CALCULATION OF THE OVERALL HEAT TRANSFER COEFFICIENTS OF EVAPORATING EQUIPMENT WITH STEAM HEATING

D. Fabri

Inzhenerno-Fizicheskii Zhurnal, Vol. 11, No. 6, pp. 797–801, 1966

UDC 66.045.2+542.48

A description is given of a simplified method of engineering calculation of evaporating equipment based on the relationship between temperature head and heat transfer coefficient.

In heat exchangers in which the temperatures of the media taking part in the heat transfer are constant (upon change in phase state), the well-known relation

$$q = K\Delta t = \alpha_{1,2}\ \Delta t_{1,2} = \frac{\lambda}{\delta}\Delta t_{2,3} = \alpha_{3,4}\Delta t_{3,4} \qquad (1)$$

exists between the overall heat transfer coefficient K and the total temperature difference Δt, and the total temperature difference between the condensing steam and the boiling liquid

$$\Delta t = \Delta t_{1,2} + \Delta t_{2,3} + \Delta t_{3,4}. \qquad (2)$$

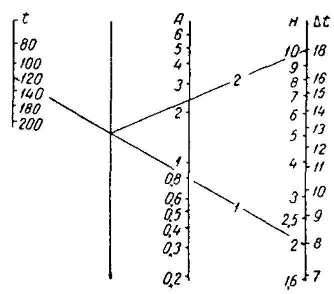

Fig. 1. Nomogram for determining the coefficient A (H in meters, t and Δt in °C).

The heat transfer coefficients for condensation and boiling may be described, respectively, by the empirical formulas

$$\alpha_{1,2} = C_{1,2}\Delta t_{1,2}^{u}, \qquad (3)$$

$$\alpha_{3,4} = C_{3,4}\Delta t_{3,4}^{v}. \qquad (4)$$

By substituting (3) and (4) into (1), we obtain

$$\Delta t_{1,2} = (K\Delta t/C_{1,2})^{1/(u+1)},$$

$$\Delta t_{2,3} = \frac{\delta}{\lambda}K\Delta t,$$

$$\Delta t_{3,4} = (K\Delta t/C_{3,4})^{1/(v+1)}. \qquad (5)$$

Because of (2) we may write

$$\left(\frac{K\Delta t}{C_{1,2}}\right)^{1/(u+1)} + \frac{\delta}{\lambda}K\Delta t + \left(\frac{K\Delta t}{C_{3,4}}\right)^{1/(v+1)} - \Delta t = 0. \qquad (6)$$

Introducing the notation

$$x = 0.1K^{1/3} \quad \text{for} \quad K = 1000x^3, \qquad (7)$$

we may express the first two terms of (6), respectively, in the following form:

$$\Delta t_{1,2} = Ax^4,$$
$$\Delta t_{2,3} = Bx^3,$$

where

$$A = 10^4\Delta t^{4/3}H^{1/3}/b_0^{4/3}.$$

$$B = 10^3\Delta t\sum_i \frac{\delta_i}{\lambda_i}.$$

For nucleate boiling, in agreement with [2–4, 6] the following relation has been proposed by the author

$$\alpha_{3,4} = 75\varphi p^{0.6}\Delta t_{3,4}^2.$$

Then the third term of (6) may be written in the form

$$\Delta t_{3,4} = Dx,$$

where

$$D = 2.375\,\Delta t^{1/3}/\varphi^{1/3}p^{1/5}.$$

To determine the coefficients A and D, nomograms 1 and 2 (Figs. 1 and 2) constructed by the author may be used.

With the above notation, and taking −Δt = E, Eq. (6) may be written in the following form

$$Ax^4 + Bx^3 + Dx + E = 0. \qquad (8)$$

The author has drawn up two nomograms (Figs. 3 and 4) for solving this equation and finding the overall heat transfer coefficient.

To use the nomogram of Fig. 3, we divide (8) by the expression −E = Δt; we then obtain

$$ax^4 + bx^3 + dx = 1, \qquad (9)$$

where

$$a = A/\Delta t, \quad b = B/\Delta t, \quad d = D/\Delta t.$$

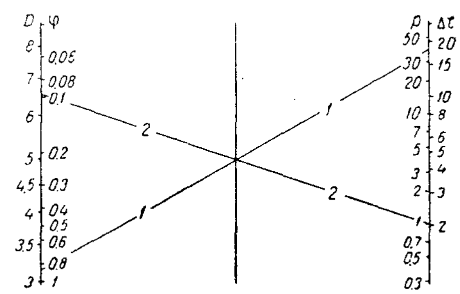

Fig. 2. Nomogram for determining the coefficient D (p in atm, Δt in °C).

