Study of Using R290 Refrigerant Replacement in a Heat Pump Application

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Abstract. The study represents a new approach in the research of the advantages obtained by the water-to-water heat pumps. This original system can use a renewable energy resource, respectively groundwater, rivers or sea water and can achieve both the heating and cooling requirements of a location. The study represents also a research in the field of energy efficiency and environmental optimization of heat pumps by changing the refrigerant R407C to R290.
For testing, an open circuit water-to-water heat pump was used, with capillary evaporators in an original spiral shape able to avoid clogging, by continuous self-washing effect.
The simulations showed that the heat pump ensures a reduction of the electricity consumption and Total Equivalent warming Impact by up to 50% compared to an ordinary air conditioning system.

Keywords. Heat pump, EER, COP, TEWI, Capillary Evaporators, Energy efficiency.
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1. Introduction

Heat transfer performance is one of the most important areas of research in the field of thermal engineering. There are a large number of refrigerants used in compression refrigeration systems. Their use implies for each case some reservations in terms of environmental impact (R11, R12), toxicity (NH3), flammability (HC) or high pressure (CO2), which gives them degrees of danger accordingly. Ashok G. Matani et al. [1] conducted an experimental study to observe the performance of different ecological refrigeration mixtures (HC and R401a mixture).
The aim of the research is to be part of the preparatory action for the replacement of high GWP freons with environmentally friendly freons and comparatively analyzes the performance of the heat pump when operating with freon R290 and R407C.

2. Method

The research method comprises two stages, respectively:

1. Documentation stage
2. Research stage by testing

Thus, in the first stage, the results of some researchers on this topic were analyzed and quantified, and in the second stage, tests were performed in order to find some conclusions.

E. Halimic et al. [1] tested the operation of a compression refrigeration system using R12, R401A,

R134A and R290 refrigerants. The results (Fig.1) indicated that the performance obtained with refrigerant R134a are close to those obtained with refrigerant R401a but lower than those obtained with refrigerant R290.

E. Navarro et al. [2] conducted a comparative study between R1234yf, R134a and R290, using a piston compressor, with two operating speeds and vaporization temperatures from -20^{0}C to 20^{0}C, with the condensation temperature variation between 40^{0}C and 65^{0}C.

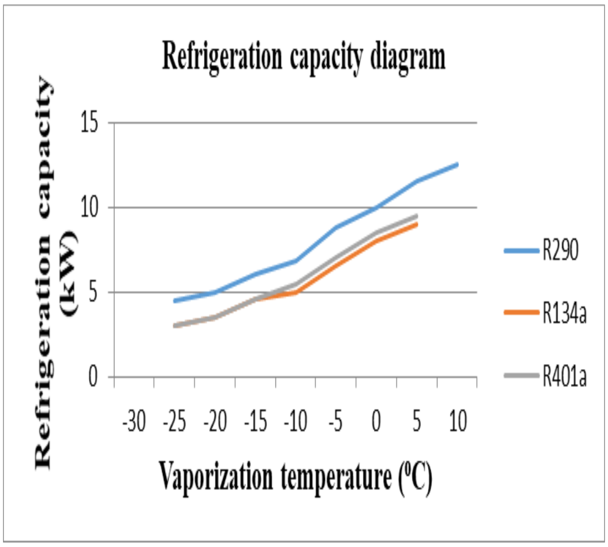

Fig. 1 - Refrigeration capacity analysis

The measurements performed and the subsequent analysis led to the following conclusions:
R-290 has shown a significant improvement in volumetric efficiency, and heat losses are considerably lower than for the other two coolants. It should be noted that R-290 has a significantly higher volumetric capacity than the other two

refrigerants, which may reduce the size of this type of system [3]

The new refrigerant, R-1234yf, has better efficiency compared to R-134a for pressure ratios greater than 8. It has less heat loss than R-134a, but 20% more than R290 [4].

From this study, it can be concluded that R-1234yf and R-290 can be good substitutes for R-134a.

In terms of efficiency, R-290 (Fig.2), demonstrated a better performance for the whole range of conditions tested (improvement on average by 30% of volumetric efficiency and by 15% of compressor efficiency). R-1234yf showed higher heat losses than R290, even with a significantly lower compressor discharge temperature.

