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Exergy Performance Assessment of Vapour Compression Based System Components

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Abstract

The aim of this paper is to evaluate the exergetic performance of a residential air conditioner working with R22 and the new ternary mixture. R32, R125, R600a are the constituents of the new mixture in the ratio of 0.4:0.4:0.2 by mass and it is designated as RM20. The experimental tests are carried out and comparative exergy analysis has been done and presented. The collective exergetic performance of the plant working with R22 is better than that of the new mixture. The exergetic performances of the individual components are also evaluated. The compressor has larger exergy destruction followed by condenser, evaporator and expansion valve.

Keywords: vapour compression system, energy, exergy, exergy efficiency.

Introduction

R22 is one of the refrigerants belong to the group hydrochloroflurocarbon (HCFC). It is widely used in residential, commercial, industrial and transport systems. HCFC is being phase out, because of its high ozone depletion potential (ODP) and global warming potential (GWP). This has led to find an alternate with environment friendly nature to R22. Alternatives to R22 should meet the requirement is the key in this attempt. Several investigations have been conducted in the research to find an alternate to R22. Hydrocarbon refrigerants such as R290, R1270 [1,2] and its mixtures R432A, R433A, hydroflurocarbon mixtures such as R404A, R407C and R410A, hydroflurocarbon/hydrocarbon (HFC/HC) mixtures like R417A, R422 series are identified as the foremost replacements for R22 among the available alternatives. Many research works has been done with R410A as an alternate to R22 in air conditioners [3]. Similarly, R407C was reported as a possible R22 alternative for compression based systems used for refrigeration, air conditioning and heat pump systems by changing the lubricant [4-7]. A number of investigators tried with R410A as a possible alternative to R22 in air conditioners and heat pumps [8-9].Many performance analysis of refrigeration system has been carried out on the basis of the first law of thermodynamics. It explained only about the change in the quantity of energy and not gives any information about the process by which it happened. The exergy analysis is the modern approach which provides realistic view of the process.

An exergetic approach based experimental study for the substitution of R22 in vapour compression based plant with R407C and R410A. The results revealed that the overall exergetic performance of the plant working with R410A is consistently better than R407C [10]. The performance of vapour compression plant working with R22 and R417A as working fluids was reported. The result showed that the COP and exergetic efficiency of the plant is better when working with R22 then with its alternate R417A [11].First and second law analysis of R422 series refrigerants (R422A, R422B, R422C and R422D) as an alternative to R22 were conducted and the results indicated that VCC, COP and exergetic efficiency for R22 were higher when compared with R422A, R422B, R422C and R422D. The efficiency defects in the condenser were larger followed by throttle valve, compressor and evaporator [12]. In connection with R22 replacement, there is no unanimous solution. Prior to this, no work has been exposed with the new mixture R32/R125/R600a. The exergy performance of R22 and RM20 are assessed individual components in terms of exergy destruction, exergy efficiency and the obtained results are presented here.

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Experimentation

The schematic diagram of an experimental test is given in Fig. 1 which is on the basis of BIS 1392 [13]. Compressor, condenser, evaporator and expansion valve are the major components with necessary accessories which are the skeleton of the setup. Along with the above, temperature sensors are used to measure the temperature with an accuracy of ±0.5°C. Bourdon pressure gauges are installed to measure the pressure and flow meters with an accuracy of ±1% are installed to measure the flow rate of refrigerant. To measure current digital wattmeter with an accuracy of ±0.5KWh is used. An electronic balance with ±0.1g accuracy is used to determine the mass proportion refrigerant charging.

The system is charged with 900g of R22. After reaching steady state condition, temperature and pressure values at various points are recorded at 1min intervals continuously. After completing the baseline test, R22 is removed from the system and the corresponding capacity of R32/R125/R600a is filled. Based on specific volume ratio the capacity required is determined for the mixture in compressor suction as 700g. Similar experimental procedures are followed for R32/R125/R600a.

Exergy analysis

Exergy analysis is commonly accepted as a useful module in obtaining an improved understanding of the overall system and system components. The analysis is done for each component in the plant and the individual component efficiency defect and the overall efficiency are evaluated.

Result and discussion

The experimental results obtained from one ton residential air conditioner experimental setup based on exergy analysis, working with R22 and RM20 are discussed in this section. The performance of the air conditioner is evaluated with four different ambient temperatures and two room temperatures.

