Northern Technical University

Kirkuk Technical College

Refrigeration & Air Conditioning Technical Eng. Dept.

3rd Class

HEAT TRANSFER

PREPARED BY

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مؤسسة المعاهد الفنية الكلية التقنية - بغداد القسم :- هندسة التبريد والتكييف السنة الدراسية : الثالثة	النظام السنوي (٣٠ أسبوع)	عدد الساعات الاسبوعية	ن	ع	م	عدد الوحدات
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مفردات مادة	انتقال حرارة	الجزء النظري

الهدف من المادة :- تعريف الطالب الاسس العامة والرئيسية لانتقال الحرارة وتطبيقاتها العملية في مجال التكييف كايجاد الحراري لبناية وكذلك ايجاد الموصله الحرارية وسمك ونوع العازل المستخدم في انابيب ومنظومات التكييف والمبادلات الحرارية بانواعها واستخداتها في التبريد .

الاسبوع	مفردات المادة
١	مقدمة - طرق انتقال الحرارة .
٢	التوصيل في الحالة المستقرة ولبعد واحد خلال مقطع جدار ، اسطوانه .
٣	التوصيل في الحالة المستقرة ولبعد واحد خلال جدار .
٤	اسطوانه من عدة طبقات .
٥	معامل انتقال الحرارة الكلي .
٦ - ٧	السمك الحرج لعازل - مقاومة التلامس السطحي .
٨ - ٩	الزعانف .
١٠	التوصيل الانتقالي (السعات المجمعه) .
١١	التوصيل في الحالة المستقرة لبعدين .
١٢	انتقال الحرارة بالحمل (مقدمة) مراجعة لجريان الموائع .
١٣	درجة الحرارة الظاهرية والمجاميع اللابعدية .
١٤	معادلة انتقال الحرارة بالحمل القسري في الحالة المستقرة ولبعد واحد .
١٥	الحمل التحليلي لمعادلة انتقال الحرارة بالحمل القسري لنوعي الجريان الكتلي والطباقي .
١٦	طريقة الحمل اللابعدي .
١٧ - ١٨	العلاقات التجريبية لانتقال الحرارة بالحمل القسري لنوعي الجريان الداخلي والخارجي .
١٩	انتقال الحرارة بالحمل الحر .
٢٠	العلاقات التجريبية لانتقال الحرارة بالحمل الحر .
٢١	المبادلات الحرارية (مقدمة) انواع المبادلات الحرارية .
٢٢	معامل انتقال الحرارة الكلي ومعامل الاتساخ .
٢٣	المتوسط اللوغارتمي لفرق درجات الحرارة - فعالية المبادل الحراري .

القسم : هندسة التبريد والتكييف	انتقـــال الحـــرارة	الجـــزء النظـــري

الاسبـــوع	مفـــــردات المـــــادة
٢٤ ـ ٢٥	تحليل الاداء الحراري لمبادل حراري لانوع جريان ومتعاكس .
٢٦	الاشعاع الحراري (مقدمة) - مفاهيم اساسية
٢٧	خصائص الاشعاع - معامل الشكل .
٢٨	التبادل الاشعاعي الحراري بين سطحين لاجسام سوداء .
٢٩	التبادل الاشعاعي الحراري بين سطحين لاجسام رمادية .
٣٠	التبادل الاشعاعي الحراري بين حاجز الاشعاع .
	التجـــارب المختبريـــــة
	قياس معامل التوصيل الحراري للمواد الصلبة .
	التناظر الكهربائي لانتقال الحرارة بالتوصيل لبعدين .
	التناظر الهيدروليكي لانتقال الحرارة بالتوصيل في الحالة الغير مستقرة .
	انتقال الحرارة بالحمل خلال انبوب (حمل قسري) .
	انتقال الحرارة بالحمل القسري من سطح اسطوانه .
	انتقال الحرارة من سطح اسطوانه بالحمل الطبيعي .
	المبادل الحراري مزدوج الانبوب .

المصادر (References)

1. **Heat Transfer J.P. Holman**
2. **A Heat Transfer Textbook Hone H. Lienhard IVand Hone H. Lienhard V**
3. **Heat Transfer (A practical Approach) Yunus A. Cengel**

The First Week

Subject: Introduction to Heat Transfer Method

Introduction

Heat transfer is the science that seeks to predict that energy transfer that may take place between materials bodies are result of a temperature difference. Thermodynamics teaches that this energy transfer is defined as heat. The science of heat transfer seeks not merely to explain how heat energy may be transferred, but also to predict the rate at which the exchange will take place under certain specific conditions. The fact that heat transfer rate is the desired objective of an analysis points out difference between heat transfer and thermodynamics. Thermodynamics deals with systems in equilibrium stat to another; it may not be used to predict how fast a change will take place since the system is not in equilibrium during the process. Heat transfer supplements the first and second principles of thermodynamics by providing additional experimental rules which may be used to establish energy transfer rates. As in the science of thermodynamics, the experimental rules used as basis of the subject of heat transfer are rather simple and easily expanded to encompass a variety of practical situations.

