Part One

Introduction

Part One serves as the introductory section to this book. It reviews engineering and science fundamentals that are an integral part of the field of heat transfer. It consists of six chapters, as noted below:

1. History of Heat Transfer
2. History of Chemical Engineering: Transport Phenomena vs Unit Operations
3. Process Variables
4. Conservation Laws
5. Gas Laws
6. Heat Exchanger Pipes and Tubes

Those individuals with a strong background in the above area(s) may choose to bypass all or some of this Part.

Chapter 1

History of Heat Transfer*

INTRODUCTION

After a review of the literature, the author has concluded that the concept of heat transfer was first introduced by the English scientist Sir Isaac Newton in his 1701 paper entitled "Scala Graduum Caloris."[1] The specific ideas of heat convection and Newton's Law of Cooling were developed from that paper.

Before the development of kinetic theory in the middle of the 19th century, the transfer of heat was explained by the "caloric" theory. This theory was introduced by the French chemist Antoine Lavoisier (1743–1794) in 1789. In his paper, Lavoisier proposed that caloric was a tasteless, odorless, massless, and colorless substance that could be transferred from one body to another and that the transfer of caloric to a body increased the temperature, and the loss of calorics correspondingly decreased the temperature. Lavoisier also stated that if a body cannot absorb/accept any additional caloric, then it should be considered saturated and, hence, the idea of a saturated liquid and vapor was developed.[2]

Lavoisier's caloric theory was never fully accepted because the theory essentially stated that heat could not be created or destroyed, even though it was well known that heat could be generated by the simple act of rubbing hands together. In 1798, an American physicist, Benjamin Thompson (1753–1814), reported in his paper that heat was generated by friction, a form of motion, and not by caloric flow. Although his idea was also not readily accepted, it did help establish the law of conservation of energy in the 19th century.[3]

In 1843, the caloric theory was proven wrong by the English physicist James P. Joule (1818–1889). His experiments provided the relationship between mechanical work and the nature of heat, and led to the development of the first law of thermodynamics of the conservation of energy.[4]

The development of kinetic theory in the 19th century put to rest all other theories. Kinetic theory states that energy or heat is created by the random motion of atoms and molecules. The introduction of kinetic theory helped to develop the concept of the conduction of heat.[5]

*Part of this chapter was adapted from a report submitted by S. Avais to L. Theodore in 2007.

Heat Transfer Applications for the Practicing Engineer. Louis Theodore

The earlier developments in heat transfer helped set the stage for the French mathematician and physicist Joseph Fourier (1768–1830) to reconcile Newton's Law of Cooling, which in turn led to the development of Fourier's Law of Conduction. Newton's Law of Cooling suggested that there was a relationship between the temperature difference and the amount of heat transferred. Fourier took Newton's Law of Cooling and arrived at a convection heat equation.[6] Fourier also developed the concepts of heat flux and temperature gradient. Using the same process as he used to develop the equation of heat convection, Fourier subsequently developed the classic equation for heat conduction that has come to be defined as Fourier's law.[7]

Two additional sections complement the historical contents of this chapter. These are:

Peripheral Equipment

Recent History

PERIPHERAL EQUIPMENT

With respect to heat transfer equipment, the bulk of early equipment involved the transfer of heat across pipes. The history of pipes dates back to the Roman Empire. The ingenious "engineers" of that time came up with a solution to supply the never-ending demand of a city for fresh water and then for disposing of the wastewater produced. Their system was based on pipes made out of wood and stone, and the driving force of the water was gravity.[8] Over time, many improvements have been made to the piping system. These improvements include material choice, shape, and size of the pipes: pipes are now made from different metals, plastic, and even glass, with different diameters and wall thicknesses. The next challenge was the connection of the pipes and that was accomplished with fittings. Changes in piping design ultimately resulted from the evolving industrial demands for specific heat transfer requirements and the properties of fluids that needed to be heated or cooled.[9]

