HEAT POWERED CYCLES 2016
EXTENDED ABSTRACTS

Editors
Ian W. Eames PhD, CEng, FIMechE
Michael J. Tierney PhD, CEng, MIChemE

Published by Heat Powered Cycles

A COMPARATIVE ECOLOGICAL AND ENERGY EFFICIENCY ANALYSIS OF VAPOR-COMPRESSION, ABSORPTION AND EJECTOR AIR CONDITIONERS OPERATING WITH "NATURAL" REFRIGERANTS

Guangming Chen[a], Kostyantyn Shestopalov[a,b], Olga Khliyeva[b], Volodymyr Ierin[b]

[a] Ningbo Institute of Technology, Zhejiang University,
No 1 QuianHu South Road, Ningbo City, 315100, Zhejiang Province, China; e-mail: gmchen@zju.edu.cn
[b] Odessa National Academy of Food Technologies, 112, Kanatnaya St., Odessa, 65039, Ukraine

INTRODUCTION

Recently, the technological development of industry all over the world is oriented to the economy of natural resources and the decrease of the anthropogenic load on the environment. More and more attention is paid to the development of the "green" technologies, which do not use the fossil fuel combustion in a technological processes. At the same time, these technologies during manufacturing of the equipment can demand more energy resources. Therefore, the "green" technologies are not always ecologically cleaner compared to traditional systems.

Modern technological progress in refrigeration equipment is based on the implementation of several international legislative acts, such as the Montreal and Kyoto Protocols, several legislative acts on the rational application of material and energy resources. The increase of CO_2 and other greenhouse gases (GHG) in the atmosphere is the result as well as the reason for global warming of the climate on the Earth.

Great attention is paid to the production of "ecologically clean" thermal and electrical energy that does not require burning of organic fuel. Therefore, a comparison of the eco-energy coefficients of the installations which use the alternative sources of energy with traditional equipment are of a considerable interest.

Applying to the refrigeration technology, the comparison of the air conditioning systems on the basis of ejector cooling systems and absorption chillers using thermal energy with traditional vapor-compressor system deserves consideration. In the present study the coefficients of the eco-energy efficiency of the three systems with the same cooling capacity operating on the same temperature level are considered.

Determination of the eco-indicators chosen for comparison is based on the calculation of specific emission of green house gases during life cycle of the studied system (calculated per unit of refrigeration). The methodology for the calculation of GHG total equivalent emission was suggested by Zhelezny et al, 2001; Zhelezny et al, 2004; Zhelezny and Semenyuk, 2012. The authors propose to consider the whole technological chain of product manufacturing (refrigeration production in considered case) from the extraction of raw materials to their disposal. The energy resources (emission of GHG is proportional to energy resources) that are necessary for the manufacturing and utilization of the equipment, buildings, etc., and also the energy equivalent of the human labor should be taken into account.

MATHEMATICAL MODEL

In accordance with the methodology from Zhelezny et al., 2001, the Total Equivalent Greenhouse Gases Emission (TEGHGE) of the analyzed system (equipment), for the life cycle, when the information about cost for its manufacturing and maintenance is known, can be calculated from the Eq. 1:

$$
\begin{aligned}
\mathrm{TEGHGE_{eq}} &= \beta \sum \left(e_{GDP} \cdot \left(c_i^{eq} + c_i^{eq.disp} \right) + e^{h.l} \cdot t_i^{h.l} \right) + e_{GDP} \cdot \beta \cdot \tau \sum c_i^{eq} \left(k_{dep} + k_{rep} \right) + \\
&+ e_{GDP} \cdot \beta \cdot \tau \sum \left(c_j \cdot G_j \cdot n \right) + \sum \left(m_k \cdot GWP_k \cdot n \right) + \quad (1) \\
&+ \sum \left(m_k^{eq} \cdot GWP_k \cdot (1-\alpha) \right) + \beta \cdot e^{h.l} \cdot t^{h.l} + e_{GDP} \cdot \beta \cdot c^{pr.disp} \cdot n \cdot \tau
\end{aligned}
$$

