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Performance Evaluation Of A Vapour Compression Refrigeration System For Simultaneous Cooling And Heating By Using R22 And Alternative Refrigerants

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Abstract

This research paper presents a vapour compression refrigeration (VCR) system for simultaneous heating and cooling utilities for different purpose in industries, hotels. The main advantage of the simultaneous is to carry out heating and cooling in dual mode, by which fossil fuel can be saved by minimize the use of the energy due to simultaneous operation. And even due to simultaneous operation the requirement individual equipment is no more so it saved the first cost of equipment. For research work water cooled condenser and evaporator is used. In which water flow rate is varied and test was conducted in three different modes by using R22 and its alternative refrigerants like R134a, R407C, R410A in existing system without replacing any parts of the system. Experimental results show that R134a has good performance than R22 and performance of R407 is in same manner as R22.

1. Introduction

In today's era, refrigeration industry is passing through evolutionary changes. Emphasis is given to save energy and to protect the environment. Refrigeration technology is expected to develop technologies which are cheap and using refrigerant other than CFC. Many food industries, textiles industries, hotels require both refrigeration and water heating. In case of textile mill, it requires central air conditioning plant which requires chilled water and hot water for steam generation and heating purpose, while in food industries, refrigeration required for product preservation and hot water required for cleaning, sterilization or process heating. It is common for the refrigeration and water heating systems to be separate and unconnected, and both consuming purchased energy. This approach wastes considerable energy, contributing to the depletion of fossil fuel reserves and the release of greenhouse gases. Even in large size VCR system required condenser and cooling tower for condensation process, while by simultaneous heating and cooling requirement of cooling tower is no more. So by the simultaneous heating and cooling by VCR system save the fossil fuel, energy and first cost of system/equipment by serving the both function of heating and cooling simultaneously. In addition, many refrigeration systems employ ozone depleting refrigerants. There are strong international moves to use naturally occurring and ecologically safe working fluids rather than harmful chemicals, in order to minimize the impact on the environment. Alternative technologies are required to limit the economic cost and environmental impact of these applications.[11]

According to the Montreal Protocol and its subsequent amendments and regional regulations, CFCs (chlorofluorocarbons) are banned since 1996 and the phase-out deadlines for HCFCs (hydro chlorofluorocarbons) are approaching (2030). Consequently, new fluids with zero ozone depleting potential (ODP), such as HFCs (hydro fluorocarbons) and natural refrigerants are being tested as substitutes for the ODSs. HCFC-22 has been widely used as working fluid in air conditioning and in medium and low-temperature applications within the commercial and industrial refrigeration. Nowadays, the replacement of HCFC-22 in existing and new systems without significant changes in equipment or lubricants constitutes a crucial challenge for the refrigeration industry. [19]

The first objective of the VCR system is to produce cooling effect, with the simultaneous mode heating and cooling energies can produce using the same electric energy input at the compressor. Hoon Kang [2] evocate a significant reduction in carbon footprint using improved heat pumps for heating and cooling. Many authors work on such systems for simultaneous production in various applications. Liu and Hong [3] compare ground source heat pumps to variable refrigerant flow systems, both able to provide heating and cooling effect to four perimeter zones and one core zone of a simulated small office building. White SD. [1] expose the advantageous performance of a transcritical CO_2 heat pump for simultaneous refrigeration and water heating. Past studies indicate that carbon dioxide based systems have great potential in two sectors in mobile air conditioning and in heat pumps for simultaneous cooling and heating. Several authors deal with the R22 replacement issues. R.Cabello et al.[10] tested 134a,R407C as alternative of R22 in a VCR system and W. Chen [6] has also replaced R22 with R410A in a heat pump. Tun-Ping et al. [15] compares the performance of R22 with R290 as a alternative of R22 in window air conditioner.

