Heat Exchange: An Important Unit Operation

Energy is consumed or produced in chemical reactions and in many of the physical processes used in the food and dairy industries (dissolution, crystallization, mixing, blending, distillation, concentration and drying). Some of that energy appears as heat and results in a change in temperature in the system and/or surroundings. It is known that rates of reactions, the stability of reactants, products and materials of construction are all sensitive to temperature. Because of this sensitivity temperature control is very important and is achieved by controlling the transfer of heat between the system and the surroundings. In fact, heat transfer may be the most common unit operation in the chemical, pharmaceutical and food processing industries.

Approaches to effective heat transfer are based upon the flow of a fluid through a specially designed unit that may be located (a) at the external surfaces of the reactor vessel, usually in the form of a jacket, (b) inside the reactor as cooling or heating tubes, or (c) as a "stand alone" unit in the system.

These units are produced in several configurations, allowing cross-flow or reverse-flow of the fluids through multiple tubes. The heat transfer surfaces are typically narrow tubes in a variety of arrangements, e.g., limpet or half-pipe coils, spirals or pancake coils. The tubes may have dimpled surfaces or fins attached.

The rate of transfer of heat, Q, may be represented as follows;

$$Q = U.A.\, \Delta T$$

Here U is the heat transfer coefficient, ΔT is the difference in temperature across the surfaces separating the system and the surroundings and A is the available surface area.

The equation indicates that a high rate of transfer requires a high heat transfer coefficient and a large available surface area. With regard to the latter, it has been shown that the increase in surface area obtained with the dimpled surface or with fins compensates for the lower thermal conductivity of the mild and stainless steels. The heat transfer coefficient is dependent upon several factors;

(a) the thermal conductivity of the materials of construction,
(b) the physical properties of the system, i.e., the densities and viscosities of the fluids involved as well as the type of fluid (for example it has been shown that water – water heat exchange units are far superior to air – air units)
(c) the fluid dynamics, i.e., the pressure drops, flow distribution and mixing are a function of the geometry of the heat exchange unit.

A consequence of the flow of fluid through the heat exchanger is the formation of films at the surfaces of the metal. These films can inhibit the heat transfer process and the thickness and structure of the film is dependent upon the fluid flow patterns. Turbulent flow minimizes the thickness of the film at the metal surfaces and therefore the fluids are usually pumped through the unit at a high velocity. Turbulence promoters (for example the use of dimpled surfaces) may be incorporated into the heat exchange unit.

It is evident that the selection of a heat transfer unit is complex but awareness of the process under consideration is essential. Several questions should be asked, such as the following;

(a) what is the required rate of heat transfer to match the amount of heat produced or consumed in the chemical reaction or physical process?
(b) what are the properties of the fluid streams?
(c) what temperatures and pressures are involved in the process?
(d) what materials of construction can be used?
(e) what is the availability of these preferred materials?
(f) what is the expected performance of the heat exchange unit
(g) what is the cost?

Heat exchangers may be fabricated from a variety of materials but the stainless steels represent a highly versatile and cost effective choice. It is possible to select from a range of alloys with varying crystal structures, allowing the metal to be tailored to specific applications. Stainless steels are readily fabricated into a wide range of designs and are compatible with most other materials used in the construction of systems for chemical and pharmaceutical processes and in the food and dairy industries. The preferred heat transfer fluids include steam, hot and cold water, glycols, oils and refrigerants.

For batch processes the use of jacketed reactors can offer an efficient and cost effective approach to heat transfer. The attachment of various coils to interior or exterior surfaces is fairly inexpensive and provides a high surface area in contact with either the process fluids or the heat transfer fluid. A more efficient method is the use of dimpled, stainless steel jackets, where the metal surface has a uniform array of dimples or depressions. These jackets can be located in different zones on the tank to accommodate different heat fluids (if required) and allow for variability in the size of the batch being processed. The dimpled jackets can be operated at high pressures and/or with high rates of fluid flow. For continuous processes, where the reactant and product streams flow through the system, a separate heat exchange unit is usually preferred. The separated unit can be designed to allow the transfer of heat from more than one fluid stream, representing a cost advantage. There are two designs of “stand alone” heat exchangers commonly used in chemical and physical processes, these being the shell-and-tube and plate-and-frame units.

The control of temperature in a chemical or physical process is known to be very important. The selection of a heat exchanger unit to achieve that control can be a challenging task. It is essential to know the process of interest in detail, together with the answers to several critical questions, to allow the best available choice to be made. With regard to the materials of construction, the stainless steels do represent a highly versatile and effective choice.