Most readers will be familiar with the terms used to denote the three modes of heat transfer; conduction, convection, and radiation. In this chapter we seek to explain the mechanism of these modes qualitatively so that each may be considered in its proper perspective. Subsequent chapters treat the three types of heat transfer in detail.

1. Conduction Heat Transfer

When a temperature gradient exists in a body, experience has shown that there is an energy transfer from the high temperature region to how temperature region. We say that the energy is transferred by conduction and that the heat transfer rate per unit area is proportional to the normal temperature gradient:

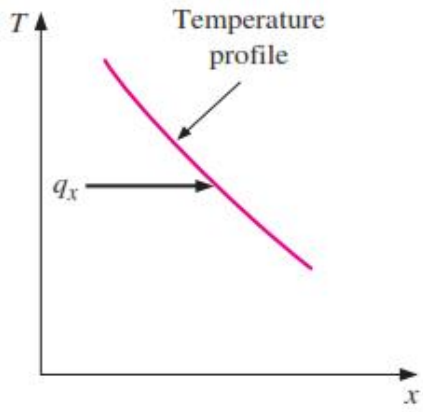
$$\frac{q}{A} \sim \frac{\partial T}{\partial x}$$

When the proportionality constant is inserted,

$$q = -kA\frac{\partial T}{\partial x} \qquad \text{……………..(1-1)}$$

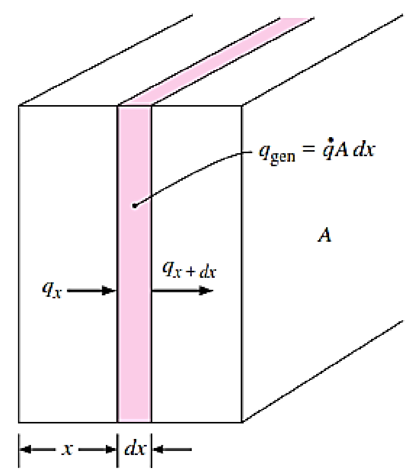
Where q is the heat transfer rate and $\frac{\partial T}{\partial x}$ is the temperature gradient in the direction of the heat flow. The positive constant ***k*** is called the *thermal conductivity* of the martial, and the minus sign is inserted to that the second principle of thermodynamics will be satisfied; i.e... Heat must flow downhill on the temperature scale, as indicated in the coordinate system of fig (1-1). Equation (1-1) is called Fourier Law of heat conduction after the French mathematical physicist Josef Fourier, who made very significant contribution to the analytical treatment of heat transfer. It is important to note that equation (1-1) is the defining equation for thermal conductivity and that *k* has the units of watt per meter per Celsius degree in a typical system of units in which the heat flow is expressed in watt.

Figure 1-1 | Sketch showing direction of heat flow.



Consider the one-dimensional system shown in fig (1-2). If the system is a steady state i.e.. If the temperature does not change with time, then the problem is a simple one, and we need only integrate eq.(1-1) and substitute the appropriate values to solve for and desired quantity. We consider general case where the temperature may be changing with time and heat source may be present within the body. For element of thickness ***dx*** the following energy balance may be made:

Figure 1-2 | Elemental volume for one-dimensional heat-conduction analysis.



Energy conducted in the left face + Heat generated within element = Change in internal energy + Energy conducted out right face

These energy quantities are given as follows:

Energy in left face = $q_x = -kA\frac{\partial T}{\partial x}$

Energy generated within element=$q^{\cdot} A dx$

Change in internal energy=$\rho c A \frac{\partial T}{\partial x} dx$

Energy out right face= $q_{x+dx} = -kA\frac{\partial T}{\partial x} = -A\left[k\frac{\partial T}{\partial x} + \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)dx\right]$