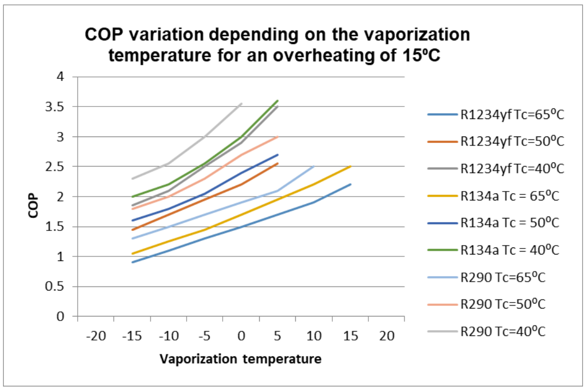

Fig.2 COP variation for tested refrigerants

Ki-Jung Park and others [5] analyzed the performance of two pure hydrocarbons and seven mixtures composed of propylene, propane, R152a and dimethyl ether in order to replace R22 refrigerant in residential air conditioners and heat pumps at evaporation temperatures and condensation of 7 ° C and 45 ° C, respectively. The test results confirmed a value of the performance coefficient of these mixtures up to 5.7% higher than in the case of operation with R22.

The conclusions were that the mixtures used led to superior performance with reasonable energy savings, without any environmental problems and, consequently, can be used in the long term as alternatives for residential air conditioning and heating applications with heat pumps.

Ki-Jung Park and others [6] analyzed the thermodynamic performance obtained with two pure hydrocarbons and seven mixtures composed of propylene (R1270), propane (R290), R152a and dimethyl ether (R170) in order to analyze the possibilities of substituting R22 refrigerant in residential air conditioning installations.

The test results led to COP values up to 5.7% higher than when using R22 refrigerant.

K. Mani and others [7] analysed the operating parameters of a refrigeration system with steam compression using the R290 / R600 mixture (68% / 32%) in order to replace the R12 and R134a refrigerants.

The results showed that the refrigerant R134a showed a slightly lower COP than R12. The R290 / R600a mixture was very close to R12. In conclusion, the mixture R290 / R600a (68/32% by weight) can be considered as a substitute refrigerant for R12 and R134a due to the real ecological advantages.

AS Dalkilic et al. [8] studied the performance of a compression refrigeration plant using mixtures of R134a, R152a, R32, R290, R1270, R600 and R600a refrigerants combined in various ratios and the results were compared with the functional parameters of the same plant using refrigerants R12, R22 and R134a.

The results showed that all alternative refrigerants investigated in the analysis have a COP slightly lower than R12, R22 and R134a for the condensation temperature of 50 ° C and the evaporation temperatures ranging from –30 ° C to 10 °C.

Mixtures of R290 / R600a refrigerants (40% / 60% by weight) can replace refrigerant R12 with close energy results and the mixture of R290 / R1270 refrigerants (20% / 80% by weight) can replace refrigerant R22 with close energy results, having in view the ecological properties of these mixtures.

Vincenzo La Rocca and others [9], analysed the performance of a refrigeration system with vapor compression using refrigerant R22 compared to those obtained by replacing this refrigerant with new refrigerants, HFC, respectively:

R417a, R422a and R422d. The conclusion was that the performances obtained with the new tested refrigerants were inferior to those achieved by operating with the R22 refrigerant.

Yunho Hwang et al. [10] compared the operating performance of a refrigeration system using R404 and R410A refrigerants compared to R290. The conclusion was that the energy performance obtained with R290 refrigerant is lower than that obtained with R404 and R410A refrigerants but the ecological performance of R290 are are absolute.

Venkataramana Murthy et al. [11] considered the possibility of replacing refrigerant R22 with environmentally friendly refrigerants (R134a,R407C and R290) in order to comply with the provisions of the Montreal Protocol using for testinga refrigeration system equipped with a rotary encapsulated compressor using SUNISO4 oil and an air-cooled condenser. The vaporizer used was a 2m long capillary.

The conclusion was that the R290 refrigerant ensures a higher COP, compared to the R134a, R407C and R22 refrigerants.

