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Heat Transfer Engineering

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CHAPTER ONE

INTRODUCTION TO HEAT TRANSFER

Introduction

Useful conversion factors

Physical quantity	Symbol	SI to English conversion	English to SI conversion
Length	L	1 m = 3.2808 ft	1 ft = 0.3048 m
Area	A	$1\ m^2 = 10.7639\ ft^2$	$1\ ft^2 = 0.092903\ m^2$
Volume	V	$1\ m^3 = 35.3134\ ft^3$	$1\ ft^3 = 0.028317\ m^3$
Velocity	v	1 m/s = 3.2808 ft/s	1 ft/s = 0.3048 m/s
Density	ρ	$1\ kg/m^3 = 0.06243\ lb_m/ft^3$	$1\ lb_m/ft^3 = 16.018\ kg/m^3$
Force	F	$1\ N = 0.2248\ lb_f$	$1\ lb_f = 4.4482\ N$
Mass	m	$1\ kg = 2.20462\ lb_m$	$1\ lb_m = 0.45359237\ kg$
Pressure	p	$1\ N/m^2 = 1.45038 \times 10^{-4}\ lb_f/in^2$	$1\ lb_f/in^2 = 6894.76\ N/m^2$
Energy, heat	q	1 kJ = 0.94783 Btu	1 Btu = 1.05504 kJ
Heat flow	q	1 W = 3.4121 Btu/h	1 Btu/h = 0.29307 W
Heat flux per unit area	q/A	$1\ W/m^2 = 0.317\ Btu/h \cdot ft^2$	$1\ Btu/h \cdot ft^2 = 3.154\ W/m^2$
Heat flux per unit length	q/L	$1\ W/m = 1.0403\ Btu/h \cdot ft$	$1\ Btu/h \cdot ft = 0.9613\ W/m$
Heat generation per unit volume	$\dot{q}$	$1\ W/m^3 = 0.096623\ Btu/h \cdot ft^3$	$1\ Btu/h \cdot ft^3 = 10.35\ W/m^3$
Energy per unit mass	q/m	$1\ kJ/kg = 0.4299\ Btu/lb_m$	$1\ Btu/lb_m = 2.326\ kJ/kg$
Specific heat	c	$1\ kJ/kg \cdot °C = 0.23884\ Btu/lb_m \cdot °F$	$1\ Btu/lb_m \cdot °F = 4.1869\ kJ/kg \cdot °C$
Thermal conductivity	k	$1\ W/m \cdot °C = 0.5778\ Btu/h \cdot ft \cdot °F$	$1\ Btu/h \cdot ft \cdot °F = 1.7307\ W/m \cdot °C$
Convection heat-transfer coefficient	h	$1\ W/m^2 \cdot °C = 0.1761\ Btu/h \cdot ft^2 \cdot °F$	$1\ Btu/h \cdot ft^2 \cdot °F = 5.6782\ W/m^2 \cdot °C$
Dynamic		$1\ kg/m \cdot s = 0.672\ lb_m/ft \cdot s$	
Viscosity	μ	$= 2419.2\ lb_m/ft \cdot h$	$1\ lb_m/ft \cdot s = 1.4881\ kg/m \cdot s$
Kinematic viscosity and thermal diffusivity	ν, α	$1\ m^2/s = 10.7639\ ft^2/s$	$1\ ft^2/s = 0.092903\ m^2/s$

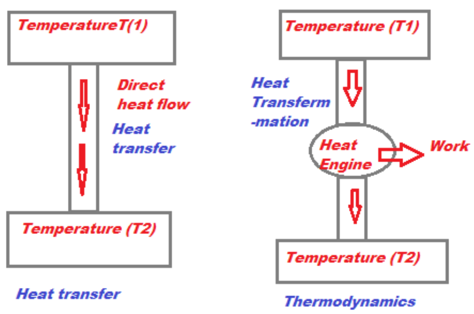
Important physical constants

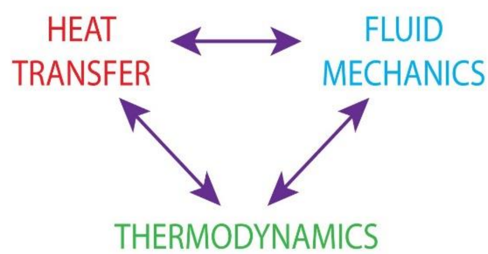
Avogadro's number	$N_0 = 6.022045 \times 10^{26}$ molecules/kg mol
Universal gas constant	$\mathcal{R} = 1545.35$ ft · lbf/lbm · mol · °R
	$= 8314.41$ J/kg mol · K
	$= 1.986$ Btu/lbm · mol · °R
	$= 1.986$ kcal/kg mol · K
Planck's constant	$h = 6.626176 \times 10^{-34}$ J · sec
Boltzmann's constant	$k = 1.380662 \times 10^{-23}$ J/molecule · K
	$= 8.6173 \times 10^{-5}$ eV/molecule · K
Speed of light in vacuum	$c = 2.997925 \times 10^{8}$ m/s
Standard gravitational acceleration	$g = 32.174$ ft/s^2
	$= 9.80665$ m/s^2
Electron mass	$m_e = 9.1095 \times 10^{-31}$ kg
Charge on the electron	$e = 1.602189 \times 10^{-19}$ C
Stefan-Boltzmann constant	$\sigma = 0.1714 \times 10^{-8}$ Btu/hr · ft^2 · R^4
	$= 5.669 \times 10^{-8}$ W/m^2 · K^4
1 atm	$= 14.69595$ lbf/in^2 $= 760$ mmHg at 32°F
	$= 29.92$ inHg at 32°F = 2116.21 lbf/ft^2
	$= 1.01325 \times 10^{5}$ N/m^2

