MASS FLOW EXERGY UPON VARIATION OF MEDIUM PARAMETERS

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An examination is made of two methods of determining the value of mass flow exergy upon variation of the parameters of the surrounding medium. The first method consists in using an exergetic diagram in dimensionless quantities, and the second in constructing correction scales on the existing diagram.

The question of allowing for variation of the parameters of the surrounding medium arises repeatedly in the numerous Russian and foreign papers in the field of thermodynamic analysis using the exergetic method. Graphical and analytical means exist for determining the error in calculating the mass flow exergy when the temperature of the surrounding medium varies [1–10].

In some fields of technology, however, there is considerable variation not only of the temperature, but also of the pressure of the surrounding medium, e.g., flight at different altitudes, the operation of various equipment deep underground, etc. It is sufficient to say that with a change in flight altitude from H = 0 to H = 12 km, the temperature of the surrounding medium varies from $T_{H=0} = 293°$ K to $T_{H=12} = 217°$ K, and the pressure from $p_{H=0} = 1$ bar to $p_{H=12} = 0.21$ bar.

Variation of the parameters of the surrounding medium is especially important in evaluating the efficiency of similar equipment and their elements in various regimes [11, 12].

It follows, from examination of the exergetic diagram, that the influence of the parameters T_0 and p_0 on the value of the flow exergy is different. It was shown in [1, 2, 4, 5, 8] that during deviation of temperature T_0 from the standard value, the magnitude and sign of the correction are determined both by the value of the deviation itself, and by the parameters of the state of the material for which the exergy values are calculated. The correction is introduced with the aid of specially constructed auxiliary lines.

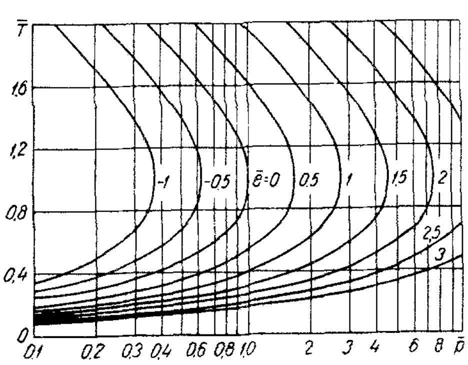

Fig. 1. Exergetic diagram in dimensionless parameters, from Eq. (5).

In contrast to this, when there is variation of p_0, the magnitude and sign of the correction are uniquely determined by the deviation of the pressure of the surrounding medium from the standard values; then the exergy values differ by some additive constant.

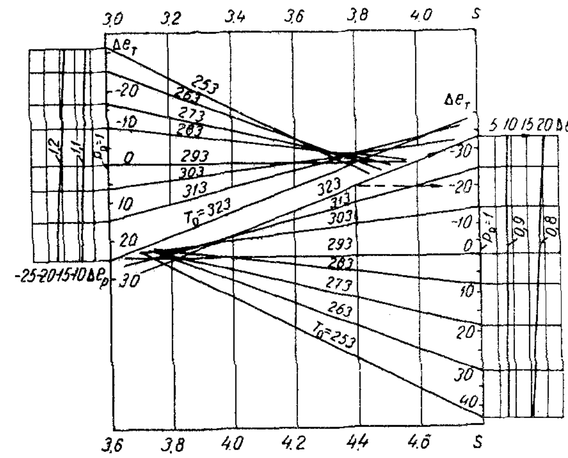

Fig. 2. Net of scales for corrections to the e, i diagram for air (T in °K, p in bars, s in kJ/kg · °K, Δe in kJ/kg).

If there are no entropy diagrams of state of the working substance, then, for an approximate determination of the mass flow exergy from the ideal gas equation, a diagram is constructed in dimensionless coordinates, this diagram being independent of the parameters of the surrounding medium [13].

