PERFORMANCE MODELLING OF REFRIGERANTS IN A VAPOR COMPRESSION REFRIGERATION CYCLE

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PERFORMANCE MODELLING OF REFRIGERANTS IN A VAPOR COMPRESSION REFRIGERATION CYCLE

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This project report is submitted as a part of the
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NOVEMBER, 2005

DECLARATION

"I declare that this thesis is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any degree"

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Istimewa Buat Suami Tersayang,

Md Norrizam Mohd Jaat

" terima kasih atas sokongan dan doronganmu"

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ABSTRACT

The simulation model based on the actual vapor compression cycle is performed in order to evaluate the performance of 14 refrigerants in terms of first law and second law efficiency. A 10% pressure drop is modelled in both the condenser and evaporator. The refrigerants that have been evaluated include R12, R22, R502, and their alternatives R134A, R401A, R401B, R402A, R402B, R404A, R407C, R410A, R408A, R409A, and R507. Effects of evaporating and condensing temperature on the COP, second law efficiency and irreversibility have been studied. The evaluation results show that R401A, R401B, and R409A are predicted as the best replacements for R12. R410A is predicted as the best alternative for R22, while R402B, R407C, and R408A are the best alternatives for R502 in terms of COP and second law efficiency. The results of actual cycle model show better predictions than that obtained with the ideal cycle model.

ABSTRAK

Model simulasi berdasarkan kitar pemampatan wap sebenar telah dihasilkan bagi tujuan menilai prestasi 14 bahan pendingin dari aspek kecekapan hukum pertama dan kedua. Kedua-dua pemeluwap dan penyejat telah dimodelkan dengan mempunyai kejatuhan tekanan sebanyak 10%. Bahan pendingin yang telah diuji termasuklah R12, R22, R502, dan bahan pendingin alternatif iaitu R134A, R401A, R401B, R402A, R402B, R404A, R407C, R410A, R408A, R409A, dan R507. Kajian kesan suhu penyejatan ke atas pekali prestasi, kecekapan hukum kedua dan ketidakbolehbalikan juga telah dijalankan. Hasil penilaian menunjukkan R401A, R401B, dan R409A sebagai alternatif terbaik mengantikan R12. R410A didapati alternatif terbaik bagi R22, manakala R402B, R407C, dan R408A untuk R502 dari aspek pekali prestasi dan kecekapan hukum kedua. Keputusan yang diperolehi menunjukkan model kitar sebenar dapat menghasilkan penilaian yang lebih baik berbanding model kitar unggul.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

COP	Coefficient Of Performance
COP_{carnot}	Coefficient Of Performance of a carnot cycle
COP_{ref}	Coefficient Of Performance of a refrigeration cycle
COP_{rev}	Coefficient Of Performance of a reversible cycle
h	Specific enthalpy, h=u+Pv, kJ/kg
i	Specific irreversibility, kJ/kg
I	Irreversibility, kJ
$\dot{m}$	Mass flow rate, kg/s
P	Pressure, kPa
Q	Total heat transfer, kJ
$\dot{Q}$	Heat transfer rate, kW
Q_{evap}	Useful refrigerating effect, kJ
s	Specific entropy, kJ/kgK
S	Total entropy, kJ/K
T	Temperature, °C or K
T_O	Ambient temperature, °C or K
T_R	Refrigerated space temperature, °C or K
T_{surr}	Surroundings temperature, °C or K
u	Specific internal energy, kJ/kg
v	Specific volume, m^3/kg
W_{net}	Net work, kJ
$\dot{W}$	Power, kJ/kg
η_{II}	Second law efficiency

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

1.1 Introduction

Chlorofluorocarbon (CFC) issues like ozone layer depletion and global warming have brought many studies for alternative refrigerants with suitable properties to replace the CFC and hydrochlorofluorocarbon (HCFC) refrigerants. Now, more new refrigerants are appearing on the market. This is due to the effort that has been made to find suitable replacements for CFC and HCFC refrigerants. R22 for example, is widely used in refrigeration system and being the most popular replacement for R12 which has been totally phase out by January 1, 1996 (unless for the continued use from existing and for continued production for very limited essential uses) **[1]**.

