THERMOPHYSICAL PROPERTIES OF CARBON DIOXIDE ALONG THE LIQUID – VAPOR EQUILIBRIUM LINES

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The essential thermophysical properties of liquid and gaseous CO_2 along the saturation lines at T = 216-304°K are tabulated here in detail. The tables list 12 quantities (p_s, ρ, c_p, r, β, γ, η, ν, Pr, a, σ, λ) and cover almost the entire temperature range from the triple point (T_0 = 216.56°K) to the critical point (T_c = 304.2°K).

The tables were calculated by equations which had been derived in [1, 2] on the basis of a statistical evaluation of most reliable test data on the thermophysical properties of CO_2 along the phase-equilibrium lines and within the single-phase region at temperatures from T_0 to 1300°K and pressures P from 1 to 3000 bars. These equations had been set up by nonconventional methods in the form:

$$z = \frac{p}{\rho RT} = 1 + \rho \sum_{i=0}^{r} \sum_{j=0}^{s_i} c_{ij} (\rho - \rho_0)^i \left(1 - \frac{1}{\tau}\right)^j, \quad (1)$$

$$\ln (\eta/\eta_0) = \sum_{i=1}^{m} \sum_{j=0}^{n_i} b_{ij} \rho^i / \tau^j, \quad (2)$$

$$\ln (\lambda/\lambda_0) = \sum_{i=1}^{m} \sum_{j=0}^{n_i} a_{ij} \rho^i / \tau^j. \quad (3)$$

The values of the function in the standard form were taken from [3].

The errors of the tabulated values were estimated in terms of the standard deviations from test data.

NOTATION

p_s is the saturated-vapor pressure;
ρ is the density;
c_p is the specific heat at constant pressure;
r is the heat of transformation;
β is the thermal expansivity;
γ is the temperature coefficient of pressure;
η is the dynamic viscosity;
ν is the kinematic viscosity;
λ is the thermal conductivity;
a is the thermal diffusivity;
Pr is the Prandtl number;
σ is the coefficient of surface tension;
τ is the referred temperature.

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COMPOSITE MEASUREMENT OF BUBBLE CHARACTERISTICS IN A LIQUID

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Certain tests where the motion of bubbles in a liquid was recorded (see, e.g., [1, 2]) did not include a simultaneous composite recording of bubble motion and thermal parameters. In view of the importance of such tests for the study of boiling characteristics during uniform-over-the-volume heating of liquids, a test stand has been developed [3] including a cinematographic camera and a multiloop oscillograph with probes and transducers for measuring the temperature along the bubble path, the density of the vapor-water mixture, of the power supplied to the liquid, and for counting the number of vapor bubbles (by recording the current of the bubble probe). In addition, various auxiliary signals were recorded for the interpretation and the comparative evaluation of accumulated data (a time–base signal, the test number, etc.).

The system could be actuated either manually, or automatically by exceeding the preset threshold signal from the electrode-type bubble probe (two platinum wires pulled through capillaries and immersed in the liquid [4]).

The temperature was measured with a direct-current microthermistor. For a systematic determination of such characteristics as the volume of vapor inclusion in the liquid, the mean density of the vapor-water layer and of the entire contents, the volume of the vapor-water layer, etc., the authors sampled and matched readings of the radioactive densitometer against direct measurements on photo frames corresponding to the same instants of time.

On the basis of these results, the authors have derived single-parameter linear equations of the regression lines for the densitometer readings of all these characteristics (a direct systematic determination of these characteristics off the photo frames would have been too laborious). The calculated error of these equations was found to be within ±10% at a 90% confidence level.

The results of these experiments with a uniform-over-the-volume heating of a liquid have confirmed the occurrence of pulsating boiling modes and the feasibility of stabilizing the process. At a specific input power of 0.35 kW/liter (total power 16 kW, height of liquid column 60 cm), for instance, intensive density and temperature pulses were noted in 48 sec intervals. As the power was dropped, the pulse frequency increased until the boiling process had stabilized. Note that there were also pulses at the beginning of boiling and the integral character of the process (its dependence on the system history).

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PARAMETERS OF INTERMOLECULAR LENNARD – JONES (12-6), STOCKMEIER (12-6-3), 6-EXP, AND KIHAR POTENTIALS IN DICHLORODIFLUOROMETHANE

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For calculating the transport properties of gases, it is necessary to know the form of intermolecular interaction potentials.

The parameters of the following potentials have been determined from viscosity data for the gas by the method of translating the coordinate axes.

