

1 Introduction and definitions

Heat transfer is a fundamental part of thermal engineering. It is the science of the rules governing the transfer of heat between systems of different temperatures. In thermodynamics, the heat transferred from one system to its surroundings is assumed as a given process parameter. This assumption does not give any information on how the heat is transferred and which rules determine the quantity of the transferred heat.

Heat transfer describes the dependencies of the heat transfer rate from a corresponding temperature difference and other physical conditions.

The thermodynamics terms “*control volume*” and “*system*” are also common in heat transfer. A system can be a material, a body or a combination of several materials or bodies, which transfer to or receive heat from another system.

The first two questions are:

- What is heat transfer?
- Where is heat transfer applied?

Heat transfer is the transport of thermal energy, due to a spacial temperature difference.

If a spacial temperature difference is present within a system or between systems in thermal contact to each other, heat transfer occurs.

The application of the science of heat transfer can be easily demonstrated with the example of a radiator design.

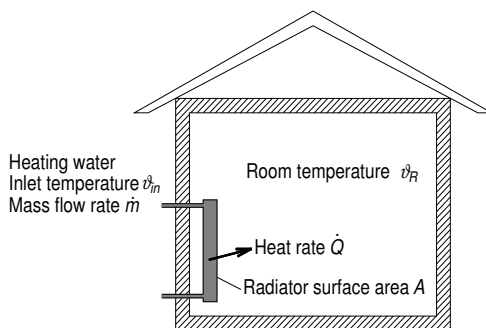


Figure 1.1: Radiator design

To obtain a certain room temperature, radiators, in which warm water flows, are installed to provide this temperature. For the acquisition of the radiators, the architect defines the required heat flow rate, room temperature, heating water mass flow rate and temperature. Based on these data, the radiator suppliers make their offers. Is the designed radiator surface too small, temperature will be too low, the owner of the room will not be satisfied and the radiator must be replaced. Is the radiator surface too large, the room temperature will be too high. With throttling the heating water flow rate the required room temperature can be established. However, the radiator needs more material and will be too expensive, therefore it will not be ordered. The supplier with the correct radiator size will succeed. With experiments the correct radiator size could be obtained, but this would require a lot of time and costs. Therefore, calculation procedures are required, which allow the design of a radiator with an optimum size. For this example, the task of heat transfer analysis is to obtain the correct radiator size at minimum costs for the given parameters .

In practical design of apparatus or complete plants, in which heat is transferred, besides other technical sciences (thermodynamics, fluid mechanics, material science, mechanical design, etc.) the science of heat transfer is required. The goal is always to optimize and improve the products. The main goals are to:

- increase efficiency
- optimize the use of resources
- reach a minimum of environmental burden
- optimize product costs.

To reach these goals, an exact prediction of heat transfer processes is required.

To design a heat exchanger or a complete plant, in which heat is transferred, exact knowledge of the heat transfer processes is mandatory to ensure the greatest efficiency and the lowest total costs.

Table 1.1 gives an overview of heat transfer applications.

Table 1.1: Area of heat transfer applications

- Heating, ventilating and air conditioning systems
- Thermal power plants
- Refrigerators and heat pumps
- Gas separation and liquefaction
- Cooling of machines
- Processes requiring cooling or heating
- Heating up or cooling down of production parts
- Rectification and distillation plants
- Heat and cryogenic isolation
- Solar-thermic systems
- Combustion plants

1.1 Modes of heat transfer

Contrary to assured knowledge, most publications describe three *modes of heat transfer*: *thermal conduction*, *convection* and *thermal radiation*.

Nußelt, however, postulated in 1915, that only two modes of heat transfer exist [1.2] [1.3]. The publication of *Nußelt* states:

“In the literature it is often stated, heat emission of a body has three causes: radiation, thermal conduction and convection.

The separation of heat emission in thermal conduction and convection suggests that there would be two independent processes. Therefore, the conclusion would be: heat can be transferred by convection without the participation of thermal conduction. But this is not correct.”

Heat transfer modes are thermal conduction and thermal radiation.

Figure 1.2 demonstrates the two modes of heat transfer.

