



Research paper

A comparative performance study of a direct expansion geothermal evaporator using R410A and R407C as refrigerant alternatives to R22



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H I G H L I G H T S

- Direct expansion geothermal evaporator has been simulated using R22, R410A and R407C.
- R407C is the best fluid for retrofit R22 system in the field of DX GHP.
- The pressure drop in R407C DX evaporators is higher than that of R410A.
- The pressure drop in R22 DX evaporator is higher than those of R407C and R410A.
- HER does not really depend to the type of refrigerant at a given soil temperature.

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This study presents a comparative performance analysis of a direct expansion geothermal evaporator using R410A, R407C and R22 as refrigerants. The main goal is to predict the best refrigerant capable of serving as a substitute for R22. A validated geothermal evaporator model developed by our research team was used. The simulation results show that for low refrigerant flow rate, the R410A DX evaporator shows better performance than that of R22, but from the pressure drop observed and superheating recorded with the former, it can be concluded that R407C is the best fluid to replace R22 in the DX GHP. That notwithstanding, to minimize pressure drop, especially for high refrigerant flow rates, R410A would be a better choice for the design of new DX systems.

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1. Introduction

With the coming into force of the Montreal Protocol in 1989, the most environmentally harmful refrigerants, such as CFCs (Table 1), have been banned since 1995 [8]. Those less damaging to the ozone layer, such as HCFCs (Table 1) have a replacement schedule extending until 2040 [24]. R22 shall be replaced by HFCs to as Montreal Protocol. Thus, to overcome these protocol challenges, several studies are ongoing in various fields, and are summarized in Fig. 1 [1,2,4,5,6,7,9,12,15,16,21,22,23,25,27,29,31,32,33,35,36,39,40,42,43,45,48,49,50].

These studies aim mainly to:

- Develop new refrigerants to be prioritized [15,41].
- Develop new heat transfer coefficient expressions [28,52].
- Define tools for analyzing new and existing systems (including components) with respect to fluid substitution.
- Choose the best refrigerant performing similarly to or better than R22.
- Develop the best strategies for system retrofit, including the choice of lubricating oil, while ensuring performance, safety and environmental protection.

Several methods have been developed to synthesize and produce new refrigerants capable of replacing R22. Specifically with respect to air conditioning and heat pumps, the substitute refrigerants currently available on the market are: R134a, R404A, R410A, R407C, R1270, CO₂ (R744) etc. ([26,53,54]), as well as future generation options discussed by James M. Calm [17] and Yunho et al. [8].

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Nomenclature

h_{tot}	Global heat transfer coefficient ($\text{Wm}^{-2}\text{K}^{-1}$)
T_{cr}	Critical temperature ($^{\circ}\text{C}$)
P_{cr}	Critical pressure (kPa)
d_e	Evaporation distance in the borehole (m)
T_{sol}	Ground temperature ($^{\circ}\text{C}$)
P	Pressure (kPa)
h	Specific enthalpy (J/kg)
h_g	Vapor specific enthalpy (J/kg)
h_f	Liquid specific enthalpy (J/kg)
M_{wt}	Molecular weight ($\text{kg mol}^{-1}\text{K}^{-1}$)
HOC	Heat of Combustion (MJ kg^{-1})
NBP	Normal Boiling Point ($^{\circ}\text{C}$)
LFL	Lower Flammability Limit (%)
k_s	Ground thermal conductivity (W/m.K)
C_{p_s}	Ground specific heat (J/kg.K)
ρ_s	Ground density (kg/m^3)

H_s	Heat transfer coefficient between pipe and grout ($\text{W.m}^{-2}\text{K}^{-1}$)
DX	Direct Expansion
SL	Secondary Loop
PDE	Partial differential equations
HT	Heat transfer in solid
ODP	Ozone Depletion Potential
GWP	Global Warming Potential
GHP	Geothermal Heat Pump
GHE	Geothermal Heat Exchanger
NIST	National Institute of Standards and Technology
CFCs	ChloroFluoroCarbons
$T_{c_{mean}}$	Mean temperature of grout ($^{\circ}\text{C}$)
COP	Coefficient of performance of heat pump
HFC	HydroFluoroCarbon
HCFC	HydroChloroFluoroCarbon
HER	Heat Extract Rate (Wm^{-1})

Many studies have been carried out as well on heat exchangers and on the overall heat pump to assess their performance versus fluids serving as candidates to replace R22, and to develop strategies for the conversion of heat pump systems currently in service, most of them operating with R22. The results vary with the experimental conditions, the design, the refrigerant and the systems used. Readers may refer to Fig. 1 for more details.

