HEAT TRANSFER APPLICATIONS IN PROCESS ENGINEERING

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Preface

Heat transfer is used extensively in diverse applications and by numerous industries such as chemical processing, food, oil and gas, metallurgical, and nuclear industries.

This book, the companion volume to *Fundamentals of Heat Transfer for Process Engineering* by this author, focuses on the practical aspects of heat transfer and illustrates many industrial applications. While many design methods supposedly achieve the same results, often there are differences, advantages and disadvantages between procedures. This book is an attempt to address problems considered by practicing engineers and especially by new graduates trying, so to say, to make bridges between academia and industry. Because it is not intended to present an overview, but rather detailed instruction, the author has elected to cover only those processes that demand a thorough understanding of heat transfer fundamentals.

This book is divided into six chapters.

Chapter 1 gives the classification and application of heat transfer equipment and develops the fundamental concepts important in setting the stage for subsequent treatment of practical heat transfer problems.

Chapter 2 studies the thermal, hydraulic, and mechanical design of heat exchangers (recuperators) in which two fluids at different temperatures flow in spaces separated by a partition. The principles and information covered in the preceding chapter are applied to the design of heat exchangers whose primary function is to transfer heat. The analysis and selection of heat-exchange equipment is emphasized.

Chapter 3 analyzes *direct contact* heat exchangers where hot and cold fluids occupy the same space not separated by a partition, thereby allowing both fluids to be in direct and physical contact. Usually this contact allows mass and heat transfer between fluids to take place until equilibrium is obtained.

Chapter 4 analyzes the regenerator-type heat exchangers based on hot and cold fluids that alternately pass over the same heat transfer surface in a channel with or without solid inserts.

Chapter 5 is devoted to the design and selection of evaporators. The subject matter is a consecutive presentation of the fundamental design of the equipment, specific features of the equipment, and an analysis of equipment operation to attain increased efficiency.

Chapter 6 describes combustion and its utilization, and furnace designs which convert the chemical energy of a fuel into heat. Considered are furnaces that burn fuel in contact with the material being processed as well as those where the material is separated; e.g., crucibles and muffle furnaces.

The author hopes that this volume may be useful to engineers who desire a refresher course in first principles and standard calculations; process engineers in first job positions; and engineering students in heat transfer.

My thanks are extended to Professor James W. Johnson, Chairman, Chemical Engineering Department, University of Missouri-Rolla, for his valuable comments, personal assistance and help.

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David Azbel is Professor of Chemical Engineering at the University of Missouri-Rolla. He was previously Research Professor at the State University of New York at Stony Brook and Visiting Professor, University of Minnesota. From 1966 to 1972 he was Professor of Chemical Engineering at the All-Union Polytechnical Institute (Moscow, USSR); from 1961 to 1965 he was Chief of the Technology Department of the Organic and Synthetic Products Research Institute (Moscow, USSR). Previously he was project chief at the Chemical Engineering Research Institute and Petrochemical Research Institute (Irkutsk, Siberia, USSR). Dr. Azbel received his Doctor of Science degree from the Mendeleev Institute of Chemical Technology, Moscow, USSR. His engineering, design, research and teaching span the broadest range of chemical, petroleum and nuclear experience. He is also the author of many publications and books in chemical engineering.

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Classification and Application of Heat Transfer Equipment

INTRODUCTION

Heat transfer equipment (heat exchangers) may be defined as apparatus in which heat is transmitted from one fluid to another. The transfer of heat between the two fluids is carried out either by direct contact or by transmission through a separating wall.

According to the different methods of carrying out the heat transfer operations, heat exchangers may be classified into the following three basic types:

1. Open or direct contact heat exchangers
2. Recuperators
3. Regenerators

In the first type of exchanger, the two or more phases between which heat is to be transferred are not separated by an intermediate solid wall. In the second type, heat passes through a separating wall which divides the hot fluid from the cold one. In the third type, the cold and hot fluids pass through the same space in the heat exchanger, but alternately, never at the same time.

DIRECT-CONTACT HEAT EXCHANGERS

Direct-contact heat exchangers are used when the mixing of cold and hot fluids is either harmless or desirable. They offer the potential of considerable economy due to the absence of costly heat-transfer surfaces. In order for the use of this equipment to be possible, one of two conditions must be satisfied: Either there must be a phase change on the part of some material involved, or a second fluid must be used which normally has to be immiscible with the main process fluid.

Many types of processes utilize direct contact heat transfer. These can be divided into the following categories:

1. Flash Evaporators.
2. Direct-contact condensers.
3. Cooling towers.
4. Heat-transfer fluids.
5. Direct heating (pneumatic drying).
6. Direct use of steam.
7. Submerged combustion.