Where

$q^{\cdot}$: Energy generated per unit volume W/m^3

c: specific heat of material, J/kg.^{o}C

ρ: density, kg/m^3

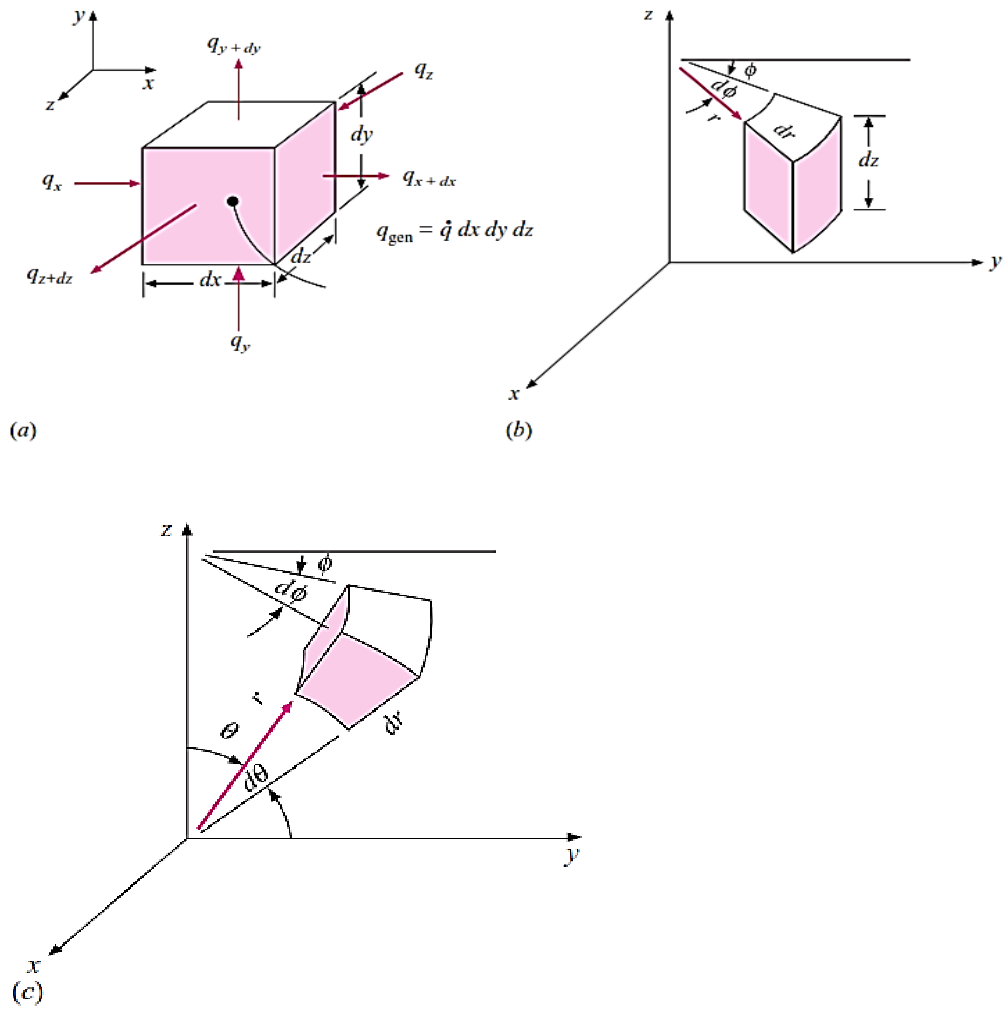
Combine the relation above gives

$$-kA\frac{\partial T}{\partial x} + q^{\cdot} A dx = \rho c A \frac{\partial T}{\partial \tau} - A\left[k\frac{\partial T}{\partial x} + \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)dx\right]$$

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + q^{\cdot} = \rho c \frac{\partial T}{\partial \tau} \qquad (1\text{-}2)$$

This is the one – dimensional heat conduction equation. To treat more than one dimensional heat flow, we need consider only the heat conducted in and out of a unit volume in all three coordinate directions, as shown in fig 1-3a. The energy balance yields

Figure 1-3 | Elemental volume for three-dimensional heat-conduction analysis: (*a*) cartesian coordinates; (*b*) cylindrical coordinates; (*c*) spherical coordinates.



$$q_x + q_y + q_z + q_{gen} = q_{x+dx} + q_{y+dy} + q_{z+dz} + \frac{dE}{d\tau}$$

And the energy quantities are given by

$$q_x = -kdydz\frac{\partial T}{\partial x}$$

$$q_{x+dx} = -\left[k\frac{\partial T}{\partial x} + \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)dx\right]dydz$$

$$q_y = -kdxdz\frac{\partial T}{\partial y}$$

$$q_{y+dy} = -\left[k\frac{\partial T}{\partial y} + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)dy\right]dxdz$$

$$q_z = -kdydx\frac{\partial T}{\partial z}$$

$$q_{z+dz} = -\left[k\frac{\partial T}{\partial z} + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)dz\right]dydx$$

$$q_{gen} = \dot{q}\,dxdydz$$

$$\frac{dE}{d\tau} = \rho c dxdydz\frac{\partial T}{\partial \tau}$$

So that the general three-dimensional heat conduction equation is

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + \dot{q} = \rho c\frac{\partial T}{\partial \tau} \qquad \text{(1-3)}$$

For constant thermal conductivity equation (1-3) is written

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{\dot{q}}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau} \qquad \text{(1-3a)}$$

Where the quantity $\alpha = {}^{k}/_{\rho c}$ is called the ***thermal diffusivity*** of the material.

Equation (1-3a) may be transformed into either cylindrical or spherical coordinates by standards calculus techniques. The results are as follows.

Cylindrical coordinates:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \emptyset^2} + \frac{\dot{q}}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau} \qquad \text{(1-3b)}$$

Spherical coordinates:

$$\frac{1}{r}\frac{\partial^2}{\partial r^2}(rT)+\frac{1}{\mathrm{r}^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial T}{\partial\theta}\right)+\frac{1}{r^2 sin^2\theta}\frac{\partial^2 T}{\partial\emptyset^2}+\frac{q^{\cdot}}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial\tau} \qquad (1\text{-}3c)$$

Steady state one dimensional heat flow (no heat generated)

$$\frac{\boldsymbol{dT}}{\boldsymbol{dx^2}}=0 \qquad (1\text{-}4)$$

Note that this equation is the same as equation (1-1) when q=constant

Steady state one dimensional heat flow in cylindrical coordinates (no heat generation):

$$\frac{\mathrm{d}^2\mathrm{T}}{\mathrm{dr}^2}+\frac{1}{\mathrm{r}}\frac{\mathrm{dT}}{\mathrm{dr}}=0 \qquad (1\text{-}5)$$

