DESIGN AND ANALYSIS OF EJECTOR AS AN EXPANSION DEVICE IN A SPLIT-TYPE AIR CONDITIONER

SUMERU

A thesis submitted in the fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

FEBRUARY 2015

Dedicated to:
My beloved wife Retno Dewi Setyawati, and
my sons: Husain Akbar Sumeru, Hamzah Kalam Sumeru,
Hassan Muhammad Sumeru and Hisyam Albana Sumeru

My parents:
Kasni and Ning Soeharti

My brothers and sisters:
Haryono, Agus Suharyanto, Susilowati and Sri Supeni

ACKNOWLEDGEMENT

All praise due to Allah the Almighty, the Beneficent the Merciful, for all His bounties and blessings throughout my life and in particular during the course of preparing the thesis. Blessings and peace of Allah be upon Prophet Muhammad and his families, through his teachings and examples I learn and gain success in this life and in the hereafter.

I am also very appreciative of my wife Retno Dewi Setyawati for her understanding and support throughout the duration of my study in PhD program. I would also like to thank to my brothers and sisters who have given me their support throughout all along.

This work would not have been possible without the help and support of many people. I would also like to acknowledge Universiti Teknologi Malaysia, Faculty of Mechanical Engineering and Thermodynamics Laboratory for allowing me to use the research facilities.

I would like to express my deepest appreciation and gratitude to my thesis advisors Prof. Dr. Farid Nasir Ani and Dr. Henry Nasution. Sheriff for their respective valuable guidance, advice, discussion and feedback throughout the years of working together. I would like to also thank all technicians from Thermodynamic Laboratory of UTM especially Mr. Abdul Halim Bin Abdul Rahman who helps in installing the experiment rig. Also, my thanks goes to my friends and collecgues, namely Dr. Shodiya Sulaiman, Dr. V. Ashokkumas and Abioye Adekunle Moshood. My gratitude to all of them and I pray may Allah bless each and every one of them.

ABSTRACT

Split-type air-conditioners are widely used in residential and commercial buildings. The air-conditioning system consumes more than 50% of the total energy in buildings. An improvement on the performance of the system will generate a significant impact on energy savings. This study introduces a novel cycle using an ejector as expansion device in an air-conditioner to improve the performance. This cycle is named as a modified ejector cycle (MEC). R22 is widely used as refrigerant in split-type air-conditioners, however due to its global warming impact, researchers recommended R290 as a substitute. Thermodynamic modeling was developed to determine the motive nozzle and mixing chamber diameters of the ejector based on the cooling capacity of the air-conditioner. In the modeling, the conservation equations of mass, momentum and energy were applied. The result shows that the COP improvements of MEC using R290 were higher than that of R22 for all ambient temperatures. The COP improvement using R290 are 34.52, 39.53 and 47.58% at the ambient temperatures of 30, 35 and 40^{o}C, respectively. Experiments were carried out on a split-type air-conditioner using a capillary tube (standard cycle) and MEC with three motive nozzle diameters, i.e. 0.9, 1.0, and 1.1 mm. The measurements were carried out at the steady-state condition and repeated five times with 2 minutes interval. Experimental results show that the highest COP improvement of MEC was achieved with a motive nozzle diameter of 1.0 mm that is 30.67%. The results also show that the COP improvements of MEC using R22 are 24.69, 26.06 and 32.12%, whereas using R290 were 27.68, 31.53 and 33.61%, at the ambient temperatures of 30, 35 and 40^{o}C, respectively. This indicates that replacing the R22 with R290 can further enhance the COP improvement of the MEC. Comparison between numerical and experimental results showed poor agreement due to large difference in the entrainment ratio of the ejector.