In Fig. 2 and 3 the exergy destruction in the compressor and in the condenser are reported for R22 and RM20 respectively. These devices are the major causes of energy destruction in the plant.

As for the compressor, the exergy destroyed is linked to the trend of the compression ratio and to the compressor volumetric isentropic efficiency. It can be noted that the exergy flow destroyed in the compressor is always greater for RM20. The greater value can be explained with the greater mechanical power input to the compressor working with RM20.

The exergy flow destroyed in the condenser working with RM20 is always higher than that pertaining to R22 which varies from 0.324KW to 0.4KW. In the condenser the temperature difference between the air and the refrigerant flow is always greater for RM20.

In Fig. 4 and 5 the exergy destruction in the evaporator and in the expansion valve are reported.
With reference to the evaporator, the destroyed exergy at fixed evaporator temperature increases with increase in condensing temperature. The exergy flow destroyed in the evaporator working with RM20 is always higher than that of R22.

As RM20 requires a compression ratio higher than R22, the exergy destroyed in the expansion valve related to RM20 is greater than R22.

In Fig. 6, 7, 8 and 9 the exergy efficiency are evaluated for R22 and RM20 in the compressor, condenser, evaporator and expansion valve respectively. It can be observed that the efficiency values of R22 are better than those of its substitute in any operating condition.

Conclusion

This paper explained with the substitution of R22 in an experimental vapour compression plant with the substitute RM20. The analysis carried out in this paper follows exergetic approach. The performance of the plants individual components has been analysed. The analysis of the exergy flow destroyed in each component of the plant has been carried out, in order to pinpoint those contributing most to the decrease in the exergetic performance. The results obtained allow the following remarks.

1. The contribution of the compressor to the overall irreversibility is the most relevant. The exergetic performance of this component working with RM20 is always lower than that of R22.
2. or the evaporator and the condenser the exergetic performance and the efficiency are lower with RM20 compared to R22.
3. The contribution of the expansion valve to the overall irreversibility is marginal.
4. In conclusion, in order to increase the overall performance of the vapour compression plant working with RM20, the compressor, but, also both the heat exchangers must be optimized because of their higher efficiency defects.

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Figure. 1 Experimental setup