Steady state one dimensional heat flow with heat source

$$\frac{d^2T}{dx^2}+\frac{q^{\cdot}}{k}=0 \qquad (1\text{-}6)$$

Two dimensional steady state conduction without heat sources

$$\frac{\partial^2T}{\partial x^2}+\frac{\partial^2T}{\partial y^2}=0 \qquad (1\text{-}7)$$

1-2 Thermal conductivity

Equation (1-1) is defining equation for thermal conductivity. One the base of this definition, experimental measurement may be made to determine the thermal conductivity of different materials. The mechanism of thermal conduction in a gas is a simple one we identify the kinetic energy of a molecular with its temperature; thus, in a high- temperature region, the molecular have higher velocities than in same lower temperature region. The molecules are in continuous random motion, colliding with another and exchanging energy and momentum. The molecules have this random motion whether or not a temperature gradient exists in the gas. Table (1-1) lists typical values of thermal conductivities for several materials to indicate the relative orders of magnitude to be expected in practices. Thermal conductivities of typical gases are shown in figure (1-4). For most gases at moderate pressures the thermal conductivity is a function of temperature alone. The physical mechanism of thermal energy conduction in liquid is qualitatively the same as in gases. However, the situation is considerably more complex the molecules are more closely spaced and molecular force exerts a strong influence on the energy exchange in the collision process. Thermal conductivities of some typical liquids are shown in fig (1-5). We noted that thermal conductivity has the units of (w/m.°C), and in the English system of units is (Btu/h.ft.°F).

Table 1-1 | Thermal conductivity of various materials at 0°C.

Material	Thermal conductivity k W/m · °C	Thermal conductivity k Btu/h · ft · °F
Metals:		
Silver (pure)	410	237
Copper (pure)	385	223
Aluminum (pure)	202	117
Nickel (pure)	93	54
Iron (pure)	73	42
Carbon steel, 1% C	43	25
Lead (pure)	35	20.3
Chrome-nickel steel (18% Cr, 8% Ni)	16.3	9.4
Nonmetallic solids:		
Diamond	2300	1329
Quartz, parallel to axis	41.6	24
Magnesite	4.15	2.4
Marble	2.08–2.94	1.2–1.7
Sandstone	1.83	1.06
Glass, window	0.78	0.45
Maple or oak	0.17	0.096
Hard rubber	0.15	0.087
Polyvinyl chloride	0.09	0.052
Styrofoam	0.033	0.019
Sawdust	0.059	0.034
Glass wool	0.038	0.022
Ice	2.22	1.28
Liquids:		
Mercury	8.21	4.74
Water	0.556	0.327
Ammonia	0.540	0.312
Lubricating oil, SAE 50	0.147	0.085
Freon 12, CCl_2F_2	0.073	0.042
Gases:		
Hydrogen	0.175	0.101
Helium	0.141	0.081
Air	0.024	0.0139
Water vapor (saturated)	0.0206	0.0119
Carbon dioxide	0.0146	0.00844

Figure 1-4 | Thermal conductivities of some typical gases [1 W/m · °C = 0.5779 Btu/h · ft · °F].

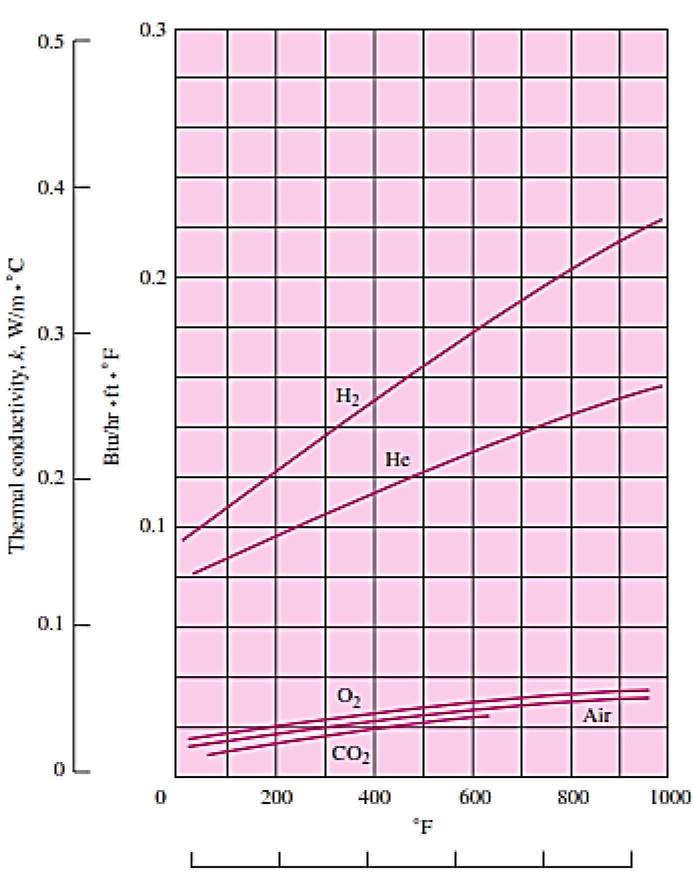


Figure 1-5 | Thermal conductivities of some typical liquids.

