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Modeling and Simulation of Heat Pump Air-Conditioning System using Ecofriendly Refrigerants

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Abstract: A simulation approach to heat pump systems is proposed in this paper. The evaluation of working fluids is conducted. Moreover, the selected refrigerants are used in the simulation. Subsequently, the system is analyzed in terms of the coefficient of performance (COP) and energy efficiency. Some alternative refrigerants, instead of R22 used R290 refrigerent. It is described the selection of refrigerants adapted to each utilization, based on the thermodynamic and -physical properties, the technological behaviour, costs and use constraints as principal aspects of the environmental protection. Also, it is performed a comparative analysis in function of the total equivalent warming impact (TEWI) for some possible substitutes of refrigerant R22 used in various refrigeration and heat pump systems.

I. INTRODUCTION

One of the problems in heating, ventilation, and air conditioning (HVAC) systems is finding an alternative refrigerant that can provide high system performance but have low environmental effects . The world's attention to environmental damage is known to continually increase; hence, efforts in finding alternative refrigerants continue to be conducted. This began from the issue of the ozone layer damage that was discussed in 1987, leading to a ban on the use of substances that can damage the ozone, namely chlorofluorocarbon (CFC) refrigerants, which led to the issuance of the Montreal Protocol. Subsequently, the effects of global warming in 1990 were the basis for the formulation of the Kyoto Protocol, which contained directions on the use of low global warming potential (GWP) refrigerants such as hydrofluoroolefin(HFO), hydrofluorocarbon(HFC), hydrochlorofluoroolefin (HCFO), and a mixture of HFC with HFO or even the consideration of refrigerants that have been used previously, such as water, ammonium, and hydrocarbons . The facts stated above indicate that energy and the environment are interrelated; therefore, considering environmental aspects in meeting energy requirements is necessary . An environmentally friendly refrigeration system is one of the solutions offered by researchers as an efficient and high-performance system . This system is considered capable of reducing primary energy consumption and offering an efficient equipment . Vapor compression refrigeration and absorption systems are two technologies that have been developed recently (Curtis et al., 2005). From the development of research on refrigeration systems and heat pumps, one of the prominent efforts in improving system efficiency and reducing the impact of systems on the environment is the evaluation of various alternative refrigerants. Recently, various alternative refrigerants have emerged such as R1234ze, R452B, R447B, etc. attempted to a simulation to determine the performance of refrigeration systems using R1234ze and R1234yf. The results demonstrated that systems had a fairly good performance with a coefficient of performance (COP) ranging from 3.4 to 4.6 . Other researchers, Ju et al. and Zhang et al., attempted reusing refrigerants from the hydrocarbon group to overcome the environmental problems caused by current systems with synthetic refrigerants. Ju used R744 and R290 for refrigeration systems, and the results indicated that systems had very good performance with a COP ranging from 4.5–4.7 (Ju et al., 2018). Similarly, the simulation conducted by Zhang et al., where a refrigeration system using the working fluid R744 had good performance with a COP ranging from 3.25– 4.25 (Zhang et al., 2017).

II. METHODOLOGY

In this study, an evaluation of some alternative refrigerants was conducted to compare some alternative refrigerants in terms of safety, environmental impact, and performance. The model of the system in this study used Matlab 2017a software and REFPROP ver. 10. The selection of working fluids that could be used in this study illustrated in Figure 1. High critical temperatures provided a significant possibility to transfer heat at high temperatures with a critical cycle. Moreover, the critical pressure had to be low. In addition, zero ozone depletion potential (ODP) and zero GWP were required to be considered. Based on Ashrae's classification, the working fluid used was to be in the A1 category, which means non-toxic and nonflammable (Ashrae, 2010). Table 1 provides information on the properties of environmentally friendly refrigerants R 290. Further during optimization study, the air cooled condenser is converted into the evaporative cooled air condenser. Evaporative cooling air condenser system made by spraying water on the top of the right and left side media pad .It includes a small pump, tank and a water injection pipe . It is used to improve performance of the system with R290 refrigerant.Increase in condenser temperature decreases cooling capacity, C.O.P of the cycle due to reduction of liquid content in the evaporator. To reduce the condenser temperature, application of evaporative cooler is one of the easiest ways. By which the condenser temperature decreases, thus the cooling capacity and performance of the unit become better.