ABSTRAK

Penghawa dingin jenis-terpisah digunakan secara meluas dalam bangunan kediaman dan komersial. Sistem penghawa dingin menggunakan lebih 50% daripada jumlah penggunaan tenaga bangunan. Peningkatan kepada prestasi sistem akan menjana kesan yang ketara kepada penjimatan tenaga. Kajian ini membentangkan suatu kitaran baharu menggunakan ejektor sebagai injap pengembangan pada penghawa dingin untuk meningkatkan prestasi. Kitaran ini dinamakan sebagai kitaran ejektor diubahsuai (MEC). R22 digunakan secara meluas sebagai bahan penyejuk dalam penghawa dingin jenis-terpisah, bagaimanapun disebabkan oleh kesan pemanasan global, para penyelidik mensyorkan R290 sebagai bahan penyejuk penggantinya. Pemodelan termodinamik telah dibangunkan untuk menentukan garis pusat daripada nozel masuk dan ruang pencampuran ejektor berdasarkan kapasiti penyejukan penghawa dingin. Pada pemodelan, persamaan pemuliharaan jisim, momentum dan tenaga digunakan. Keputusan menunjukkan bahawa peningkatan COP daripada MEC menggunakan R290 adalah lebih tinggi berbanding dengan R22 untuk semua suhu sekeliling. Peningkatan COP menggunakan R290 adalah 34.52, 39.53 dan 47.58% pada suhu sekeliling 30, 35 dan 40^oC. Uji kaji telah dijalankan ke atas kitaran piawai yang menggunakan tiub kapilari dan juga MEC dengan tiga garis pusat nozel masuk, iaitu 0.9, 1.0 dan 1.1 mm. Pengukuran dijalankan pada keadaan mantap dan diulang sebanyak lima kali dengan selang 2 masa minit. Keputusan uji kaji menunjukkan bahwa peningkatan COP tertinggi dicapai dengan garis pusat nozel masuk 1.0 mm iaitu sebanyak 30.67%. Uji kaji menunjukkan bahawa MEC dengan menggunakan R22 sebagai cecair penyejuk meningkatkan COP pada kadar 24.69, 26.06 dan 32.12%, sedangkan menggunakan R290 pula memberikan 27.68, 31.53 dan 33.61%, pada suhu sekeliling 30^oC, 35^oC dan 40^oC. Hasil ini menunjukkan bahawa penggantian R22 kepada R290 boleh meningkatkan lagi COP daripada MEC. Perbandingan antara keputusan kaedah berangka dan uji kaji menunjukkan terdapat perbezaan di antara dua keputusan tersebut kerana perbedaan yang tinggi pada nisbah kemasukan ejektor.

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LIST OF ABBREVIATIONS

A/C - air conditioner
AR - area ratio
COP - coefficient of performance
EERC - ejector-expansion refrigeration cycle
ERC - ejector refrigeration cycle
I - current
MEC - modified ejector cycle
P - pressure
PW - input power
R - Refrigeration
SC - standard cycle
SEC - standard ejector cycle
VCRC - vapor compression refrigeration cycle
V - voltage
W - compressor work

LIST OF SYMBOLS

h - specific enthalpy (kJ/kg)

$\dot{m}$ - mass flow rate of refrigerant (k/s)

R - gas constant

T - temperature (^{o}C)

T_H - High temperature (K)

T_L - Low temperature (K)

u - uncertainty

η - efficiency

ω - entrainment ratio of ejector

Subcript

1,2, …, n - Measurement points

abs - absolute

cond - condenser

ca - constant-area

comp - compressor

dif - diffuser

evap - evaporator

ejt - ejector

exp - expansion

f - liquid

g - gas

imp - improvement

in - input

mc - mxing chamber

mn - motive nozzle

o - outdoor

r - room

red - reduction

rjt - rejected

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CHAPTER 1

INTRODUCTION

1.1 Background

The air-conditioner uses approximately 57% of the total energy consumption in buildings in Malaysia (Saidur, 2009). More than that, in commercial building, such as five star hotels in India, air-conditioning systems consumes about 80% of the total energy (Ananthanarayanan, 2006). As a result, an improvement on the coefficient of performance (COP) of air-conditioner will generate a significant impact on energy savings. The use of ejector as an expansion device in the vapor compression refrigeration cycle (VCRC) is a method to increase performance and to reduce power consumption system.