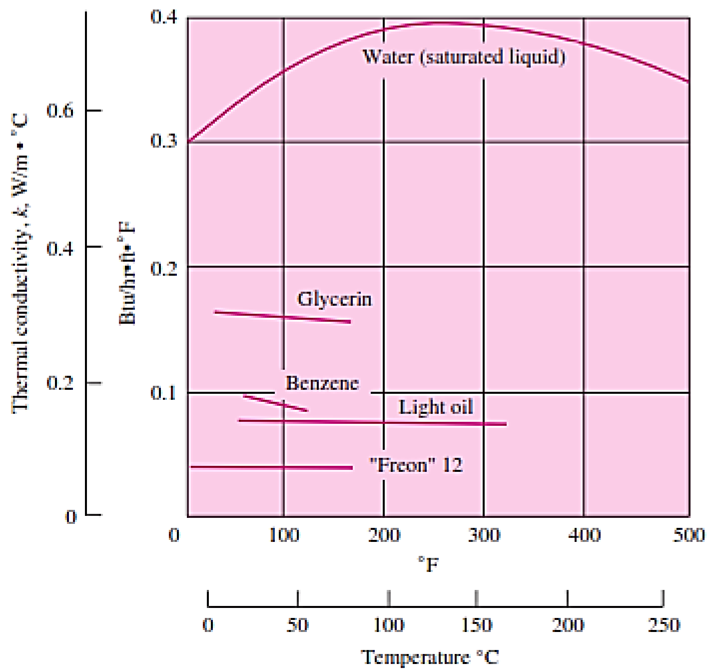


Table 1-2 | Effective thermal conductivities of cryogenic insulating materials for use in range 15°C to −195°C. Density range 30 to 80 kg/m^3.

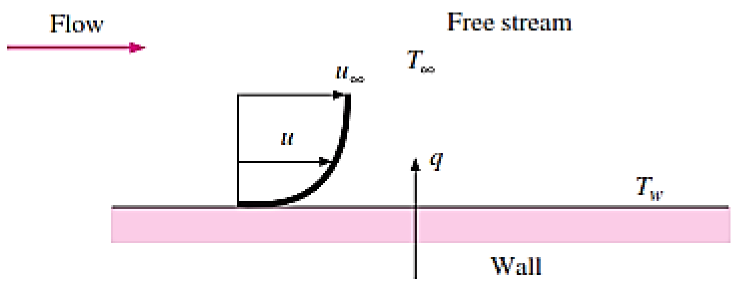
Type of insulation	Effective k, mW/m · °C
1. Foams, powders, and fibers, unevacuated	7–36
2. Powders, evacuated	0.9–6
3. Glass fibers, evacuated	0.6–3
4. Opacified powders, evacuated	0.3–1
5. Multilayer insulations, evacuated	0.015–0.06

1-3 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 convicted away, and we call the process *convection heat transfer*. The term convection provides the reader with an intuitive notation concerning the heat- transfer process; however, this intuitive notation must be expanded to enable one to arrive at anything like an adequate analytical treatment of the problem. For example, we know that the velocity at which the air blows over the hot plate obviously influences the heat transfer rate. But does influence the cooling in a linear way; i.e.. if the velocity is doubled, will the heat transfer

rate double? We should suspect that the heat transfer rate might be different if we cooled the plate with water instead of air.

Figure 1-7 | Convection heat transfer from a plate.



Consider the heated plate shown in fig (1-7). The temperature of the plate is T_w , and the temperature of the fluid is T_∞. the velocity of the flow will appear as shown, being reduced to zero at the plate as a result of viscose action. Since the velocity of the fluid layer at the wall be zero, the heat must be transferred only by conduction at that point. Thus we might compute the heat transfer, using equation (1-1), with the thermal conductivity of the fluid and the fluid temperature gradient at the wall. Thus the temperature gradient at the wall depends on the flow field, and we must develop in our later analysis an expression relating the two quantities. Nevertheless, it must be remembered that the typical mechanism of heat transfer at the wall is a conduction process.

To express the overall effect of convection, we use Newton's law of cooling:

$$q = hA(T_w - T_\infty) \qquad (1\text{-}8)$$

Here the heat transfer rate is related to overall temperature difference between the wall and fluid and the surface area *A*. the quantity *h* is called the *convection heat transfer coefficient*, and Equation (1-8) is the defining equation. If a heated plate were exposed to ambient room air without an external source of motion, a movement of the air would be experience as a result of density gradient near the plate. We called this *natural or free* convection as opposed to *force* convection, which is experienced in the case of the fan blowing air over a plate, boiling and condensation phenomena are also grouped under the general subject of convection heat transfer. The approximate ranges of convection heat transfer coefficient are indicated in table (1-3).

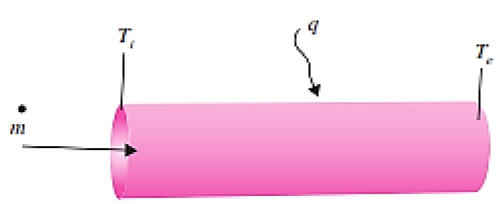
Table 1-3 | Approximate values of convection heat-transfer coefficients.

