[2] Convection Heat Transfer.

It is well known that a hot plate of metal will cool faster when placed in front of a fan than when exposed to still air. We say that the heat is convected away, and we call the process ***convection heat transfer***.

Convection
- Natural
  eg:- [Hot plate exposed to fluid]
- Forced
  [External effect for pump, fin]
- mix
  Forced + Natural

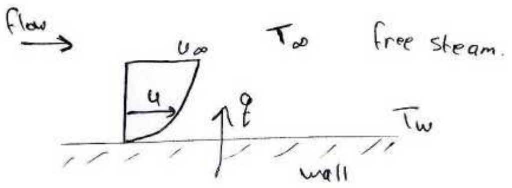
بشكل عام هذا الحمل يحدث بين سطح صلب مع fluid
- gas
- liquid.

* Newton cooling low.

* $q = hA(T_w - T_\infty)$

- q : Rate of H.T
- h : convection H.T coefficient. $(W/m^2.c)$ oR $(W/m^2.K)$
- A : H.T area
- T_w : wall temp
- T_∞ : Fluid temp.

* Fig 1-7 : convection H.T. from a plate.



* Note : h
- Free convection
  - gas : 2 - 25
  - liq : 50 - 1000
- Forced convection
  - gas : 25 - 250
  - liq : 100 - 20000

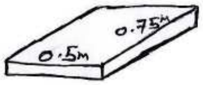
EXAMPLE 1-2

Air at 20°C blows over a hot plate 50 by 75 cm maintained at 250°C. The convection heat-transfer coefficient is 25 W/m^2 · °C. Calculate the heat transfer.

Soly :- Find q :- $A = 0.5 * 0.75$, $h = 25$, $T_w = 250°C$, $T_\infty = 20°C$

$$q = hA(T_w - T_\infty) \Rightarrow q = 25 * 0.5 * 0.75 (250 - 20)$$

$$\boxed{q = 2156.25 \text{ W}}$$



EXAMPLE 1-4

An electric current is passed through a wire 1 mm in diameter and 10 cm long. The wire is submerged in liquid water at atmospheric pressure, and the current is increased until the water boils. For this situation $h = 5000$ W/m^2 · °C, and the water temperature will be 100°C. How much electric power must be supplied to the wire to maintain the wire surface at 114°C?

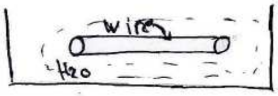
Soly :- Find q , $D = 1\text{mm}$, $L = 10\text{cm}$, $h = 5000 \frac{W}{m^2 . c°}$, $T_\infty = 100°c$
$T_w = 114°C$.

$$\Rightarrow q = hA(T_w - T_\infty)$$

$$- A = \pi dL = \pi * 0.001 * 0.1 = 3.142 * 10^{-4} \text{ m}^2$$

$$\Rightarrow q = 5000 * 3.142 * 10^{-4} * (114 - 100)$$

$$q = 21.994 \text{ W} \equiv$$ Electric power must be applied



* Convection in a channel

$$q = \dot{m}\,(i_e - i_i) = \dot{m}\,\Delta i$$

$$\Delta i = c_p \Delta T = c_p (T_e - T_i)$$

$i \rightarrow$ entholpy.

$\dot{m} \rightarrow$ fluid mass flow rate Kg/s

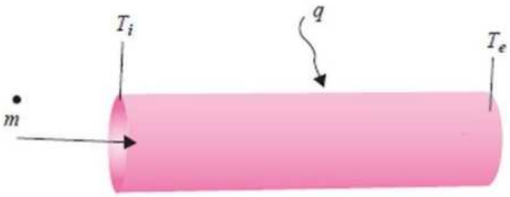


Figure 1-8 | Convection in a channel.

$$q = \dot{m}\, c_p (T_e - T_i) = hA (T_w - T_\infty)$$

c_p :- specific heat in J/kg.°C

* T_e, T_i, T_∞ : called bulk Temp.

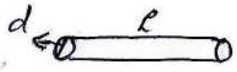
* $\dot{m} = \rho \, U_{mean} \, A_c$

$\rho \rightarrow$ density kg/m3
$U_{mean} \rightarrow$ velocity m/s
$A_c \rightarrow$ cross sectional area $\rightarrow$ for circular Tube $A_c = \frac{\pi}{4} d^2$

* A : Surface area for convection in this case is.

