Pearson BTEC Levels 4 Higher Nationals in Engineering (RQF)

Unit 30: Operations and Plant Management

Unit Workbook 4

in a series of 4 for this unit

Learning Outcome 4

Heat Transfer

Contents

GUIDANCE

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures;

Purpose — Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.

Theory — Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.

Example — The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself. Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.

Question — Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.

Challenge — You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.

Video — Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

Due to the presence of a viscous boundary layer close to the wall, shown by Fig. 3.2, the flow velocity at the wall is zero. This means that heat is transferred through conduction at the surface of the solid. The role of convection is to make the thermal boundary layer thin (its thickness is related to thickness of the velocity boundary layer). This leads to large temperature gradients and higher overall heat transfer rates.

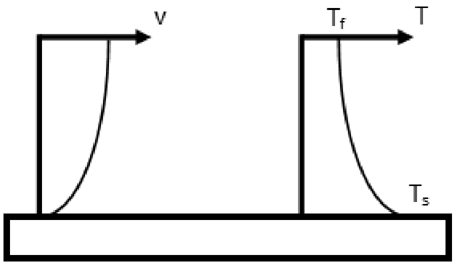


Fig. 3.2: Velocity and temperature change with convective heat transfer

In engineering, the rate of heat transfer is given as Eq. 3.2, where $h\ [W \cdot m^{-2} \cdot K^{-1}]$ is the convective heat transfer coefficient, T_f is the average temperature of the fluid and T_s is the temperature of the surface of the solid.

$$\dot{Q} = hA\left(T_s - T_f\right) \qquad \text{(Eq. 3.2)}$$

To evaluate how much more effective convection is than conduction of a certain length L, the dimensionless Nusselt number (Nu) is defined using Eq. 3.3

$$\frac{\dot{Q}_{conv}}{\dot{Q}_{cond}} = \frac{UL}{k} = Nu \qquad \text{(Eq. 3.3)}$$

3.1.3 Radiation

Theory

Radiation is the weakest of the three forms of heat transfer, and in most heat transfer simulations is ignored. The only time radiation is realistically considered is when there is no convection or conduction possible (in space). There are two important aspects of radiative heat transfer: emission, and absorption of the radiation.

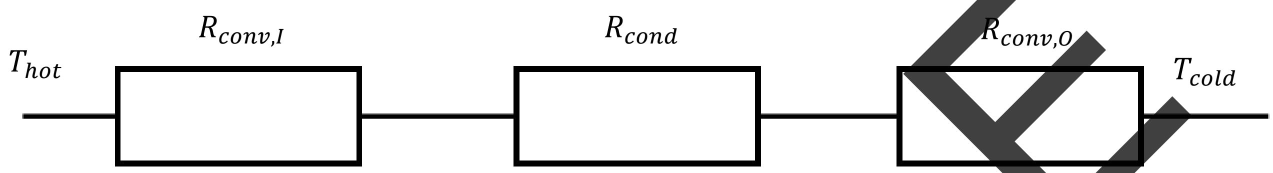
Black bodies: A black body is an ideal material which absorbs all radiation at all wavelengths, nothing is reflected off it. A black body is also a perfect emitter of radiation, and it emits radiation uniformly in all direction, so it is described as a diffuse emitter. If the body itself did not emit radiation, it would appear black.

brick is 100 mm thick. The thermal conductivity of the brick is 0.6 $Wm^{-1}K^{-1}$, and the coefficient of the air inside and outside the room is 5 $Wm^{-2}K^{-1}$ and 10 $Wm^{-2}K^{-1}$ respectively. Calculate:

a. The total heat loss of the environment
b. The temperature on the outside surface of the brick.

Answer:

The first thing we need to do is create the resistance circuit through the wall. There is the convection of the air inside the room $R_{conv,I}$, then there is the conduction through the brick R_{cond}, and finally the convection on the outside of the wall $R_{conv,O}$. The resistance map looks like the one below.