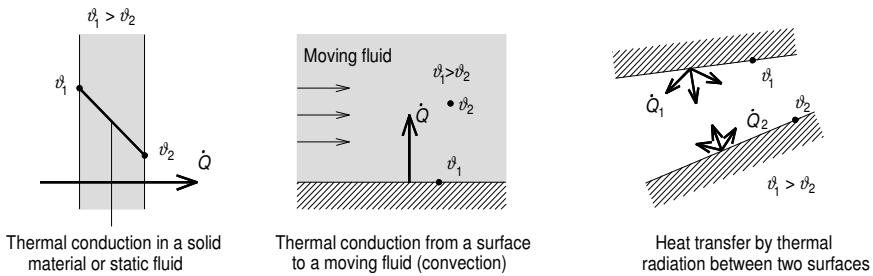


Figure 1.2: Modes of heat transfer

1. *Thermal conduction* develops in materials when a spacial temperature gradient is present. With regard to calculation procedures there is a differentiation between static materials (solids and static fluids) and moving fluids. Heat transfer in static materials depends only on the spacial temperature gradient and material properties.

Heat transfer between a solid wall and a moving fluid occurs by thermal conduction between the wall and the fluid and within the fluid. Furthermore, the transfer of enthalpy happens, which mixes areas of different temperatures. The heat transfer is determined by the thermal conductivity and the thickness of the boundary layer of the fluid, the latter is dependent on the flow and material parameters. In the boundary layer the heat is transferred by conduction.

Because of the different calculation methods, the heat transfer between a solid wall and a fluid is called *convective heat transfer* or more concisely *convection*. A further differentiation is made between *free convection* and *forced convection*.

In free convection the fluid flow is generated by gravity due to the density difference caused by the spacial temperature gradient. At forced convection the flow is established by an external pressure difference.

2. *Thermal radiation* can occur without any intervening medium. All surfaces and gases consisting of more than two atoms per molecule of finite temperature, emit energy in the form of electromagnetic waves. Thermal radiation is a result of the exchange of electromagnetic waves between two surfaces of different temperature.

In the examples shown in [Figure 1.3](#) the temperature ϑ_1 is larger than ϑ_2 , therefore, the heat flux is in the direction of the temperature ϑ_2 . In radiation both surfaces emit and absorb a heat flux, where the emission of the surface with the higher temperature ϑ_1 has a higher intensity.

Heat transfer may occur through combined thermal conduction and radiation. In many cases, one of the heat transfer modes is negligible. The heat transfer modes of the radiator, discussed at the beginning of this chapter are: forced convection inside from the water to the inner wall, thermal conduction in the solid wall and a combination of free convection and radiation from the outer wall to the room.

The transfer mechanism of the different heat transfer modes are governed by different physical rules and therefore, their calculation methods will be discussed in separate chapters.

1.2 Definitions

The parameters required to describe heat transfer will be discussed in the following chapters.

In this book the symbol ϑ is used for the temperature in Celsius and T for the absolute temperature.

1.2.1 Heat (transfer) rate and heat flux

The *heat rate*, also called *heat transfer rate* $\dot{Q}$ is the amount of heat transferred per unit time. It has the unit Watt **W**.

A further important parameter is the *heat flux density* $\dot{q} = \dot{Q}/A$, which defines the heat rate per unit area. Its unit is Watt per square meter **W/m²**.

1.2.2 Heat transfer coefficients and overall heat transfer coefficients

The description of the parameters, required for the definition of the heat flux density will be discussed in the example of a heat exchanger as shown in [Figure 1.3](#). The heat exchanger consist of a tube that is installed in the center of a larger diameter tube.

A fluid with the temperature ϑ_1' enters the inner tube and will be heated up to the temperature ϑ_1'' . In the annulus a warmer fluid will be cooled down from the temperature ϑ_2' to the temperature ϑ_2'' . Figure 1.3 shows the temperature profiles in the fluids and in the wall of the heat exchanger.

The governing parameters for the heat rate transferred between the two fluids will be discussed now. The quantity of the transferred heat rate $\dot{Q}$ can be defined by the *heat transfer coefficient* α , the heat transfer surface area A and the temperature difference $\Delta\vartheta$.