Typically, the split-type air-conditioner (A/C) uses a capillary tube device as an expansion device. Due to energy loss during expansion process, the pressure drop from the condenser and evaporator pressure is considered constant enthalpy (isenthalpic), because during the process generates energy losses (entropy generation). To reduce the energy losses during throttling are required a process that generates as small as possible entropy generation. In other words, the process during expansion is almost entropy constant or isenthalpic. An ejector can be used to transform isenthalpic to isentropic in the expansion process. The advantages of an ejector as an expansion device to improve the COP have been demonstrated by several researchers. Numerical and experimental analysis showed that replacing a conventional expansion device with an ejector generates COP improvement on the VCRC. In this study, the ejector as an expansion device in refrigeration systems that have been investigated by many researchers called standard ejector cycle (SEC). Meanwhile, a novel cycle named modified ejector cycle (MEC) is introduced in this research to enhance the COP improvement produced by the SEC. The main advantage of MEC compared to SEC is the amount of refrigerant which flows through the evaporator. In the MEC, all refrigerant in the system flow through the evaporator, while in the SEC, the amount of refrigerant flows through the evaporator depending on entrainment ratio of the ejector.

The experimental results of effect of motive nozzle diameter on an ejector as expansion device in an air-conditioner were reported by Chaiwongsa and Wongwises (2007). In their experiment, they used three diameters of motive nozzle, viz. 0.8, 0.9 and 1.0 mm with R134a as working fluid. They reported that the motive nozzle with diameter of 0.8 mm resulted in the highest COP. However, they did not explain the numerical modeling how to determine the motive nozzle diameter. This research will describe a numerical modeling how to determine the motive nozzle and mixing chamber diameter based on cooling capacity of air-conditioner . A better understanding of geometric parameter effect on an ejector is required to obtain the minimum energy losses during the throttling process. Also, because the split-type A/C may be installed in geographical areas which have outdoor temperature from medium to hot, as a result, the ambient temperature on the condenser will be varied, that is, 30^{o}C, 35^{o}C and 40^{o}C. The objective of the ambient temperature variation is to investigate its effect to COP improvement.

The working fluid R22 family of HCFCs (hydro-chlorofluorocarbons) is the most widely used as the working fluid in split-type air-conditioner s. Because of the negative impact on the environment, many countries have accelerated the phase out of using HCFC22 (R22) as working fluid. Europe and Japan have banned the import of air-conditioner s using R22 since January 1st, 2004. In the developing countries, such as China, have started to reduce the use of R22 in 2012, and will ban the use of R22 in air-conditioner s industry from 2040 (Chen, 2008). In addition, in the developed countries, the use of HCFCs has already been phased out in new equipment for below 100 kW capacities, in 2002. Furthermore, the total phase out of HCFCs is scheduled for 2015 in developed countries. Hydrocarbons (HCs) are a refrigerant alternative to replace HCFCs.

In addition, replacing R22 with hydrocarbon refrigerant, i.e. propane (R-290) is recommended by Loretzen (1995). As a result, there are two working fluids will be used in this study, i.e. R22 and R290. Besides as a green working fluid, the use of R290 replacing R22 in the standard refrigeration system could improve the COP (Lorentzen, 1995; Urchueguia, 2004; Devotta, et at., 2005).

The geometric parameters of the ejector that used on the experimental are determined by thermodynamics modeling. Based on the developed model, the exergy analysis will be carried out on the SEC and MEC.

1.2 Problem Statement

Increasing the economic community causes increasing energy use. Because the energy consumed by the refrigeration system is quite high, so efforts to enhance the performance of the refrigeration system are needed. The ejector as an expansion device is one of the alternatives is used to enhance e the performances of the VCRC.

In the SEC, the working fluid that flows out from diffuser enters to a separator. From the separator, the working fluid is distributed to the compressor and the evaporator. Vapor phase of the working fluid from the separator flows into suction of the compressor, whereas liquid phase flows through the separator. Due to not all the working fluid flows through evaporator resulting decrease in cooling capacity. Also, because the separator is close to the compressor suction resulting in most of the working fluid tends to flow into the compressor and only a small portion which flows through the evaporator. As a result, the cooling capacity and COP tends to decrease.

To overcome the drawback of the SEC, a novel cycle, that is, the MEC is developed. The difference between SEC and MEC is located at the separator. In the SEC, the separator has an inlet that flow refrigerant from the ejector and two outlets that flow out the vapor refrigerant to compressor suction and liquid refrigerant to the evaporator.

Meanwhile, in the MEC, the separator only has an inlet and an outlet. All of the working fluid from the separator flow through the evaporator; as a result the cooling capacity increases compared to the SEC.