Mode	h W/m^2 · °C	h Btu/h · ft^2 · °F
Across 2.5-cm air gap evacuated to a pressure of 10^{-6} atm and subjected to $\Delta T = 100°C - 30°C$	0.087	0.015
Free convection, $\Delta T = 30°C$		
Vertical plate 0.3 m [1 ft] high in air	4.5	0.79
Horizontal cylinder, 5-cm diameter, in air	6.5	1.14
Horizontal cylinder, 2-cm diameter, in water	890	157
Heat transfer across 1.5-cm vertical air gap with $\Delta T = 60°C$	2.64	0.46
Fine wire in air, $d = 0.02$ mm, $\Delta T = 55°C$	490	86
Forced convection		
Airflow at 2 m/s over 0.2-m square plate	12	2.1
Airflow at 35 m/s over 0.75-m square plate	75	13.2
Airflow at Mach number = 3, $p = 1/20$ atm, $T_\infty = -40°C$, across 0.2-m square plate	56	9.9
Air at 2 atm flowing in 2.5-cm-diameter tube at 10 m/s	65	11.4
Water at 0.5 kg/s flowing in 2.5-cm-diameter tube	3500	616
Airflow *across* 5-cm-diameter cylinder with velocity of 50 m/s	180	32
Liquid bismuth at 4.5 kg/s and 420°C in 5.0-cm-diameter tube	3410	600
Airflow at 50 m/s across fine wire, $d = 0.04$ mm	3850	678
Boiling water		
In a pool or container	2500–35,000	440–6200
Flowing in a tube	5000–100,000	880–17,600
Condensation of water vapor, 1 atm		
Vertical surfaces	4000–11,300	700–2000
Outside horizontal tubes	9500–25,000	1700–4400
Dropwise condensation	170,000–290,000	30,000–50,000

Convection Energy Balance on a Flow Channel

The energy transfer expressed by equation (1-8) is used for evaluating the convection loss for flow over an external surface. Of equal importance is the convection gain or loss resulting from a fluid flowing inside a channel or tube as shown in fig(1-8). In this case the heated wall at T_w loses heat to the cooler fluid which consequently rises in temperature as flows from inlet condition at T_i to exit condition T_e. Using the symbol *i* to designate enthalpy (to avoid confusion with *h*, the convection coefficient), the energy balance on the fluid is

Figure 1-8 | Convection in a channel.



$$q^{\cdot} = m^{\cdot}(i_e - i_i)$$

Where $m^{\cdot}$ is the fluid mass flow rate. For many signal phase liquids and gases operating over reasonable temperature range $\Delta i = c_p \Delta T$

$$q = m^{\cdot} c_p (T_e - T_i)$$

This may be equated to a convection relation like equation (1-8)

$$q = m^{\cdot} c_p (T_e - T_i) = hA(T_{w,avg} - T_{fluidavg}) \ldots\ldots \quad . \text{(1-8a)}$$

1-4 Radiation Heat Transfer

In contrast to mechanisms of conduction and convection, where energy transfer through a material medium is involved, heat may also be transferred through regions where a perfect vacuum exits. The mechanism in this case is electromagnetic radiation which is propagated as a result of temperature difference; this is called *thermal radiation.*

Thermodynamic considerations show that an ideal thermal radiator, or *black body,* will emit energy at a rate proportional to the fourth power of absolute temperature of the body and direct proportional to its surface area. Thus

$$q_{emitted} = \sigma A T^4 \qquad \text{(1-9)}$$

Where σ is proportionality constant and is called the Stefan-Boltzmann constant with the value of 5.669×10^{-8} W/m^2.^{o}K. equation (1-9)is called the Stefan-Boltzmann Law of thermal radiation, and is applies only on black bodies. It is important to note that this equation is valid only for thermal radiation; other types of electromagnetic radiation may not be treated so simply. Equation (1-9) governs only radiation *emitted* by blackbody. The net radiant exchange between two surfaces will be proportional to the difference in absolute temperature to the fourth power, i.e..,

$$\frac{q_{netexchange}}{A} \propto \sigma(T_1^4 - T_2^4) \qquad \text{(1-10)}$$

$$q = F_c F_G \sigma A (T_1^4 - T_2^4) \qquad \text{(1-11)}$$

Where F_c is an emissivity function and F_G is a geometric (view factor) function

Radiation in an Enclosure

A simple radiation problem is encountered when we have a heat transfer surface at temperature T_1 completely enclosed by a much large surface maintained at T_2. The net radiant heat exchange in this case can e calculated with

$$q = \epsilon_1 \sigma A_1 (T_1^4 - T_2^4) \qquad (1\text{-}12)$$

Dimensions and units

In this section we outline the systems of units that are used throughout the book. One must be careful not to confuse the meaning of the *units* and *dimensions*. A dimension is a physical variable used to specify the behavior of a particular system. For example the length of the rod is a dimension of the rod. In like manner, the temperature of a gas may be considered one of the thermodynamic dimensions of the gas. In our development of heat transfer we use the dimensions:

L= length (m- meter)

M= mass (kg-kilogram)

F= force (N-Newton)

τ= time (sec- second)