The heat transfer coefficient defines the heat rate $\dot{Q}$ transferred per unit transfer area A and per unit temperature difference $\Delta\vartheta$.

The unit of the heat transfer coefficient is $\text{W}/(\text{m}^2 \text{K})$.

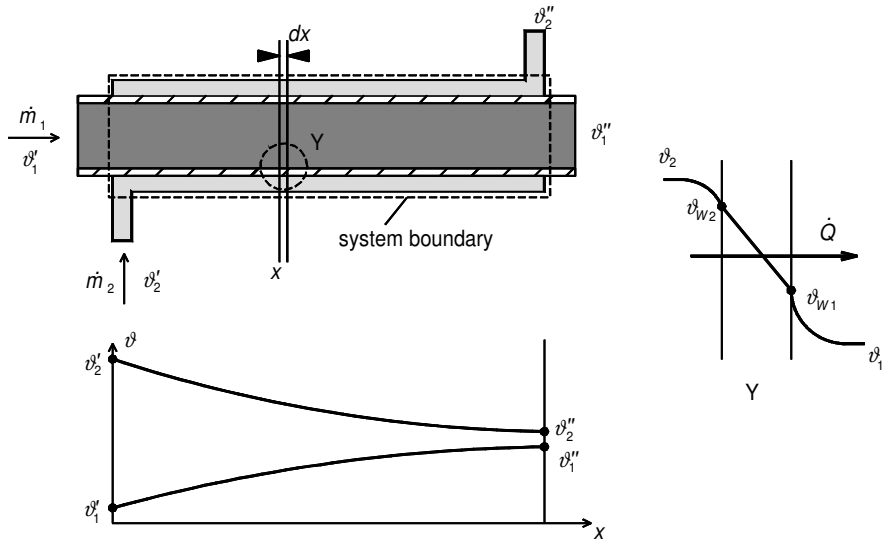


Figure 1.3: Temperature profile in the heat exchanger

With this definition, the finite heat rate through a finite surface element is:

$$\delta\dot{Q}_2 = \alpha_2 \cdot (\vartheta_2 - \vartheta_{W2}) \cdot dA_2 \quad (1.1)$$

$$\delta\dot{Q}_1 = \alpha_1 \cdot (\vartheta_{W1} - \vartheta_1) \cdot dA_1 \quad (1.2)$$

$$\delta\dot{Q}_W = \alpha_W \cdot (\vartheta_{W2} - \vartheta_{W1}) \cdot dA_W \quad (1.3)$$

The symbol $\delta\dot{Q}$ shows that the heat rate has an inexact differential, because the value of its integral depends on the heat transfer processes and path.

The integral of $\delta\dot{Q}$ is $\dot{Q}_{12}$ and not $\dot{Q}_2 - \dot{Q}_1$.

Here the temperature differences were selected such that the heat rate has positive values. For a heat exchanger with a complete thermal insulation to the environment, the heat rate coming from fluid 2 must have the same value as the one transferred to fluid 1 and also have the same value as the heat rate through the pipe wall.

$$\delta\dot{Q}_1 = \delta\dot{Q}_2 = \delta\dot{Q}_w = \delta\dot{Q} \quad (1.4)$$

In most cases, the wall temperatures are unknown and the engineer is interested in knowing the total heat rate transferred from fluid 2 to fluid 1. For its determination the *overall heat transfer coefficient* k is required. It has the same unit as the heat transfer coefficient.

$$\delta\dot{Q} = k \cdot (\vartheta_2 - \vartheta_1) \cdot dA \quad (1.5)$$

Using equations (1.1) to (1.5) the relationships between the heat transfer and overall heat transfer coefficients can be determined. It has to be taken into account that the surface area in- and outside of the tube has a different magnitude. The determination of the overall heat transfer coefficient will be shown in the following chapters.

In this chapter the heat transfer coefficients are assumed to be known values. In the following chapters the task will be to determine the heat transfer coefficient as a function of material properties, temperatures and flow conditions of the involved fluids.

1.2.3 Rate equations

Equations (1.1) to (1.3) and (1.5) define the heat rate as a function of heat transfer coefficient, surface area and temperature difference. They are called *rate equations*.

The rate equations define the heat rate, transferred through a surface area at a known heat transfer coefficient and a temperature difference.

