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Small ammonia heat pumps for space and hot tap water heating

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Abstract

In this study a small ammonia ground source heat pump with a capacity of 8,4 kW has been designed to provide space heating and hot water preparation with estimated max heat load of 7,5 kW for space heating and 2 kW for hot tap water preparation. The main components and materials have been chosen to avoid corrosion and to be compatible for work with ammonia. Calculations with engineering equation solver (EES) have been done to estimate heat pump performance and evaluate the necessary size of the water tank for the heating system. Heat transfer from the heat pump to the storage tank has been calculated considering seven different working regimes with variable heating demand from 1 to 7 kW. Usually the storage tank for heat pumps is designed to prevent very frequent on/off operation of the compressor due to variations in the heating load. In this case the optimal volume of the tank was found in order to cover heating demand during the peak hours of high electricity price according to the Nordic power market. Calculated COP = 4 (T_{evap} = -3°C , T_{cond} = 40°C) provides energy savings of up to 75% in comparison with the electrical heaters. In case of the variable price of the electricity it is possible to achieve more savings with the installation of the storage tank. Optimal volume of the tank is 1000 litres to cover 2-3 hour peaks of the high electricity price.

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Keywords: small scale; heat pump; ammonia; ground heat source; storage tank;

Nomenclature

ODP	ozone depletion potential	PHX	plate heat exchangers
GWP	global warming potential	EXV	expansion valve
EES	engineering equation solver	LMTD	logarithmic mean temperature difference

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1. Introduction

Nowadays the problem with climate change is gaining importance. Due to big CO_2 emissions and greenhouse effect, global policy starts to focus on actions which could contribute a reduction of harmful impact on the environment. According to data about household energy consumption in Norway (2012), almost 80% of energy is used for space and hot tap water heating. [1] Considering the fact that the biggest part of this demand is covered by electrical energy wide use of residential heat pumps could make significant energy savings. The heat pump market offers a wide variety of different small-scale heat pumps where most of them utilize refrigerant R-410A which has high global warming potential. Considering the fact that global policy starts to focus on issues related to energy efficiency and harmful impact on the environment it is necessary to investigate over new refrigerants. An alternative solution is to utilize natural refrigerants, such as ammonia, which has almost zero global warming potential and zero ozone depletion potential. Since the beginning of the refrigeration era, ammonia has been used in large capacity systems where no attention has been paid to medium and small scale units. It is related to lack of components and specific design due to physical and chemical properties of the ammonia. The main focus of this study is to find designing features and to estimate the performance of the small ammonia heat pump for one family house.

2. Refrigerants and case studies

2.1. Refrigerants

The refrigeration and heat pump industry have been experienced many changes in the last 25 years considering the refrigerants. The beginning of changes was Montreal protocol in 1989 with the main idea to protect the ozone layer. Many refrigerant substitutes were made. For example, R22 which has ozone depletion potential (ODP) of 0,055 was substituted with R-410A (ODP=0), which nowadays, is the most used refrigerant in the residential sector. However, R-410A is not long term refrigerant because of high global warming potential (GWP) of 1725. High GWP of R-410A leads to explore new refrigerants and one of them are natural refrigerants, such as ammonia (NH3). [2] During the last 10 years many attempts were made to make prototypes of small capacity ammonia system. Unfortunately, most of them have failed, basically due to lack of components. Ammonia is thermodynamically preferable. It has a higher heating capacity and heat transfer coefficients compared to R-410A. GWP and ODP are very close to 0. Main disadvantages of ammonia are toxicity, flammability and its destructiveness towards materials, such as copper or brass. In applications with big pressure ratio, the high temperature of the ammonia discharge gas could be an obstacle.

Table 1. *Comparison of ammonia and R-410A refrigerants (EES Library) (Values given at T = 0 °C)*

Parameters	Ammonia	R-410A
Boiling point (oC)	-33	-48,5
Critical point (oC)	133	72,8
Gas heat capacity (kJ/(kg·°C)) *	2,68	1,13
Liquid heat capacity (kJ/(kg·°C))*	4,16	1,52
GWP	<1	1725
ODP	0	0

It is impossible to use ammonia as a substitute for R-410A because of the big difference in pressure and performance. Another issue is that majority components for residential systems are made of copper and ammonia is very destructive towards them. Specific components should be used to provide long-term operation of ammonia heat pump.

Another substance, which could be used instead of ammonia is R723 which is a mixture of ammonia (60%) and dymethilether (40%). The benefit of using R723 is lower discharge gas temperatures and slightly lower pressure ratio than for R717. [3]

2.2. Previous case studies

Nowadays, heat pumps market does not offer small capacity ammonia heat pumps, however, few pilot plants were made for scientific purposes. Analysis of those plants was made to evaluate specific components and designing