Air-conditioner may be installed in the areas which have medium to high ambient temperature. It is well known that the COP of air-conditioner s will decrease with increase in the ambient temperature. As a result, besides to determine diameters of motive nozzle and mixing chamber of an ejector, the numerical analysis also investigates the effect of ambient temperature to the COP improvement on the air-conditioner using an ejector as an expansion device. Thermodynamics analysis in the SEC showed that the COP improvement yielded above 20% for certain working fluids (Kornhauser, 1990; Bilir and Ersoy, 2009; Sarkar, 2010). However, none of the experimental results generates COP improvement over 10% (Wongwises and Disawas, 2005; Elbel and Hrnjak, 2008; Elbel, 2011). The present study introduces a novel cycle using ejector as an expansion device based on the SEC modification, called the MEC. The novel cycle is to enhance the COP improvement of the standard ejector cycle. To obtain optimum results, the dimensions of the motive nozzle and mixing chamber are calculated using three equations, i.e., conservation of mass, energy and momentum.

To the best of author’s knowledge, the geometric parameters analysis of an ejector based on the cooling capacity of the air-conditioner is still relatively scarce. This study will complete and enhance previous research. In addition, losses energy in each component, such as the compressor, expansion valve, ejector, evaporator and condenser can be calculated by exergy analysis.

1.3 Objective of Study

There are two refrigerants that will be investigated in this study, namely R22 and R290. Working fluid R22 is the most widely used as the working fluid in split-type air-conditioner s, whereas R290 as a green refrigerant was considered to be long-term alternative refrigerant for replacing R22. Also, it is not yet available in open literature data for determining motive nozzle and mixing chamber diameters of an ejector in the split-type A/C based on the cooling capacity and ambient temperature. As a result, using thermodynamics model and experimental on the split-type A/C, the objectives of the study are:

1. To develop a numerical correlation on motive nozzle and mixing chamber diameters of an ejector based on the cooling capacity of the air-conditioner.
2. To investigate the performance of a novel cycle, that is MEC, in a split-type air-conditioner using R22 and R290 as working fluid.
3. To validate the thermodynamic modeling of the use of an ejector as expansion device in a split-type air-conditioner with experimental data.

1.4 Scope of Research

An ejector is utilized to reduce energy losses during expansion process in a capillary tube. Most of split-type air-conditioner use capillary tube as an expansion device, as a result, replacing a capillary tube with an ejector will improve the performance of the air-conditioner. Thermodynamic modeling is used to determine the motive nozzle and mixing chamber diameters which are applied in the experiment. The COP improvement of the ejector-expansion system is influenced by geometry of an ejector. The motive nozzle and mixing chamber diameters are the most important of ejector geometric parameters. In developing the model, conservation laws of mass, momentum and energy equations were applied to each part of the ejector. Also, based on the thermodynamic modeling, the performances of the air-conditioner using a capillary tube and an ejector as expansion device are able to be determined. Experiment will be performed to validate the numerical model. Furthermore, the scopes of this research are:

1. Building an experimental rig of a split-type air-conditioner using standard cycle (SC), standard ejector cycle (SEC) and modified ejector cycle (MEC) with R22 and R290 as working fluid.
2. To collect experimental data to determine the performance of the air-conditioner using SC, SEC and MEC with varying ambient temperature.
3. To validate the developed modeling with the experimental data.

1.5 Thesis Outline

There are five chapters in the present study. Chapter 1 presents the introduction that highlights the importance of the study.

Chapter 2 presents the literature review. This chapter describes a comprehensive review of two-phase ejector as an expansion device in the VCRC over the past two decades. The chapter also covers research opportunities that are still open in the ejector as an expansion valve. In addition, the effect of the ambient temperature and working fluid on the ejector as an expansion in the VCRC is covered.

Chapter 3 presents the research methodology. This chapter describes a thermodynamics modeling and experimental methodology on the SC, SEC and MEC. In developing the model, conservation laws of mass, momentum and energy equations were applied to each part of the ejector. This chapter calculates diameters of motive nozzle and mixing chamber based on the cooling capacity of the A/C. Based on the numerical modeling of dimension of the ejector, the COP improvement and irreversibility of each component of the SEC and MEC can be determined. Also, this chapter presents the experimental procedure and system characteristic. The development of experiment rig, test conditions and procedures of collecting data are also explained.

Chapter 4 presents the experimental results and discussion. This chapter explains the analysis of experiment results compared to numerical modeling. Statistical analyses are performed to calculate the percentages of the experimental uncertainties.