The total resistance for the system is:

$$\boldsymbol{R} = R_{conv,O} + R_{cond} + R_{conv,O} = \frac{1}{h_I A} + \frac{L}{k_B A} + \frac{1}{h_O A} = \frac{1}{5(3 \cdot 2)} + \frac{0.1}{0.6(3 \cdot 2)} + \frac{1}{10(3 \cdot 2)} = \mathbf{0.0777\ W.K^{-1}}$$

The overall heat transfer is therefore:

$$\dot{\boldsymbol{Q}} = \frac{T_{hot} - T_{cold}}{R} = \frac{5}{0.0777} = \mathbf{64.35\ W}$$

With the overall heat transfer, we can find the temperature around throughout the brick.

$$\boldsymbol{T_{b,out}} = \mathrm{T}_{cold} + \mathrm{Q}\mathrm{R}_{conv,O} = 13 + \frac{64.35}{10(3 \cdot 2)} = \mathbf{14.07°C}$$

Example 1B

A 3 m high by 5 m wide wall of a house is composed of two bricks of length 0.1 m with a 0.05 m gap in between. The temperature inside the room is 20$°C$, and the temperature outside the house is 3$°C$ Determine the heat transfer through the wall when:

a) The gap is filled with cotton wool insulation.
b) The gap is filled with foam insulation.

Assume the thermal conductivity is brick $k_b = 0.8\ Wm^{-1}K^{-1}$, the thermal conductivity of the cotton wool insulation is $k_w = 0.029\ Wm^{-1}K^{-1}$, the thermal conductivity of foam insulation is $k_f = 0.045\ Wm^{-1}K^{-1}$,

3.2 Water Pipes

Pipes are defined into two categories, either lagged or unlagged. An unlagged pipe is one that is not insulated. Pipe lagging is a special type of insulation fitted around water pipes that prevents condensation on cold pipes. Insulating pipes is important, as it not only saves on energy, but prevents pipes from freezing and bursting, which can cause lots of damage and halt production.

3.2.1 Unlagged Pipes

Theory

The parameters for the equation of heat loss in a pipe are defined in Fig. 3.4. T_I and T_O are the temperature on the inside and outside of the pipe, respectively; r_I and r_O are the radii between the centre to the inside pipe, and the centre to the outside of the pipe, respectively; and L is the length of the pipe.

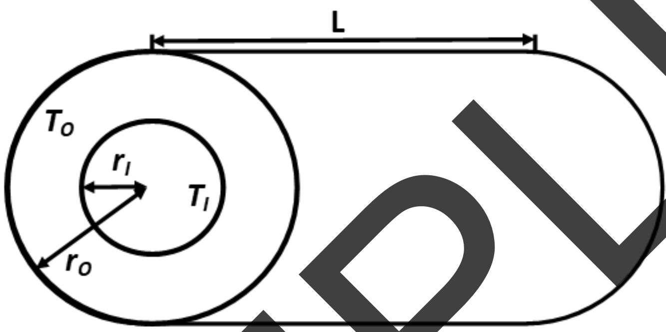


Fig. 3.4: An unlagged pipe

We can also measure the rate of heat loss across the pipe as Eq. 3.15:

$$\dot{Q} = \frac{T_I - T_O}{[ln(r_O/r_I)/2\pi kL]} \qquad \text{(Eq. 3.15)}$$

Once we have worked out the rate of heat loss, we can work out the temperature across the pipe as a function of r by rearranging Eq. 3.15 to get Eq.3.16, where $r_I \leq r \leq r_O$.

$$T_r = T_I - \frac{\dot{Q} ln(r/r_I)}{2\pi kL} \qquad \text{(Eq. 3.16)}$$

Example 2

A 1 m copper pipe with an overall diameter of 25 mm, with thickness 5 mm is moving water at 80°C. The outside temperature of the room is 25°C and the thermal conductivity of the pipe is 401 $Wm^{-1}K^{-1}$.

a) Calculate the rate of heat loss
b) Plot the temperature profile across the pipe

Answer:

a) The rate of heat loss is calculated with Eq.3.15 and Eq.3.16

We will consider the impact of convection in Example 2, where h_f and h_a are 3000 $Wm^{-2}K^{-1}$ and 5 $Wm^{-2}K^{-1}$, respectively.

