Numerical Problems in Thermodynamics and Kinetics of Chemical Engineering Processes

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PREFACE

This book has been prepared as a necessary companion to the second book by R. Pohorecki and S. Wroński, *Thermodynamics and Kinetics of Chemical Engineering Processes*, which is expected to be published in 1999. Both books have been conceived as a link among basic subjects (like mathematics, physics, physical chemistry, or fluid mechanics) and process calculations forming the final stage of chemical engineering education. We try to follow the ideas developed in the past by such classical books as O. A. Hougen, K. M. Watson, and R. A. Ragatz, *Chemical Process Principles*; P. Grassman, *Physikalische Grundlagen der Verfahrenstechnik*; V. G. Levich, *Physicochemical Hydrodynamics*; or R. B. Bird, W. Stewart, and E. N. Lightfoot, *Transport Phenomena.*

Since much user-friendly software is now easily available, we emphasise the understanding of the underlying principles and methods of solution rather than the purely computational skills. For this reason, no computer or calculator programs have been included.

We are pleased to address our thanks to the many colleagues and collaborators who helped in the preparation of this book. Special thanks are due to Dr. A. Biń, who translated the whole text and contributed significantly to its final form, supplying a number of new solutions, and to the Editor for his patience and help during the translation.

The Authors

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I. GENERAL THERMODYNAMICS

I.1. Overall energy balance of a process

A gas turbine having the power of 15,000 kW is supplied with 75 kg/s of a hot gas at 600°C. The gas velocity at the turbine inlet equals 30 m/s. As a result of expansion in the turbine the gas temperature decreases to 400°C at the outlet, while its velocity increases to 130 m/s. Within the given range of temperature the average heat capacity of gas is 1.1 kJ/(kg·K). Determine the heat loss in the system.

Solution

In order to calculate the heat transferred from the gas to the surroundings we will use the equation of energy balance for the steady-state flow system (Table A-1, § 6).[1]

$$\left(H + gz + \frac{\upsilon^2}{2\alpha}\right)_2 + \left(H + gz + \frac{\upsilon^2}{2\alpha}\right)_1 = Q + L_t$$

In the case of gas flow through the turbine the change in the potential energy [$\Delta(gz)$] is negligible, and the correction factor in the kinetic energy terms, which accounts for the turbulent flow of the gas through the turbine, is close to unity ($\alpha \approx 1$). Hence the above cited equation can be simplified to

$$Q = (H_2 - H_1) + \frac{\upsilon_2^2 - \upsilon_1^2}{2} - L_t \qquad (1)$$

In this equation subscript "1" refers to the inlet conditions, and subscript "2" to the outlet conditions of the turbine.

The inlet gas temperature equals 873 K, and the gas outlet temperature is 673 K; hence, the enthalpy variation of 1 kg of the gas, calculated here in a simplified way as a product of the heat capacity at constant pressure and the temperature difference, is

$$H_2 - H_1 = c_p(T_2 - T_1) = 1.1(673 - 873) = -220\,\text{kJ/kg}$$

The change in the kinetic energy amounts to

$$\frac{\upsilon_2^2 - \upsilon_1^2}{2} = \frac{130^2 - 30^2}{2} = 8000\ \text{J/kg} = 8\ \text{kJ/kg}$$

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[1] The tables containing equations begin on page 326.

The technical work done by 1 kg of the gas is equal to the quotient of the turbine power, N, and the mass flow rate of the gas, W, and, in accord with the adopted convention, that work done by a system is negative, and thus in the expression we put the minus sign

$$L_t = -\frac{N}{W} = -\frac{15000}{75} = -200\,\mathrm{kJ/kg}$$

After substitution of the calculated values to eq. (1) we get

$$Q = -220 + 8 - (-200) = -12\ \mathrm{kJ/kg}$$

(The minus sign means that heat is transferred from the gas to the surroundings). Heat transferred to the surroundings during 1 second is

$$q = W\,Q = 75(-12) = -900\ \mathrm{kW}$$

The heat loss amounts then to 900 kW.

I.2. Energy balance of a non-stationary process

In a thermally insulated tank, 1.5 m^3 of water is contained at an initial temperature of 15°C. The tank is equipped with a stirrer and a heating coil. Power transferred to the liquid as a result of agitation amounts to 3.9 kW, whereas heat transferred from the steam flowing in the coil provides 38 kW. Water at 55°C is fed to the tank at the flow rate $2 \cdot 10^{-3}$ m^3/s. The same amount of water is removed from the tank.

Assuming that the liquid in the tank is perfectly mixed and the water density remains constant and neglecting the changes in kinetic and potential energies of the liquid, determine the time after which the outlet stream temperature will be equal to the inlet stream temperature. Determine also the outlet stream temperature at the steady-state conditions.

Solution

The system described above is shown in Figure I-1.

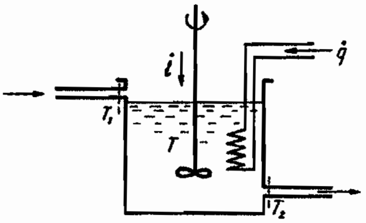

Figure I-1

In calculations we will use the general equation of energy balance (Table A-1, § 1)

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