where, β is an average indirect emission factor for a certain region (country), $kgCO_2e/kW \cdot h$; e_{GDP} is an energy intensity of GDP, $kW \cdot h\,(US\$)^{-1}$; c_i^{eq} is a cost of *i*-element (equipment) of the considered system, US$; k_{dep} and k_{rep} are the coefficients, considering the annual expenses (from investment) required for the depreciation and repairing of the system elements, $year^{-1}$; τ is the operation life of the equipment of the considered system, years; $c_i^{eq.disp}$ is a cost of the disposal of the *i*-element (equipment) of the considered system, US$; $e^{h.l}$ is an energy equivalent for human labor, $kW \cdot h(man\text{-}hour)^{-1}$; $t_i^{h.l}$ is labor expenditures for the production of the *i*-element (equipment), man-hour; c_j is a cost of the production of the j-type raw material, half-finished material, energy resources needed for the manufacturing of the product in the considered system, US$ per unit of raw material; G_j is the consumption of the j-type raw material, material, half-finished material, energy resources, etc., during manufacturing of the unit of product; n is the yearly capacity of the plant, quantity of the product per year; m_k is a mass of k-type GHG that emits during manufacturing of the unit of product, kg per unit of product; GWP_k is a GWP of k-type GHG, kg of CO_2e per kg of GHG; m_k^{eq} is a mass of the k-type greenhouse gas in the equipment at the moment of its disposal, kg; α is a rate of the disposed refrigerant; $t^{h.l}$ is labor expenditures that are necessary for the manufacturing of the products, man-hours per year; $c^{pr.disp}$ is the cost of the product disposal, US$.

Eq. 1 can be easily adapted to any type of the equipment or technology if there are schematic diagrams of the direct and indirect GHG flows of the studied system (Zhelezny et al., 2001; Zhelezny et al, 2004; Zhelezny and Semenyuk, 2012).

The methodology of the eco-energy analysis of power-intensive equipment, based on the calculation of the green house gas emissions during its life cycle, is presented. According to the presented methodology, a comparative eco-energy analysis of ejector, absorption and vapor compressor air conditioners operating at different working conditions in China and Ukraine, is carried out. For the present study the natural refrigerant R600a was chosen for operation of vapor-compression and ejector air conditioners, and water solution of LiBr – for absorption system. New eco-energy indicators, which allow the determination of the prospective of the alternative air conditioning system implementation, are offered. It is shown, that heat driven air conditioners have eco-energy prospects for implementation if they are operated by waste heat from several industries.

From the obtained results of the calculations it can be seen that the value of TEGHGE depends on the electrical power production structure and the energy intensity of the country's GDP, in which the air conditioner is used, and on the energy efficiency of the equipment. The most important factor influencing the decrease of TEGHGE is the energy efficiency of the equipment. Therefore, refrigerant selection and the thermodynamic efficiency of the equipment are of the highest priority for the solution to the global environmental problems in this area. Although refrigerant R600a has a low value of GWP, this refrigerant may not have obvious advantages from the ecological and energy view points. This can be associated with higher indirect emission from the manufacturing of the equipment for the flammable refrigerant and the energy consumption during operation of the equipment. It is shown that eco-energy practicability of the heat-driven air conditioners is determined by the structure of the electricity production and energy intensity of GDP of the country where they would be used.

References

Zhelezny V, Bikovez N, Khliyeva O, Stepanova V, Suhodolskaya V, 2004. Methodology of the total green house gases emission calculation in industry, Ecotechnology and resources saving 6, 34-43.

Zhelezny, V.P., Semenyuk, Y.V., 2012. Working fluids of the vapor compression refrigerating: properties, analysis, application. Phoenix, Odessa, Ukraine.

Zhelezny, V.P., Zhelezny, P.V., Khlieva, O.Y., 2001. New indicators for efrigeration management. In: Proc. Refrigerant Management and Destruction Technologies of CFC, Dubrovnik, Croatia.