1.2.4 Energy balance equations

In heat transfer processes the first law of thermodynamics is valid without any restrictions. In most practical cases of heat transfer analysis, the mechanical work, friction, kinetic and potential energy are small compared to the heat rate. Therefore, for problems dealt with in this book, they are neglected. The *energy balance equation* of thermodynamics then simplifies to [1.1]:

$$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} + \sum_e \dot{m}_e \cdot h_e - \sum_a \dot{m}_a \cdot h_a \quad (1.6)$$

The temporal change of energy in the control volume is equal to the total heat rate to the control volume and the enthalpy flows to and from the control volume. In most

cases of heat transfer problems only one mass flow enters and leaves a control volume. The change of the enthalpy and energy in the control volume can be given as a function of the temperature. The heat rate is either transferred over the system boundary or originates from an internal source within the system boundary (e.g. electric heater, friction, chemical reaction). Equation (1.7) is presented here as it is mostly used for heat transfer problems:

$$V_{cv} \cdot \rho \cdot c_p \frac{d\vartheta}{dt} = \dot{Q}_{12} + \dot{Q}_{in} + \dot{m} \cdot (h_2 - h_1) \quad (1.7)$$

In Equation (1.7) $\dot{Q}_{12}$ is the heat rate transferred over the system boundary and $\dot{Q}_{in}$ the heat rate originating from an internal source. For stationary processes the left side of Equation (1.7) has the value of zero:

$$\dot{Q}_{12} + \dot{Q}_{in} = \dot{m} \cdot (h_1 - h_2) = \dot{m} \cdot c_p \cdot (\vartheta_1 - \vartheta_2) \quad (1.8)$$

The Equations (1.7) and (1.8) are called energy balance equations.

1.2.5 Log mean temperature difference

With known heat transfer coefficients, the heat rate at every location of the heat exchanger, shown in [Figure 1.3](#), can be determined. In engineering, however, not the local but the total transferred heat is of interest. To determine the overall heat transfer rate, the local heat flux density must be integrated over the total heat transfer area. The total transferred heat rate is:

$$\dot{Q} = \int_0^A k \cdot (\vartheta_2 - \vartheta_1) \cdot dA \quad (1.9)$$

The variation of the temperature in the surface area element dA can be calculated using the energy balance equation (1.8).

$$\delta \dot{Q} = \dot{m}_1 \cdot dh_1 = \dot{m}_1 \cdot c_{p1} \cdot d\vartheta_1 \quad (1.10)$$

$$\delta \dot{Q} = -\dot{m}_2 \cdot dh_2 = -\dot{m}_2 \cdot c_{p2} \cdot d\vartheta_2 \quad (1.11)$$

The temperature difference $\vartheta_2 - \vartheta_1$ will be replaced by $\Delta\vartheta$. The change of the temperature difference can be calculated from the change of the fluid temperatures.

$$d\Delta\vartheta = d\vartheta_2 - d\vartheta_1 = -\delta \dot{Q} \cdot \left(\frac{1}{\dot{m}_1 \cdot c_{p1}} + \frac{1}{\dot{m}_2 \cdot c_{p2}} \right) \quad (1.12)$$

Equation (1.12) set in Equation (1.5) results in:

$$\frac{d\Delta\vartheta}{\Delta\vartheta} = -k \cdot \left(\frac{1}{\dot{m}_1 \cdot c_{p1}} + \frac{1}{\dot{m}_2 \cdot c_{p2}} \right) \cdot dA \quad (1.13)$$

Assuming that the overall heat transfer coefficient, the surface area and the specific heat capacities are constant, Equation (1.13) can be integrated. This assumption will never be fulfilled exactly. However, in practice the use of mean values has proven to be an excellent approach. The integration gives us:

$$\ln \left(\frac{\vartheta'_2 - \vartheta'_1}{\vartheta''_2 - \vartheta''_1} \right) = k \cdot A \cdot \left(\frac{1}{\dot{m}_1 \cdot c_{p1}} + \frac{1}{\dot{m}_2 \cdot c_{p2}} \right) \quad (1.14)$$

With the assumptions above, Equations (1.10) and (1.11) can also be integrated.