From the total differential exergy equation

$$de = di - T_0\, ds, \tag{1}$$

replacing the quantity ds from the equations for an ideal gas, we obtain

$$de = di - T_0\left(c_p \frac{dT}{T} - R\frac{dp}{p} \right). \tag{2}$$

Integrating (2) over the range of variation of state from some point to the parameters of the surrounding medium, we write

$$e = c_p(T - T_0) - T_0\left(c_p \ln \frac{T}{T_0} - R \ln \frac{p}{p_0} \right). \tag{3}$$

Dividing the left and right sides of (3) by the quantity T_0, we obtain an equation in dimensionless quantities,

$$e/T_0 = c_p\,(T/T_0 - 1) - c_p \ln (T/T_0) + R \ln (p/p_0). \tag{4}$$

For convenience of calculation and construction of the diagram in dimensionless quantities, Eq. (4)

should be written in the form

$$\ln\bar{p} = \bar{e} - \frac{c_p}{R}(\bar{T} - 1) + \frac{c_p}{R}\ln\bar{T}, \qquad (5)$$

where $\bar{T} = T/T_0$, $\bar{p} = p/p_0$, $\bar{e} = e/RT_0$ are, respectively, dimensionless temperature, pressure, and mass exergy.

From (5), assigning different values to the quantities $\bar{T}$ and $\bar{e}$, the dimensionless pressure $\bar{p}$ is determined.

The scale of the $\bar{p}$ axis in Fig. 1 is logarithmic, which is an additional convenience of the diagram, since the lines of equal values of the dimensionless quantities of exergy $\bar{e}$ are located uniformly over the field of the diagram. This permits one to obtain values of the quantity $\bar{e}$ on the diagram by dividing integrals over the abscissa axis by any equal number of intercepts.

If the working substance used is a material for which there are entropy diagrams of state, there is an expedient method of constructing the correction scales.

The straight lines of Fig. 1, which take into account variation of temperature of the surrounding medium in the range 323–253° K, were constructed according to the well-known method [1, 5, 8].

In order to determine the corrections at various pressures of the surrounding medium, auxiliary pressure correction scales were constructed, the value of the correction Δe_p being found according to the formula

$$\Delta e_p = RT_0' \ln (p_0'/p_0). \qquad (6)$$

For greater convenience of calculation of the corrections, the net of scales is divided into sections; the upper and left sections refer to values of entropy less than 4.2 kJ/kg · °K, and to pressures of the surrounding medium $p_0 < 1$ bar, while the lower and right sections refer to $s > 3.6$ kJ/kg · °K and $p_0 < 1$ bar.

Thus, the total correction upon variation of the parameters of the surrounding medium from T_0, p_0 to T_0', p_0' is found by adding the two components:

$$\Delta e_\Sigma = \Delta e_T + \Delta e_p. \qquad (7)$$

The quantity Δe_p is found from the appropriate value of the entropy of the substance at the point of determination of the exergy and of the line $T_0' = \text{const}$ [1, 5, 8]. The quantity Δe_p is determined by the intercept between the auxiliary lines p_0 and p_0' at the temperature T_0' of the surrounding medium.

We shall give an example of determining the correction from Fig. 2 for variation of the parameters of the surrounding medium from $T_0 = 293°$ K and $p_0 = 1$ bar to $T_0' = 323°$ K and $p_0' = 0.8$ bar, with $s = 4.4$ kJ/kg · °K. The quantity $\Delta e_T = -19$ kJ/kg, $\Delta e_p = 20.7$ kJ/kg. The total correction is $\Delta e_\Sigma = -19 + 20.7 = +1.7$ kJ/kg.

NOTATION

e—mass flow exergy; i—enthalpy of substance; T—temperature; p—pressure; s—entropy; c_p—isobaric specific heat; R—gas constant; H—altitude; Δe_p—correction in determining exergy upon variation of pressure of surrounding medium; Δe_T—correction in determining exergy upon variation of temperature of surrounding medium; Δe_Σ—total correction in determining exergy upon variation of parameters of surrounding medium. Subscripts: 0 refers to the pressure and temperature of the surrounding medium, the primes refer to new values of the parameters of the surrounding medium, and the overscore refers to dimensionless parameters.

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