentage of refrigeration effect is achieved by 16% more in case-2.

In addition, the same parameters are observed with different considered cooling cabinet volumes to find the suitable area for optimum comfort condition. The result is shown in Fig. 1.7. It is clearly shown in figure that the refrigeration effect increases with cooling cabinet decrease for both cases.

It can clearly be seen from above reading that case-2 is more suitable condition for running the combined system. Considering the result analysis, the nine sets of reading were recorded after every 10 min with case-2 conditions for investigating the performance in long time period, and the recorded results are illustrated in Table 1.4.

It is seen from Table 6 last set of reading shows the maximum temperature difference of 8 °C between atmosphere and cabinet area as well as pressure difference of 2758 kPa. The system runs with 23 °C with air flow of 1.2 m/s, and 50% relative humidity was obtained without affecting the performance of actual refrigeration system.

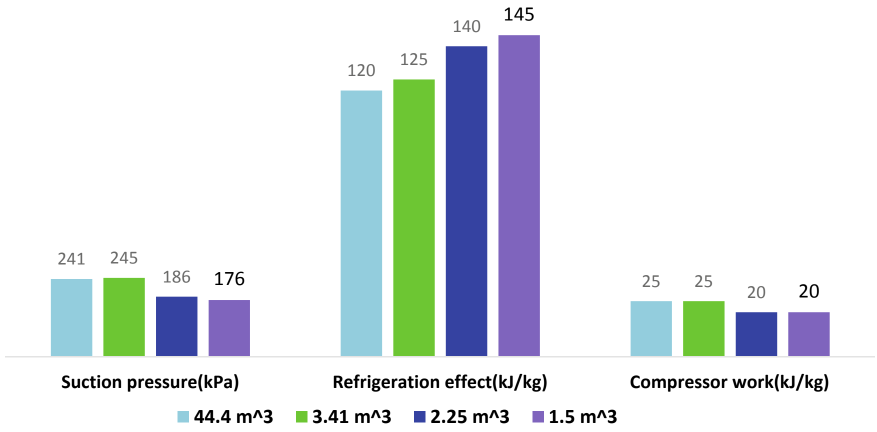

Fig. 1.7 Parameter variation for different volumes

Table 1.4 Results of Case-2

Set of readings	Compressor inlet pressure (kPa)	Compressor discharge pressure (kPa)	Atmospheric temperature (°C)	Cabinet temperature (°C)
1	241	2206	32	28
2	172	1620	34	32
3	172	1930	33	30
4	186	1862	34	33
5	290	2537	32	30
6	241	2275	32	28
7	207	1496	31	27
8	348	3103	34	23

1.4 Conclusion

An attempt has been made to investigate the feasibility for running the air conditioning evaporator unit by existing refrigerator system and concluded based on the experimental results that, a human comfort can be achieved by running a same cycle of refrigerator requires 230 V, with 1.2 A current requirement.

The following findings are drawn from the investigation:

(i) The system provides the temperature of 23 °C, air flow of 1.2 m/s and 50% of relative humidity without affecting the performance of actual refrigeration system.

(ii) The power consumption can be reduced to 1/3rd times of existing same capacity of air conditioner. This study may be more viable for small confined area.

(iii) However, there is a problem of compressor tripping. It could be eliminated by designing the proper components are to be proposed in future work.