$$\dot{Q} = \dot{m}_1 \cdot c_{p1} \cdot (\vartheta'_1 - \vartheta'_2) \quad (1.15)$$

$$\dot{Q} = \dot{m}_2 \cdot c_{p2} \cdot (\vartheta'_2 - \vartheta''_2) \quad (1.16)$$

In Equation (1.14) the mass flow rates and specific heat capacities can be replaced by the heat rate and fluid temperatures. This operation delivers:

$$\dot{Q} = k \cdot A \cdot \frac{\vartheta'_2 - \vartheta'_1 - \vartheta''_2 + \vartheta''_1}{\ln \frac{\vartheta'_2 - \vartheta'_1}{\vartheta''_2 - \vartheta''_1}} = k \cdot A \cdot \Delta\vartheta_m \quad (1.17)$$

The temperature difference $\Delta\vartheta_m$ is the temperature difference relevant for the estimation of the heat rate. It is called the log mean temperature difference and is the integrated mean temperature difference of a heat exchanger.

The *log mean temperature difference* is valid for the special case of the heat exchanger shown in [Figure 1.3](#). For heat exchanger with parallel-flow, counterflow and if the temperature of one of the fluids remains constant (condensation and boiling) a generally valid log mean temperature difference can be given. For its formulation the temperature differences at the inlet and outlet of the heat exchangers are required. The greater temperature difference is $\Delta\vartheta_{gr}$, the smaller one is $\Delta\vartheta_{sm}$.

$$\Delta\vartheta_m = \frac{\Delta\vartheta_{gr} - \Delta\vartheta_{sm}}{\ln(\Delta\vartheta_{gr} / \Delta\vartheta_{sm})} \quad \text{if } \Delta\vartheta_{gr} - \Delta\vartheta_{sm} \neq 0 \quad (1.18)$$

If the temperature differences at inlet and outlet are approximately identical, Equation (1.18) results in an indefinite value. For this case the log mean temperature difference is the average value of the inlet and outlet temperature differences.

$$\Delta\vartheta_m = (\Delta\vartheta_{gr} + \Delta\vartheta_{kl}) / 2 \quad \text{if } \Delta\vartheta_{gr} - \Delta\vartheta_{kl} = 0 \quad (1.19)$$

The log mean temperature of a heat exchanger in which the flow of the fluids is perpendicular (cross-flow) or has changing directions will be discussed in Chapter 8.

1.2.6 Thermal conductivity

Thermal conductivity λ is a material property, which defines the magnitude of the heat rate that can be transferred per unit length in the direction of the flux and per unit temperature difference. Its unit is **W/(m K)**. The thermal conductivity of a material is temperature and pressure dependent.

Good electric conductors are usually also good thermal conductors, however, exceptions exist. Metals have a rather high thermal conductivity, liquids a smaller one and gases are “bad” heat conductors. In [Figure 1.4](#) thermal conductivity of several materials is plotted versus temperature.

The thermal conductivity of most materials does not vary much at a medium temperature change. Therefore, they are suitable for calculation with constant mean values.

1.3 Methodology of solving problems

This chapter originates from [1.5], with small changes. For *solving problems* of heat transfer usually, directly or indirectly, the following basic laws and principles are required:

- law of *Fourier*
- laws of heat transfer
- conservation of mass principle
- conservation of energy principle (first law of thermodynamics)
- second law of thermodynamics
- *Newton*’s second law of motion
- momentum equation
- similarity principles
- friction principles

Besides profound knowledge of the basic laws, the engineer has to know the *methodology*, i.e. *how* to apply the above mentioned basic laws and principles to concrete problems. It is of great importance to learn a systematic analysis of problems. This consist mainly of six steps as listed below. They are proven in practice and can, therefore, highly be recommended.

