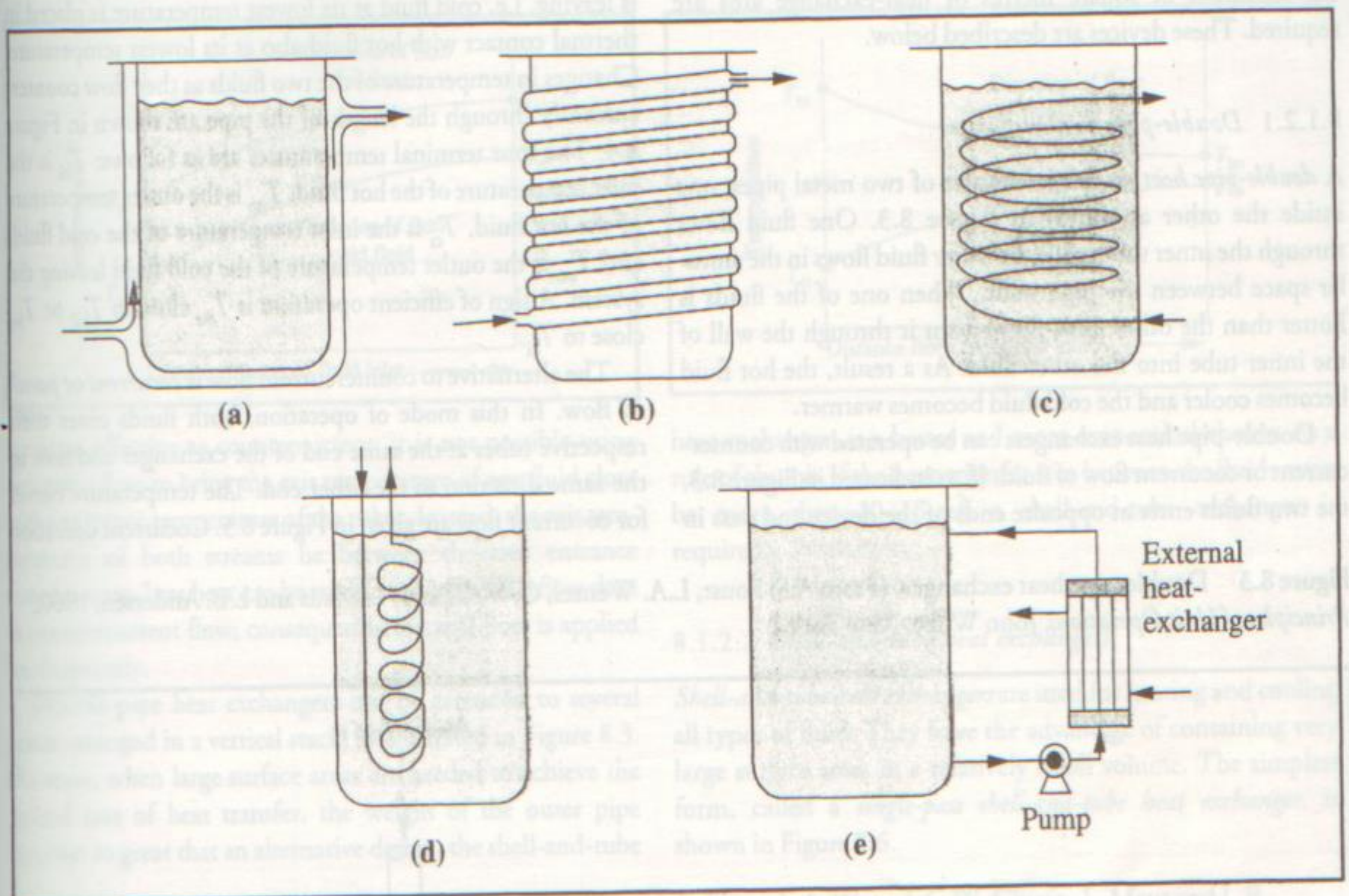
BT 208
Heat transfer in Bioprocessing

- Two applications of heat transfer are common in bioreactor operation.
  - 1. *in situ batch sterilization* of liquid medium…..(heating to 121°C, holding and cooling to fermentation temp)
  - 2. *Temperature control* during reactor operation…… Metabolic activity of cells generates a substantial amount of heat in fermentors; this heat must be removed to avoid temperature increases.
- …….So….design of HEAT EXCHANGERS………

