INTERNATIONAL JOURNAL OF REFRIGERATION 46 (2014) 123–141

Available online at www.sciencedirect.com

ScienceDirect

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

Review

A review on substitution strategy of non-ecological refrigerants from vapour compression-based refrigeration, air-conditioning and heat pump systems

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ARTICLE INFO

Article history:
Received 7 January 2014
Received in revised form
18 April 2014
Accepted 27 April 2014
Available online 9 May 2014

Keywords:
Environmental protection
Vapour compression systems
Refrigerants
Environmental impact
Ecological substitutes
Performance analysis

ABSTRACT

The paper presents a review on recent development of possible substitutes for non-ecological refrigerants from HVAC&R equipment based on thermodynamic, physical and environmental properties and TEWI (Total Equivalent Warming Impact) analysis. This review contains a good amount of information regarding the environmental pollution produced by the working fluids of the air-conditioning, heat pump and commercial refrigeration applications and the ecological refrigerant trend. Overall, it is useful for those readers who are interested in current status of alternative refrigerant development related to vapour compression-based refrigeration, air-conditioning and heat pump units. The study describes the selection of refrigerants adapted to each utilisation based on the thermodynamic, physical and environmental properties and explores the studies reported with new refrigerants in domestic refrigerators, commercial refrigeration systems, air-conditioners, heat pumps, chillers and in automobile air-conditioners. Additionally, a comparative analysis of the TEWI for possible substitutes of refrigerant R22 used in various air-conditioning, heat pump and refrigeration systems is performed.

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Une synthèse des stratégies de substition pour des frigorigènes non écologiques pour les systèmes frigorifiques, de conditionnement d'air et de pompe à chaleur à compression de vapeur

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http://dx.doi.org/10.1016/j.ijrefrig.2014.04.023
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Mots clés : Protection de l'environnement ; Systèmes à compression de vapeur ; Frigorigènes ; Impact environnemental ; Substituts écologiques ; Analyse de la performance

Nomenclature

α_{rec}	refrigerant recycling factor
β	CO_2 emission factor
COP	coefficient of performance
E	annual energy consumption, kWh
EES	energy efficiency ratio, Btu $(Wh)^{-1}$
E_u	cooling usable energy, kWh
E_c	consumed energy, kWh
η_{is}	isentropic efficiency
GWP	global warming potential
l	annual leakage rate, %
M	refrigerant charge, kg
M	molecular mass, g mol^{-1}
m	mass flow rate, kg s^{-1}
ODP	ozone depletion potential
p_0	evaporation pressure, MPa
p_c	condensation pressure, MPa
p_{cr}	critical pressure, MPa
P_e	consumed electric power, kW
P_{ef}	effective power, kW
P_{is}	isentropic compression power, kW
P_t	compressor power, kW
Q_0	refrigeration power (cooling capacity), kW
q_0	specific cooling power, kJ kg^{-1}
q_{0v}	volumetric refrigerating capacity, kJ m^{-3}
ρ_l	liquid density, kg m^{-3}
t_0	evaporation temperature, °C
t_{0n}	boiling point, °C
t_2	discharge temperature on the compressor outlet, °C
t_c	condensation temperature, °C
t_{cr}	critical temperature, °C
t_e	outdoor air temperature, °C
t_i	indoor air temperature, °C
τ	system running time per year, h
TEWI	total equivalent warming impact
w	specific compression work, kJ kg^{-1}

1. Introduction

Environmental pollution represents a major risk for all life on our planet (men, flora, fauna), because it consists not only of the local noxious effects of different pollutants but also the imbalances produced on a large scale over the entire planet. Environmental protection represents the fundamental condition of the society's sustainable development and a high priority of national interest that is realised in institutional framework in which the legal norms regulate the development of activities with environmental impact and exerts control on such activities.

The purpose of environmental protection is to maintain the ecological balance, to maintain and improve the natural factors, to prevent and control pollution, to promote the development of natural values, to ensure better life and work condition for the present and future generations and it refers to all actions, means and measures undertaken for these purposes.

One of the minor components of the atmosphere, the ozone layer, has a special importance in maintaining the ecological balance. Ozone is distributed primarily between the stratosphere (85–90%) and troposphere. Any perturbation of the atmospheric ozone concentration (which varies between 0 ppm and 10 ppm, depending on the regions) has direct and immediate effects upon life (Hera, 2004).

For most of the states the problems of forming and maintaining the earth's ozone layer, represents a major priority. In this context during the last 30 years, the European Union has adopted a large number of laws and regulations concerning environmental protection to correct the pollution effects, frequently by indirect directives, through imposition of the levels of allowable concentrations by asking for government collaboration, programs and projects for the regulation of industrial activities and productions. The Alliance for Responsible Atmospheric Policy is an industry coalition and leading voice for ozone protection and climate change policies, which maintains a brief summary of the regulations for some countries (ARAP web site).

Refrigerants are the working fluids in refrigeration, air-conditioning, and heat pump systems (UNEP, 1994). They absorb heat from one area, such as an air-conditioned space, and reject it into another, such as outdoors, usually through evaporation and condensation. These phase changes occur both in absorption and mechanical vapour compression systems, but not in systems operating on a gas cycle using a fluid such as air.

Working fluids escaped through leakages from cooling equipment during normal operation (filling or empting) or after accidents (damages) gather in significant quantities at high levels of the atmosphere (stratosphere). In the stratosphere, through catalytically decompounding, pollution from working fluid leakage depletes the ozone layer that normally is filtering the ultraviolet radiation from the sun, which is a threat to living creatures and plants on earth. Stratospheric ozone depletion has been linked to the presence of chlorine and bromine in the stratosphere. In addition, refrigerants contribute to global warming (also called global climate change) because they are gases that exhibit the greenhouse effect when in the atmosphere.

Concerning the polluting action upon the environment, for atmospheric ozone, as presented through the Montreal Protocol (UNEP, 1987) and the subsequent amendments, as well as for the greenhouse effect according to the Kyoto Protocol (GECR, 1997), refrigerants can be classified as follows:

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