References

1. U.V. Kongre, A.R. Chiddarwar, P.C. Dhumatkar, A.B. Aris, Testing and performance analysis on air conditioner cum water dispenser. Int. J. Eng. Trends Technol. (IJETT) **4**(4) (2013)
2. A.S. Dhunde, K.N. Wagh, P.V. Washimkar, An effective combined cooling with power reduction for refrigeration cum air conditioner, air cooler and water cooler: a review. Int. J. Eng. Res. General Sci. **4**(2), Mar-Apr 2016. ISSN 2091-2730 (2016)
3. Iyer, R., Gohil, P., Nagarsheth, H., Channiwala, S., Development of a vapor compression air conditioning system utilizing the waste heat potential of exhaust gases in automobiles. SAE Technical Paper 2005-01-3475 (2005). https://doi.org/10.4271/2005-01-3475.
4. P. Gohil, S.A. Channiwala, Feasibility of design and operation of exhaust driven turbine to run an air conditioning system. Adv. Mech. Eng. (AIME), New Delhi, pp. 888–893 (2006)
5. Himanshu, Upadhyay, K., Sehgal N., Jaraut, M., Gautam, P., Kalra, S., Gupta, S.K.: Feasibility study and development of refrigerator cum air conditioner. Int. J. Sci. Res. Publ. **4**(12) (2014). ISSN 2250-3153 (2014)
6. Liu, F., Huang, H., Yingjiang, M., Zhuang, R.: Research on the air conditioning water heater system. In: International Refrigeration and Air Conditioning Conference, paper 893 (2008)
7. H. Doyong, J.H. Jeong, Performance characteristics of a combined air-conditioner and refrigerator system interconnected via an intercooler. Int. J. Refrig. **49**, 57–68 (2015)
8. Upadhyay, N.: Analytical study of vapour compression refrigeration system using diffuser and sub cooling. IOSR J. Mech. Civil Eng. (IOSR JMCE). e-ISSN: 2278-1684, p-ISSN: 2320–334X, vol. 11, Issue 3 Ver. VII (May–June 2014), pp. 92–97 (2014)
9. Shashank, S., Chauhan, P. S.: Effect of capillary tube on the performance of a simple vapour compression refrigeration system. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278–1684, 11(3), pp. 05–07 (2014)
10. Tekade, N.P., Wankhede, U.S..: Selection of spiral capillary tube for refrigeration appliances. Int. J. Modern Eng. Res. (IJMER) **2**(3), 1430–1434 (2012).
11. Chandramouli, J., Sreedhar, C., Subbareddy, E.V.: Design, fabrication and experimental analysis of vapour compression refrigeration system with ellipse shaped evaporator coil. Int. J. Innov. Res. Sci. Eng. Technol. **4**(8) (2015)
12. P.K. Bansal, A.S. Rupasinghe, An empirical model for sizing capillary tubes. Int. J. Refrig. **19**, 497–505 (1996)
13. O. Garcia-Valladares, Review of numerical simulation of a capillary tube using refrigerant mixtures. Appl. Therm. Eng. **24**, 949–966 (2004)
14. C. Zhang, G. Ding, Approximate analytic solutions of adiabatic capillary tube. Int. J. Refrig. **27**, 17–24 (2004)
15. A.A.A.A. Al-Rashed, Effect of evaporator temperature on vapor compression refrigeration system. Alexandria Eng. J. **50**, 283–290 (2011)
16. E. Bjork, P. Bjorn, Performance of a domestic refrigerator under influence of varied expansion device capacity, refrigerant charge and ambient temperature. Int. J. Refrig. **29**, 789–798 (2006)
17. Basha, T. M.: Optimum length of a condenser for domestic vapor compression refrigeration system. Int. J. Sci. Eng. Technol. Res. (IJSETR) **4**(2) (2015)
18. ASHRAE Handbook Fundamental (1997)

Chapter 2
Stabilizing Molten Salts Through Additives for High Temperature CSP Applications

Siddhesh C. Pawar, Varun Shrotri, and Luckman Muhmood

Abstract Solar salt, an equimolar concentration of KNO_3 and $NaNO_3$ is currently being used as the heat transfer fluid in concentrating solar power plants. It decomposes around 600 °C. Hitec® salt, another potential salt mixture, is not stable beyond 538 °C. There has been work directed toward improving its high temperature stability of Hitec® salt by adding a chloride component. It was observed that the stability of the mixture increased by 50 °C enabling its use at temperatures above 600 °C. A new ternary mixture comprising of $Ca(NO_3)_2$–KNO_3–$NaNO_3$ termed as "Base salt" was prepared in the lab which has a significantly lower freezing temperature (145 °C), and the high temperature stability is above 600 °C. In the current work, additions of other components like NaCl, KCl, LiCl, and $CaCl_2$ in various proportions were done to the Base salt and the thermogravimetric studies were carried out in a custom-made TGA set up to analyze any further improvement in high temperature stability of the mixture. Among all the chloride additions, 5% sodium chloride (NaCl) and 5% NaCl + 5% KCl addition by weight to the Base salt proved to be most promising.

Keywords CSP · Molten nitrate salt · Thermal stability

2.1 Introduction

Solar energy is one of the best alternatives to produce electric energy in more sustainable manner. Solar radiation can be directly converted into electricity by means of solar-photovoltaic cells. The indirect conversion of solar energy into electrical energy is achieved by concentrated solar power plants (CSP's). In this technology, the solar

S. C. Pawar (✉) · V. Shrotri · L. Muhmood
Department of Mechanical Engineering, K.J. Somaiya College of Engineering, Vidyavihar, Mumbai 400077, India
e-mail: pawar.sc@somaiya.edu

V. Shrotri
e-mail: varun.shrotri@somaiya.edu

L. Muhmood
e-mail: luckman@somaiya.edu

P. V. Baredar et al. (eds.), *Advances in Clean Energy Technologies*,
Springer Proceedings in Energy, https://doi.org/10.1007/978-981-16-0235-1_2