- Modes of heat transfer
- Conduction: Steady state one dimensional heat flow – Fourier's law
- Convection: Natural and forced convection- Forced convection
- Heat transfer with phase change – types of condensation –
- Evaporation – types of evaporators
- Process design of heat exchangers
- Radiation
- **Reference Books:**
  - McCabe & Smith, Unit Operations of Chemical Engineering, 5th edn., 1993, McGraw Hill Inc.
  - *Transport processes & Unit operations by Geankoplis*
  - Pauline M. Doran. Bioprocess Engineering principles, Academic press.
  - Coulson and Richardson, Chemical Engineering, Vol. I
  - ***Class notesssssssssssssss***

Heat transfer configurations for bioreactors

Figure 8.1 Heat-transfer configurations for bioreactors: (a) jacketed vessel; (b) external coil; (c) internal helical coil; (d) internal baffle-type coil; (e) external heat exchanger.



- Heat transfer is a study of the exchange of thermal energy through a body or between bodies which occurs when there is a temperature difference.

- When two bodies are at different temperatures, thermal energy transfers from the one with higher temperature to the one with lower temperature.

- *Heat always transfers from hot to cold.*

Table 1. Units and Conversion Factors for Heat Measurements

	SI Units	English Units
Thermal Energy (Q)	1 J	9.4787×10^{-4} Btu
Heat Transfer Rate (q)	1 J/s or 1 W	3.4123 Btu/h
Heat Flux (q'')	1 W/m^2	0.3171 Btu/h ft^2

Three Modes of Heat Transfer

- There are three modes of heat transfer: conduction, convection, and radiation.

- Any energy exchange between bodies occurs through one of these modes or a combination of them.

- *Conduction* is the transfer of heat through solids or stationary fluids.
- *Convection* uses the movement of fluids to transfer heat.
- *Radiation* does not require a medium for transferring heat; this mode uses the electromagnetic radiation emitted by an object for exchanging heat.

Conduction

- Conduction is the transfer of heat through solids or stationery fluids.
- When you touch a hot object, the heat you feel is transferred through your skin by conduction.
- Two mechanisms explain how heat is transferred by conduction:
  - lattice vibration and
  - particle collision.
- Heat is conducted through stationery fluids primarily by molecular collisions.

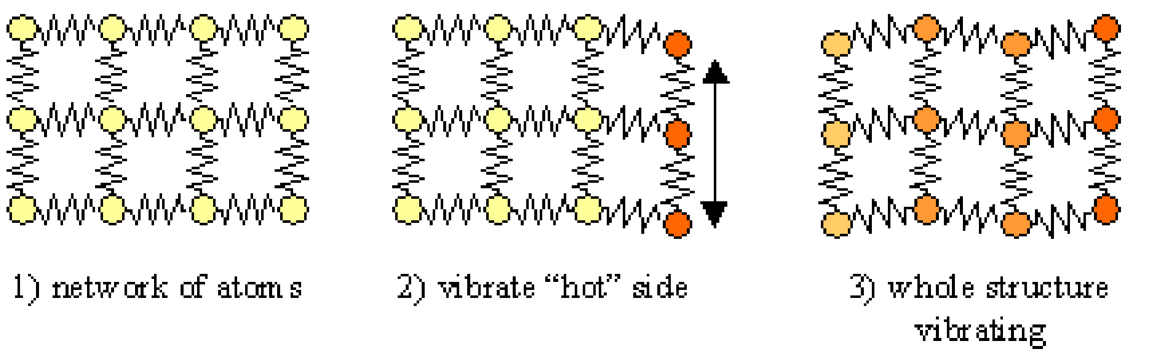


Figure 1.1 Conduction by lattice vibration

- Solids, especially metals, have free electrons, which are not bound to any particular atom and can freely move about the solid.
- The electrons in the hot side of the solid move faster than those on the cooler side. This scenario is shown in **Fig1.2**.

