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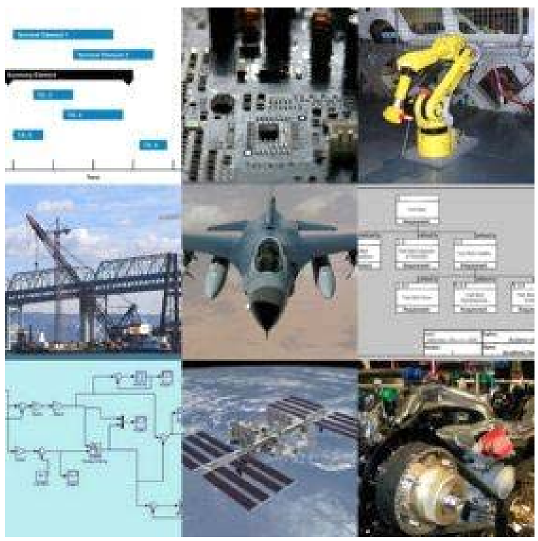

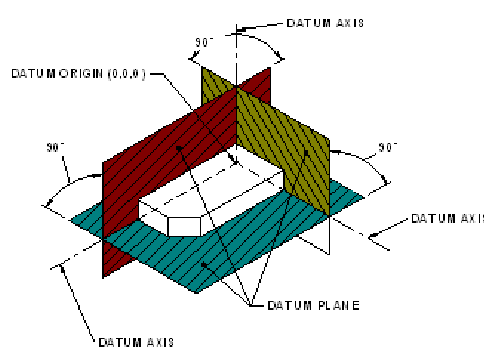

PDH Storm, by Engineers Edge, LLC

Department of Energy
Fundamentals Handbook

THERMODYNAMICS, HEAT TRANSFER, AND FLUID FLOW, Module 2 Heat Transfer

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TERMINAL OBJECTIVE

1.0 Given the operating conditions of a thermodynamic system and the necessary formulas, **EVALUATE** the heat transfer processes which are occurring.

ENABLING OBJECTIVES

1.1 **DESCRIBE** the difference between heat and temperature.

1.2 **DESCRIBE** the difference between heat and work.

1.3 **DESCRIBE** the Second Law of Thermodynamics and how it relates to heat transfer.

1.4 **DESCRIBE** the three modes of heat transfer.

1.5 **DEFINE** the following terms as they relate to heat transfer:
- a. Heat flux
- b. Thermal conductivity
- c. Log mean temperature difference
- d. Convective heat transfer coefficient
- e. Overall heat transfer coefficient
- f. Bulk temperature

1.6 Given Fourier's Law of Conduction, **CALCULATE** the conduction heat flux in a rectangular coordinate system.

1.7 Given the formula and the necessary values, **CALCULATE** the equivalent thermal resistance.

1.8 Given Fourier's Law of Conduction, **CALCULATE** the conduction heat flux in a cylindrical coordinate system.

1.9 Given the formula for heat transfer and the operating conditions of the system, **CALCULATE** the rate of heat transfer by convection.

1.10 **DESCRIBE** how the following terms relate to radiant heat transfer:
- a. Black body radiation
- b. Emissivity
- c. Radiation configuration factor

ENABLING OBJECTIVES (Cont.)

1.11 **DESCRIBE** the difference in the temperature profiles for counter-flow and parallel flow heat exchangers.

1.12 **DESCRIBE** the differences between regenerative and non-regenerative heat exchangers.

1.13 Given the temperature changes across a heat exchanger, **CALCULATE** the log mean temperature difference for the heat exchanger.

1.14 Given the formulas for calculating the conduction and convection heat transfer coefficients, **CALCULATE** the overall heat transfer coefficient of a system.

1.15 **DESCRIBE** the process that occurs in the following regions of the boiling heat transfer curve:
   a. Nucleate boiling
   b. Partial film boiling
   c. Film boiling
   d. Departure from nucleate boiling (DNB)
   e. Critical heat flux

TERMINAL OBJECTIVE

2.0 Given the operating conditions of a typical nuclear reactor, **DESCRIBE** the heat transfer processes which are occurring.

ENABLING OBJECTIVES

2.1 **DESCRIBE** the power generation process in a nuclear reactor core and the factors that affect the power generation.

2.2 **DESCRIBE** the relationship between temperature, flow, and power during operation of a nuclear reactor.

2.3 **DEFINE** the following terms:
- a. Nuclear enthalpy rise hot channel factor
- b. Average linear power density
- c. Nuclear heat flux hot channel factor
- d. Heat generation rate of a core
- e. Volumetric thermal source strength

2.4 **CALCULATE** the average linear power density for an average reactor core fuel rod.

2.5 **DESCRIBE** a typical reactor core axial and radial flux profile.

2.6 **DESCRIBE** a typical reactor core fuel rod axial and radial temperature profile.

2.7 **DEFINE** the term decay heat.

2.8 Given the operating conditions of a reactor core and the necessary formulas, **CALCULATE** the core decay heat generation.

2.9 **DESCRIBE** two categories of methods for removing decay heat from a reactor core.

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HEAT TRANSFER TERMINOLOGY

To understand and communicate in the thermal science field, certain terms and expressions must be learned in heat transfer.

EO 1.1 DESCRIBE the difference between heat and temperature.

EO 1.2 DESCRIBE the difference between heat and work.

EO 1.3 DESCRIBE the Second Law of Thermodynamics and how it relates to heat transfer.

EO 1.4 DESCRIBE the three modes of heat transfer.