As the production of R22 is being totally phase out by January 1, 2030, the rush to find its alternative continues. The study of performance evaluation of the R22 and its possible replacement has become important especially by compressor manufacturers. Before an experimental test in an actual system is carried out, the test through simulation program becomes useful as a preliminary evaluation of a refrigerant performance.

Comparison and evaluation of the performance of a refrigerant and its possible replacement, is done through the theoretical testing or testing in actual application **[2]**. Theoretical testing and comparison are usually made using a simulation program. Tests enable the performance of refrigerant alternatives to be evaluated across a broad range of operating conditions.

Theoretical testing would depend on refrigerant properties while an actual test would depend more on detailed specification of the equipment. The way refrigerants behave and perform in theory or simulation differs from which it perform in an actual system. However, a theoretical test is very useful as a preliminary evaluation before an extreme experimental test which involved a high cost is carried out in a full size equipment.

1.2 Refrigerants and Its Alternatives.

CFC and HCFC have taken the leading stand in refrigerating system since 1930s until early eighties. They became very popular and were found as the refrigerants with good performance compared with other refrigerants. However, by the eighties, CFC was considered as detrineutral to the environment, causing significant damage to the ozone layer. This resulted in the phasing out of the use and manufacture of CFCs, and later of HCFCs. It generates many studies as the search for alternative refrigerants with suitable properties to replace the CFCs and HCFCs. Continues now, many new refrigerants have been produced and commercialized by refrigerant manufacturers like DuPont, ICI, and Honeywell. Most of them are hydrofluorocarbons (HFC) which do not contain chlorine and have zero Ozone Depletion Potential (ODP).

The most common CFCs and HCFC that are being phased out are R12, R22 and R502. R12 is used in domestic refrigerators and freezers, and in automotive air conditioners. The most popular alternative for R12 when the CFCs phase out began is R22. It is pure fluid and has a very good efficiency characteristic on medium temperature range applications. But when the phase out of R22 began, the search for R12 alternatives continues. There are several alternative refrigerants that are potential substitutes for R12 and most of them are mixtures but some are pure fluids. They include R134A, R401A, R401B, R402B, and R409A.

R22 which is a HCFC is widely used in window air conditioners, heat pumps, air conditioners of commercial building and in large industrial refrigeration systems. It is considered as transitional or "interim" alternatives and has a high performance characteristic. Its contain chlorine and will eventually be phased out but can be manufactured and used until 2030. The "long-term" alternatives for R22 that have been produced are mostly mixtures that do not contain any chlorine such as HFCs. They include R404A, R407C, R410A, and R507. R407C was the first to replace R22, but it was found out in recent research that new replacements R410A and R404A show better performance compared to R407C.

Other pure fluids alternatives for R22 are ammonia (R717) and propane (R290). Ammonia has been used for over 100 years. It is a low cost refrigerant with excellent thermodynamic properties and zero ODP. But it is toxic and flammable. Similar to ammonia, propane is no longer of interest because it is flammable even though it has similar thermophysical properties as R22 **[2]**. Other HCFC that has been considered is R134A which is a widely used as substitute for R22 in large chillers, as well as in automotive air conditioners and refrigerators.

R502 which is a blend of R115 and R22 is the dominant refrigerant used in commercial refrigeration systems such as those in supermarkets because it allows low evaporating temperatures while operating in a single-stage compressor. One of the replacements that have been produced for R502 is R404A. As discussed by David Wylie and Davenport **[2]**, the data of Alternative Refrigerants Evaluation Program (AREP) indicates that R404A has about the same capacity as R502 at lower condensing temperatures, but rapidly decreasing at higher condensing temperatures. For a fixed evaporating temperature, R404A has a lower efficiency when condensing temperature increase compared to R502. It has less efficiency when compared to R502 at high condensing temperature. Other mixtures that have replaced R502 include R402A, R402B, R407C, R408A and R507.