LIST OF SYMBOLS

a	Local velocity of sound
a	Attenuation coefficient (Chap. 8)
A	Area
A	Albedo (Chap. 8)
A_m	Fin profile area (Chap. 2)
c	Specific heat, usually kJ/kg · °C
C	Concentration (Chap. 11)
C_D	Drag coefficient, defined by Eq. (6-13)
C_f	Friction coefficient, defined by Eq. (5-52)
c_p	Specific heat at constant pressure, usually kJ/kg · °C
c_v	Specific heat at constant volume, usually kJ/kg · °C
d	Diameter
D	Depth or diameter
D	Diffusion coefficient (Chap. 11)
D_H	Hydraulic diameter, defined by Eq. (6-14)
e	Internal energy per unit mass, usually kJ/kg
E	Internal energy, usually kJ
E	Emissive power, usually W/m^2 (Chap. 8)
f	Friction factor
F	Force, usually N
F_{m-n} or F_{ij}	Radiation shape factor for radiation from surface i to surface j
g	Acceleration of gravity
g_c	Conversion factor, defined by Eq. (1-14)
G	Irradiation (Chap. 8)
$G = \frac{\dot{m}}{A}$	Mass velocity
h	Heat-transfer coefficient, usually W/m^2 · °C
$\bar{h}$	Average heat-transfer coefficient
h_{fg}	Enthalpy of vaporization, kJ/kg
h_r	Radiation heat-transfer coefficient (Chap. 8)
i	Enthalpy, usually kJ/kg
I	Intensity of radiation
I	Solar insolation (Chap. 8)
I_0	Solar insolation at outer edge of atmosphere
J	Radiosity (Chap. 8)
k	Thermal conductivity, usually W/m · °C

The science of thermodynamics deals with the amount of heat transfer as a system undergoes a process from one equilibrium state to another, and makes no reference to how long the process will take. But in engineering, we are often interested in the rate of heat transfer, which is the topic of the science of heat transfer.





Thus, it is important to know the major differences between Thermodynamics and Heat Transfer

Thermodynamics:

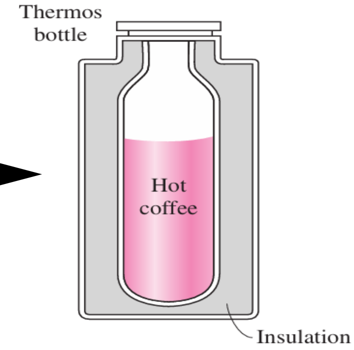
- Focuses on the amount of energy that transferred such as heat or work.
- Examines on the initial and final thermodynamics states of a thermal system.
- Does not consider how fast or by which mechanism the heat moves.
- Based on laws (e.g., First Law, Second Law).
- It’s more about equilibrium and energy conservation.

Heat Transfer:

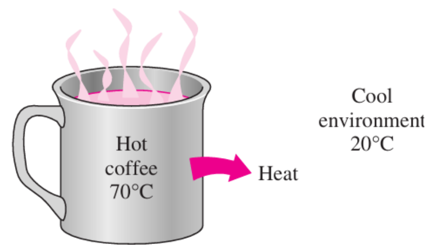
- Focuses on how heat moves from one place to another.
- Deals with mechanisms: such as Conduction, convection, radiation.
- Describes temperature distributions, heat flux, heat transfer rates.
- Involves solving differential equations
- Solutions to various heat transfer problems using numerical methods such as FDM, FEM, FVEM, etc.

Illustrative examples on Thermodynamics and Heat Transfer Analysis

We are normally interested in how long it takes for the hot coffee in a thermos to cool to a certain temperature, which cannot be determined from a thermodynamic analysis alone.



Heat flows in the direction of decreasing temperature.



Application Areas of Heat Transfer

- Heat transfer is commonly encountered in engineering systems and other aspects of life, and one does not need to go very far to see some application areas of heat transfer.
- In fact, one does not need to go anywhere. The human body is constantly rejecting heat to its surroundings, and human comfort is closely tied to the rate of this heat rejection. We try to control this heat trans fer rate by adjusting our clothing to the environmental conditions.