The nomogram of Fig. 3 has been constructed for the constant values b = 0.1, i.e., for a clean wall

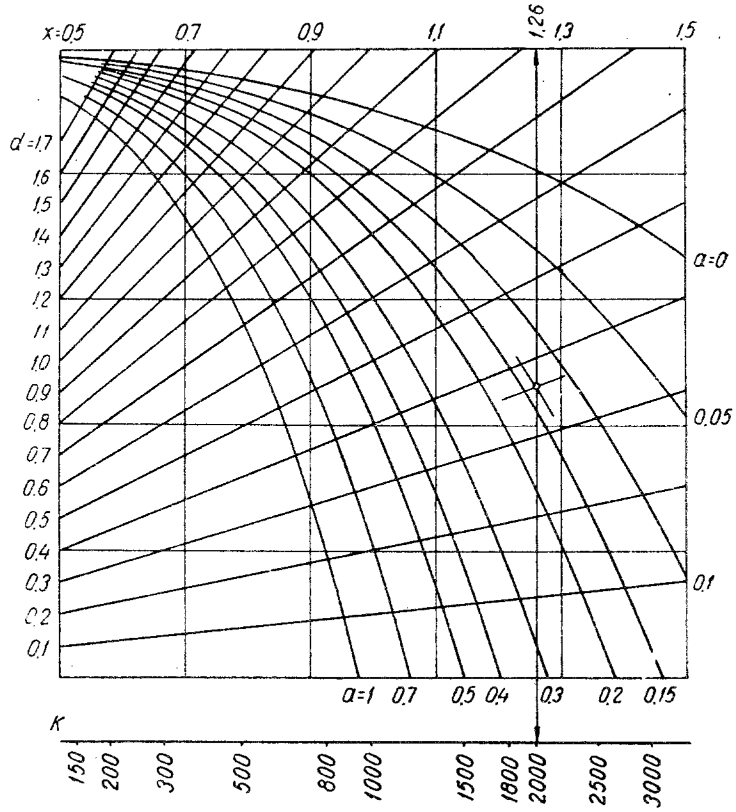

Fig. 3. Nomogram for determining the overall heat transfer coefficient of evaporating equipment with a clean heating surface (b = 0.1 – 0.5).