Nomenclature

COP	coefficient of performance
Cp	specific heat at constant pressure (kJ/kg K)
h	enthalpy (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
$\dot{W}$	compressor electrical power consumption (kW)
P	pressure (bar)
Q_k	heat absorbed (kW)
Q_o	heat rejected (kW)
s	entropy (kJ/kg K)
T	temperature (˚C)

Subscripts

0	evaporator
k	condenser
wi	water inlet
wo	water outlet
ci	condenser inlet
co	condenser outlet
ei	evaporator inlet
eo	evaporator outlet

In this paper, attention has been focused on studying, from an experimental point of view, utilize the waste heat from the condenser by simultaneous mode and how operating variables affect the performance of a refrigeration plant when using R134a, R407C, R410A and R22 as working fluids. The rest of the paper is organized as follows. In section 2, the theoretical analysis is described. In Section 3, the refrigeration test facility used to obtain the experimental data is described.. In Section 4, the experimental results are presented and discussed via heating and cooling effect and the COP analysis. Finally, in Section 5, the main conclusions of the paper are summarized.

2. Theoretical analysis

The overall performance of the plant is determined by evaluating its COP, calculated as the ratio between refrigerating capacity and electrical power supplied to the compressor. The p-h diagram shown in Fig. 1 is frequently used in the analysis of vapour compression refrigeration cycle. In the refrigeration system, the representative performance characteristics are compressor power ($\dot{W}$, kW), refrigerating effect (Q_k, kW) and Coefficient of Performance (COP).

Fig. 2 shows a schematic diagram of a vapour compression refrigerator, which consists essentially of a hermetic reciprocating compressor, an evaporator, a condenser and a capillary tube. These components are connected by pipelines in which a refrigerant with suitable thermodynamic properties circulates.

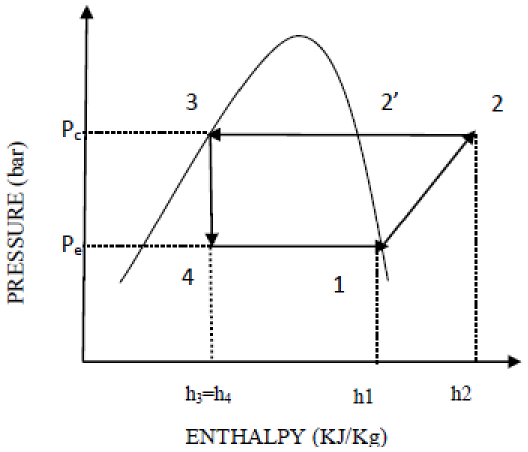

Fig. 1 Vapour compression refrigeration system on p-h diagram

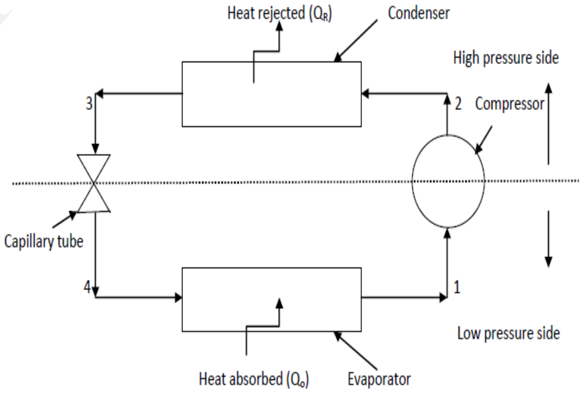

Fig.2 Schematic diagram of VCR system

The rate of heat absorbed by evaporator is given by

$$Q_k = \dot{m}(h_1 - h_4)$$

The rate of heat rejected by condenser is given by

$$Q_0 = \dot{m}(h_2 - h_3)$$

Compressor power consumption is given by

$$\dot{W} = \dot{m}(h_2 - h_1)$$

Coefficient of performance for cooling

$$\mathrm{COP}_{\mathrm{cooling}} = \frac{\mathrm{Q_k}}{\dot{\mathrm{W}}} \qquad \mathrm{COP}_{\mathrm{cooling}} = \frac{\mathrm{h_1 - h_4}}{\mathrm{h_2 - h_1}}$$

Coefficient of performance for heating

$$\mathrm{COP}_{\mathrm{heating}} = \frac{\mathrm{Q_o}}{\dot{\mathrm{W}}} \qquad \mathrm{COP}_{\mathrm{heating}} = \frac{\mathrm{h_2 - h_3}}{\mathrm{h_2 - h_1}}$$