Chapter 5 presents the conclusions and recommendation for the future works.

REFERENCES

Abdulateef, J. M., Sopian, K., Alghoul, M. A. and Sulaiman, M. Y. (2009). Review on solar-driven ejector refrigeration technologies. *Renewable and Sustainable Energy Reviews*. 13(6-7): 1338-1349.

Al-Klalidy, N. (1997). Performance of solar refrigeration ejector refrigerating machine. *ASHRAE Transactions*. 103(1): 56-64.

Ananthanarayanan, P. N. (2006). *Basic refrigeration and air conditioning*. Third edition, New Delhi: Tata McGraw-Hill Publishing Company Limited.

Aphornratana, S., Chungpaibulpatana, S. and Srikhirin, P. (2001). Experimental investigation of an ejector refrigerator: Effect of mixing chamber geometry on system performance. *International Journal of Energy Research*. 25(5): 397-411.

Arora, C. P. (2001). *Refrigeration and Air Conditioning*. Third ed., Singapore: McGraw-Hill.

ASHRAE (1979). *Equipment Handbook. Steam-jet Refrigeration Equipment*. Chapter 13, Atlanta, GA, USA American of Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

ASHRAE (1983). *Equipment Handbook. Steam-jet Refrigeration Equipment*. Chapter 13. 3.1-13.6, Atlanta, GA, USA American of Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

ASHRAE (1997). *Handbook of Fundamental*. Atlanta, GA, USA American of Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

ASHRAE (1998). *Handbook of Refrigeration*. Atlanta, GA, USA: American of Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

Banasiak, K. and Hafner, A. (2011). 1D Computational model of a two-phase R744 ejector for expansion work recovery. *International Journal of Thermal Science*. 50: 2235-2247.

Bell, S. (2001). *Measurement Good Practice Guide No. 11 (Issue 2): A Beginner's Guide to Uncertainty of Measurement*. Issue 2, National Physical Laboratory, Teddington, Middlesex, United Kingdom, TW11 OLW.

Bergander, M. J. (2006). Refrigeration cycle with two-phase condensing ejector. *International Refrigeration and Air Conditioning Conference. Purdue University,* July 17-20, R0008, 1-8.

Bergander, M. J., Butrymowics, D., Smierciew, K. and Karwacki, J. (2010). Refrigeration cycle with ejector for second step compression. *International Refrigeration and Air Conditioning Conference at Purdue,* July 12-15, R2211, 1-8.

Bilir, N. and Ersoy, H. K. (2009). Performance improvement of the vapour compression refrigeration cycle by a two-phase constant area ejector. *International Journal of Refrigeration*. 33(5): 469-480.

Chaiwongsa, P. and Wongwises, S. (2007). Effect of throat diameters of the ejector on the performance of the refrigeration cycle using a two-phase ejector as an expansion device. *International Journal of Refrigeration*. 30(4): 601-608.

Chunnanond, K. and Aphornratana, S. (2004). Ejectors: applications in refrigeration technology. *Renewable and Sustainable Energy Reviews*. 8(2): 129-155.

Chang, V., Gravalos, J. and Chitty, A. (1986). Thermal performance of an ejector-compressor colar cooling system. *Proceeding of the Ninth Biennial Congress of the International Solar Energy Society*, Montreal, Canada, 744-748.

Chen, X., Zhou, Y. and Yu, J. (2011). A theoretical study of an innovative ejector enhanced vapor compression heat pump cycle for water heating application. *Energy and Buildings*. 43(12): 3331-3336.

Chen, W. (2008). A comparative study on the performance and environmental characteristics of R410A and R22 residential air conditioners. *Applied Thermal Engineering*. 28(1): 1-7.

Chen, Y. M. and Sun, C. Y. (1997). Experimental study of the performance characteristics of a steam-ejector refrigeration system. *Experimental Thermal and Fluid Science*. 15(4): 384-394.

Dahmani, A., Aidoun, Z. and Galanis, N. (2011). Optimum design of ejector refrigeration systems with environmentally benign fluids. *International Journal of Thermal Sciences*. 50(8): 1562-1572.

Deng, J. Q., Jiang, P. X., Lu, T. and Lu, W. (2007). Particular characteristics of transcritical CO_2 refrigeration cycle with an ejector. *Applied Thermal Engineering.* 27(2-3): 381-388.