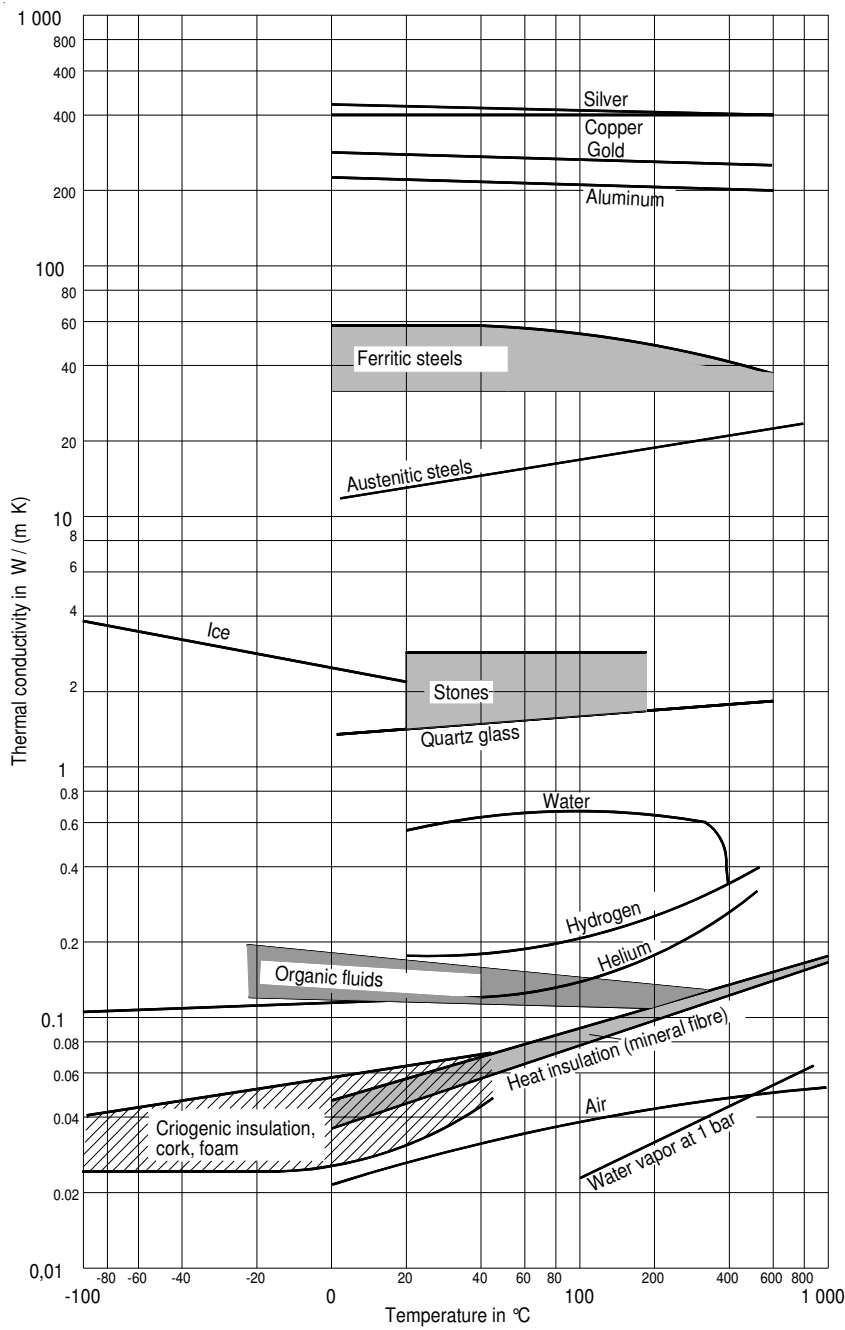


Fig. 1.4: Thermal conductivity of materials versus temperature [1.5]

1. What is given?

Analyze, what is known about the problem you have to investigate. Note all parameters which are given or may be necessary for further considerations.

2. What are you looking for?

At the same time as the first step, analyze which parameter has to be determined and which questions have to be answered.

3. How is the system defined?

Make schematic sketches of the system and decide which types of system boundaries are best for the analysis.

- Define the system boundary(ies) clearly!

Identify the *transactions* between systems and environment.

State which changes of state or processes are acting on or are passing through the system.

- Create clear system schematics!

4. Assumptions

Consider how the system can be modelled as simple as possible, make *simplifying assumptions*. Specify the boundary values and assumptions.

Check if *idealizing assumptions* are possible, e.g. physical properties determined with mean temperatures and negligible heat losses assumed as perfect heat insulation.