Second law efficiency of vapour compression cycle

$$\eta_{II} = \frac{\text{Minimum available energy required for the cycle}}{\text{Actual available energy consumed in the cycle}}$$

$$\eta_{II} = \frac{\mathrm{COP}}{\mathrm{COP}_{\mathrm{Carnot}}} \qquad \mathrm{COP}_{\mathrm{carnot}} = \frac{\mathrm{T_o}}{\mathrm{T_k - T_o}}$$

3. Experimental Study

3.1 Experimental setup

The experiment was carried out in fabricated test rig in which tube-tube heat exchanger is used for evaporation and condensation process. Reciprocating compressor of 1 ton capacity is used in test rig. with the capillary tube as a expansion device. The system was instrumented with three pressure gauges at the inlet and outlet of the evaporator and inlet of compressor for measuring the suction and discharge pressures. The temperature of the refrigerant at eight different points as indicated in Fig. 3 was measured with copper-constantan thermocouples.

3.2 Data analysis

Test was conducted by varying the water flow rate through water cooled condenser and evaporator in three different modes. In first mode, water flow rate through evaporator is kept constant (2 LPM) while flow rate through condenser is varied from 2 LPM to 10 LPM, in second mode condenser water flow rate is kept constant (2 LPM) and evaporator water flow rate is varied from 2 LPM to 10 LPM, in third mode water flow rate through both condenser and evaporator are varied from 2 LPM to 10 LPM.

The thermodynamic properties of refrigerants are evaluated using COOL PACK. The heating effect and cooling effect produced by VCR system is calculated as follows;

$$\text{heating effect} = \dot{\mathrm{m}}\,\mathrm{C_p}\,(T_{wo} - T_{wi})$$

$$\text{cooling effect} = \dot{\mathrm{m}}\,\mathrm{C_p}\,(T_{wi} - T_{wo})$$

Following parameters are measured during the test
1) Condenser inlet temperature (˚C)
2) Condenser outlet temperature (˚C)
3) Evaporator inlet temperature (˚C)
4) Evaporator outlet temperature (˚C)
5) Condenser inlet pressure (bar)
6) Evaporator inlet pressure (bar)
7) Evaporator outlet pressure (bar)

After it in existing system without any replacement or modification of any parts in system R22 is replaced by R134 after it with R407C and R410A. Compressor used in system is fabricated by Kirloskar(KCJ513HAE) for R22 only. So to replace it with other refrigerant the amount of refrigerant was changed. Approximately charged amount of refrigerant are R22-600 gm, R134a 600gm, R407C-400gm, R410A-300gm.

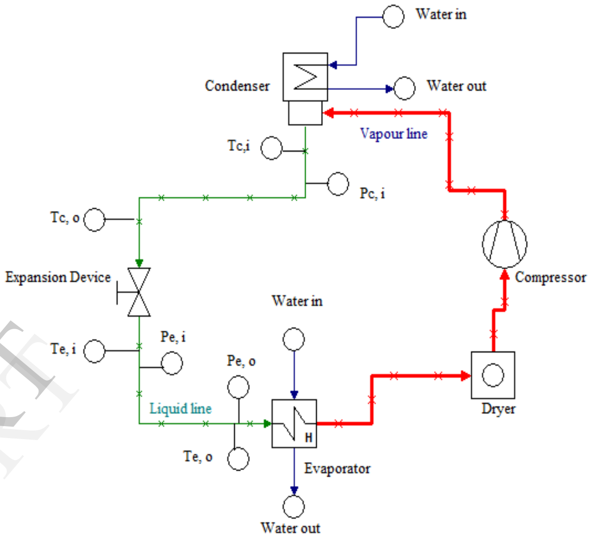

Fig. 3 Schematic diagram of test rig. Of VCR system

4. Results and discussion

The variation of the actual coefficient of performance with the condenser water flow rate changing from 2 LPM to 10 LPM and evaporator water flow rate is at constant (2 LPM) is as described in Fig.2 . As water flow rate is increase the COP of the VCR system is increase. At 10 LPM condenser water flow rate system performance is maximum. This is due to an increase of the heat exchanger overall heat transfer coefficient that resulting too high for the evaporation power fixed, determines an increase of the evaporation pressure, a decrease of the compression ratio and of the compression work and so an increase of the COP.