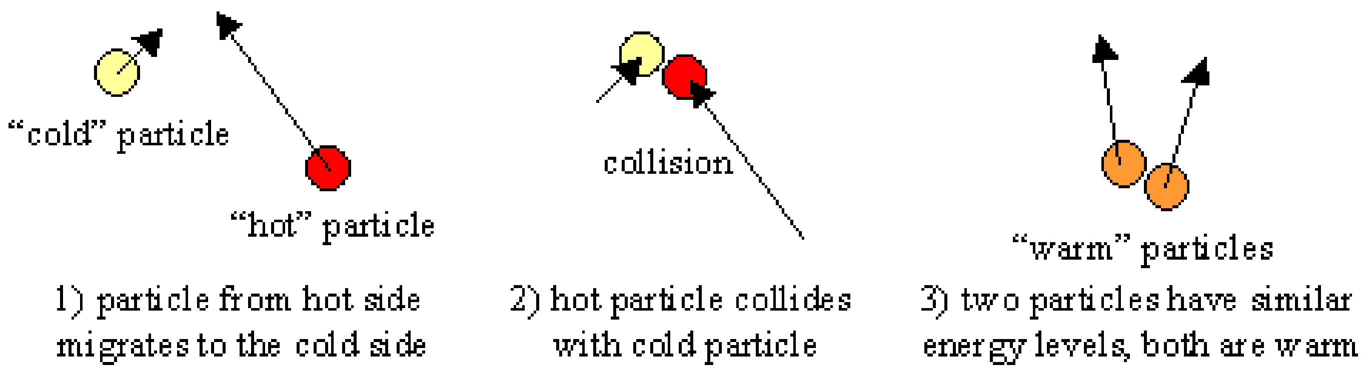


Figure 1.2 Conduction by particle collision

- As the electrons undergo a series of collisions, the faster electrons give off some of their energy to the slower electrons.

- Conduction through electron collision is more effective than through lattice vibration; <u>this is why metals generally are better heat conductors than ceramic materials, which do not have many free electrons.</u>

- *In fluids,* conduction occurs through collisions between freely moving molecules. The mechanism is identical to the electron collisions in metals.

- The effectiveness by which heat is transferred through a material is measured by the *thermal conductivity, k.*

- A good conductor, such as copper, has a high conductivity; a poor conductor, or an insulator, has a low conductivity.

- Thermal conductivity is measured in watts per meter per Kelvin *(W/m K).*

Convection

- Convection uses the ***motion*** of fluids to transfer heat.
- In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction.
- The presence of bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid.
- In a typical convective heat transfer, a hot surface heats the surrounding fluid, which is then carried away by fluid movement such as wind.
- The warm fluid is replaced by cooler fluid, which can draw more heat away from the surface.
- Since the heated fluid is constantly replaced by cooler fluid, the rate of heat transfer is enhanced.

Natural convection

- *Natural convection* (or free convection) refers to a case where the fluid movement is created by the warm fluid itself.
- The density of fluid decrease as it is heated; thus, hot fluids are lighter than cool fluids.
- Warm fluid surrounding a hot object rises, and is replaced by cooler fluid.
- The result is a circulation of air above the warm surface, as shown in **Figure 1.4**.