$q = hA(T_w - T_\infty)$

$\boxed{A = \pi d L}$ $L \rightarrow$ Length of tube.



P. 1-16

Water flows at the rate of 0.5 kg/s in a 2.5-cm-diameter tube having a length of 3 m. A constant heat flux is imposed at the tube wall so that the tube wall temperature is 40°C higher than the water temperature. Calculate the heat transfer and estimate the temperature rise in the water. The water is pressurized so that boiling cannot occur.

Sol : Find ① q ② $(T_e - T_i)$

$T_w - T_\infty = 40°C$ إنتبه

$h \rightarrow$ from Table 1-3. $\Longrightarrow h = 3500 \; W/m^2.K$

① $q = hA(T_w - T_\infty) = h\pi dL \, (T_w - T_\infty)$

$q = 3500 * \pi * 0.025 * 3 * 40 \Longrightarrow \boxed{q = 32.9867 \text{ KW}}$

② $q = \dot{m} \, C_p \, (T_e - T_i)$

given $C_{P_{water}} = 4186 \; J/kg.c$

$$T_e - T_i = \frac{q}{\dot{m} \, c_p} = \frac{32986.7}{0.5 * 4186} = \boxed{15.76 \, °C}$$

P. 1-23 A flat wall is exposed to an environmental temperature of 38°C. The wall is covered with a layer of insulation 2.5 cm thick whose thermal conductivity is 1.4 W/m · °C, and the temperature of the wall on the inside of the insulation is 315°C. The wall loses heat to the environment by convection. Compute the value of the convection heat-transfer coefficient that must be maintained on the outer surface of the insulation to ensure that the outer-surface temperature does not exceed 41°C.

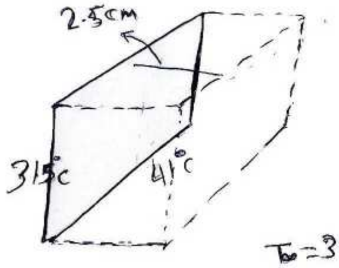
Soly :: Find h

$$\overset{\text{المكتسبة بالتوصيل}}{q_{\text{conduction}}} = \overset{\text{المفقودة بالحمل}}{q_{\text{convection}}}$$

$$-K \cancel{A} \frac{\Delta T}{\Delta x} = h \cancel{A} (T_w - T_\infty)$$

$$-1.4 * \frac{(41-315)}{0.025} = h \quad (41-38)$$

$$\boxed{h = 5114.66 \ W/m^2 . C^\circ}$$



$T_\infty = 38°c$
$K = 1.4 W/m.c$

P. 1-26 How does the free-convection heat transfer from a vertical plate compare with pure conduction through a vertical layer of air having a thickness of 2.5 cm and a temperature difference the same at $T_w - T_\infty$? Use information from Table 1-3.

Soly :: -1 Free convection From vertical plate

$$q = hA (T_w - T_\infty) = h A \Delta T$$

$\Rightarrow$ From Table 1-3

من الجدول $\left[\begin{array}{l} \text{free convection } \Delta T = 30°C \\ \text{vertical plate 0.3m high in air} \end{array} \right] \rightarrow h = 4.5 \ W/m^2 . C^\circ$

$$q = 4.5 * (0.3)^2 * 30 \Rightarrow \boxed{q = 12.15 \ W}$$

-2 conduction through avertical layer of air $\Delta x = 2.5$ cm

$$\Delta T \equiv (T_w - T_\infty) = 30°c$$

$\Rightarrow$ From table A-5

K نحول درجة الحرارة الى كلفن لايجاد
$T(K) = 273.15 + 30 = 303.15$ Kelvin.
$T(K) \Leftarrow K = 0.027 \ W/_{m.C^\circ}$

$$q = K A \frac{\Delta T}{\Delta x} = 0.027 * (0.3)^2 * \frac{30}{0.025}$$

$$\boxed{q = 2.916 \ W}$$

3 Radiation Heat transfer

- opposite to conduction and convection.
- Radiation may achieved in vacuum.
- It depends on electro magnetic waves.

* Thermal Ideal radiation.