Flash Evaporators [1]

Probably the most common use of flash evaporation is in crystallizing plants, where the process fluid is introduced into an environment with a pressure lower than the equilibrium vapor pressure of the fluid. Equilibrium is achieved by cooling the fluid, which occurs through the almost instantaneous evaporation of part of the fluid.

The use of flash evaporation is not confined to the crystallization process. It should also be considered in cases involving fouling fluids, heat sensitive liquids, and high viscosity liquids. In the case of fouling fluids, sensible heat transfer may be a fouling-free method of providing an evaporative duty, as opposed to evaporative heat transfer. When evaporating salt solutions near their saturation point, boiling on the surfaces of the heat exchanger may be suppressed by providing sufficient back pressure, resulting in little or no fouling.

Direct-Contact Condensers [2] (Fig. 1.1)

An obvious example of this common type of equipment is the water-spray condenser used with vacuum equipment. Because of the extremely high surface area in a spray, high efficiency is easily obtained, which can be particularly valuable when incondensibles are present. Condensing fluids used in spray condensers include water, organic liquids, and salt solutions. When the latter two are used, the heated liquid cannot simply be disposed of in a drain or cooling tower because of the value of the chemicals or the effluent problems they pose.

Cooling Towers [3,4] (Figs. 1.2 - 1.7)

Cooling towers are widely used to dispose of waste heat from industrial processes, especially to transfer heat from large quantities of hot water where space is limited to a stream of colder air in direct contact with it. Air from the atmosphere is drawn into the tower and then returned to the atmosphere, usually at a higher temperature.

The simplest form of cooling tower consists of a series of upward-facing sprays surrounded by louvered walls to prevent the water droplets from carrying over onto the surrounding area (Fig. 1.2). Providing horizontal

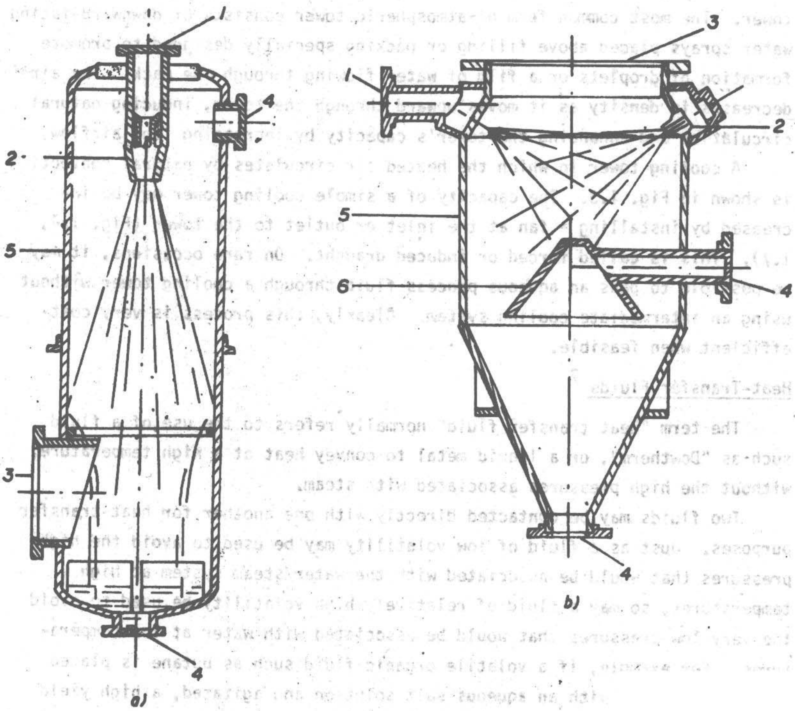

FIGURE 1.1
SPRAY CONDENSERS FOR USE WITH STEAM/WATER.
Fig. 1.1.a Counter-Current Type   Fig. 1.1.b Co-Current Type

1. Liquid inlet
2. Spray nozzle(s)
3. Manhole
4. Vent (vapour outlet)
5. Shell
6. Vent cover

surfaces inside the tower reduces the average velocity of the falling droplets and increases the time that they are exposed to the cooling air stream while falling, thus increasing the capacity per unit area of the cooling tower. The most common form of atmospheric tower consists of downward-facing water sprays placed above filling or packing specially designed to promote formation of droplets or a film of water flowing through the pack. The air decreases in density as it moves upward through the tower, inducing natural circulation and enhancing the tower's capacity by increasing the airflow.

A cooling tower in which the heated air circulates by natural convection is shown in Fig. 1.3. The capacity of a simple cooling tower may be increased by installing a fan at the inlet or outlet to the tower (Fig. 1.4, 1.7). This is called forced or induced draught. On rare occasions, it may be possible to pass an aqueous process fluid through a cooling tower without using an intermediate cooling system. Clearly, this process is very cost-efficient when feasible.