1.3 Performance Evaluation of Refrigerants in Refrigeration Cycle.

The study of refrigerant performance is very important because the behaviour of refrigerants or refrigerant mixtures strongly influence the design of the refrigeration system. Different refrigerants have performed differently based on their thermodynamic properties and behavior. According to Vaisman **[3]**, different refrigerants shows different heat transfer ratios and pressure drops in condensors and evaporators.

Yana Motta and Domanski [4], reported on how the refrigerant's critical temperature affects the refrigerant performance in the vapor compression cycle. As shown conceptually in **Figure 1.1**, differences in refrigerant's critical temperature and the shape of the two-phase dome on T-s diagram explain the different performance trends of the refrigerants.

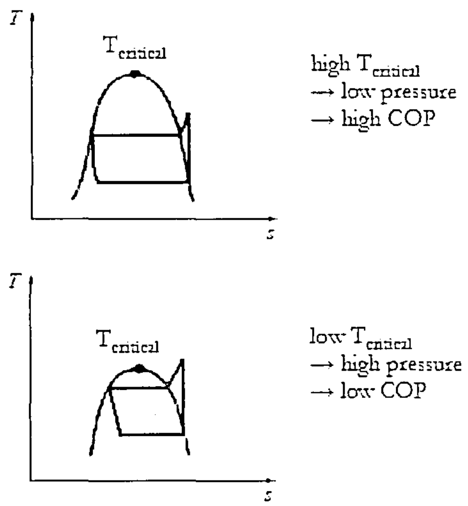

Figure 1.1 : Impact of critical temperature of volumetric capacity and COP [4].

For the same condensing and evaporating temperature, a fluid with a lower critical temperature will tend to have a higher volumetric capacity and a lower Coefficient of Performance (COP) while a fluid with a higher critical temperature will tend to have a lower volumetric capacity and a higher COP. The difference in COPs is related to the different levels of irreversibility on the superheated-horn side and at the throttling process. These levels of irreversibility vary with operating temperatures because the slopes of the saturated liquid and vapor lines change, particularly when approaching the critical point [4]. These are important issues besides considerations like safety, availability, and cost.

The performance comparison which was carried out by simulation had been done by many researchers in terms of first law and second law analysis. Yana Motta and Domanski [4] studied the performance of refrigerant R22 and its possible replacements which are R134a, R290, R410A and R407C in an air-cooled air conditioner system. All these refrigerants have been evaluated using the NIST's simulation program Cycle 11. The study focuses on the COP and the effect of outdoor temperature on system capacity. It includes performance results for the basic cycle and for the cycle with a liquid line and suction line heat exchanger. The result shows a decreasing in system performance with increasing outdoor temperature. It also shows that the fluids with a low critical temperature experience a larger degradation of cooling capacity.

Vaisman [3] has presented the performance evaluation of R22 and R407C in an air conditioner system with a rotary vane compressor. The exergy approach is applied and performance evaluation is produced taking into account the actual system configuration including compressor data, coil's design, suction line, discharge line and liquid line design, and the data from the fan and blower. The result shows that R407C is compatible with R22 in terms of air conditioner performance.

Spatz and Yana Motta [5] evaluated the performance of R22 but in medium temperature refrigeration systems with its potential alternatives of R410A, R404A, and R290. The studies include thermodynamic analysis, comparison of heat transfer and pressure drop characteristics, system performance comparisons using a validated detailed system model, safety issues, and determination of the environmental impact of refrigerant selection. The result shows that the R410A is an efficient and environmentally acceptable option to replace R22 in medium temperature applications.

Stegou-Sagia and Paignigiannis [6] have focused on exergy analysis of 10 working fluids including R401B, R401C, R402A, R404A, R406A, R408A, R409A, R410A, R401B, R410B and R507. The performances of these mixtures have been compared with the old refrigerants they replace which are R12, R22 and R502. When comparing the exergy efficiencies at constant evaporating temperature, the exergy losses of old refrigerants are found lower. The compression process has been predicted as the process which involved higher exergy losses followed by condensation process. R406A shows the highest value of exergy efficiency, while the lowest value is belongs to the mixture R409A.

C.K Sia [7] has developed a simulation program based on an ideal cycle to evaluate the performance of R12 and its possible replacements R134A and R401A, R22