Black Body :

$q = \sigma A T^4$ ⟹ Stefan - Boltzmann law

- q: rate of heat Transfer from a Black Body.
- σ: stefan - Boltzmann constant
  $\sigma = 5.67 * 10^{-8}$ $W/m^2.K^4$
- A: heat Transfer area.
- T: Absolute temp (Kelvin)

P. 1-20 Calculate the energy emitted by a blackbody at 1000°C.

Soly: $q = \sigma A T^4 \Rightarrow \frac{q}{A} = \sigma T^4 = 5.67 * 10^{-8} * (1000 + 273.15)^4$

$$\boxed{q/A = 1.4897 * 10^5 \ w/m^2}$$

P.1-21 If the radiant flux from the sun is 1350 W/m^2, what would be its equivalent blackbody temperature?

Soly: Find T? , $q/A = 54 * 10^6$ W/m^2

$$T = \sqrt[4]{\frac{q}{\sigma A}} \Rightarrow \boxed{T = 5555.23 \ K}$$

* Heat Exchange Between tow Black surfaces:

$$q = \sigma A \left(T_1^4 - T_2^4\right) \qquad T_1, T_2 \rightarrow \text{in Kelvin}$$

P. 1-13 Two very large parallel planes having surface conditions that very nearly approximate those of a blackbody are maintained at 1100 and 425°C, respectively. Calculate the heat transfer by radiation between the planes per unit time and per unit surface area.

Sol:

$T_1 = 1100\,^\circ C = 1373\ K$

$T_2 = 425\,^\circ C = 698\ K.$

Find q/A (W/m^2) . ?

$$\frac{q}{A} = \sigma \left(T_1^4 - T_2^4\right) \Rightarrow \boxed{\frac{q}{A} = 188\ KW/m^2}$$

---

* Radiation in an Enclosure.

Black Body مو

$$q = \sigma A \epsilon \left(T_1^4 - T_2^4\right)$$

$\epsilon \rightarrow$ Emissivity. $\qquad 0 < \epsilon < 1 \rightarrow$ from App. A.

P. 1-19 A small radiant heater has metal strips 6 mm wide with a total length of 3 m. The surface emissivity of the strips is 0.85. To what temperature must the strips be heated if they are to dissipate 2000 W of heat to a room at 25°C?

Sol: wide $= 0.006\,m$, length $= 3\,m$, $\epsilon = 0.85$, $q = 2000\,W$, $T_2 = 298\,K$

$$q = \sigma A \epsilon \left(T_1^4 - T_2^4\right) \Rightarrow 2000 = 5.67\times10^{-8} \times 0.006 \times 3 \times 0.85 \times \left(T_1^4 - 298^4\right)$$

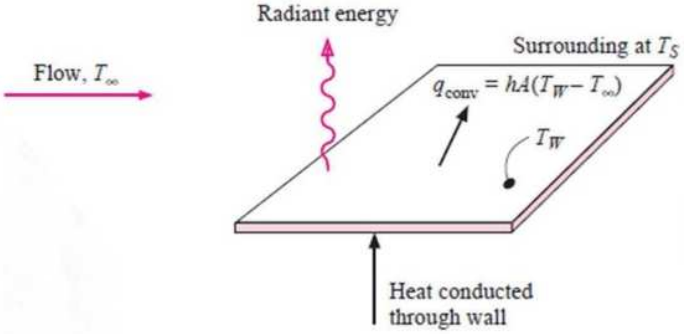
$T_1 = 1233.$[illegible]7 K

EXAMPLE 1.3

Assuming that the plate in Example 1-2 is made of carbon steel (1%) 2 cm thick and that 300 W is lost from the plate surface by radiation, calculate the inside plate temperature.

Find ΔT ?

Figure 1-9 | Combination of conduction, convection, and radiation heat transfer.



Soly :

$q_{rad} = 300$ W

$q_{conv} = 2156$ W

from Table A-2 ⇒ $K_{carbon} = 43$ W/m.°C

$$q_{cond} = q_{conv} + q_{rad}$$

$$-KA\frac{\Delta T}{\Delta x} = 2156 + 300$$

$$\Delta T = \frac{-2456 * 0.02}{0.5 * 0.75 * 43}$$

$$T_2 - T_1 = -3.05$$

$$T_1 = T_2 + 3.05 \Rightarrow T_1 = 250 + 3.05$$

$$\boxed{T_1 = 253.05\,°C}$$