<u>Heat-Transfer Fluids</u> [7]

The term "heat transfer fluid" normally refers to the use of a fluid such as "Dowtherm", or a liquid metal to convey heat at a high temperature, without the high pressures associated with steam.

Two fluids may be contacted directly with one another for heat-transfer purposes. Just as a fluid of low volatility may be used to avoid the high pressures that would be associated with the water/steam system at high temperatures, so may a fluid of relatively high volatility be used to avoid the very low pressures that would be associated with water at low temperatures. For example, if a volatile organic fluid such as butane is placed in direct contact with an aqueous salt solution and agitated, a high yield of crystals can be obtained when the organic fluid evaporates. The basic process is both simple and effective; however, there may be considerable problems in recovering and reusing the organic fluid. Therefore, this technique is economically feasible only under special circumstances, in spite of the high heat transfer rates possible.

<u>Direct Heating (Pneumatic Drying)</u> [8]

Hot air is widely used as a heat transfer fluid in many chemical engineering processes, for example in the great majority of drying processes. In one technique, heated air is used to dry a solid in direct contact with the air. Sufficient air for combustion, plus excess air, is fed into a furnace to produce an exit gas at 400 - 500°C. Wet solid is then dropped into this air stream and conveyed to some separation equipment. The air is quickly cooled, and the solid is not damaged since, under atmospheric pressure, its temperature cannot rise above 100°C as long as there is any water left to evaporate from the surface. Although a high degree of process control is required, this technique has been in use for many years. In addition to deliberately planned uses of this technique, its application might also be considered in cases such as the recovery of heat from furnace exhaust gases.

Direct Steam Injection

In a number of instances, heating can be provided by the direct use of steam. When steam is used in this way, there is no recovery of the condensate. The value of the condensate depends on its heat content and its treated water content. The cost of water and demineralization is rarely sufficient to justify the installation of equipment to recover the condensate. The thermal value of the condensate is several times the water value. In live steam injection, some of the thermal value of the condensate is transferred directly to the process, although there is generally more value in recovering heat from the total process stream rather than from the condensate alone.

Submerged Combustion[9] (Fig. 1.7)

Submerged combustion involves direct contact between a flame and its hot gases, and the fluid which is to be heated. The fluid in this case is almost invariably evaporated. Gas-fired equipment is cheaper in initial cost; however, the fuel is usually more expensive. Operating costs are relatively high, but the size of the main boiler house can often be considerably reduced since this technique is applied to high heat loads which form a large or even major part of the thermal load of the complete process.

Direct contact heat transfer is also one of the component processes in some equipment in the chemical processing industries, such as gas absorption or liquid-liquid extraction between streams of unequal temperatures. Even if the feed streams are injected at equal temperatures, further complications arise from the generation or absorption of heat due to mass transfer and phase change. For simple interphase transfer without chemical reaction, the heat is generated or absorbed at the physical interface. If chemical reaction is occurring, heat is generated or absorbed where the reaction occurs.

Recuperator-type Heat Exchangers[10-12]

The heat exchangers used in most industrial applications are of the recuperator type. In this type of equipment, heat is transferred by convection to and from the solid wall, and by conduction through the wall.

The many types of recuperative heat exchangers may be classified into a number of categories, as follows:

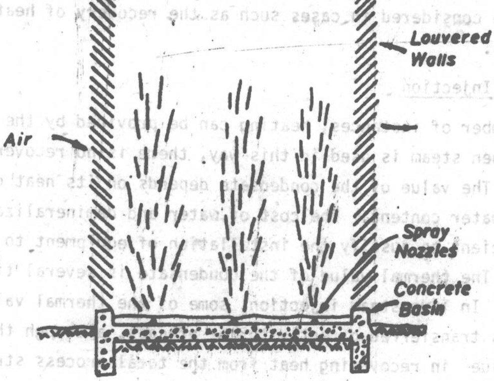

Figure 1.2 Section through a simple cooling tower formed by enclosing a spray pond with louvered walls. (Ref. 3).

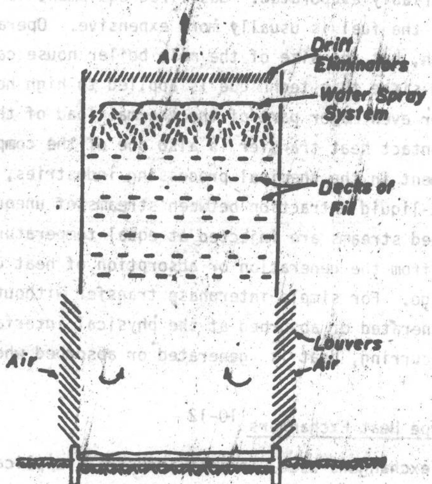

Figure 1.3a Section through a natural convection cooling tower with "fill" to increase the effective water droplet surface area by multiple splashing. (Ref. 3).