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The energy efficiency of refrigerants: An assessment based on thermophysical properties

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ABSTRACT

A method is presented which ranks single fluid refrigerants in order of thermodynamic effectiveness. Blends can be included in the ranking if their viscosity is adjusted to account for blend constituent interactions. This is achieved by the empirical use of molecular acentricity and dipole moment values for the constituent fluids. Only public domain property data are needed.

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L'efficacité énergétique de frigorigènes: une évaluation basée sur les propriétés thermophysiques

Mots clés : Frigorigènes ; Thermique ; Efficacité ; Classement

1. Introduction

The man-made contribution to climate change is widely acknowledged. Refrigerant manufacturers have responded by developing new refrigerants which are lower in global warming effect when released into the environment – the direct effect. To maximise effectiveness this has to be combined with low energy consumption when the plant is running – the indirect effect.

The power consumed by a refrigerator or a heat pump is a function of the efficiency of the plant–refrigerant combination. This makes the contribution of the refrigerant on its own difficult to assess. This paper investigates the development of a method capable of giving a ranking order, best to worst, for the thermal effectiveness of refrigerants. It requires commonly available thermophysical properties only. Blends can be included in the assessment when an empirical adjustment is made to account for the dissipative interactions between blend components.

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Nomenclature

Latin alphabet

C1, C2 etc condensation factors
C_1, C_2 empirical constants
C_p, C_v specific heat: constant press, vol (J Kg^{-1} K^{-1})
D tube inner diameter(m)
E1, E2 etc evaporation factors
f_i constant in equation (4)
g acceleration of gravity (m s^{-2})
G mass flux (kg m^{-2} s^{-1})
h_{cond} condensation heat transfer coefficient (W m^{-2} K^{-1})
h_{cc} convective condensation heat transfer coefficient (W m^{-2} K^{-1})
h_{fc} falling film condensation heat transfer coefficient (W m^{-2} K^{-1})
h_v vapour heat transfer coefficient (W m^{-2} K^{-1})
h_{fg} latent heat of vaporisation (kJ kg^{-1})
$I = C_p/C_v$ ratio of specific heats
$J_G = xG/[gD\rho_v(\rho_l - \rho_v)]^{0.5}$ dimensionless vapour velocity
k_l, k_v conductivity: liquid, vapour (W m^{-1} K^{-1})
K_1 blend empirical constant
M molecular weight
P molecular polar moment (debye)
P, P_{red} pressure, reduced pressure (Pa)
Pr_l, Pr_v Prandtl number: liquid, vapour
q heat flux (W m^{-2})
$Re_{film} = [4G(1-x)\delta/[(1-\alpha)\mu_l]]$ Reynolds #:film
$Re_l = [G(1-x)D]/\mu_l$ Reynolds #: liquid
T_{sat}, T_{wall} temperature: saturation, wall (°C)
u_l, u_v velocity: liquid, vapour (m s^{-1})
x vapour quality
$X_{tt} = \left(\frac{\mu_l}{\mu_v}\right)^{0.1}\left(\frac{\rho_v}{\rho_l}\right)^{0.5}\left[\frac{(1-x)}{x}\right]^{0.9}$ =Martinelli parameter

Greek alphabet

α void fraction
δ film thickness (m)
μ_l, μ_v, $\bar{\mu}_l$ viscosity: liquid, gas, blend (Pa s)
π circle: circumference/dia ratio
ρ_l liquid density (kg m^{-3})
ρ_v gas density kg m^{-3})
σ surface tension (N m^{-1})
ω molecular acentricity (–)

Subscripts

cond condensation
cc convective condensation
fc falling film condensation
v vapour
l liquid

2. The basis of the method

The ASHRAE Fundamentals Handbook of 2001 (2001) explains the methodology by which its coefficient of performance (cop) values are determined for refrigerants. In the method presented here a cycle factor is determined for each refrigerant which is a function of fluid properties alone. The cycle factors are compared with the cop values and the trend examined. Where it gives the same order for the factors as for the cop values this is taken to be a strong indication that the method has value in ranking refrigerants in order of thermal effectiveness.

3. Refrigeration and heat pump applications

The essential features of refrigerators and heat pumps are identical as represented in diagrammatic form in Fig. 1.

4. The cycle factor method

Interest has grown in the use of natural substances such as carbon dioxide, ammonia, hydrocarbons, and air as refrigerants. In addition, new less polluting synthetic refrigerants have been introduced. Heat transfer, already a heavily researched area, received increased effort, especially that occurring during evaporation and condensation, the most common methods in use for drawing heat from the cold reservoir and releasing heat to the hot reservoir, respectively.

The cycle factor used here is a function of three factors: one for the evaporator, one for the compressor and one for the condenser. The ratio of the specific heats is used as the compression factor. The evaporation and condensation factors are derived from two sources:

- heat transfer expressions from the literature,
- a qualitative consideration of the behaviour of refrigerants during phase change.

5. Published work on heat transfer during phase change

5.1. General comments

More work has been published on phase change in a fluid flowing in a horizontal tube than in any other arrangement. The heat transfer calculations for this case are complex due to the combined influence of: fluid properties, the liquid/gas ratio which changes along the tube length and the flow regime

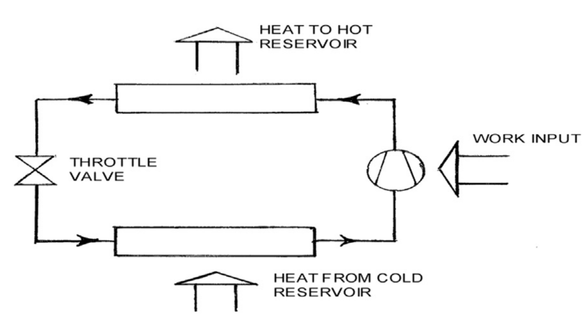

Fig. 1 – Basic circuit of heat pump and refrigeration systems.

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