Applied Thermal Engineering 100 (2016) 768–774

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Alternative refrigerants for the heat pump of a ground source heat pump system

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ARTICLE INFO

Article history:
Received 16 September 2015
Accepted 11 February 2016
Available online 26 February 2016

Keywords:
Heat pump
Ground system
Refrigerant
Thermodynamic
Geothermal energy

ABSTRACT

It is attempted to define more environment friendly working fluids for the heat pump of ground source heat pump systems (GSHPSs). The examined case is an office building with total cooled area 1000 m^2, which is connected with such a system. The energy demands are computed by TRNSYS 16.1 and the ground loop is modeled by GLD2009. Alternative refrigerants are proposed instead of the one that has been extensively used worldwide, for many years, the R-22. The proposed replacements are the binary mixtures R-32/R-134a in compositions 20/80%, 30/70%, 40/60% by mass, and the ternary blends R-407B (10wt% R-32, 70wt% R-125, 20wt% R-134a), R-152a/R-125/R-32 (48wt% R-152a, 18wt% R-125, 34wt% R-32), R-410B (45wt% R-32, 55wt% R-125) and R-507A (50wt% R-125, 50wt% R-143a). A MATLAB code is developed in order to calculate coefficient of performance (COP) values for one stage vapor compression reference cycle with no evaporator superheating and condenser subcooling. The thermodynamic properties of refrigerants are derived from previous works of our laboratory, REFPROP 8.0 and international bibliography. The choice of the most suitable refrigerant depends on the criteria which are set.

1. Introduction

Nowadays, more and more people have experienced the benefits of geothermal energy applications for space heating and cooling [1–3]. The common root of all these installations is to establish a ground plant, which exploits the earth's subsoil potential for being a huge heat source or sink. A typical ground source heat pump system (GSHPS) consists of a series of closed loops buried in the ground, in which the heat carrier fluid is circulating, coupling with heat pump and distribution circuit to the building.

An important part of GSHPSs is the heat pump or the set of heat pumps that they include. The heat pump is an unbreakable part of them as this is recognized by their name. In the current work, emphasis is given on the heat pump's operation within a GSHPS. The role of the heat pump in such type of systems is crucial, as it covers the extra air-conditioning demands when the ground's potential is not adequate. The thorough examination of heat pump's operation is an intriguing topic in the field of thermodynamics, but the same examination within the field of geothermal energy sounds even more attractive.

In an attempt to propose alternative refrigerants for the heat pump of such a system, many different factors should be taken into consideration. The most important among them are the types of ground loop, the type of heat pump, the connection between them, the load that should be covered by the system and the refrigerant properties. Closed ground loops are more preferable compared to open ones due to the fact that they restrict geothermal fluid circulation into closed tubes and thus reduces the possibility of environmental pollution. By the same way of thinking, direct expansion systems are less popular than indirect ones due to the fact that a possible leakage of the refrigerant that circulates around the ground loop may cause a significant damage to the nearby living environment. The total amount of load and its distribution during the time of the year determines the system's operation temperature, whereas the refrigerant selection remains a challenge for engineers.

There are previous research studies that attempt to evaluate the performance of heat pump working fluids under certain conditions of GSHPS operation. The performance of air-source heat pumps have been assessed in ground plants [4,5]. The binary mixture (37wt% R152a and 63wt% R245fa) is recommended for high temperature heat pumps in which the condensation temperature ranges from 70 °C to 90 °C [6]. Mixtures performance in Organic Rankine Cycle (ORC) is better than that of pure fluids at high source temperatures, which range from 80 °C to 120 °C [7]. The hydrocarbons

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http://dx.doi.org/10.1016/j.applthermaleng.2016.02.048
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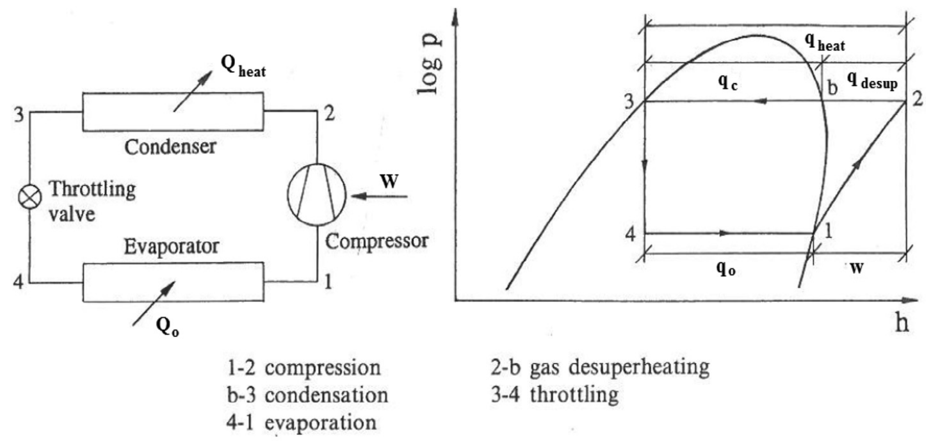

Fig. 1. Schematic diagram and a pressure – enthalpy diagram for one stage reference refrigeration cycle of a pure substance [14].

improve their performance as refrigerants when the inlet temperature of geothermal water increases significantly [8,9]. The efficiency of R410A and R407C as alternative proposals to R22 in direct expansion systems has been also estimated [10–12]. Whereas, the commonly used R22 still remains one of the best refrigerants by increasing heat pump's heating capacity 10% compared to the one that uses R744 in a hybrid ground source heat pump system (HGSHPS) [13].