The alternative refrigerants to R22 evaluated vary significantly: (i) R407C and R410A in a 10.5 kW residential heat pump [3]; (ii) R134a, R290, R407C and R407C in a theoretical vapor compression cycle model [55]; (iii) R407A and R407C in a domestic heat pump [37]; (iv) R134a and various mixtures of R22/R134a in a domestic heat pump [44]; (v) R22, R134a, R290, R600, R404A, R407A, R407B, R407C, 407D, R410A, R410B, and R417A in residential air conditioners (simulation NIST software Cycle_D) [24]; (vi) the mixture of R290/R600/R123 in a geothermal heat pump system [14]; (vii) R134a in the experimental direct expansion ground-coupled heat pump (DX-GCHP); (viii) CO_2 in a direct expansion geothermal evaporator model [46], etc. The results obtained vary greatly, and are usually measured against those of R22, which are considered as the reference. The following are some interesting conclusions concerning air-to-air systems:

- It is possible to replace R22 by R407C because they have a neighboring thermodynamic property [3,51,53].

- The use of R410A has required that the original reciprocal compressor be changed to a smaller displacement scroll compressor (approximately 66% of R22 capacity) to achieve the same cooling capacity of R22 [3].
- Systems using R410A experience more pronounced performance degradation than those using R22, R407C, R290 and R134a because of the low critical temperature of R410A [55].
- The mixture ratio affects the COP (ratio between the heating capacity and the power consumption of the compressor) significantly, and the COP could be improved by using R134a or an appropriate mixture of R134a/R22 instead of pure R22 [44].
- R404A, R507, R407C, R427A and R422D are used to retrofit R22, and compressor tests with these fluids reveal a drop in performance of about 5–15% compared to R22 [19].
- The electric consumption values of units operating with R404A, R407C, and R410A are about 22–31% higher versus the case with R22. For the units operating with R407A, R407B, R407D, R407E, and R410B, the electric consumption is about 10–23% higher. For R600, the consumption is 6–8% higher than with R22. For all these fluids, the COP is 7–24% lower than with R22, except for R600, for which the COP is higher by 7–9%, and R134a and R290, which exhibit the same COP as R22 [24].
- When considering thermal and environmental parameters, R290 is identified as the best candidate for R22, provided the safety aspects are resolved [24].

Table 1
Environmental effects of refrigerants [8].

Refrigerants	ODP	GWP
CFCs		
R11	1	3800
R12	1	8100
HCFCs		
R22	0.055	1500
R141b	0.11	630
R142b	0.065	2000
HFCs		
R32	0	650
R125	0	2500
R134a	0	1300
R407C	0	1520
R410A	0	1725
Natural refrigerants		
R744	0	1
R717	0	0
R600a	0	3
R290	0	3

In the field of geothermal heat pumps, and especially that of DX heat pumps systems [56], most of the experimental work and modeling (see Fig. 1) are usually carried out with only one replacement fluid. Wang et al. [10], for example, conducted an experimental performance evaluation of a direct expansion ground-coupled heat pump (DX-GCHP) system in heating mode that uses R134a as the refrigerant. During the on–off operations, the heat pump supplied hot water to the fan-coil at 50.4°C , and its heating capacity was 6.43 kW. The COP values of the heat pump and of the whole system were found respectively to be 3.55 and 3.28 on average at an evaporating temperature of 3.14°C and a condensing temperature of 53.41°C . The authors also discussed some practical points such as: (i) the heat extraction rate from the ground, (ii) refrigerant charge, and (iii) two possible new configurations to deal simultaneously with the misdistribution and instability of parallel GHE evaporators. Cerit and Erbay [18] evaluated the roll bond evaporator design which gives maximum COP for the direct

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