T= temperature (ºK, ºC)

Temperature conversions are performed with familiar formulas

ºF= 9/5 ºC+32 ºR= ºF+459.69

ºK= ºC+273.16 ºR=9/5 ºK

Some conversions factors for the various units of work and energy are

1 Btu=778.1 Ib_f.ft 1 Btu= 1055 J

1 Kcal= 4182 J 1 Ib_f.ft= 1.356 J

1 Btu= 252 cal

Examples

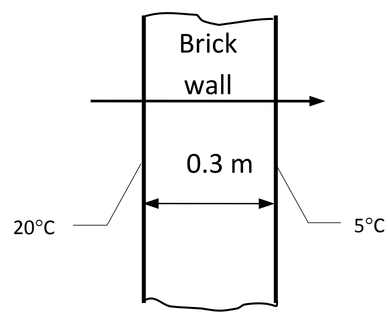
1-1 The inner and outer surfaces of a brick wall are maintained at (20 and 5°C). The rate of heat transfer through the wall is to be determined.

Assumptions **1** steady operating conditions exist since the surface temperatures of the wall remain constant at the specified values. **2** Thermal properties of the wall are constant.

Properties The thermal conductivity of the wall is given to be k = 0.69 W/m·°C.

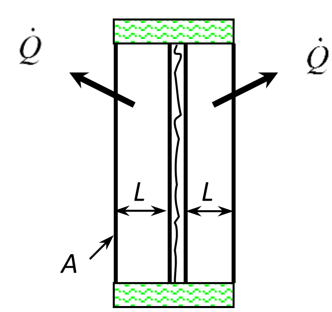
Analysis Under steady conditions, the rate of heat transfer through the wall is

$$\dot{Q}_{cond} = kA\frac{\Delta T}{L} = (0.69\text{W/m}\cdot°\text{C})(5\times 6\text{m}^2)\frac{(20-5)°\text{C}}{0.3\text{m}} = \mathbf{1035W}$$



1-2 The thermal conductivity of a material is to be determined by ensuring one-dimensional heat conduction, and by measuring temperatures when steady operating conditions are reached.

Assumptions 1 steady operating condition exists since the temperature readings do not change with time. **2** Heat losses through the lateral surfaces of the apparatus are negligible since those surfaces are well-insulated, and thus the entire heat generated by the heater is conducted through the samples. **3** The apparatus possesses thermal symmetry.



Analysis For each sample we have

$$\dot{Q} = 28/2 = 14 \text{ W}$$
$$A = (0.1 \text{ m})(0.1 \text{ m}) = 0.01 \text{ m}^2$$
$$\Delta T = 82 - 74 = 8°\text{C}$$

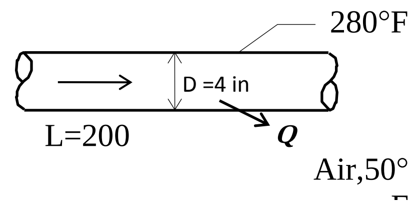
Then the thermal conductivity of the material becomes

$$\dot{Q} = kA\frac{\Delta T}{L} \longrightarrow k = \frac{\dot{Q}L}{A\Delta T} = \frac{(14 \text{ W})(0.005 \text{ m})}{(0.01 \text{ m}^2)(8°\text{C})} = \mathbf{0.875 \text{ W/m.°C}}$$

1-3 A 200-ft long section of a steam pipe passes through an open space at a specified temperature. The rate of heat loss from the steam pipe and the annual cost of this energy lost are to be determined.

Assumptions **1** steady operating condition exists. **2** Heat transfer by radiation is disregarded. **3** The convection heat transfer coefficient is constant and uniform over the surface.

Analysis (*a*) The rate of heat loss from the steam pipe is



$$A_s = \pi DL = \pi(4/12 \text{ ft})(200 \text{ ft}) = 209.4 \text{ ft}^2$$

$$\dot{Q}_{\text{pipe}} = hA_s(T_s - T_{air}) = (6 \text{ Btu/h.ft}^2.°\text{F})(209.4 \text{ ft}^2)(280-50)°\text{F}$$
$$= \mathbf{289{,}000 \text{ Btu/h}}$$

(*b*) The amount of heat loss per year is

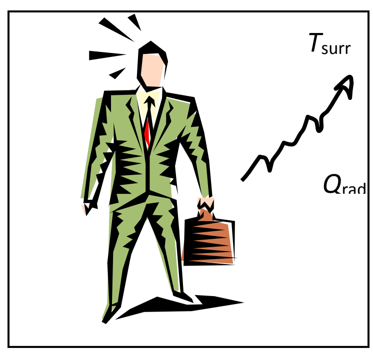
The amount of gas consumption per year in the furnace that has an efficiency of 86% is

$$\text{Annual Energy Loss} = \frac{2.532\times10^9 \text{ Btu/yr}}{0.86}\left(\frac{1 \text{ therm}}{100{,}000 \text{ Btu}}\right) = 29{,}438 \text{ therms/yr}$$

Then the annual cost of the energy lost becomes

1-4 The rate of radiation heat transfer between a person and the surrounding surfaces at specified temperatures is to be determined in summer and in winter.

