direct-contact heat transfer

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DIRECT-CONTACT HEAT TRANSFER

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PREFACE

It is common engineering practice to use a closed heat exchanger to transfer heat between two streams. In a closed heat exchanger each fluid has its own flow channel and the fluids are separated by a solid wall. The variety of closed heat exchanger types marketed is increasing each year. They range from simple devices made of plastic or paper for low temperatures to the sophisticated ceramic configurations specifically for high temperatures. Since each type of exchanger has a number of different geometries available, several choices are at the designer's fingertips. Moreover, simplified design techniques are available for most closed configurations either by a Modified Log Mean Temperature Difference approach or by the use of the Effectiveness—NTU technique. Hence, the typical engineer generally uses closed devices without considering alternatives.

However, other options for heat exchange do exist: direct-contact processes. As implied by the name, this approach accomplishes heat transfer by bringing a higher temperature stream and a lower temperature stream into contact. Specific examples of direct-contact heat transfer devices are cooling towers, open feed water heaters, distillation units, and barometric condensers. These devices are often viewed as special situations, and empirical design techniques for them have been developed over time but without the underpinnings of a basic physical understanding of direct-contact phenomena.

As the costs of energy and industrial facilities increase, direct contact devices are being given new consideration because these devices offer the possibility of increased performance and decreased first cost. In addition, they may have application to processes in which closed exchangers encounter problems such as corrosion and high initial cost.

In order to explore the potential of direct heat transfer processes, and establish a pool of knowledge summarizing our current understanding, as well as to delineate what needs to be done in research and development to provide information necessary to increase the use of direct contact processes, the National Science Foundation supported a workshop on direct contact heat transfer at the Solar Energy Research Institute in the summer of 1985. We served as organizers for this workshop, which emphasized an area of thermal engineering that, in our opinion, has great promise for the future, but has not yet reached the point of wide-spread commercial application. Hence, a summary of the state of knowledge at this point is timely.

The workshop had a dual objective:

1. To summarize the current state of knowledge in such a form that industrial practitioners can make use of the available information.
2. To indicate the research and development needed to advance the state-of-the-art, indicating not only what kind of research is needed, but also the industrial potential that could be realized if the information to be obtained through the proposed research activities were available.

In order to achieve these objectives, we invited some of the leading researchers, engineers and practitioners in the field of direct-contact heat transfer for a two-day workshop to discuss the key issues in the field. The workshop consisted of 8 lectures and 4 discussion sessions. Each discussion session dealt with two related lecture topics. The lectures were tutorial in nature, thus presenting the best available correlation of data and summaries of techniques in the field and also showing how this information could be used for practical applications in industry. We have attempted to summarize all the information on research needs from this workshop as the final chapter in this book for the use of the engineering research community and funding agencies.

After completing the workshop, we decided that it would be helpful if in addition to the technical summaries, there would also be appendixes that would illustrate the manner in which direct-contact heat transfer devices can be designed and evaluated. Searching for readily available information, we found that a majority of applications of direct-contact processes have been made in areas in which energy use and efficiency of utilization is at a premium. These areas are in the evolving fields of energy conservation and renewable energy conversion, where often low grade energy sources must be utilized and high second law thermodynamic efficiencies are required in order to make these processes viable. Hence, the examples in the appendixes are chosen from energy production in a geothermal installation, energy conversion in a solar pond application, energy conversation in open cycle OTEC, and in a cooling tower. However, these illustrative examples are not intended to be exhaustive, but rather to provide a background for other applications that imaginative engineers and designers can utilize.

We hope that the presentations from eminent authorities in the field that we have collected here will serve the engineering community and that the appendix material will help in generating more applications of direct-contact heat transfer processes.

Frank Kreith
R. F. Boehm

DIRECT-CONTACT HEAT TRANSFER

CONTENTS

CHAPTER

1

DIRECT-CONTACT HEAT TRANSFER PROCESSES

R. F. Boehm and Frank Kreith

1 INTRODUCTION

A key challenge in the design of efficient energy conversion systems is to achieve effective heat transfer at temperatures that can extract the maximum thermodynamic potential of the system's heat source. In classical heat exchangers, heat transfer takes place through a wall separating the hot and the cold fluid streams. Thus, conventional heat exchangers are limited in their ability to tap the maximum thermodynamic potential because they have built-in thermal losses associated with the separation of the fluid streams by an intervening solid wall. This type of configuration also leads to a deterioration of the heat transfer effectiveness as the heat transfer coefficients decrease with time due to fouling. In the case of high-temperature applications, thermal stress and corrosion problems are imposed on the wall materials themselves. These situations are present irrespective of whether the two fluid streams are solid, liquid, vapor, gaseous, or some mixtures of them.