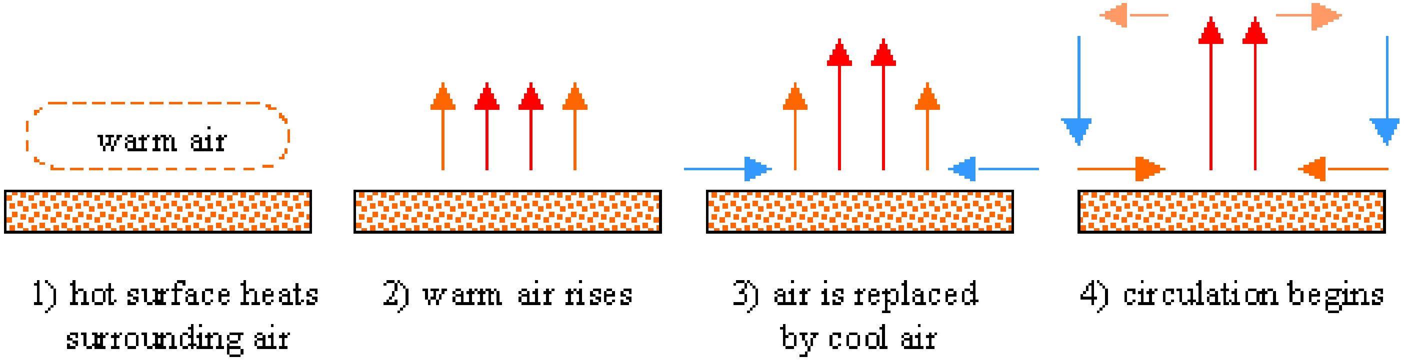


Figure 1.4 Natural convection

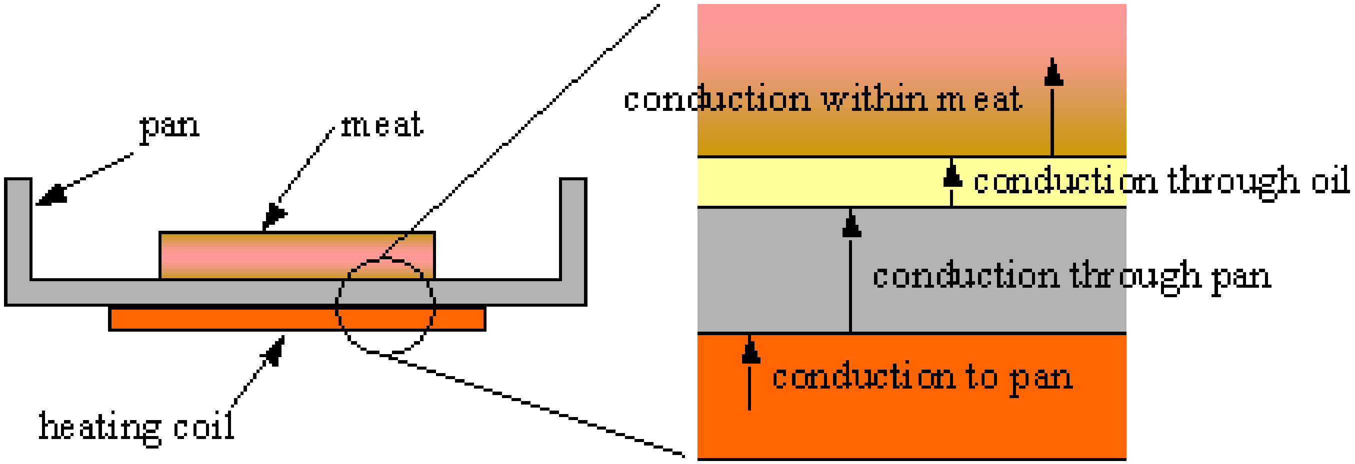
Forced convection

- *Forced convection* uses external means of producing fluid movement.
- *Forced convection is what makes a windy, winter day feel much colder than a calm day with same temperature.*
- The heat loss from your body is increased due to the constant replenishment of cold air by the wind.

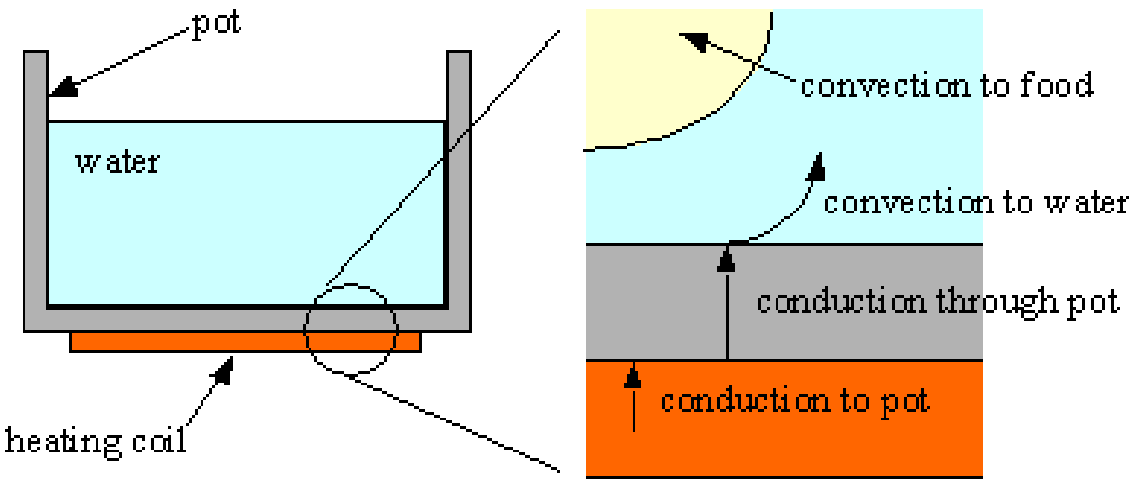
- Convection coefficient, *h (heat transfer coefficient)*, is the measure of how effectively a fluid transfers heat by convection.
- It is measured in W/m^2K, and is determined by factors such as the fluid density, viscosity, and velocity.

Radiation

- Radiative heat transfer does not require a medium to pass through; thus, it is the only form of heat transfer present in vacuum.
- It uses electromagnetic radiation (photons), which travels at the speed of light and is emitted by any matter with temperature above 0 degrees Kelvin (-273 °C).
- Radiative heat transfer occurs when the emitted radiation strikes another body and is absorbed.
- We all experience radiative heat transfer everyday; solar radiation, absorbed by our skin, is why we feel warmer in the sun than in the shade.



Dry heat cooking on the stovetop



Moist heat cooking