The movement of the fluids to be heated or cooled was accomplished with prime movers, particularly pumps. The first pump can be traced back to 3000 B.C., in Mesopotamia, where it was used to supply water to the crops in the Nile River Valley.[10] The pump was a long lever with a weight on one side and a bucket on the other. The use of this first pump became popular in the Middle East and was used for the next 2000 years. At times, a series of pumps would be put in place to provide a constant flow of water to crops far from the source. The most famous of these early pumps is the Archimedean screw. The pump was invented by the famous Greek mathematician and inventor Archimedes (287–212 B.C.). The pump was made of a metal pipe in which a helix-shaped screw was used to draw water upward as the screw turned. Modern force pumps were adapted from an ancient pump that featured a cylinder with a piston "at the top that create[d] a vacuum and [drew] water upward."[10] The first force pump was designed by Ctesibus (285–222 B.C.) of Alexandria, Egypt. Leonardo Da Vinci (1452–1519) was the first to come up with the idea of lifting water by means of centrifugal force; however, the operation of the centrifugal pump was first described scientifically by the French physicist Denis Papin (1647–1714) in 1687.[11] In 1754, Leonhard Euler further developed the principles on which centrifugal pumps operated; today, the ideal pump performance term, "Euler head," is named after him.[12]

RECENT HISTORY

Heat transfer, as an engineering practice, grew out of thermodynamics at around the turn of the 20th century. This arose because of the need to deal with the design of heat transfer equipment required by emerging and growing industries. Early applications included steam generators for locomotives and ships, and condensers for power generation plants. Later, the rapidly developing petroleum and petrochemical industries began to require rugged, large-scale heat exchangers for a variety of processes. Between 1920 and 1950, the basic forms of the many heat exchangers used today were developed and refined, as documented by Kern.[13] These heat exchangers still remain the choice for most process applications. Relatively speaking, there has been little since in terms of "new" designs. However, there has been a significant amount of activity and development regarding peripheral equipment. For example, the 1930s saw the development of a line of open-bucket steam traps, which today are simply referred to as steam traps. (*Note*: Steam traps are used to remove condensate from live steam in heat exchangers. The trap is usually attached at the bottom of the exchanger. When condensate enters the steam trap, the liquid fills the entire body of the trap. A small hole in the top of the trap permits trapped air to escape. As long as live steam remains, the outlet remains closed. As soon as sufficient condensate enters the trap, liquid is discharged. Thus, the trap discharges intermittently during the entire time it is in use.)

Starting in the late 1950s, at least three unrelated developments rapidly changed the heat exchanger industry.

1. With respect to heat-exchanger design and sizing, the general availability of computers permitted the use of complex calculational procedures that were not possible before.
2. The development of nuclear energy introduced the need for precise design methods, especially in boiling heat transfer (see Chapter 12).
3. The energy crisis of the 1970s severely increased the cost of energy, triggering a demand for more-efficient heat utilization (see Chapter 21).[14]

As a result, heat-transfer technology suddenly became a prime recipient of large research funds, especially during the 1960s and 1980s. This elevated the knowledge of heat-exchanger design principles to where it is today.[15]

REFERENCES

1. E. Layton, *History of Heat Transfer: Essays in the Honor of the 50th Anniversary of the ASME Heat Transfer Division*, date and location unknown.
2. Y. Cengel, *Heat Transfer*, 2nd edition, McGraw-Hill, New York City, NY, 2003.
3. http://en.wikipedia.org/wiki/Benjamin_Thompson#Experiments_on_heat
4. http://en.wikipedia.org/wiki/James_Prescott_Joule
5. http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/thercond.html
6. J. P. Holman, *Heat Transfer*, 7th edition, McGraw-Hill, New York City, NY, 1990.
7. J. B. Fourier, *Théorie Analytique de la Chaleur*, Gauthier-Villars, Paris, 1822; German translation by Weinstein, Springer, Berlin, 1884; *Ann. Chim. Phys.*, **37**(2), 291 (1828); *Pogg. Ann.*, **13**, 327 (1828).
8. http://www.unrv.com/culture/roman-aqueducts.php,2004.
9. P. Abulencia and L. Theodore, *Fluid Flow for the Practicing Engineer*, John Wiley & Sons, Hoboken, NJ, 2009.
10. http://www.bookrags.com/sciences/sciencehistory/water-pump-woi.html
11. A. H. Church and J. Lal, *Centrifugal Pumps and Blowers*, John Wiley & Sons Inc., Hoboken, NJ, 1973.
12. R. D. Flack, *Fundamentals of Jet Propulsion with Applications*, Cambridge University Press, New York City, NY, 2005.
13. D. Kern, *Process Heat Transfer*, McGraw-Hill, New York City, NY, 1950.
14. L. Theodore, F. Ricci, and T. Van Vliet, *Thermodynamics for the Practicing Engineer*, John Wiley & Sons, Hoboken, NJ, 2009.
15. J. Taborek, Process Heat Transfer, *Chem. Eng*., New York City, NY, August 2000.