Devotta, S., Padalkarb, A.S. and Sane, N.K. (2005). Performance assessment of HC290 as drop-in substitute to HCFC22 in a window air conditioner. *International Journal of Refrigeration* 28: 594-604.

Diaz, N. F. (2009). Methodology for uncertainty calculation of net total cooling effect estimation for rating room air conditioners and packaged terminal air conditioners. *International Journal of Refrigeration*. 32(6): 1472-1477.

Dincer, I. (2003). *Refrigeration Systems and Applications*. Chichester, England: John Wiley & Sons.

Disawas, S. and Wongwises, S. (2004). Experimental investigation on the performance of the refrigeration cycle using a two-phase ejector as an expansion device. *International Journal of Refrigeration*. 27(6): 587-594.

Dossat, R. J. (1991). *Principles of Refrigeration, Prentice Hall, New Jersey, USA.*

Eames, I. W., Aphornratana, S. and Haider, H. (1995). A theoretical and experimental study of a small-scale steam jet refrigerator. *International Journal of Refrigeration*. 18(6): 378-386.

Elbel, S. and Hrnjak, P. (2008). Experimental validation of a prototype ejector designed to reduce throttling losses encountered in transcritical R744 system operation. *International Journal of Refrigeration*. 31(3): 411-422.

Elbel, S. and Hrnjak, P. (2008). Ejector Refrigeration: an overview of historical and present developments with an emphasis on air-conditioning applications. *International Refrigeration and Air Conditioning Conference, Purdue University*, July 14-17, Paper 884, 1-8.

Elbel, S. (2011). Historical and present developments of ejector refrigeration systems with emphasis on transcritical carbon dioxide air-conditioning applications. *International Journal of Refrigeration*. 34(7): 1545-1561.

Ersoy, H. K. and Bilir, N. (2010). The influence of ejector component efficiencies on performance of Ejector Expander Refrigeration Cycle and exergy analysis. *International Journal of Exergy*. 7: 425-438.

Gay, N. H. (1931). *Refrigerating system*. US Patent: No.1,836,318.

Harrel, G. S. and Kornhauser, A. A. (1995). Performance test of two-phase ejector. *Proceeding of the 30th Intersociety Energy Conversion Engineering Conference*, Orlando, FL, 49-53.

He, S., Li, Y. and Wang, R. Z. (2009). Progress of mathematical modeling on ejectors. *Renewable and Sustainable Energy Reviews*. 13(8): 1760-1780.

Huang, B. J. and Chang, J. M. (1999). Empirical correlation for ejector design. *International Journal of Refrigeration*. 22(5): 379-388.

Huang, B. J., Chang, J. M., Wang, C. P. and Petrenko, V. A. (1999). A 1-D analysis of ejector performance. *International Journal of Refrigeration*. 22(5): 354-364.

Jones J. B. and Hawkins G.A. (1986). *Engineering Thermodynamics: An Introduction Textbook*, second ed., John Wiley & Sons, Inc., New York, 1986.

Keenan, J. H. and Neumann, E. P. (1942). A simple air ejector. *ASME Journal of Applied Mechanics*. 64: 75-82.

Keenan, J. H., Neumann, E. P. and Lustwerk, F. (1950). An investigation of ejector design by analysis and experiment. *ASME Journal Applied Mechanics*. 17: 299-309.

Kemper, G. A., Harper, G. F. and Brown, G. A. (1966). *Multiple phase ejector refrigeration system*. US Patent No.3,277,660.

Kornhauser, A. A. (1990). The use of an ejector as a refrigerant expander. *Proceeding of the USN/IIR-Purdue Refrigeration Conference*, West Lafayette, IN, USA, 10-19.

Kwong, Q. J. and Ali, Y. A. (2011). A review of energy efficiency potentials in tropical buildings – Perspective of enclosed common areas. *Renewable and Sustainable Energy Reviews* 15(9): 4548-4553.

Levy, A. Jelinek, M., and Borde, I. (2002). Numerical study on the design parameters of a jet ejector for absorption systems. *Applied Energy*. 72(4): 467-478.

Li, D. and Groll, E. A. (2005). Transcritical CO_2 refrigeration cycle with ejector-expansion device. *International Journal of Refrigeration*. 28(5): 766-773.