Despite these potential problems the transfer of heat between two streams is achieved in most engineering applications by closed heat-exchange devices in which a solid surface separates the two streams, and the variety of closed heat-

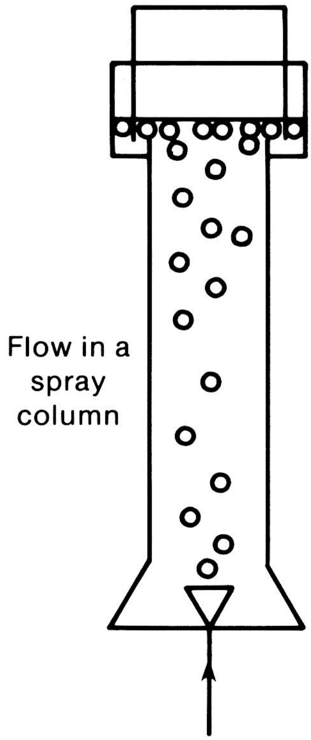

Figure 1.1 Schematic diagram of spray tower.

exchanger types available is increasing each year. These exchangers range from simple devices made of plastic or paper for low-temperature applications to the sophisticated ceramic exchangers for high-temperature applications, such as gas turbine regenerators. Since each type of exchanger comes in a variety of different geometries from several manufacturers, a great deal of flexibility and choice is available at a designer's fingertips. More importantly, however, simplified design techniques have been developed for almost any closed heat-exchanger configuration, either with the modified log mean temperature difference (LMTD) method or with the effectiveness-NTU approach. Both of these methods have been available in the form of graphs or simple computer programs for many years, and, as a result, most engineers have usually selected closed heat exchange devices without considering alternatives.

In addition to their thermodynamic limitations, closed-type heat exchangers may also have problems related to first cost and operating expense. To improve the performance of closed-type heat exchangers the usual approach is to increase the surface area. This, of course, leads to increased initial cost. If the properties of one or both steams produce corrosion or fouling of the surface, maintenance and operational costs are incurred. To combat these problems, special materials may have to be used in the construction of the exchanger, and frequent cleaning may be necessary. Both of these measures lead to increased operational cost.

In view of the limitations of closed-type heat-exchanger devices, increasing interest in another type of heat-exchange approach has developed in recent years: *direct-contact heat transfer.* The term direct contact encompasses a wide range of devices, but all of them have one thing in common: heat transfer is achieved through intimate contact of two material streams without the presence of an intervening surface. More efficient and lower-cost heat transfer equipment is the promise of these types of processes.

Direct-contact processes have been used for many years for operations in which the primary goal was mass transfer, and initial applications to heat transfer processes have emphasized situations where heat and mass transfer are intimately coupled. However, the inclusion of a chapter on heat transfer in packed and fluidized beds in the 1985 *Handbook on Heat Transfer Applications* is a recognition of the increasing importance of direct-contact heat transfer to engineering practice in applications such as energy conversion and combustion of fossil fuels.

A problem facing the engineer who wants to use direct-contact heat transfer is the limited general understanding of the processes and a lack of a reliable methodology for predicting the thermodynamic performance. Current practice usually relies on empirical correlations for a given geometry that are difficult, if not impossible, to transfer to another geometric configuration. Except for some limited use of mass transfer data to predict heat transfer characteristics by means of the analogy between heat and mass transfer, there exist no generalized approaches to predict the performance of direct-contact heat transfer devices similar to the LMTD or effectiveness-NTU method in closed heat exchangers. A few examples of direct-contact heat transfer applications will illustrate the situation.

2 DIRECT-CONTACT DEVICES AND APPLICATION

As an example of a simple countercurrent flow, direct-contact heat transfer device, consider the spray tower shown in Fig. 1.1. It consists essentially of a cylindrical vessel in which one fluid moves downward by gravity dispersed in droplets within a continuous immiscible second fluid stream flowing upward. It is known that this type of contact device has a high capacity but low efficiency. The low efficiency is largely the result of the low dispersed phase holdup (less than 40%) due to the loose packing flow.

To combine the high capacity with a good efficiency, chemical engineers in the early 1960s placed inside the cylinder a packing capable of increasing the dispersion of droplet to 90% holdup as shown in Fig. 1.2. In addition, the dense-packing flow provided a large interfacial area and a low value of axial dispersion. But since there are many different packing materials that can be used, the kind of correlation will depend on the specific geometry of the device. Figure 1.3 shows several kinds of commercial packings that are widely used in industry. Other types of internal configurations have been used to improve the contactor performance.

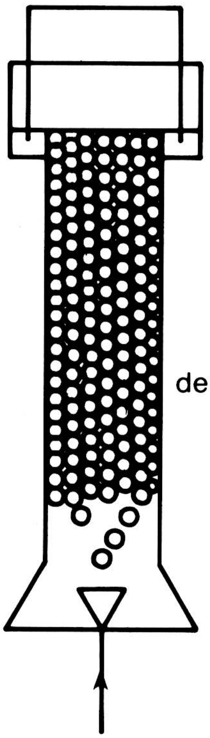

Figure 1.2 Schematic diagram of a packed-bed device.

Most of the direct heat-exchanger applications are commercially accomplished in one of the following devices: spray columns, baffle tray columns, packed columns, crossflow tray columns, and pipeline contactors. Figure 1.4 illustrates a perforated plate contactor. Figure 1.5 illustrates the heat transfer section of a heavy hydrocarbon fractionator that uses both baffles and crossflow trays. Figure 1.6 illustrates a spray chamber in which pyrolysis gases are cooled in a device similar to that in Fig. 1.1. Figure 1.7 is a special packing condenser reflux in a vacuum steam fractionator, and Fig. 1.8 shows a barometric type of steam condenser. Figure 1.9 shows a type of agitated column. All of these devices will be discussed in more detail later; at this point they are shown mainly to illustrate the kind of applications that direct-contact heat transfer offers.

Another major application of direct-contact heat transfer is in closed cycle cooling of various types of power plants. Prior to 1970, more than 75% of the power plants used open circuit water cooling in their condensers, but in response to a shortage of water and specific environmental regulations from the clean water act, use of closed cycle cooling has increased dramatically. There are essentially three types of cooling devices in common use: cooling towers, cooling ponds, and spray systems. All three use direct-contact heat transfer.