5. Analysis

Collect all necessary material properties. Some of them may be given in the appendices of this book. If not, a research in the literature is requested (e.g. VDI Heat Atlas [1.7]).

Take into account the idealizing and simplifying assumptions, formulate the heat balance and rate equations.

Recommendation: Finish all formulations, transformations, simplifications and solutions in symbolic equations, before inserting numeric values.

Check the equations and data of correctness of units and dimensions before the numeric evaluation is started.

Check the order of magnitude of the results and the correctness of algebraic signs.

6. Discussion

Discuss the results and its basic aspects, comment on the main results and their correlations.

Do remember: Step 3 is of greatest importance, as it clarifies how the analysis was performed and step 4 is as important, as it determines the quality and validity range of the results. The examples in this book are treated according to the above described methodology. The definition of the examples is according to steps 1 and 2, the solution starts with step 3.

EXAMPLE 1.1: Determination of the heat rate, temperature and heat transfer surface area

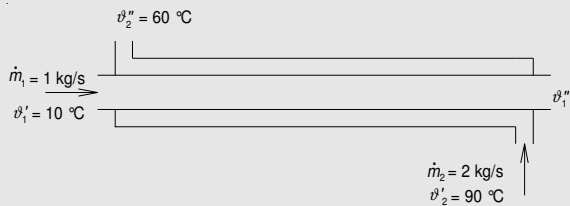
The counterflow heat exchanger is a pipe, installed concentrically in a pipe of larger diameter. The fluid in the pipe and in the annulus is water in this example. The mass flow rate in the pipe is 1 kg/s and the inlet temperature 10 °C . In the annulus we have a mass flow rate of 2 kg/s and the water is cooled from 90 °C down to 60 °C The overall heat transfer coefficient is 4000 W/(m² K). The specific heat capacity of the water in the pipe is 4.182 kJ/(kg K) and that in the annulus 4.192 kJ/(kg K).

Find

The heat rate, the outlet temperature of the water in the pipe and the required heat transfer surface area.

Solution

Schematic See sketch.



Assumptions

- The heat exchanger does not transfer any heat to the environment.
- The process is stationary.

Analysis

The heat rate transferred from the water in the annulus to the water in the tube can be calculated with the energy balance Equation (1.15).

$$\begin{aligned}\dot{Q} &= \dot{m}_2 \cdot c_{p2} \cdot (\vartheta_2' - \vartheta_2'') = \\ &= 2 \cdot \text{kg/s} \cdot 4192 \cdot \text{J/(kg} \cdot \text{K)} \cdot (90 - 60) \cdot \text{K} = \mathbf{251.52 \text{ kW}}\end{aligned}$$

The outlet temperature of the water determined with Equation (1.16) is:

$$\vartheta_1'' = \vartheta_1' + \frac{\dot{Q}}{\dot{m}_1 \cdot c_{p1}} = 10 \text{ °C} + \frac{251520 \text{ W}}{1 \cdot \text{kg/s} \cdot 4182 \cdot \text{J/(kg} \cdot \text{K)}} = \mathbf{70.1 \text{ °C}}$$

For the determination of the required surface area Equations (1.17) and (1.18) are used. First with Equation (1.18) the log mean temperature difference $\Delta\vartheta_m$ is calculated. At the inlet of the tube the large temperature difference has the value of 50 K, the small one at the outlet 19.9 K.

$$\Delta\vartheta_m = \frac{\Delta\vartheta_{gr} - \Delta\vartheta_{kl}}{\ln(\Delta\vartheta_{gr} / \Delta\vartheta_{kl})} = \frac{(50 - 19.9) \cdot \text{K}}{\ln(50/19.9)} = 32.6 \text{ K}$$

With Equation (1.17) the required surface area results as:

$$A = \frac{\dot{Q}}{k \cdot \Delta\vartheta_m} = \frac{251520 \text{ W}}{4000 \cdot \text{W/(m}^2 \cdot \text{K)} \cdot 32.6 \cdot \text{K}} = \mathbf{1.93 \text{ m}^2}$$

Discussion

With a known heat rate and energy balance equations the temperature change of the liquids can be calculated. To determine the required heat exchanger surface area the rate equation is required, however first the overall heat transfer coefficient has to be known. Its calculation will be discussed in the following chapters. This example shows that with water, a relatively small surface area is sufficient to transfer a fairly large heat rate.