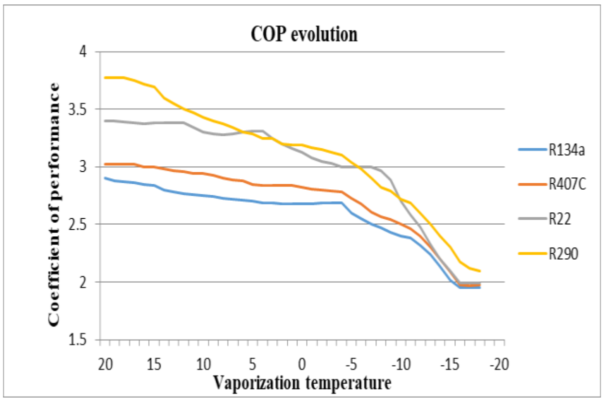

Fig.3 COP evolution for the refrigerants tested in the refrigeration installation

3. Results and discussion

In order to determine the energy performance of the use of the R290 refrigerant compared to the R407C refrigerant at a heat pump, operation simulations were performed using specialized programs provided by the manufacturers, respectively Danfoss and Scroll Copeland. The tests were performed on a capillary heat pump with an Archimedean spiral evaporator.
The COP value was analyzed for the entire usual range of condensation temperatures. Fig. 4-9 represents the COP variation depending on the condensation temperatures.