EO 1.5 DEFINE the following terms as they relate to heat transfer:

- **a. Heat flux**
- **b. Thermal conductivity**
- **c. Log mean temperature difference**
- **d. Convective heat transfer coefficient**
- **e. Overall heat transfer coefficient**
- **f. Bulk temperature**

Heat and Temperature

In describing heat transfer problems, students often make the mistake of interchangeably using the terms heat and temperature. Actually, there is a distinct difference between the two. *Temperature* is a measure of the amount of energy possessed by the molecules of a substance. It is a relative measure of how hot or cold a substance is and can be used to predict the direction of heat transfer. The symbol for temperature is T. The common scales for measuring temperature are the Fahrenheit, Rankine, Celsius, and Kelvin temperature scales.

Heat is energy in transit. The transfer of energy as heat occurs at the molecular level as a result of a temperature difference. Heat is capable of being transmitted through solids and fluids by conduction, through fluids by convection, and through empty space by radiation. The symbol for heat is Q. Common units for measuring heat are the British Thermal Unit (Btu) in the English system of units and the calorie in the SI system (International System of Units).

Heat and Work

Distinction should also be made between the energy terms *heat* and *work*. Both represent energy in transition. Work is the transfer of energy resulting from a force acting through a distance. Heat is energy transferred as the result of a temperature difference. Neither heat nor work are thermodynamic properties of a system. Heat can be transferred into or out of a system and work can be done on or by a system, but a system cannot contain or store either heat or work. Heat into a system and work out of a system are considered positive quantities.

When a temperature difference exists across a boundary, the Second Law of Thermodynamics indicates the natural flow of energy is from the hotter body to the colder body. The Second Law of Thermodynamics denies the possibility of ever completely converting into work all the heat supplied to a system operating in a cycle. The Second Law of Thermodynamics, described by Max Planck in 1903, states that:

> It is impossible to construct an engine that will work in a complete cycle and produce no other effect except the raising of a weight and the cooling of a reservoir.

The second law says that if you draw heat from a reservoir to raise a weight, lowering the weight will not generate enough heat to return the reservoir to its original temperature, and eventually the cycle will stop. If two blocks of metal at different temperatures are thermally insulated from their surroundings and are brought into contact with each other the heat will flow from the hotter to the colder. Eventually the two blocks will reach the same temperature, and heat transfer will cease. Energy has not been lost, but instead some energy has been transferred from one block to another.

Modes of Transferring Heat

Heat is always transferred when a temperature difference exists between two bodies. There are three basic modes of heat transfer:

> *Conduction* involves the transfer of heat by the interactions of atoms or molecules of a material through which the heat is being transferred.
>
> *Convection* involves the transfer of heat by the mixing and motion of macroscopic portions of a fluid.
>
> *Radiation,* or radiant heat transfer, involves the transfer of heat by electromagnetic radiation that arises due to the temperature of a body.

The three modes of heat transfer will be discussed in greater detail in the subsequent chapters of this module.

Heat Flux

The rate at which heat is transferred is represented by the symbol $\dot{Q}$. Common units for heat transfer rate is Btu/hr. Sometimes it is important to determine the heat transfer rate per unit area, or *heat flux*, which has the symbol $\dot{Q}''$. Units for heat flux are Btu/hr-ft^2. The heat flux can be determined by dividing the heat transfer rate by the area through which the heat is being transferred.

$$\dot{Q}'' = \frac{\dot{Q}}{A} \tag{2-1}$$

where:

$\dot{Q}''$ = heat flux (Btu/hr-ft^2)

$\dot{Q}$ = heat transfer rate (Btu/hr)

A = area (ft^2)

Thermal Conductivity

The heat transfer characteristics of a solid material are measured by a property called the *thermal conductivity* (k) measured in Btu/hr-ft-°F. It is a measure of a substance's ability to transfer heat through a solid by conduction. The thermal conductivity of most liquids and solids varies with temperature. For vapors, it depends upon pressure.

Log Mean Temperature Difference

In heat exchanger applications, the inlet and outlet temperatures are commonly specified based on the fluid in the tubes. The temperature change that takes place across the heat exchanger from the entrance to the exit is not linear. A precise temperature change between two fluids across the heat exchanger is best represented by the *log mean temperature difference* (LMTD or ΔT_{lm}), defined in Equation 2-2.

$$\Delta T_{1m} = \frac{(\Delta T_2 - \Delta T_1)}{\ln(\Delta T_2 / \Delta T_1)} \tag{2-2}$$

where:

ΔT_2 = the larger temperature difference between the two fluid streams at either the entrance or the exit to the heat exchanger

ΔT_1 = the smaller temperature difference between the two fluid streams at either the entrance or the exit to the heat exchanger

Convective Heat Transfer Coefficient

The convective heat transfer coefficient (h), defines, in part, the heat transfer due to convection. The *convective heat transfer coefficient* is sometimes referred to as a film coefficient and represents the thermal resistance of a relatively stagnant layer of fluid between a heat transfer surface and the fluid medium. Common units used to measure the convective heat transfer coefficient are Btu/hr - ft^2 - ^{o}F.

Overall Heat Transfer Coefficient

In the case of combined heat transfer, it is common practice to relate the total rate of heat transfer ($\dot{Q}$), the o... ture difference (ΔT_o) u... *sfer coefficient* combine... mal conductivity of the ... that are used in the hea...

$\dot{Q} = U_oA_o\Delta$ ... (2-3)

where:

$\dot{Q}$ =

U_o =

A_o =

ΔT_o =

Bulk Temperat...

The fluid temperatu... s of the situation. For ... that is "far" from the ... or condensation, T_b is ...