Chapter 6, Solution 1C.

In forced convection, the fluid is forced to flow over a surface or in a tube by external means such as a pump or a fan. In natural convection, any fluid motion is caused by natural means such as the buoyancy effect that manifests itself as the rise of the warmer fluid and the fall of the cooler fluid. The convection caused by winds is natural convection for the earth, but it is forced convection for bodies subjected to the winds since for the body it makes no difference whether the air motion is caused by a fan or by the winds.

Chapter 6, Solution 2C.

If the fluid is forced to flow over a surface, it is called external forced convection. If it is forced to flow in a tube, it is called internal forced convection. A heat transfer system can involve both internal and external convection simultaneously. Example: A pipe transporting a fluid in a windy area.

Chapter 6, Solution 3C.

The convection heat transfer coefficient will usually be higher in forced convection since heat transfer coefficient depends on the fluid velocity, and forced convection involves higher fluid velocities.

Chapter 6, Solution 4C.

The potato will normally cool faster by blowing warm air to it despite the smaller temperature difference in this case since the fluid motion caused by blowing enhances the heat transfer coefficient considerably.

Chapter 6, Solution 5C.

Nusselt number is the dimensionless convection heat transfer coefficient, and it represents the enhancement of heat transfer through a fluid layer as a result of convection relative to conduction across the same fluid layer. It is defined as $Nu = \frac{hL_c}{k}$ where $L_c$ is the characteristic length of the surface and $k$ is the thermal conductivity of the fluid.

Chapter 6, Solution 6C.

Heat transfer through a fluid is conduction in the absence of bulk fluid motion, and convection in the presence of it. The rate of heat transfer is higher in convection because of fluid motion. The value of the convection heat transfer coefficient depends on the fluid motion as well as the fluid properties. Thermal conductivity is a fluid property, and its value does not depend on the flow.
Chapter 6, Solution 11.

The expression for the heat transfer coefficient for air cooling of some fruits is given. The initial rate of heat transfer from an orange, the temperature gradient at the orange surface, and the value of the Nusselt number are to be determined.

**Assumptions** 1 Steady operating conditions exist. 2 Orange is spherical in shape. 3 Convection heat transfer coefficient is constant over the entire surface. 4 Properties of water is used for orange.

**Properties** The thermal conductivity of the orange is given to be \( k = 0.50 \, \text{W/m.}^\circ\text{C} \). The thermal conductivity and the kinematic viscosity of air at the film temperature of \((T_s + T_\infty)/2 = (15+5)/2 = 10^\circ\text{C}\) are (Table A-15)

\[
k = 0.02439 \, \text{W/m.}^\circ\text{C}, \quad \nu = 1.426 \times 10^{-5} \, \text{m}^2/\text{s}
\]

**Analysis**

(a) The Reynolds number, the heat transfer coefficient, and the initial rate of heat transfer from an orange are

\[
A_s = \pi D^2 = \pi (0.07 \, \text{m})^2 = 0.1539 \, \text{m}^2
\]

\[
\text{Re} = \frac{VD}{\nu} = \frac{(0.3 \, \text{m/s})(0.07 \, \text{m})}{1.426 \times 10^{-5} \, \text{m}^2/\text{s}} = 1473
\]

\[
h = \frac{5.05k_{\text{air}} \, \text{Re}^{1/3}}{D} = \frac{5.05(0.02439 \, \text{W/m.}^\circ\text{C})(1473)^{1/3}}{0.07 \, \text{m}} = 20.02 \, \text{W/m}^2.\circ\text{C}
\]

\[
\dot{Q} = hA_s(T_s - T_\infty) = (20.02 \, \text{W/m}^2.\circ\text{C})(0.01539 \, \text{m}^2)(15 - 5)^\circ\text{C} = 3.08 \, \text{W}
\]

(b) The temperature gradient at the orange surface is determined from

\[
\dot{q}_{\text{conv}} = \dot{q}_{\text{cond}} = -k \left( \frac{\partial T}{\partial r} \right)_{r=R} = h(T_s - T_\infty)
\]

\[
\frac{\partial T}{\partial r} \bigg|_{r=R} = -\frac{h(T_s - T_\infty)}{k} = -\frac{(20.02 \, \text{W/m}^2.\circ\text{C})(15-5)^\circ\text{C}}{0.50 \, \text{W/m.}^\circ\text{C}} = -400 \, \circ\text{C/m}
\]

(c) The Nusselt number is

\[
Nu = \frac{hD}{k} = \frac{(20.02 \, \text{W/m}^2.\circ\text{C})(0.07 \, \text{m})}{0.02439 \, \text{W/m.}^\circ\text{C}} = 57.5
\]

Chapter 6, Solution 12C.

Viscosity is a measure of the “stickiness” or “resistance to deformation” of a fluid. It is due to the internal frictional force that develops between different layers of fluids as they are forced to move relative to each other. Viscosity is caused by the cohesive forces between the molecules in liquids, and by the molecular collisions in gases. Liquids have higher dynamic viscosities than gases.

Chapter 6, Solution 13C.
The fluids whose shear stress is proportional to the velocity gradient are called *Newtonian fluids*. Most common fluids such as water, air, gasoline, and oil are Newtonian fluids.

**Chapter 6, Solution 14C.**

A fluid in direct contact with a solid surface sticks to the surface and there is no slip. This is known as the *no-slip condition*, and it is due to the viscosity of the fluid.

**Chapter 6, Solution 15C.**

The ball reaches the bottom of the container first in water due to lower viscosity of water compared to oil.

**Chapter 6, Solution 16C.**

(a) The dynamic viscosity of liquids decreases with temperature. (b) The dynamic viscosity of gases increases with temperature.

**Chapter 6, Solution 17C.**

The fluid viscosity is responsible for the development of the velocity boundary layer. For the idealized inviscid fluids (fluids with zero viscosity), there will be no velocity boundary layer.

**Chapter 6, Solution 18C.**

The Prandtl number \( \Pr = \frac{\nu}{\alpha} \) is a measure of the relative magnitudes of the diffusivity of momentum (and thus the development of the velocity boundary layer) and the diffusivity of heat (and thus the development of the thermal boundary layer). The \( \Pr \) is a fluid property, and thus its value is independent of the type of flow and flow geometry. The \( \Pr \) changes with temperature, but not pressure.

**Chapter 6, Solution 19C.**

A thermal boundary layer will not develop in flow over a surface if both the fluid and the surface are at the same temperature since there will be no heat transfer in that case.