EXAMPLE 1.2: Determination of the outlet temperature

In the heat exchanger in Example 1.1, the inlet temperature of the water in the tube has changed from 10 °C to 25 °C. The mass flow rates, material properties and the inlet temperature of the water into the annulus remain the same as in Example 1.1.

Find

The outlet temperatures and the heat rate.

Solution

Assumptions

- The heat transfer coefficient in the whole heat exchanger is constant.
- The process is stationary.

Analysis

The Equations (1.15) to (1.17) provide three independent equations for the determination of the three unknown values: $\dot{Q}$, ϑ_1'' and ϑ_2'' . The energy balance equations for the two mass flow rates are:

$$\dot{Q} = \dot{m}_1 \cdot c_{p1} \cdot (\vartheta_1'' - \vartheta_1') \quad \text{and} \quad \dot{Q} = \dot{m}_2 \cdot c_{p2} \cdot (\vartheta_2' - \vartheta_2'')$$

The rate equation is:

$$\dot{Q} = k \cdot A \cdot \frac{\vartheta_2'' - \vartheta_1' - (\vartheta_2' - \vartheta_1'')}{\ln \frac{\vartheta_2'' - \vartheta_1'}{\vartheta_2' - \vartheta_1''}} = k \cdot A \cdot \Delta \vartheta_m$$

The temperatures in the numerator of the above equation can be replaced by the heat rate divided by the product of mass flow rate and heat capacity. The above three equations deliver:

$$\frac{\vartheta_2'' - \vartheta_1'}{\vartheta_2' - \vartheta_1''} = e^{k \cdot A \left(\frac{1}{\dot{m}_1 \cdot c_{p1}} - \frac{1}{\dot{m}_2 \cdot c_{p2}} \right)} = e^{4000 \cdot 1.93 \cdot \frac{\text{W}}{\text{K}} \cdot \left(\frac{1}{1 \cdot 4182} - \frac{1}{2 \cdot 4192} \right) \frac{\text{K}}{\text{W}}} = 2.518$$

With the energy balance equation the temperature ϑ_2'' can be given as a function of the temperature ϑ_1'' and inserted in the equation above. The equation solved for ϑ_2'' delivers.

$$\begin{aligned} \vartheta_2'' &= \vartheta_2' - \frac{\dot{m}_1 \cdot c_{p1}}{\dot{m}_2 \cdot c_{p2}} \cdot (\vartheta_1'' - \vartheta_1') = 90^\circ\text{C} - 0.4988 \cdot (\vartheta_1'' - 25^\circ\text{C}) = \\ &= 102.47^\circ\text{C} - 0.4988 \cdot \vartheta_1'' \end{aligned}$$

$$\vartheta_1'' = \frac{2.522 \cdot \vartheta_2' + \vartheta_1' - 102.47^\circ\text{C}}{2.0232} = \frac{2.522 \cdot 90^\circ\text{C} + 25^\circ\text{C} - 102.47^\circ\text{C}}{2.0232} = 73.9^\circ\text{C}$$

The result for temperature ϑ_1'' is:

$$\vartheta_2'' = 102.47^\circ\text{C} - 0.4988 \cdot \vartheta_1'' = 65.6^\circ\text{C}$$

The heat rate can be determined with the energy balance equation.

$$\dot{Q} = \dot{m}_1 \cdot c_{p1} \cdot (\vartheta_1'' - \vartheta_1') = 1 \cdot \frac{\text{kg}}{\text{s}} \cdot 4182 \cdot \frac{\text{J}}{\text{kg} \cdot \text{K}} \cdot (73.9 - 25) \cdot \text{K} = 204.5 \text{ kW}$$

Discussion

With the energy balance and the rate equations, the outlet temperatures of an already designed heat exchanger (of which the physical dimensions are known) can be calculated. With increased inlet temperature of the cold water in the pipe, the outlet temperature increases but the heat rate decreases as the temperature changes of both water flows decrease.

Heat Transfer

Basics and Practice

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