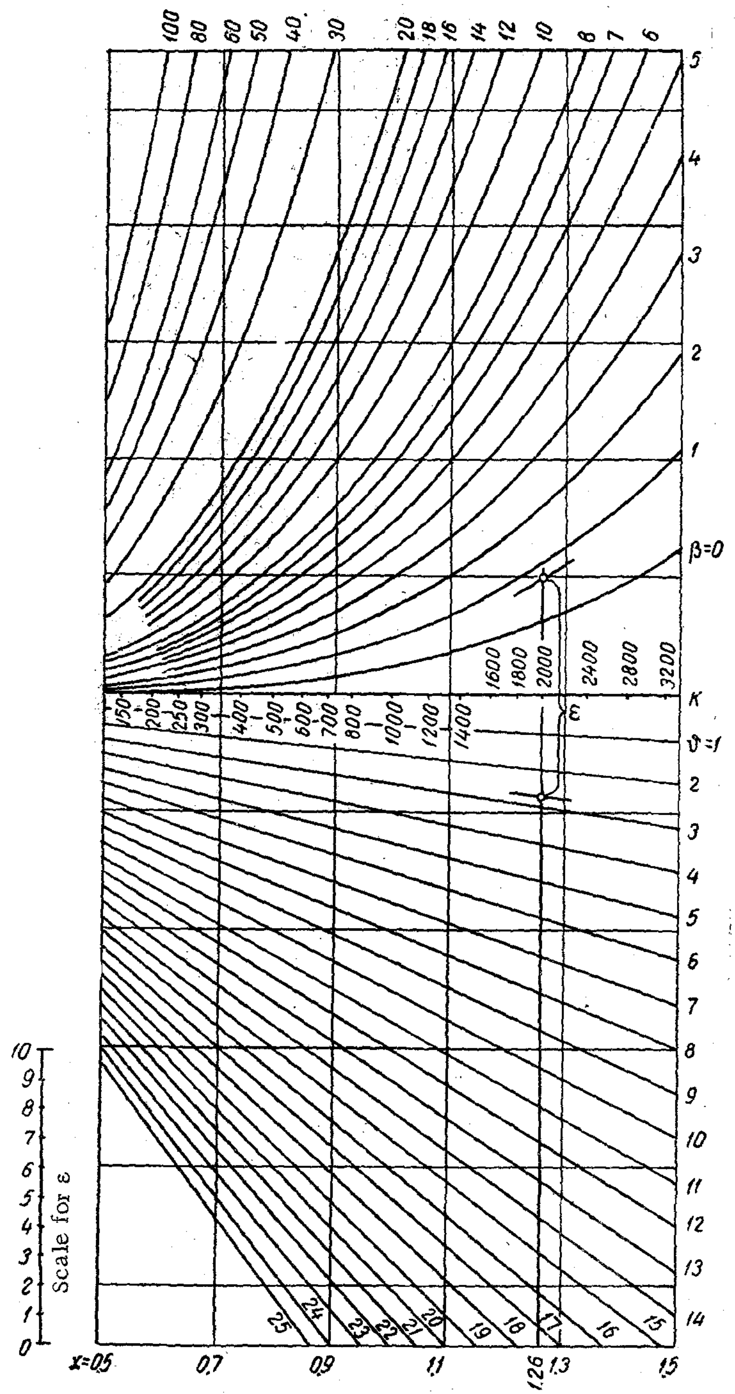

Fig. 4. Nomogram for calculation of a multisectional fluosolids clinkering furnace. The figures on the right of the curves are the values of n and those on the left are the values of m.

without deposits. For walls with deposits, for b = 0.5, the nomogram also gives a good approximation.

The coefficients a and d in (9) are determined from the values of A and D found from the nomograms of Figs. 1 and 2. From these values of a and d we find the point of intersection on the nomogram of Fig. 3, this corresponding to the desired value of x or K.

By way of illustration we shall consider an example, the evaporation of a 9% aqueous solution of NaCl by steam at a pressure of 2 atm ($t_1 = 119.6°$ C) in an evaporating equipment with vertical tubes of length 2 m. The pressure in the steam compartment is 1 atm. The coefficient A, as determined from the nomogram of Fig. 1, is 2.41. The coefficient D, as determined from the nomogram of Fig. 2, is 6.55; from these we calculate

$$a = A/\Delta t = 2.41/18 = 0.134,$$

$$d = D/\Delta t = 6.55/18 = 0.364.$$

From the values of a and d thus determined we find the values x = 1.26 or K = 2000 kcal/m^2 · hr · ° C on the nomogram of Fig. 3.

A defect of the nomogram of Fig. 3 is that it pertains to a constant value of b. This defect is avoided in the nomogram of Fig. 4, which operates for any value of b.

To use the nomogram of Fig. 4, we divide (8) by the quantity A and obtain

$$x^4 + \beta x^3 + \vartheta x = \varepsilon.$$

For the above example

$$\beta = B/A = 0.746; \quad \vartheta = D/A = 2.72; \quad \varepsilon = \Delta t/A = 7.46.$$

On the nomogram of Fig. 4, in accordance with the conditions of the example considered, we find the position of the curve corresponding to the value $\beta = 0.746$, and of the straight line corresponding to the value $\vartheta = 2.72$. Then on the scale to the left of the diagram we mark the value $\varepsilon = 7.46$ on a "moving straight-edge," and, moving the straight-edge strictly vertically from right to left over the diagram, we find the distance between the curve β and the straight line ϑ, equal to ε. In our example this is 7.46 arbitrary units. The distance may be plotted by means of a pair of dividers. The intersection of the vertical straight line corresponding to the distance between the curve $\beta = 0.746$ and the straight line $\vartheta = 2.72$, equal to $\varepsilon = 7.46$, and the x axis gives the desired value of K directly. In our example this is K = 2000 kcal/m^2 · hr · ° C.

NOTATION

$C_{1,2}$, $C_{3,4}$ are the constants; H is the height of heat exchanger; b_0 is the coefficient incorporating the physical properties of the condensate; φ is the coefficient to take account of the physical properties of a liquid other than water; p is the pressure. Subscripts 1 and 2 refer to steam; 3 and 4 to the boiling liquid.

REFERENCES

1. W. Z. Nusselt, VDI, 60, 541–546, 569–575, 1916.

2. R. Gregorig, Wärmeaustauscher, Aarau, 103, 1959.

3. H. Hausen, Wärmeübertragung im Gengenstrom, Gleichstrom, und Kreuzstrom. München, 54, 1950.

4. E. Kirschbaum, Chem.-Ing.-Technik, 26, 25–28, 1954.

5. F. F. Bogdanov, DAN SSSR, OTN, 137, 1954.

23 May 1966

Budapest Food Institute