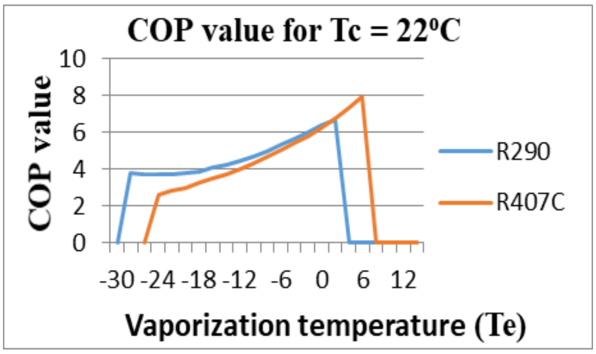

Fig 4. COP value for Tc = 22°C

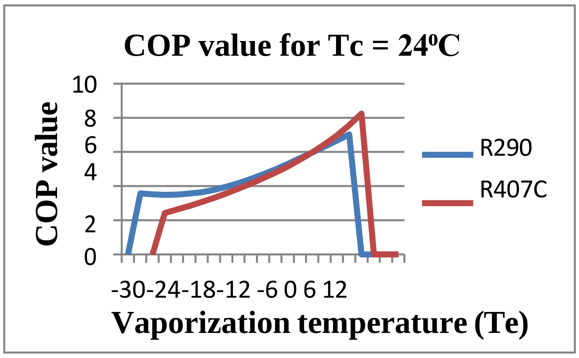

Fig 5. COP value for Tc = 24°C

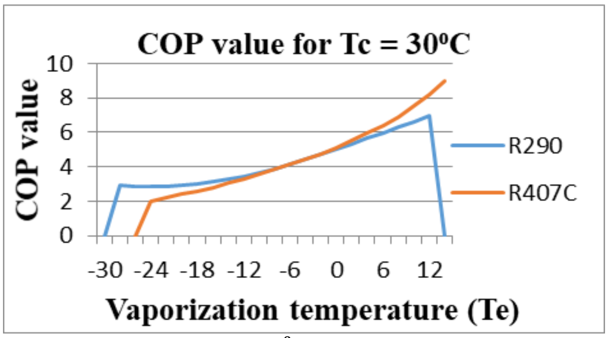

Fig 6. COP value for Tc = 30°C

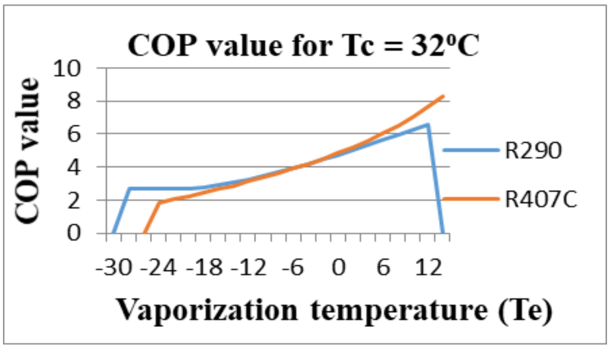

Fig 7. COP value for Tc = 32°C

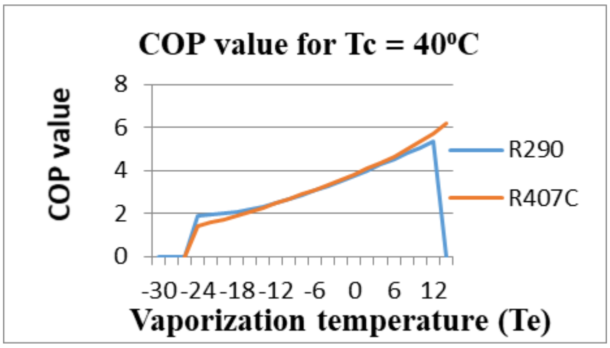

Fig 8. COP value for Tc = 40°C

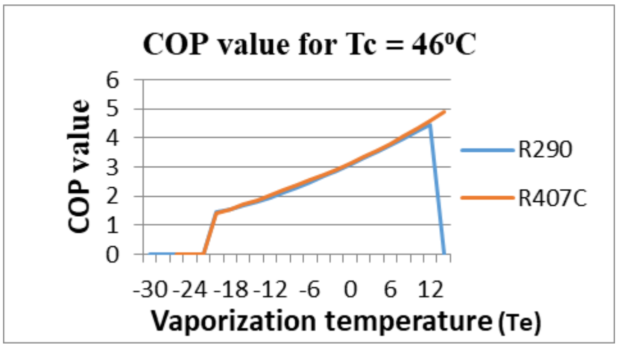

Fig 9. COP value for Tc = 46°C

Tab. 1 - TEWI (Total Equivalent Warming Impact) calculation for R407C and R290

		R407C	R290
GWP		1624	3
L	kg/an	0,09	0,09
n	ani	30	30

m	kg	4,5	4,5
αrecover		0,8	0,8
Eannual	kwh/an	2.462	2.462
β	kg/Kwh	0,28985	0,28985
GWP x L x n		4.384,80	8,10
GWP x m(1- $\alpha_{recover}$)		1.461,60	2,70
n x E_{annual} x β		21.404,8	21.404,8
TEWI in kg CO2		27.251,2	21.415,6
TEWI in tones CO2		27,25	21,42

5. Conclusion

For conclusions, the energetic, ecological and financial parameters were analyzed comparing two systems that use respectively the R407C and R290 refrigerant, using the Pack Calculation pro program.

The results offered by the program were the following:

1) For a year-long operation in climatic conditions in Bucharest, the average COP achieved by the heat pump system using the R407C refrigerant calculated by the program was 2.34 while the system using the R290 refrigerant provides an average COP of3.03;

2) In front of the heat pump that uses the R407C refrigerant, the heat pump that uses the R290 refrigerant achieves an energy saving of 971kWh, which represents at the annual consumption level of the heat pump that uses the R407C refrigerant, a saving of 22%.

3) From the point of view of ecological analysis, during operation, the heat pump that uses the R407C refrigerant generates an indirect CO2 emission of 22,632kg compared to the heat pump that uses the R290 refrigerant at which the amount of CO2 emitted indirectly is only 17,486 kg., As it results fromfig.28

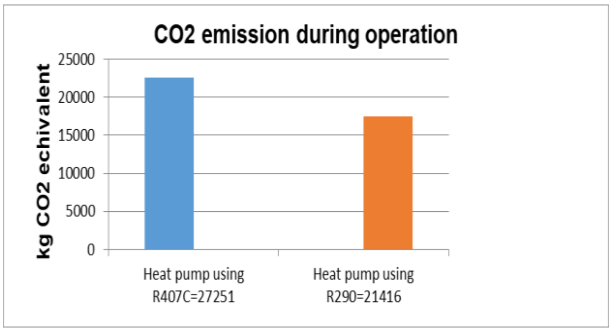

Fig. 10. CO2 emission during operation

The operating tire for the R290 refrigerant is much larger than for the R407C.

4) From the point of view of condensation temperature, the R290 refrigerant operating tire starts at 16^{0}C and ends at 68^{0}C, while the R407C refrigerant operating tire starts at 22^{0}C condensing and ends at condensation temperature of 64^{0}C

5) For condensation temperatures up to 36^{0}C and low vaporization temperatures, between -26^{0}C and -6^{0}C the heat pump with Refrigerant R290 ensures a higher COP than when using refrigerant R407C.

6) For condensation temperatures between 46^{0}C-48^{0}C, the COP is identical for operation with both refrigerants over the entire range of usual values of the vaporization temperature.

7) Operation with the R290 refrigerant ensures the possibility of obtaining condensation temperatures in the range 66-68^{0}C, which exceed the R407C refrigerant operating tire.

8) An important conclusion is that at low values of condensation temperature up to 35^{0} C, corresponding to underfloor heating systems, the use of R290 freon in heat pumps, allows operation at much lower vaporization temperatures than in the case of R407C which allows the use of much colder sources and the obtaining of much better performances than in the case of using the R407C.

9) From the point of view of the TEWI factor, operation with the R290 refrigerant is the ideal option.

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