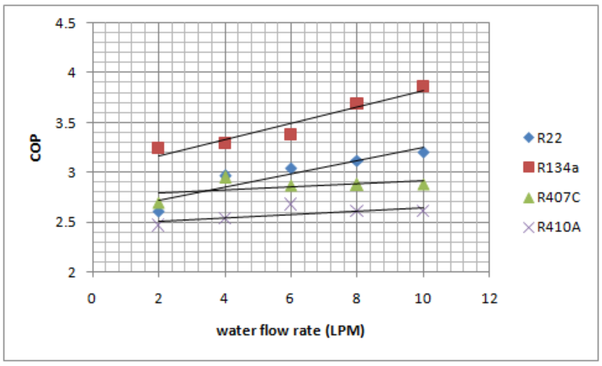

Fig. 2 Effect of water flow rate on COP (evaporator water flow rate constant)

While the effect on COP by keeping the condenser water flow rate constant and by varying evaporator water flow rate is depicted in Fig.3 As the water flow rate change from 2 LPM to 10 LPM, COP of system is increase. This is due to as the water flow rate is decrease it decrease the refrigerating effect and power required to run the compressor is increase. The performance of VCR system varies considerably with both vaporizing and condensing temperature. As the condenser water flow rate is increase, the condensing temperature decrease and COP of the system is improved as described in Fig.3.

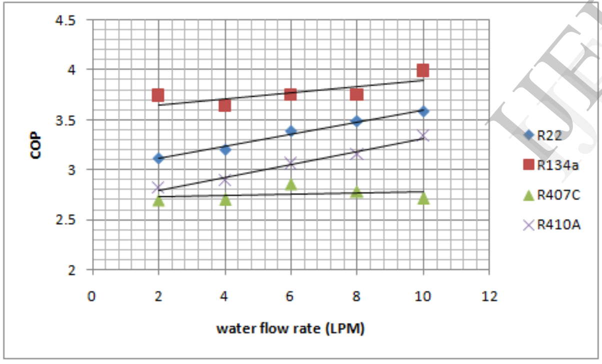

Fig. 3 Effect of water flow rate on COP (condenser water flow rate constant)

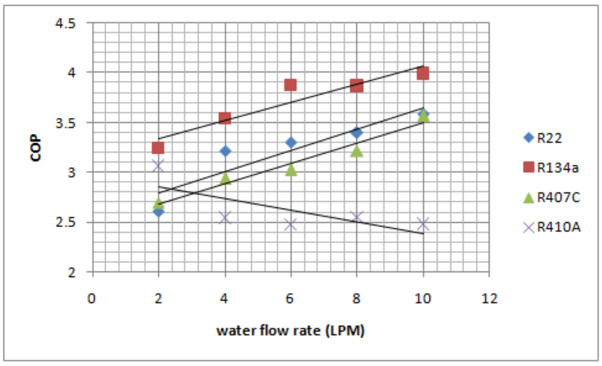

Fig. 4 Effect of water flow rate on COP (both water flow rate varying)

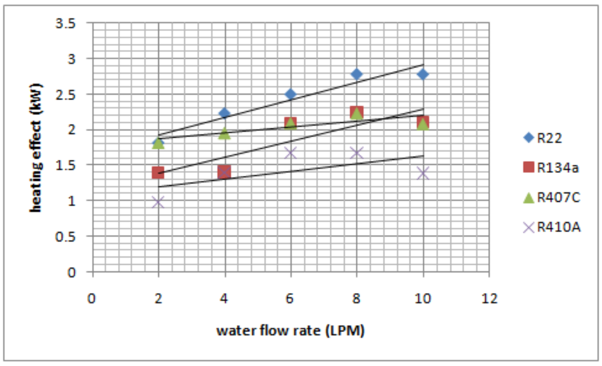

Fig. 5 Effect of water flow rate on heating effect (kW) (evaporator water flow rate constant)

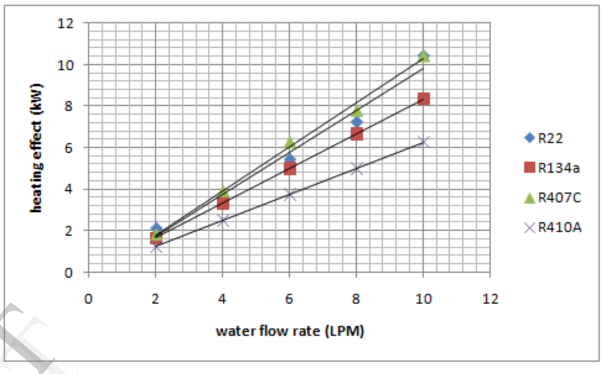

Fig. 6 Effect of water flow rate on heating effect (kW) (condenser water flow rate constant)