III. EVALUATION OF REFRIGERANT SELECTION

The evaluation of refrigerants plays an important role in the heat transfer process that occurs in a system. This was the initial stage carried out in this study. As explained in the previous section, various aspects are considered in the selection of refrigerants, beginning with physical properties, safety, and the impact of the system on the environment. Figures 2 and 3 are the results of evaluations conducted by considering various alternative refrigerants. Furthermore, Figure 3 presents the results of evaluating various refrigerants with regard to physical properties that include low pressure and high critical temperature. Moreover, environmental aspects such as ODP values at approximately 0 and GWP that are approximately 1 were the best selection criteria for refrigerants. Finally, the other criteria were the safety aspect and the refrigerant being classified as toxic and flammable. The physical and chemical **properties** of the **R290** are as follows: Zero potential for destruction of the ozone layer and negligible global warming potential, GWP = 3; Low toxicity: Acceptable Exposure Limit **-** AEL = 1000 ppm; Flammable: ignition limits between 1.7 and 10.9% by volume in air.

IV. HOW DOES AIR CONDITIONING WORK USING REFRIGERANT?

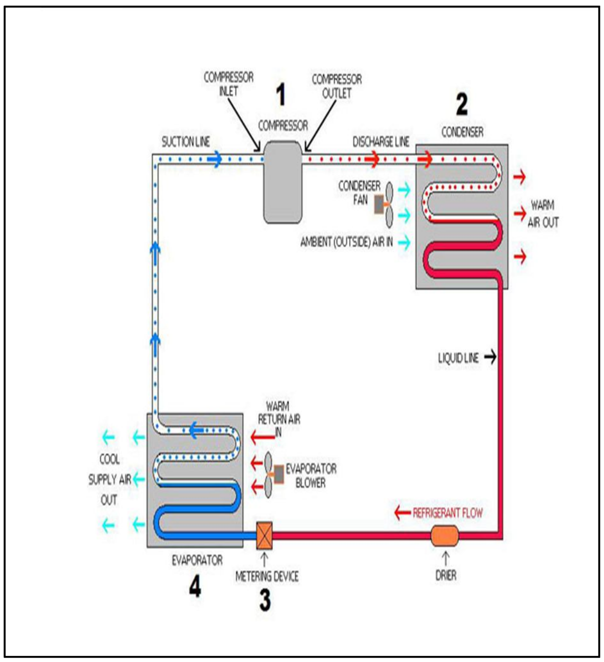

Fig.1

In the above fig.1. the compressor (1) compresses the refrigerant vapor and moves it towards the condenser. The heat of compression raises the temperature of the refrigerant vapor causing it to be a high pressure superheated vapor. As this refrigerant moves into the condenser (2), the condenser rejects the heat in the refrigerant, causing it to change state and condense into a high pressure, high temp liquid. As the refrigerant passes through the metering device (3), its temperature, pressure and state change once again. Some of the low pressure liquid refrigerant instantly boils off forming “flash gas”. As this mixture of liquid and gas pass through the evaporator (4) heat is absorbed and the remaining liquid refrigerant changes it state back into a vapor. At the outlet of the evaporator 100% of the low pressure vapor flows back through the suction line to the compressor.

