3. DESIGNING AND OPTIMISING HEAT EXCHANGERS

3.1. Introduction

In any heat exchanger calculation, the aim is to recover a certain amount of heat under optimum economic conditions, which is a compromise between investment costs and operating costs.

3.2. Assumptions

Firstly, the calculations are based on some simplifying assumptions:

- Steady state.
- The characteristics of the fluids (ρ, μ, λ, Cp) are constant.
- Temperatures are variable in the exchanger.
- Pressure varies little.
- The fluids are single-phase "no phase change".
- Heat is transferred only by convection and conduction.
- Adiabatic exchanger.

3.3. Designing

The problem of thermal sizing in an industrial installation begins with the selection of the type of heat exchanger best suited to the problem posed. Then comes the thermal sizing phase itself, which is designed to determine the exchange surface required to transfer power to the fluids under consideration.

There are two methods of calculating and sizing heat exchangers:

- Analytical methods: such as the LMTD method and the NTU method.
- Numerical methods: finite volume, finite element and finite difference methods.

3.3.1. Principles of Calculation

Two types of thermal calculation can be used to characterize the heat exchanger:

- Determining the exchange surface area S, given the power exchanged and the input and output temperatures of the two fluids.
- Determining the output temperatures of the fluids, knowing their input temperatures and the exchange surface.

3.3.2. LMTD method

The heat exchanged in the exchanger is determined by:

$$\phi = k \ S \ \Delta T_{LMTD}$$

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{Log\frac{\Delta T_2}{\Delta T_1}}$$

The exchange surface can be calculated using the relationship:

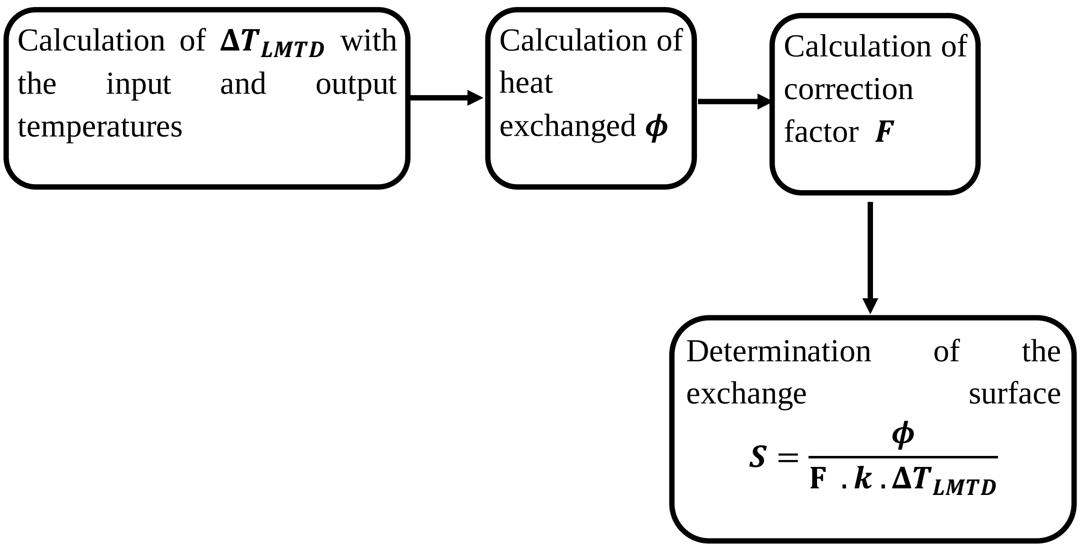
$$S = \frac{\phi}{k \,.\, \Delta T_{LMTD}}$$

Practically, we prefer to express this mean difference using the logarithmic mean difference of a counter-current exchanger calculated with the same fluid input and output temperatures, multiplied by a correction factor F:

$$S = \frac{\phi}{k \,.\, \mathrm{F} \,.\, \Delta T_{LMTD}}$$

This correction factor F is 1 in the case of a counter-current exchanger.

The calculation procedure is shown schematically in the figure:

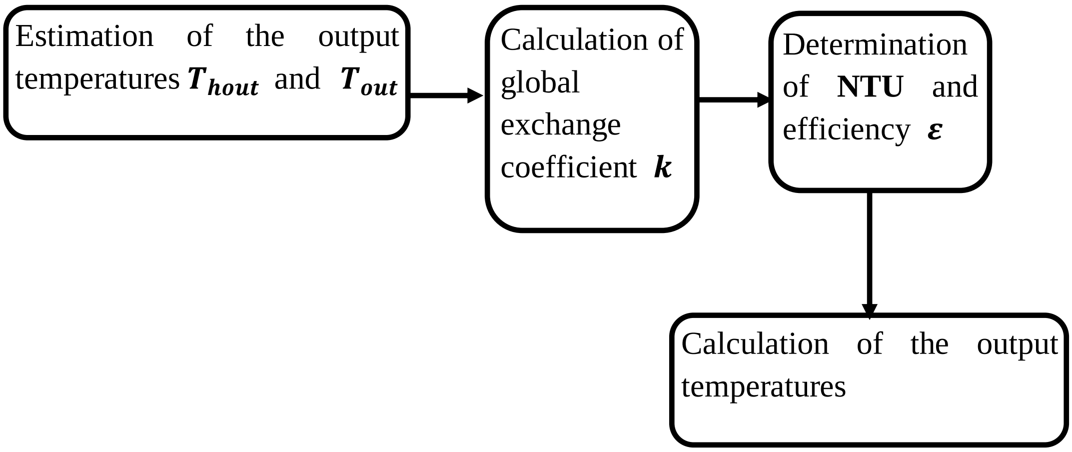


3.3.3. NTU method

The NTU method provides an elegant and rapid response to most of the problems encountered in heat exchanger studies.

These fall into two main categories:

- Design problems in which the input temperatures and an output temperature are imposed, the flow rates being known.
- Performance problems where the data are the type and size of the heat exchanger, the flow rates and the input temperatures. The output power and temperatures must then be determined. The method calculates NTU from the initial data, from which the efficiency value and the two output temperatures are deduced. The thermal power is obtained from the overall enthalpy balance.



3.3.4. Calculation steps

- Determination of the second fluid temperature du second fluid from equations:

$$\phi = \dot{m}_h \, C_{ph}(T_{hin} - T_{hout}) = \dot{m}_c \, C_{pc}(T_{cout} - T_{cin})$$

- Calculation of the logarithmic mean temperature difference : ΔT_{LMTD}
- Calculation of the number of transfer units **NTU** defining the thermal service required and the efficiency of the exchanger.
- Knowing the geometry of the exchanger, it is necessary to choose a characteristic flow velocity in the tubes.
- Calculation of the heat transfer coefficients on each side of the fluids under consideration, using the appropriate correlations.
- Evaluation of the overall heat transfer coefficient **k**, without taking fouling into account (clean exchange coefficient) for a first calculation, and taking fouling into account for a second calculation (fouled exchange coefficient).
- Calculation of the exchange surface corresponding to the calculated exchange coefficient, depending on the method used (**NTU** method, **LMTD** method).
- Comparison between the surface area required to provide the service requested and the surface area initially considered.
- Calculation of the pressure losses on each circuit using the appropriate correlations.
- Comparison with maximum permissible pressure drops.

3.4. Optimizing heat exchangers

3.4.1. Introduction

Heat exchangers have many and varied applications, resulting in a huge variety of configurations. These can be differentiated by the nature of the materials used (metal, glass, plastic, ceramic, graphite); the choice of material is often the result of constraints of use, but also of economic considerations, for example:

- Thermomechanical constraints (temperature and pressure levels); aggressive nature of the products processed (chemical attack, corrosion); ammonia requires steel pipes;
- The nature and flow of transfer fluids: liquid, gas, polyphonic mixtures (liquid gas), liquid-particles, gas-particles); powder flows (powders, grains);

The wide variety of possible solutions leads to the optimization of the exchanger in a given situation. This leads to two successive types of optimization:

- Static optimization of the heat exchanger in the system or process: this optimization must meet an optimum sizing of the heat exchanger for a given operation (design optimization) or an optimized operation for an existing sizing. This alternative to global optimization can give rise to intermediate variants.
- The global (systematic) approach described above can be matched by a local approach, which corresponds to dynamic optimization of the heat exchanger: as the heat exchanger is in operation, its operating conditions may vary over time. The aim is to optimize the heat exchanger's performance over time: optimization of transient behavior.

3.4.2. Static optimization of heat exchangers

Optimization in the sense of the first principle: The general problem takes on three essential practical approaches; when using an exchanger, we seek either to increase its performance, or to reduce the costs associated with it, or to reduce its overall dimensions. It should be noted that these three objectives may correspond to different constraints.

Furthermore, the search for maximum thermodynamic efficiency generally coincides with minimum operating costs (first approach).

A few global criteria: Among the criteria used to evaluate the performance of an exchanger, we would highlight the reduction in S (manufacturing cost); the reduction in mechanical cost (pumping power, pressure losses or operating cost).

The above objective functions are often associated with constraints.

3.4.3. Dynamic optimization of heat exchangers

- Long or short transients:

Transients can lead to very different exchanger responses. A distinction is made between long transients and short transients.

An example of a long transient in a heat exchanger (or sliding transient) is the clogging of heat exchangers. An example of short transients is the opening of an on-off fluid supply valve. These two examples lead to completely different time constants: of the order of a day at least in the first case, of the order of a second or a minute, depending on whether the mechanical or thermal aspects are considered in the second case.

- Transients in temperature or power exchanged:

The response of the heat exchanger can be sought either in terms of temperature T (intensive variable) or in terms of the quantity of heat exchanged (extensive variable).

The most common studies in the literature relate to the intensive variable T.