Assumptions **1** steady operating condition exists. **2** Heat transfer by convection is not considered. **3** The person is completely surrounded by the interior surfaces of the room. **4** The surrounding surfaces are at a uniform temperature.



Properties The emissivity of a person is given to be ε = 0.95

Analysis Noting that the person is completely enclosed by the surrounding surfaces, the net rates of radiation heat transfer from the body to the surrounding walls, ceiling, and the floor in both cases are:

(*a*) Summer: T_{surr} = 23+273=296

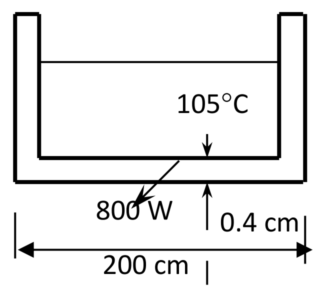
$$\dot{Q}_{rad} = \varepsilon\sigma A_s (T_s^4 - T_{surr}^4)$$
$$= (0.95)(5.67\times10^{-8}\ \text{W/m}^2.\text{K}^4)(1.6\ \text{m}^2)[(32+273)^4 - (296\ \text{K})^4]\text{K}^4$$
$$= \mathbf{84.2\ W}$$

(*b*) Winter: T_{surr} = 12+273= 285 K

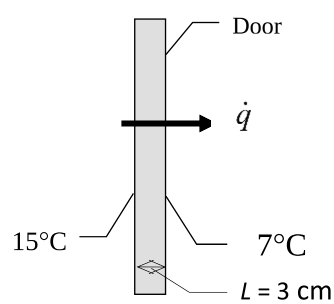
$$\dot{Q}_{rad} = \varepsilon\sigma A_s (T_s^4 - T_{surr}^4)$$
$$= (0.95)(5.67\times10^{-8}\ \text{W/m}^2.\text{K}^4)(1.6\ \text{m}^2)[(32+273)^4 - (285\ \text{K})^4]\text{K}^4$$
$$= \mathbf{177.2\ W}$$

PROBLEMS

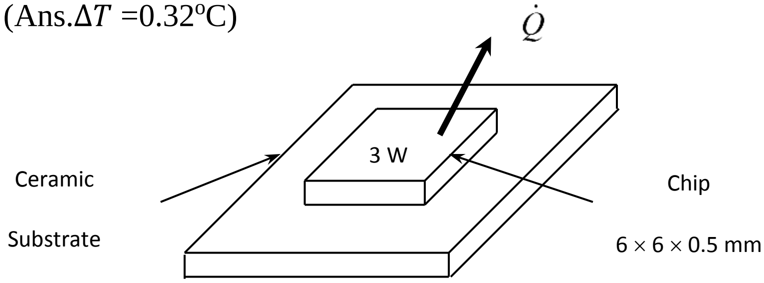
1-1 Heat is transferred steadily to boiling water in the pan through its bottom. The inner surface of the bottom of the pan is given. The temperature of the outer surface is to be determined. (Ans. T2 = 105.43 ^{o}C)



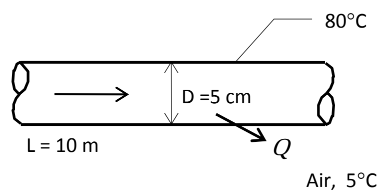
1-2 The thermal conductivity of a refrigerator door is to be determined by measuring the surface temperatures and heat flux when steady operating conditions are reached. (Ans. Q=0.09375 W)



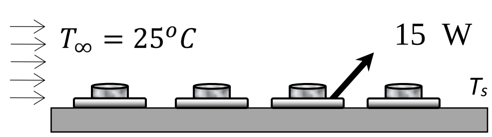
1-3 The heat generated in the circuitry on the surface of a 3-W silicon chip is conducted to the ceramic substrate. The temperature difference across the chip in steady operation is to be determined. (Ans.ΔT =0.32°C)



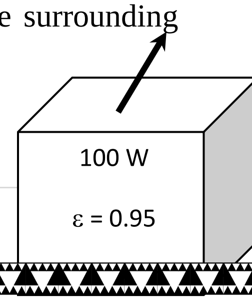
1-4 A hot water pipe at 80°C is losing heat to the surrounding air at 5°C by natural convection with a heat transfer coefficient of 25 W/ m^2.°C. The rate of heat loss from the pipe by convection is to be determined.(Ans.Q=2945W)



1-5 Four power transistors are mounted on a thin vertical square aluminum plate (22 cm) that is cooled by a fan. The temperature of the aluminum plate is to be determined, if the coefficient of heat transfer is 25 W/m^2.°C . (Ans. T_s=74.6°)



1-6 A sealed electronic box of (0.4*0.4*0.2) m. dissipating a total of 100 W of power is placed in a vacuum chamber. If this box is to be cooled by radiation alone and the outer surface temperature of the box is not to exceed 55°C, the temperature the surrounding surfaces must be kept is to be determined. (Ans $T_\infty = 23.3^\circ C$)



1-7 The backside of the thin metal plate is insulated and the front side is exposed to solar radiation. The surface temperature of the plate is to be determined when it stabilizes. (Ans T_s=26.3^{o}C)