1. The Lennard–Jones (12-6) potential

$$u(r) = 4\varepsilon\left[\left(\frac{\sigma}{r}\right)^{12} - \left(\frac{\sigma}{r}\right)^{6}\right],$$

$$u(\sigma) = 0.$$

2. The Stockmeier (12-6-3) potential

$$u(r) = 4\varepsilon\left[\left(\frac{\sigma}{r}\right)^{12} - \left(\frac{\sigma}{r}\right)^{6} + \delta\left(\frac{\sigma}{r}\right)^{3}\right],$$

$\delta = \frac{\mu^2}{2\varepsilon\sigma^3}$ is the dipole moment.

3. The 6-exp potential

$$u(r) = \frac{\varepsilon}{1 - \frac{6}{\alpha}}\left\{\frac{6}{\alpha}\exp\left[\alpha\left(1 - \frac{r}{r_m}\right)\right] - \left(\frac{r_m}{r}\right)^{6}\right\}.$$

4. The Kihar potential

$$u(r) = 4\varepsilon\left[\left(\frac{\sigma - a}{r - a}\right)^{12} - \left(\frac{\sigma - a}{r - a}\right)^{6}\right]$$

or

$$u(r) = 4\varepsilon\left[\left(\frac{1 - \gamma}{r^* - \gamma}\right)^{12} - \left(\frac{1 - \gamma}{r^* - \gamma}\right)^{6}\right],$$

where $\gamma = a/\sigma$ and $r^* = r/\sigma$.

The values of the parameters here are listed in Table 1.

TABLE 1

Parameter	Potential					
	$\frac{\varepsilon}{k}$, °K	σ, Å	r_m, Å	γ	δ	α
Lennard–Jones	223	5,42	6,07	—	—	—
Stockmeier	214	5,14	5,75	—	0	—
6-exp	240	6,00	6,01	—	—	15
Kihar	225	5,40	6,04	0	—	—

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TEMPERATURE FIELD AND THERMAL FLUX FIELD IN THE HOT CATHODE OF AN ELECTRIC-ARC HEATER

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The equation of steady-state heat conduction for a circular rod cathode inside a cylindrical sleeve, with convective and radiative heat transfer taken into account as well as with internal sources and with the temperature assumed uniform over the rod section, can be written as follows:

$$\frac{d^2T}{dx^2} = \frac{P_1\sigma_0\varepsilon_1 T^4}{f\left[1+\frac{P_1}{P_2}\left(\frac{1}{A_2}-1\right)A_1\right]\lambda} - \frac{P_1\sigma_0\varepsilon_2 T_W^4}{f\left[\frac{A_2}{A_1}+\frac{P_1}{P_2}(1-A_2)\right]\lambda} + \frac{P_1 B}{f\lambda}x^m T - \frac{P_1 B\theta}{f\lambda}x^m - \frac{d(\ln\lambda)}{dT}\left(\frac{dT}{dx}\right)^2 - \frac{\rho I^2}{f^2\lambda},$$

where T (°K) is the temperature of the rod; T_W (°K) is the temperature of the surrounding wall; P_1 is the rod perimeter; P_2 is the wall perimeter; f is the rod section area; ε_1 is the emissivity of the rod; ε_2 is the emissivity of the wall; A_1 is the radiative absorptivity of the cathode; A_2 is the radiative absorptivity of the wall; λ is the thermal conductivity of the rod material; I is the electric current; ρ is the electrical resistivity of the cathode material; θ (°K) is the mean temperature of the gas flowing along the rod; and α is the coefficient of heat transfer from rod to gas

$$\alpha = Bx^m.$$

If the temperature and the thermal flux at the cooled end of the cathode are known, then the initial conditions can be stated as

$$\text{for } x=0;\ T=T_0;\ \frac{dT}{dx} = -\frac{q_0}{\lambda_0} \equiv P_0.$$

The resulting Cauchy problem is solved by the Picard method of successive approximations, with the temperature-dependence of the physical properties expressed as fourth-power polynomials.

The authors have obtained the following third-approximation solution:

$$T = T_0 + P_0 x + \sum_{n=1}^{9}\frac{P_n}{n+1}x^{n+1} + \sum_{n=1}^{6}\frac{P_{9+n}}{m+n+1}x^{m+n+1} - \sum_{n=3}^{6}\frac{P_{13+n}}{2m+n+1}x^{2m+n+1}.$$

Expressions have been obtained for $P_1 - P_{19}$ as functions of T_0, P_0, and the polynomial approximation factor.