In the current work, it is attempted to define more environment friendly working fluids for the heat pump of a GSHPS. The examined ground loop is closed and no direct expansion of heat pump is taken place. The operation temperatures of the water-to-water heat pump are low. Alternative proposals to the widely used R22 are suggested from the hydrofluorocarbons (HFCs) family. The selection and the performance study of the proposed mixtures under the given conditions is our contribution to the existing pool of knowledge.

2. Theoretical background

Heat pumps' presence in GSHPSs shows that in this type of systems, the required heat exchange between the building and the ground is not enough to cover the building's energy demands all year round. The heat pump is the supplementary device that provides the building's heating and/or cooling system with extra heat or cool when it is needed. Its effective sizing is crucial to GSHPS's operation [14–18].

The heat pump consists of four main parts [14–17]; two heat exchangers, which are the evaporator and the condenser, the compressor and the throttling valve. Heat pump's working fluid, the refrigerant, runs the refrigeration cycle, which is the same as that which refrigerators' refrigerant runs. Fig. 1 [14] depicts a schematic diagram of heat pump's arrangement and the reference cycle in a pressure–enthalpy diagram. The thermodynamic cycle is considered as simple regarding variations of its indicative operation. The reliability of choice is enhanced by the approved selection of the equations, which define the thermophysical properties [19,20].

It should be noted that in the reference refrigeration cycle or in other words in the reference vapor – compression cycle the evaporation and condensation temperatures are practically constant. This cycle is referred to one-component refrigerant or to azeotropic refrigerant mixture.

Fig. 2 illustrates the same type of diagram as the one which is depicted in Fig. 1, but for two-or-more component refrigerant or zeotropic refrigerant mixture. The refrigeration cycle of refrigerant mixtures differs from the one of pure substances. For mixtures, the phase change from gas to liquid is accompanied with a temperature drop whereas, for one-component refrigerants, the temperature value remains the same. This deviation accounts for the existing glide, which is seen in Fig. 2. Correspondingly, for refrigerant mixtures, the phase change from liquid to gas is accompanied with a temperature increase whereas, for one-component refrigerant, the process is taking place at constant temperature. It is essential to refer that these phasing changing processes, which are happening in the pump's heat exchangers, condenser and evaporator, are also influenced by mixture's liquid-gas composition at specific conditions. The international bibliography [19–22] provides a set of vapor–liquid equilibrium diagrams for a variety of refrigerant mixtures. In these diagrams, one out of the

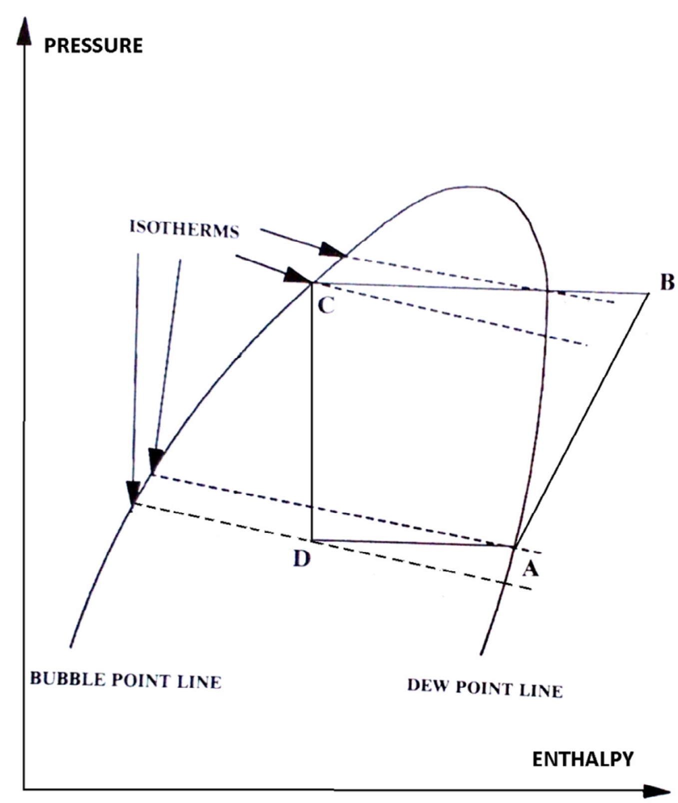

Fig. 2. Pressure–enthalpy diagram for one stage reference refrigeration cycle of a mixture.