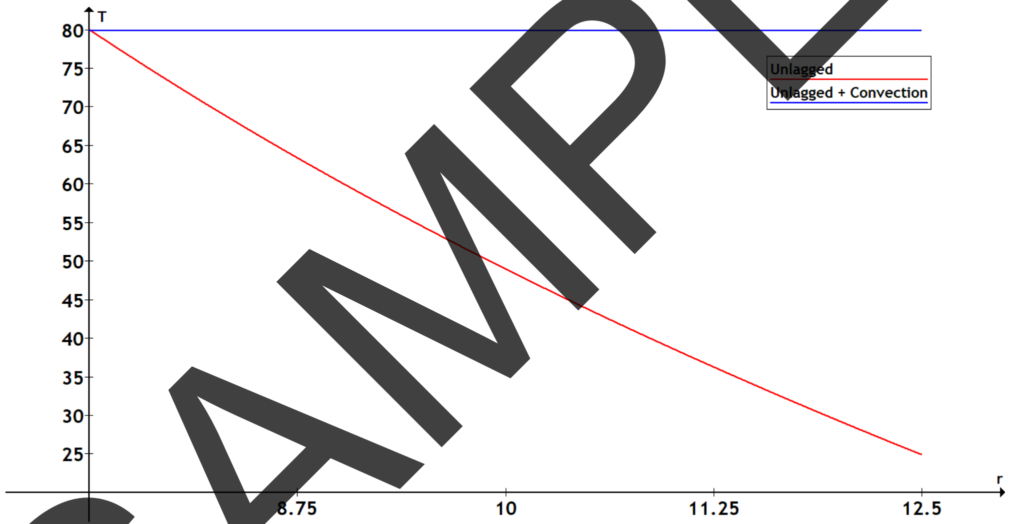
$$\dot{Q} = \frac{55}{\left[\frac{1}{2\pi \cdot (7.5 \cdot 10^{-3}) \cdot 3000 \cdot 1} + \frac{ln(12.5/7.5)}{2\pi \cdot 401 \cdot 1} + \frac{ln(12.5/12.5)}{2\pi \cdot k_s \cdot 1} + \frac{1}{2\pi \cdot (12.5 \cdot 10^{-3}) \cdot 5 \cdot 1}\right]}$$

$$\therefore \quad \dot{Q} = \frac{55}{(7.07 \times 10^{-3}) + (2.03 \times 10^{-4}) + (0) + (2.55)} = \mathbf{21.51\ W}$$

The temperature at the inside surface of the pipe is:

$$T_I = T_f - \frac{\dot{Q}}{2\pi \cdot 7.5 \cdot 10^{-3} \cdot 3000 \cdot 1} = 79.84\ K$$

We can compare this to Example 2:



Which is what you would expect - if you touch a bare pipe it feels hot, it doesn't feel the same temperature as the room.

Example 5

Building from Example 3, we will now consider the convection of the fluid inside the pipe and the surrounding air.

$$\dot{Q} = \frac{55}{\left[\frac{1}{2\pi \cdot (7.5 \cdot 10^{-3}) \cdot 3000 \cdot 1} + \frac{ln(12.5/7.5)}{2\pi \cdot 401 \cdot 1} + \frac{ln(32.5/12.5)}{2\pi \cdot 0.055 \cdot 1} + \frac{1}{2\pi \cdot (32.5 \cdot 10^{-3}) \cdot 5 \cdot 1}\right]} = \mathbf{14.67\ W}$$

The temperature at the inside wall of the pipe is