It is shown that this solution is also valid for electric-arc generators with inert-gas cooled cathodes and with a shielding tube between the cathode rod and the sleeve.

The solution can be used for estimating the potential fall at the cathode and for determining the temperature fields in rods inside coaxial cylindrical chambers, if the temperature and the thermal flux at any rod section are known.

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POWER-LAW FILTRATION FROM A SOURCE THROUGH A POROUS HALF-SPACE

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The authors solve the problem of steady-state two-dimensional filtration through a porous half-space with a constant pressure at the boundary. The flow from a point source is analyzed on the basis of a power-law drag characteristic.

It is assumed, moreover, that the source with an intensity 2M lies at a point A on the symmetry axis 0x in a uniformly porous half-space. Inasmuch as the flow pattern is symmetrical with respect to line 0x, only the upper half of the filtration region (first quadrant) is considered here. The values of the flow function at the boundary of this quadrant are $\tilde{\psi} = 1$ on 0A and $\tilde{\psi} = 0$ on AB (B is an infinitely far point on the 0x axis, $\tau = -\infty$).

With the aid of the Chaplygin transformation, the problem reduces to solving the Helmholtz equation with mixed boundary conditions within the $(-\infty < \tau < \infty,\ 0 \leq \beta \leq \pi)$ region. The Fourier integral transformation yields the following equation in the mapped plane:

$$\frac{d^2\bar{Q}}{d\beta^2} - q^2\bar{Q} = 0. \tag{1}$$

Here

$$\bar{Q} = \bar{Q}_-(\lambda, \beta) + \bar{Q}_+(\lambda, \beta);\quad \bar{Q}_-(\lambda, \beta) = \int_{-\infty}^{0} \exp(-i\lambda\xi)\, Q(\xi, \beta)\, d\xi;$$

$$\bar{Q}_+(\lambda, \beta) = \int_{0}^{\infty} \exp(-i\lambda\xi)\, Q(\xi, \beta)\, d\xi.$$

The boundary conditions are

$$\bar{Q} = 0 \quad \text{at} \quad \beta = 0;$$
$$\bar{Q} = \bar{Q}_-(\lambda, \pi) - \frac{i}{\lambda + i\varepsilon} \quad \text{at} \quad \beta = \pi. \tag{2}$$

The solution to (1) with the boundary conditions (2) is

$$\bar{Q}(\lambda, \beta) = \left[\bar{Q}_-(\lambda, \pi) - \frac{i}{\lambda + i\varepsilon}\right] \frac{\operatorname{sh} q\beta}{\operatorname{sh} q\pi}, \tag{3}$$

where $\bar{Q}_-(\lambda, \pi)$ is an unknown function. This function is determined by the Wiener–Hopf method [1]. The final solution is

for $\tau > 0$

$$Q(\tau, \beta) = \frac{\beta}{\pi} \exp \varepsilon\tau + \varkappa \sum_{k=1}^{\infty} (-1)^k \frac{k\Phi(r_k) \exp(-r_k\tau) \sin k\beta}{r_k(r_k + \varepsilon)}; \tag{4}$$

for $\tau < 0$

$$Q(\tau, \beta) = \frac{\varkappa}{\pi} \sum_{k=1}^{\infty} (-1)^{k+1} \frac{\exp s_k\tau}{s_k(s_k - \varepsilon)\Phi(s_k)} \sin\frac{2k-1}{2}\beta. \tag{5}$$

A graph has been plotted of $Q_-(\tau, \pi)$ as a function of τ, for n = 1.

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NOTATION

τ, β are the Chaplygin variables;

λ is the Fourier parameter;

$n + 1$ is the exponent of the power-law filtration characteristic;

$\psi = \psi/M$ is the dimensionless flow function;

$\varepsilon = n/2\sqrt{n+1}$;

$q = \sqrt{\lambda^2 + \varepsilon^2}$;

$r_k = \sqrt{k^2 + \varepsilon^2}$;

$$s_k = \sqrt{\frac{(2k-1)^2}{4} + \varepsilon^2};$$

$$\varkappa = \frac{1}{\pi} \prod_{m=1}^{\infty} \frac{2m}{2m-1} \frac{\varepsilon - s_m}{\varepsilon - r_m};$$

$$\Phi(z) = \prod_{m=1}^{\infty} \frac{2m-1}{2m} \cdot \frac{z + r_m}{z + s_m}.$$

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