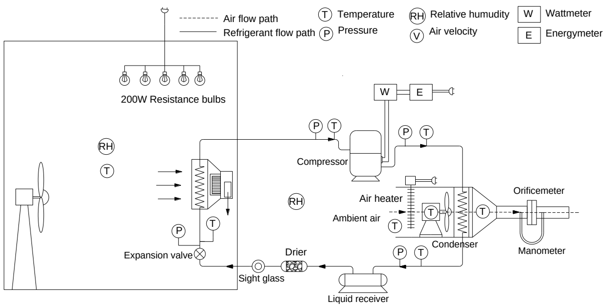

Figure 2. Compressor exergy destruction versus condenser temperature

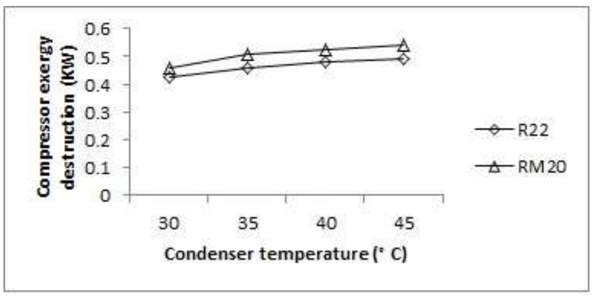

Figure 3. Condenser exergy destruction versus condenser temperature

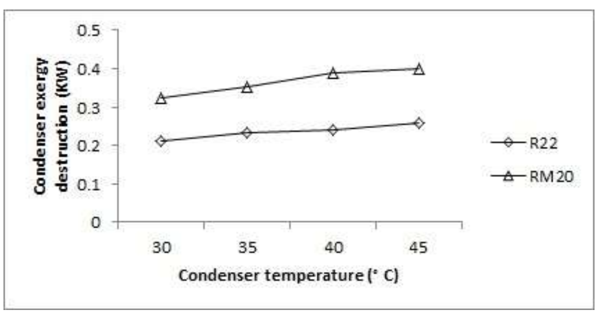

Figure 4. Evaporator exergy destruction versus condenser temperature

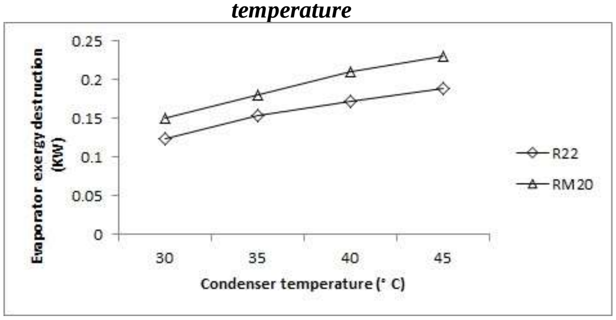

Figure 5. Expansion valve exergy destruction versus condenser temperature

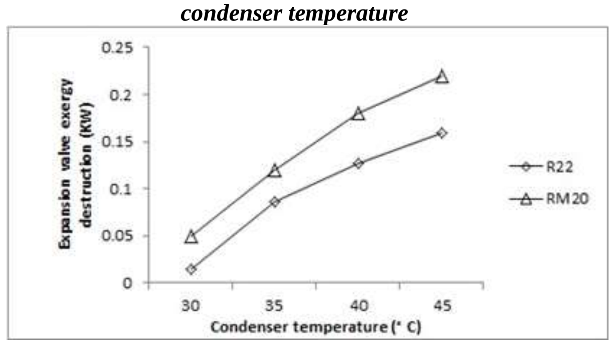

Figure 6. Compressor exergy efficiency versus condenser temperature

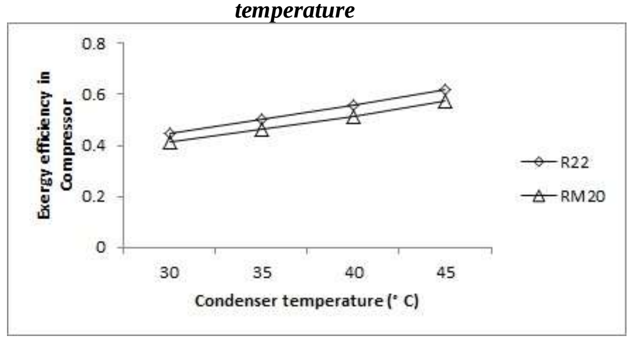

Figure 7. Condenser exergy efficiency versus condenser temperature

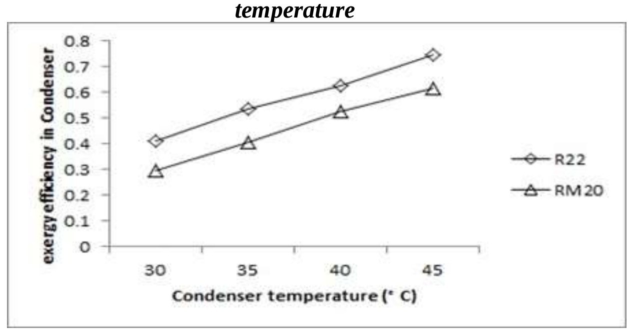

Figure 8. Evaporator exergy efficiency versus condenser temperature

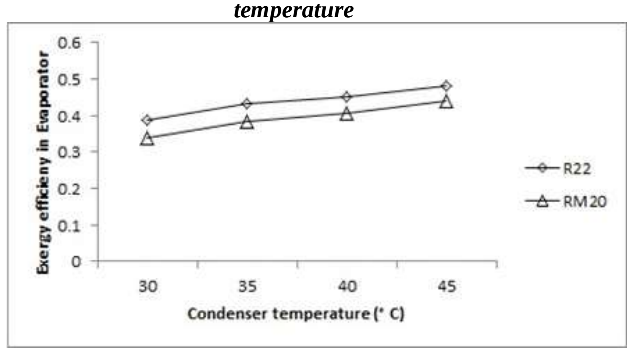

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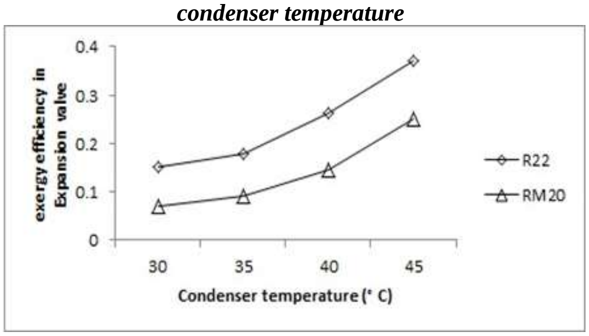
Figure 9. Expansion valve exergy efficiency versus condenser temperature



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