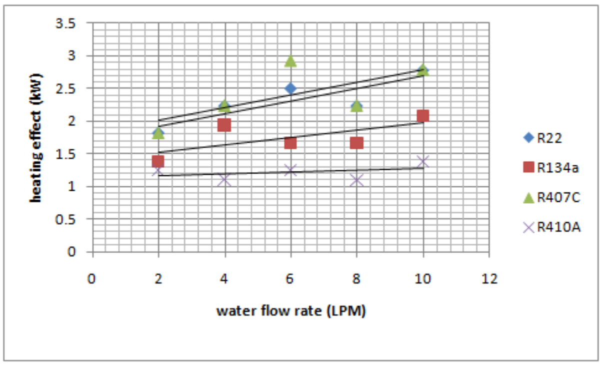

Fig. 7 Effect of water rate on heating effect (kW) (both water flow rate varying)

It is seen that the capacity and performance of the refrigerating system improve as the vaporising temperature increase and the condensing temperature decrease. And the performance of R134a is better than R22 in existing system during all three mode, while performance of R407C and R410A is better but less than R22 as depicted in Fig.2, 3, 4.

For experimental work tube-tube heat exchanger is used in which three tube is used which one is in contact with each tube by thermal bonding material (tin). In it middle tube is carried refrigerant while remaining two tube carried water.

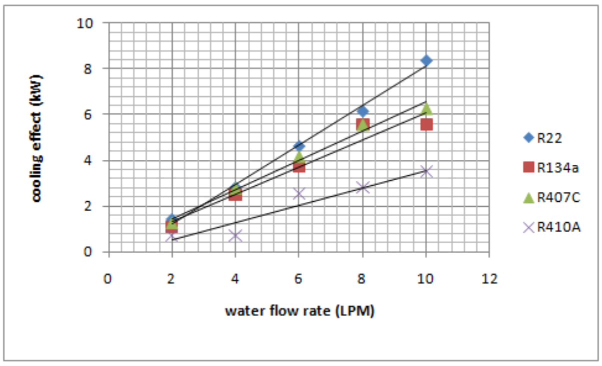

Fig. 8 Effect of rate on cooling effect (kW) (evaporator water flow rate constant)

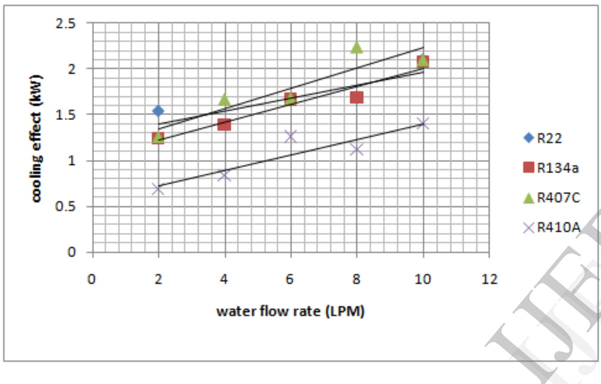

Fig. 9 Effect of water flow rate on cooling effect (condenser water flow rate constant)

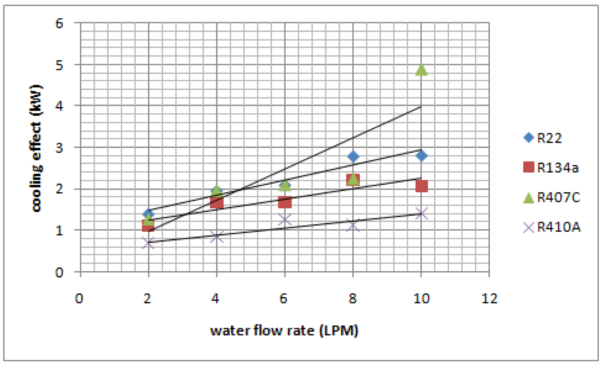

Fig. 10 Effect of water flow rate on cooling effect (both water flow rate varying)

During the minimum water flow rate through condenser maximum heating effect and during the minimum water flow rate through evaporator maximum cooling effect can be achieved. As shown in fig. 6, 8. And by utilising waste heat from the condenser overall performance of VCR system is increasing.