A. Heating Effect Diagram

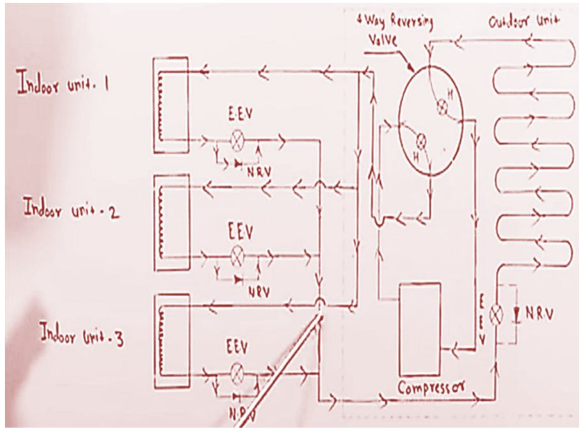

Fig.2

B. Cooling Effect Diagram

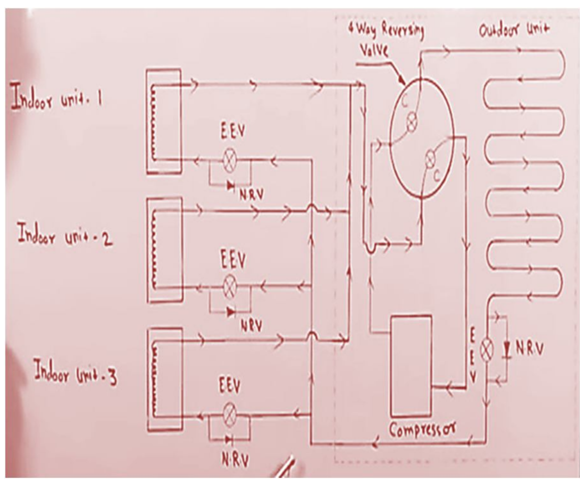

Fig 3

V. OPERATING MODES

Three operating modes can be run. - The simultaneous mode produces hot and cold water using the water condenser and the water evaporator (electronic valves Evr1 and Evr3 are open). - The heating mode produces hot water using the water condenser, the air evaporator (electronic valves Evr2 and Evr3 are open) and also uses the subcooler to store the subcooling energy in the cold water tank. - The cooling mode only produces cold water using the water evaporator and the air condenser (electronic valves Evr1 and Evr4 are open). The variables used to activate the mode of operation are the temperatures of water entering the water condenser and the water evaporator. Every simulation time step, the values are compared to set points using on/off differential controllers with hysteresis. The controllers deliver a signal at 1 if heating and/or cooling is needed. The corresponding operating mode, heating only, cooling only or simultaneous mode is consequently activated.

VI. PERFORMANCE PARAMETER CALCULATION

A. Pressure ratio is calculated using

$$\text{Pressure ratio} = \frac{P_{condenser}}{P_{evaporator}}$$

B. Refrigeration effect is calculated using

Refrigeration effect (Qe) = $\triangle h_{evaporator} = (h1 - h4)$ KJ/kg

C. C.O.P is calculated using

$$\text{C.O.P.} = \frac{\triangle h\ evaporator}{\triangle h\ compressor}$$

$$= \frac{(h1 - h4)}{(h2 - h1)}\ \text{KJ/kg}$$

VII. RESULT AND ANALYSIS

A. Coefficient of Performance

Figure shows the variation coefficient of performance under different set point temperature. In terms of the C.O.P. R290 is better than R22. When air cooled condenser was used the C.O.P. of R290 is less than that of R22 refrigerant. But when evaporative condenser was used in the experiment C.O.P. of air conditioner increases significantly by 15.84%, 18.23%, and 22.92% at 16˚C, 20˚C and 25˚C set point temperature.