Liu, J. P., Chen, J. P. and Chen, Z. J. (2002). Thermodynamic analysis on transcritical R744 vapor compression/ejection hybrid refrigeration cycle. *The Fifth IIR Gustav Lorentzen Conference on Natural Working Fluid*, Guangzhou, China, 184-188.

Lorentzen, G. (1995). The use of natural refrigerants: a complete solution to the CFC/HCFC predicament, Int. J. Refrig. 18(3): 190-197. *International Journal of Refrigeration*. 18(3): 190-197.

Lucas, C. and Koehler, J. (2012). Experimental investigation of the COP improvement of a refrigeration cycle by use of an ejector. *International Journal of Refrigeration*. 35: 1595-1603.

Menegay, P. and Kornhauser, A. A. (1996). Improvement to the ejector expansion refrigeration cycle. *Proceeding of the Intersociety Energy Conversion Engineering Conference*, Washington DC, 702-706.

Nakagawa, M., Marasigan, A. R., Matsukawa, T. and Kurashina, A. (2011). Experimental investigation on the effect of mixing length on the performance of two-phase ejector for CO_2 refrigeration cycle with and without heat exchanger. *International Journal of Refrigeration*. 34(7): 1604-1613.

Nehdi, E., Kairouani, L. and Bouzaina, M. (2007). Performance analysis of the vapour compression cycle using ejector as an expander. *International Journal of Energy Research*. 31(4): 364-375.

Newton, A. B. (1972a). *Capacity control for multiphase-phase ejector refrigeration system*. US Patent No. 3,670,519.

Newton, A. B. (1972b). *Controls for multiphase-phase ejector refrigeration system*. US Patent: No. 3,701,264.

Ozaki, Y., Takeuchi, H. and Hirata, T. (2004). Regeneration of expansion energy by ejector in CO_2 cycle. *Proceeding of Sixth IIR Gustav Lorentzen Conference on Natural Working Fluid*, Glasgow, UK, 11-20.

Pita, E. G. (2002). *Air Conditioning Principles and Systems: An Energy Approach*. Fourth ed., New York: Prantice Hall. Pridasawas, W. (2006). *Solar-driven refrigeration system with focus on the ejector cycle*. Sweden, Royal Institute of Technology: PhD Thesis.

Saidur, R. (2009). Energy consumption, energy savings, and emission analysis in Malaysia office buildings. *Energy Policy*. 37(10): 4104-4113.

Sarkar, J. (2010). Geometric parameter optimization of ejector-expansion refrigeration cycle with natural refrigerants. *International Journal of Energy Research*. 34(1): 84-94.

Selvaraju, A. and Mani, A. (2006). Experimental investigation on R134a vapour ejector refrigeration system. *International Journal of Refrigeration*. 29(7): 1160-1166.

Stoecker, W. F. (1988). *Industrial Refrigeration. Troy*. Troy, MI: Business News Publishing Corporation.

Urchueguia, J.F., Corberan, J.M., Gonzalvez J. and Diaz, J.M. 2004. Experimental characterization of a commercial-size scroll and reciprocating compressor working with R22 and propane (R290) as refrigerant. *Ecobirium Journal of AIRAH* 23-25.

Wongwises, S. and Disawas, S. (2005). Performance of the two-phase ejector expansion refrigeration cycle. *International Journal of Heat and Mass Transfer*. 48(19-20): 4282-4286.

Yapıcı, R., Ersoy, H. K., Aktoprakoğlu, A., Halkacı, H. S. and Yiğit, O. (2008). Experimental determination of the optimum performance of ejector refrigeration system depending on ejector area ratio. *International Journal of Refrigeration*. 31(7): 1183-1189.

Yari, M. and Sirousazar, M. (2008). Cycle improvements to ejector-expansion transcritical CO_2 two-stage refrigeration cycle. *International Journal of Energy Research*. 32(7): 677-687.

Zhou, G. and Zhang, Y. (2010). Performance of a split-type air conditioner matched with coiled adiabatic capillary tubes using HCFC22 and HC290. *Applied Energy*. 87(5): 1522-1528.

Zhu, Y. and Li, Y. (2009). Novel ejector model for performance evaluation on both dry and wet vapors ejectors. *International Journal of Refrigeration*. 32(1): 21-31.