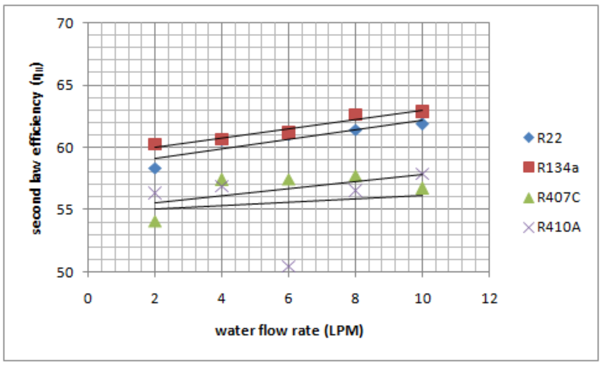

Fig. 11 Effect of water flow rate on second law efficiency (evaporator water flow rate constant)

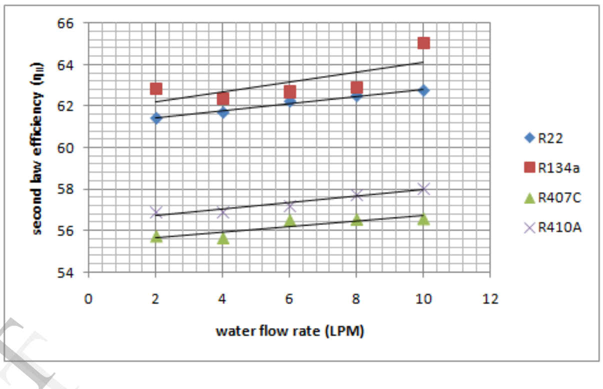

Fig. 12 Effect of water flow rate on second law efficiency (condenser water flow rate constant)

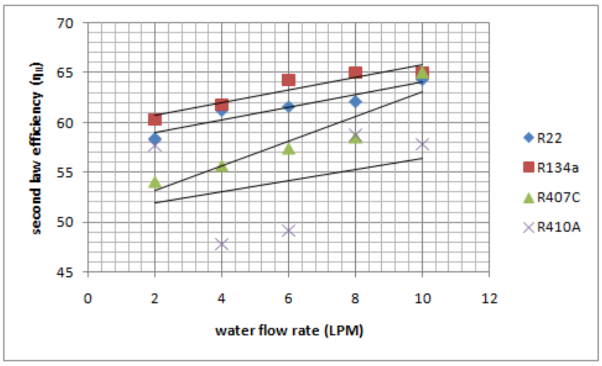

Fig. 13 Effect of water flow rate on second law efficiency (both water flow rate varying)

The ideal Carnot cycle is completely reversible, it does not involve any irreversibilities. The vapour compression cycle involves internal irreversibilities due to the throttling process and also due to the superheat horn. Hence, the value of second law efficiency (η_{II}) is less than 1. Second law efficiency is indication of closeness of actual cycle to Carnot cycle. The actual vapour compression cycle would have the external irreversibilities of condensation and evaporation process due to finite temperature differences required for heat transfer.[20] As water flow rate is increase it decrease the condenser pressure and due to which Carnot COP and actual

COP is increase due to which as water flow rate increase second law efficiency also increase, as depicted in fig.11, 12, 13.

5. Conclusion

Due to simultaneous heating and cooling energy can be saved and also first cost of equipment. As water flow rate increase in evaporator (condenser water flow rate at minimum level) 26 % heating effect is increase while as condenser water flow rate increase (evaporator water flow rate at minimum level) 20 % cooling effect is increased by R407C. Replacement of R22 in existing system with R134a, R407C, R410A shows that R22 has higher heating and cooling effect than other refrigerant. Performance of R134a is better in system as compare remaining three refrigerant. COP of the system is increase 20% by replacing R22 with R134a and decreasing 10% with R407C and R410A with 18% so R134a is most promisible alternative refrigerant.

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