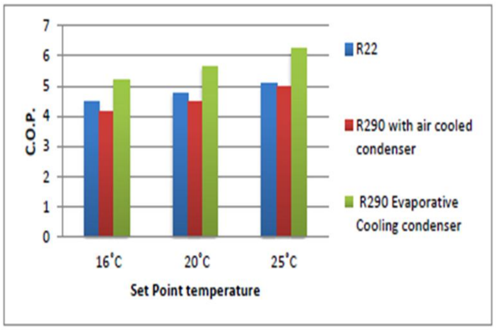

Fig 4. C.O.P of R22 and R290 for various test conditions

VIII. CONCLUSIONS

A. R290 is a natural refrigerant with negligible global warming potential long term alternative to R22.

B. C.O.P. was increased by 22.92%, 18.23% and 15.84%.

C. Power consumption was lowered by 57.69%, 40% and 45%.

D. Discharge temperature was significantly lowered by 22˚C, 23˚C and 23˚C.

E. Refrigeration effect fount to be large as compared to the baseline R22 system for various test condition.

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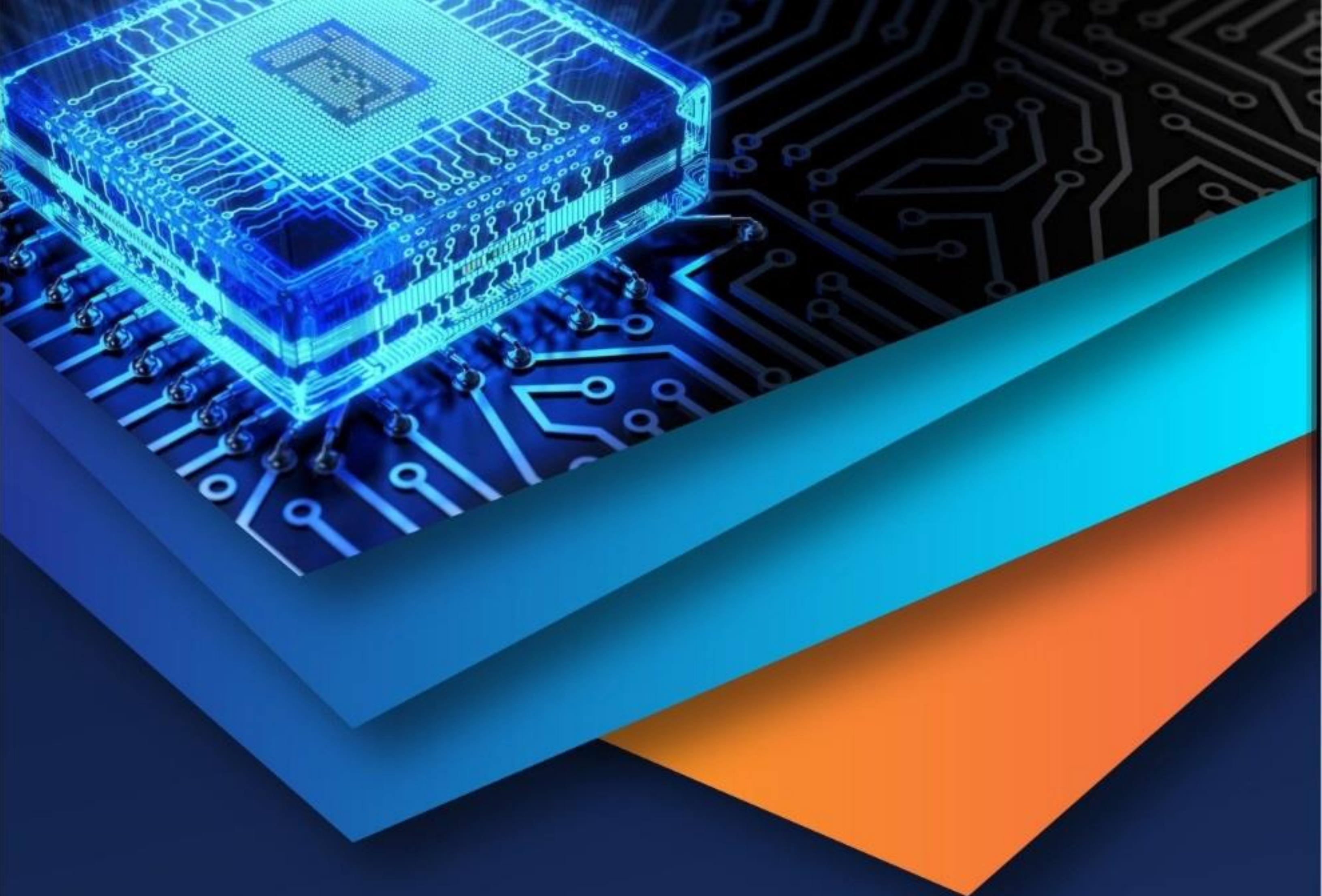

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